NI 43-101 Preliminary Economic Assessment on the Langis Silica Deposit and a Metallurgical Silicon Processing Plant in the Matapedia Region, Province of Québec, Canada

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Acronyms

AD	Anti-Dumping
AC	Alternating Current
Al	Aluminum
Alumina	Aluminum oxide, Al_2O_3
AS	Anti-Subsidy
ASP	Average Selling Price
a	Annum
B	Boron
BE	Basic Engineering
BOP	Balance-of-Plant
bps	Basis Points
CAD	Canadian Dollar
CAGR	Compounded Annual Growth Rate
C	Carbon
Ca	Calcium
cm	Centimeter
CME	Canadian Metals Inc.
CMEx	Chicago Mercantile Exchange
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Companion Policy 43-101 CP	Companion Policy 43-101CP to National Instrument 43-101 “Standards of Disclosure for Mineral Projects”
CSA	Canadian Securities Administrators
CSE	Canadian Stock Exchange
CTMP	Centre de Technologie Minerale et de Plasturgie
d	Day
DFC	Direct Field Costs
DFS	Definitive Feasibility Study
EBT	Earnings Before Tax
EBIT	Earnings Before Interest Tax
EIA	Environmental Impact Analysis
FCFF	Free Cash Flow to Firm
Fe	Iron
Fe_2O_3	Hematite, Iron Ore
FeSi	Ferrosilicon
FeSi75	Ferrosilicon with 75% Silicon Content
Form 43-101F1	Technical Report form for NI 43-101
FS	Feasibility Study
HP	Horsepower
HFP	Hybrid Flex Plant
ICP	Inductively Coupled Plasma
IFC	Indirect Field Costs
IFRS	International Accounting Standards Board
IRR	Internal Rate of Return
kg	Kilogram
kPa	Kilopascal
kt	Kiloton (1,000 Metric Tons)
ktpy	Kilotons per Year (1,000 Metric Tons per Year)
LCOE	Levelized Cost of Electricity / Energy
LME	London Metal Exchange
LOI	Loss on Ignition
LOM	Life-of-Mine

M	Million
m^3	Cubic Meter
Micron or µm	Micrometer
mm	Millimeter
Mg	Magnesium
mgSi	Metallurgical-grade Silicon (~99.0-99.9% Si)
NAFTA	North American Free Trade Agreement
NI 43-101	National Instrument 43-101 relating to “Standards of Disclosure for Mineral Projects” set forth by CSA for filing on SEDAR
NPV	Net Present Value
NI 44-101	National Instrument 44-101 related to Short Form Prospectus Distributions” set forth by CSA/CSM
NI 55-102	National Instrument SEDI – System for Electronic Disclosure by Insiders Reporting
NI 55-104	National Instrument Insider Reporting Requirements and Exemptions
NSR	Net Smelter Royalty /Return
O_2	Oxygen
PEA	Preliminary Economic Assessment
P	Phosphorous
RAF	Revenue Adjustment Factor
ROW	Rest of World
SAF	Submerged (Electric) Arc Furnace
SEDAR	Electronic Document Analysis and Retrieval
SiC	Silicon Carbide
SiO	Silicon Monoxide
SiO_2	Silica, Silicon Dioxide, Quartz, Quartzite
SEM	Scanning Electron Microscopy
Ti	Titanium
Titania	Titanium dioxide, TiO_2
Ton	Metric Ton (unless specified otherwise)
t	Metric Ton
TV	Terminal Value
USD	United States Dollar
VIQ	Viridis.iQ GmbH
wacc	Weighted Average Cost of Capital
WTO	World Trade Organization
XRF	X-Ray Fluorescence
y-o-y	Year-over-Year

1 Summary

1.1 Overview

Canadian Metals Inc. (CME), which is headquartered in Trois-Rivières, Québec, is the issuer of this Technical Report. Canadian Metals Inc retained Viridis.iQ GmbH (VIQ) and a number of other specialists in the fields of metallurgy, geology, mining, and environmental engineering to write this Technical Report and conduct a Preliminary Economic Assessment (PEA) for a proposed integrated silica quarry and silica processing plant in the Province of Québec, Canada. CME is a publicly listed company on the Canadian Stock Exchange (CSE), trading under the stock symbol CME since August 1, 2013. The company is solely focused on the exploration and development of its Langis silica deposit in connection with a proposed downstream integration into silicon and ferrosilicon production. VIQ is an independent engineering, consulting and technology firm with unique expertise in the areas of silicon and ferroalloys, with headquarters in Konstanz, Germany.

This report provides a comprehensive assessment of geological, technical, engineering, operational and commercial aspects (economic analysis), as well as presenting estimated measured and indicated resources, related to the vertical integration project concerning a silicon and ferrosilicon smelting facility that utilizes silica feedstock from the Canadian Metals Inc. Langis deposit. Both operations are planned to be located in the Province of Québec, Canada.

This report has been prepared in accordance with the Canadian "Standards of Disclosure for Mineral Projects", National Instrument 43-101 (NI 43-101), and refereed forms, companion policy and other instruments supporting it, as set forth by the Canadian Securities Administrators (CSA) for electronic filing and disclosure on CSA's "System for Electronic Document Analysis and Retrieval" (SEDAR).

This study also takes into consideration the following reports filed by qualified persons within specialized fields:

- **GENIVAR, 2013,** J.D. Charlton and M.D. Paganon, Characterization Study of the Langis Silica Deposit NTS: 22B11, Matapedia Region, Quebec, Canada. Prepared by GENIVAR for Canadian Metals Inc according to NI 43-101 standards, December 6, 2013 (Genivar Inc. has been formally rebranded to WSP Global Inc. as of January 2, 2014);

- **Géo-Logic, 2016,** A. Tremblay and É. Forbes, NI 43-101 Technical Report Pertaining to Langis Property, (Langis Township), Matapedia Area, Province of Québec NTS 22/B11, Volume I and II. Prepared by Consultations Géo-logic for Canadian Metals Inc, January 26, 2016 and revised March 21, 2016;
- **Biofilia, 2016,** C. Lachance and M. Pérusse, Section 20 (Environmental Studies, Permit and Social or Community) and excerpts appearing in Section 1.8 (Environmental and Social) of this report. Prepared by Biofilia for Canadian Metals Inc, February 4, 2016;

As well as the following external project and market-related reports:

- **Roskill, 2014,** Silicon and Ferrosilicon: Global Industry Markets and Outlook, Fourteenth Edition, 2014. Market study prepared by Roskill Information Services Ltd, May 2014;
- **CRU, 2015,** Silicon Cost Data Service, CRU, May 2015;
- **MINTEK, 2015,** T. Kekana, M. Thethwayo, and K. Bisaka, principal lead authors; External Report 7204: Investigations on the Production of Ferrosilicon from Canadian Quartzite Using Mintek's 100KVA DC Arc Facility. Prepared by Mintek for Canadian Metals Inc, August 10, 2015;
- **BBA, 2015,** M. Brisson, L. Charron and A. Grandillo, Analyse des sites potentiels pour l'implantation d'une fonderie de ferro-silicium, Document No. BBA / Rev.: 3635001-000000-47-ERA-0001 / R00. Prepared by BBA for Canadian Metals Inc, May 20, 2015;

The PEA is intended to support CME's decision makers in the determination of the technical and commercial feasibility of both the exploitation of the Langis silica deposit with downstream processing of the feedstock in a dedicated hybrid flex plant (smelter). The planned smelter is designed such that it is flexible to produce metallurgical silicon (mgSi) and ferrosilicon (FeSi) in various quantities and grades and can also be switched to single product production in accordance with different end-market dynamics. As current North-American FeSi prices are suppressed due to a cyclical downturn in the global steel market, the PEA base-case presumes that the smelter will be operated in single-product mode as a dedicated metallurgical silicon plant for North American off-take markets. Later-stage switches to FeSi production and production capacity scaling options are in principle possible, but have not been included in the base-case assessment of the present PEA.

1.2 Description of Langis Silica Deposit

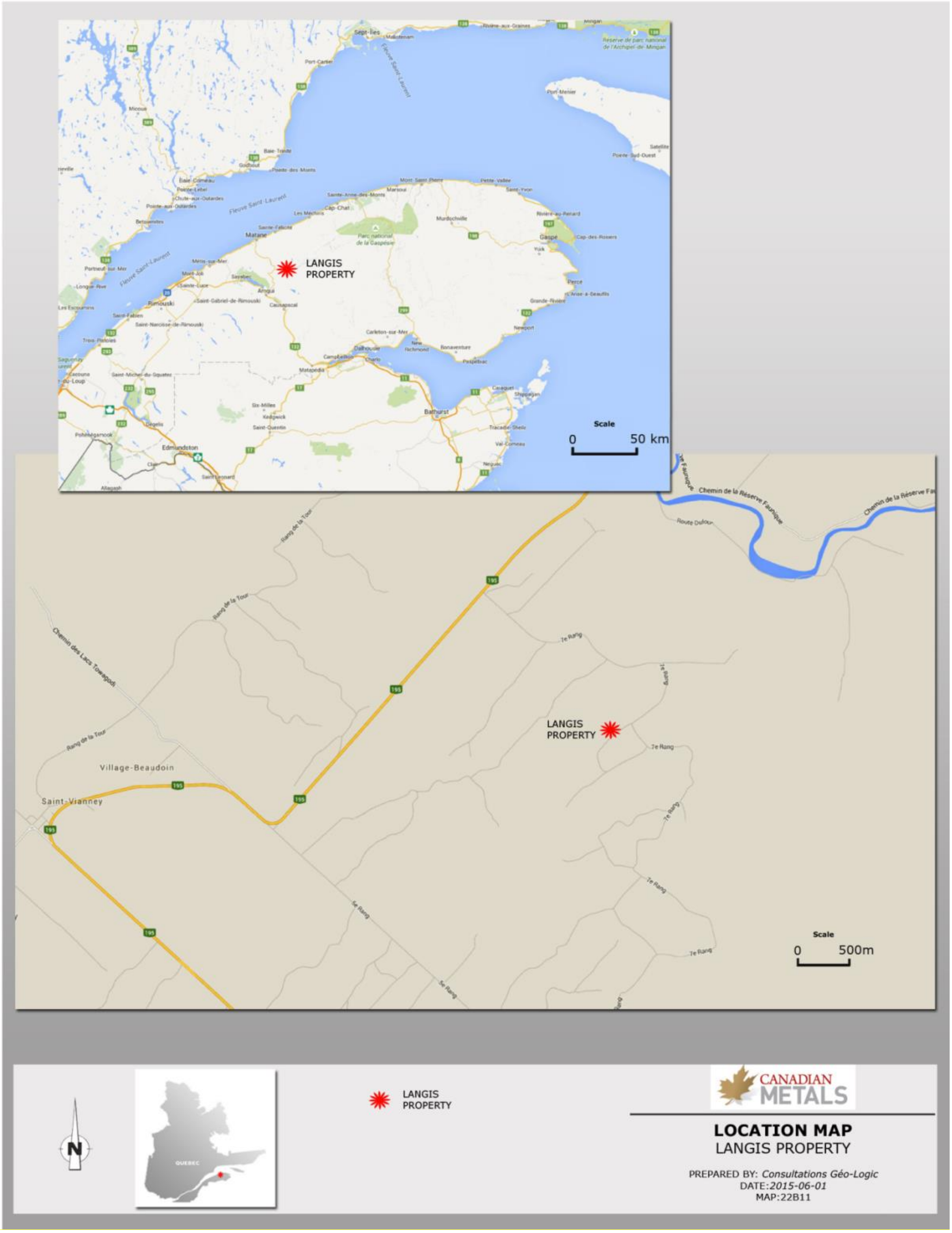
The Langis Property is made up of four regular MDC (map-designated claims) covering a total surface area of 227.62 ha. The MDC are valid till July 11, 2017, with plenty of accrued works for subsequent renewal. The Property is located within NTS map sheet 22B11, in the Matapedia Region of the Gaspe Peninsula of Québec, within the Regional County Municipality (RCM) of Matapedia. The geographic center of the Property is approximately at latitude 48° 37' 30" N and longitude 67° 20' 00" W or 5,387,200 N and 622,800 E in UTM Zone 19. The Property covers parts of Ranges VI and VII of Langis Township.

The Property was bought from 9285-3696 Québec Inc. Canadian Metals Inc. now holds 100% of the mining titles. Production from the Property is subject to a 3% net smelter return (NSR) payable to 9285-3696 Québec Inc, according to Canadian Metals Inc.

To the knowledge of the authors, there are no environmental liabilities pertaining to the Langis Property, based on information received from Canadian Metals Inc. The claims cover both private and crown land but current exploration is limited to crown land, so the only permit required to carry out exploration on the Property is the usual forestry management permit.

The Property is located in gently rolling Appalachian terrain. A set of elongate hills oriented NNE dominates the topography. The Property is largely covered by a mixed forest of hardwoods such as maple, poplar and birch mixed with conifers such as white spruce, white pine and cedar.

Figure 1: Location map



The Property is easily road accessible via paved provincial Highway 195 and a gravel road in good condition (Range VII road). The Property is 20 km by road (Highway 195) from the town of Amqui (the administrative centre of the Matapedia RCM) on Highway 132. It is also accessible via Highway 195 from Highway 132 in the town of Matane, a distance of 40 km.

There are several smaller villages in the area of the Property, such as St-Vianney, St-Tharcisius, Saint-Rene-de-Matane, Lac-au-Saumon and Val-Brillant, with adequate skilled labor for the operation of a silica quarry.

The nearest source of a continuous substantial flow of fresh water is a stream called Riviere Tamagodi, 1.8 km to the east-southeast of the present Langis quarry. High voltage transmission lines cross the Property 300 meters south of the existing quarry, and there is already a transformer substation 400 meters southwest of the existing quarry.

The Property experiences a cool humid continental climate with warm summers and cold winters. The spring-summer-fall period begins in early May and ends in the latter part of October. Winter conditions normally last from early November through to late April. Precipitation is moderate and is fairly evenly distributed throughout the year.

Geological mapping and exploration of the area by governmental institutions began with the investigations of Logan in 1844. Gradually, over the years, many regional and local surveys were done on the Langis area and the Gaspe Peninsula by the Geological Survey of Canada and the Québec Ministry of Natural Resources. A synthesis of the Gaspe regional geology was produced by Slivitsky et al (1991), and the stratigraphy was reinterpreted and integrated into the Appalachian geology by Brisebois and Morin (2003).

The first known investigations and comprehensive report on the sandstones of Langis and Tessier Townships were done by R. A. Marleau (1979) for Placement Appalaches Inc. Uniquartz Inc. took over the project from Placement Appalaches Inc. in 1982. Between August and October of 1982, an extensive diamond drilling program was completed on Langis and the neighbouring Tessier sandstone occurrences. A total of 4,102.5 feet (1,243.1 meters) were drilled in 25 drill holes, eight of which, totalling 1,568 feet (475.1 meters), were drilled on the Langis Property. Subsequently (1983), extensive physical and geochemical testing was done on the drill cores in order to determine the physical and geochemical characteristics of the sandstones of the Langis and Tessier deposits.

In 1984, historical tonnages published in the environmental study for the project (GM 42387) stood at 25.5 million tons at average grades of 0.11% Fe_2O_3 and 0.41% Al_2O_3, including 9.0 million tons at 0.11% Fe_2O_3 and 0.26% Al_2O_3 or 5.7 million tons at 0.05% Fe_2O_3 and 0.183% Al_2O_3. SiO_2 grade calculated from 750 feet of core was reported to be 99.25%. This was classified as an Indicated Reserve. *This resource is historical in nature and does not meet the requirements for resource categorization as set out in NI 43-101.*

In 1985, Uniquartz obtained Mining Lease No. 741. In December 1985 and May 1986, a total of some 22,000 tons of lump silica were sent to Norway and Iceland for testing in existing ferrosilicon smelting facilities. The results were positive and a 150,000 ton-per-year supply contract was signed. In 1988, the cost of project start-up was estimated at $8.4 million. There is no record of difficulties encountered but the project never went into production. Apparently, material was extracted intermittently after 1991 for construction purposes. Several elongate piles of crushed waste rock remain to the west of the quarry. From the current size of the quarry, it is estimated that around 400,000 tons have been extracted from the site over the years.

The Matapedia Region forms part of the Appalachian Geological Province, which stretches from Alabama, in the southeast USA, to Newfoundland. The portion of Québec that hosts the rocks pertinent to this Report is known as the Connecticut Valley–Gaspe Synclinorium (CVGS). These rocks were folded, faulted, intruded and weakly metamorphosed during what is generally known as the Appalachian Orogeny.

The CVGS rocks of Matapedia-Gaspe are of Ordovician-Siluro-Devonian age. They are comprised of wackes and conglomerates of the Cabano Group (Ordovician to Silurian in age), overlain by the Siluro-Devonian rocks of the Chaleurs Group. The stratigraphy of the Chaleurs Group comprises green shales of the Awantjish Formation at the base, overlain by the white-to-pink quartz arenites of the Val-Brillant Formation. The quartz arenite of the Val-Brillant Formation is highly siliceous. It appears as thick (up to several meters) white layers, and locally, pink to mauve layers that result from hematite discolouration. Total thickness is usually 40 to 60 meters. This highly siliceous sandstone constitutes the exploration target at the Langis Project.

Canadian Metals Inc. completed prospecting, mapping and sampling along with two drilling programs in 2013 and 2015 on the Langis Property. The 2013 reconnaissance drilling program included nine holes/456.97 meters, while the 2015 infill program consisted of 18 holes/701.6 meters. Other work done on the Langis sandstones includes metallurgical tests in 2015 by MINTEK of South Africa, which confirmed the favorable physical and chemical characteristics of material to produce ferrosilicon.

This work led to the understanding of the local stratigraphy and structures and the preparation of a sufficiently reliable geological model of the deposit to define measured and indicated resource blocks.

On the Langis Property, it is now established that the underlying shales of the Awantjish Formation are overlain successively by a transition zone (impure sandstones, 10 meters), a Lower White Sandstone (pure sandstone, 15-35 meters), a Red Bedded Sandstone (impure, 15 meters) and an Intermediate Sandstone (pure). The Lower White Sandstone constitutes the resource of the Langis deposit. About 25% of the Lower White Sandstone is covered by the Red Bedded and Intermediate sandstones in the eastern part of the deposit.

The laboratory results obtained were found to be reliable by the QA/QC program realized by Canadian Metals Inc. Estimated measured resource of the Langis deposit currently stands at 3,495,000 tons grading 98.57% SiO_2, with 2,673,000 tons sitting directly under some two meters of overburden. The remaining 822,000 tons are covered by an impure sandstone that varies in thickness from 0 to 12 meters.

The indicated resource contiguous to the measured resource is estimated at 3,536,000 tons with 1,501,000 tons grading 98.52% SiO_2 with less than 12 meters of waste coverage, and 2,035,000 tons grading 98.92% SiO_2 with more than 12 meters of overlying waste.

All measured and indicated resources show impurity levels within the required specifications for ferrosilicon silica feed.

As Canadian Metals Inc’s objective was to secure silica feed for the ferrosilicon plant project and it was estimated that some 2.5 million tons would be sufficient, no other exploration work is recommended at this time.

1.3 Site for Downstream Processing

The Municipality of Matane, with a population of about 14,500 inhabitants, is about 40 km northwest of the quarry site by Highway 195. The base-case site for the silicon/ferrosilicon downstream smelter operation is located in Matane, Québec along highway 132 (Avenue du Phare) in the southwest part of the city and 3 km from the port of Matane.

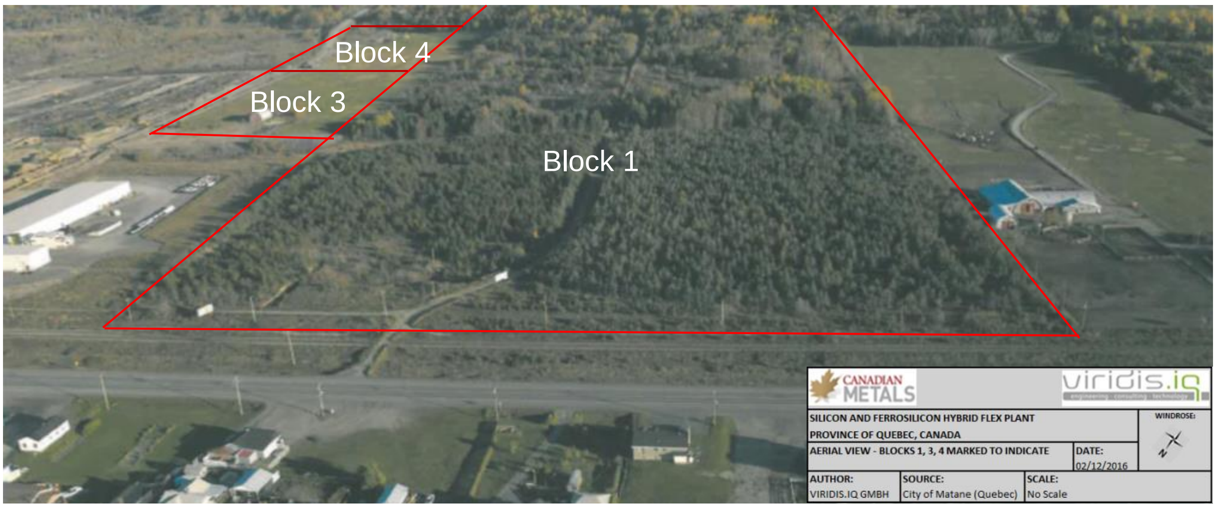
Alternative locations for the smelter operation are reviewed in Section 26.5.

The selected site for the base-case is located 3 km from the port of Matane which can be used to transport some raw materials and end products.

Figure 2: Aerial view, City of Matane, Québec

The site is an industrial zoned site and is virtually untouched in its natural form and heavily wooded with one gravel access road on the southwest side of the property. The main railway line crosses the site and power and sewer/water services are available.

Figure 3: Base-case site – industrial zone, Matane



The site consists of 3 blocks of property (1, 3 & 4) that can be used for the project. The largest block, number 1, is owned by the City of Matane, while blocks 3 and 4 are privately owned and will need to be acquired. Preliminary assessments indicate that the entire property is suitable for the proposed downstream project. The three blocks comprise of approx. 372,500 m^2 as shown in Figure 4:

Figure 4: Top view – industrial site, Matane

1.4 Mineral Resource Estimate

As discussed in Section 6.2, a historical resource was estimated by Uniquartz in 1982-84. The resources at the time were established at:

Millions short tons	%SiO_2	%Fe_2O_3	%Al_2O_3	
25.5	not specified	0.12	0.41	including
9.0	not specified	0.11	0.26	including
5.7	not specified	0.05	0.183	

(The authors recommend a more detailed study in the work of have not done sufficient work to classify the historical estimates as current resources and the owner of the Property is not treating the historical estimate as current mineral resources.)

Efforts by Uniquartz to define resources with minimal iron and alumina content were driven by a different market outlook than the current work by Canadian Metals Inc. The resources calculated by Uniquartz were based on holes drilled on a fairly large, irregular drilling pattern with a spacing of around 200-250 meters. Some 12 holes covering almost 30 hectares were drilled to investigate the Val-Brillant Formation. With such a density of holes, the geological model presented was essentially conceptual. Done in the early 1980s, the Uniquartz estimate does not meet current NI 43-101 standards.

Following the 2013-15 drilling programs completed by Canadian Metals Inc., the current resource estimate was prepared. This estimate is significantly different from the historical one described above, as 27 holes were drilled on an area of some 10 hectares. The drilling pattern of 100 meters in 2013 was reduced to 50 meters in 2015, which was deemed sufficient to construct a reliable geological model.

The database used to estimate the Langis resource was therefore restricted to recent work by Canadian Metals, and included:

- 27 drill holes
- 1,157.6 meters
- 479 assays
- 31 deviation tests

1.4.1 Measured Resources

Measured resources based on the mineral resources estimation is shown in the following table.

Table 1: Overview of measured resources

A) Zone without waste coverage Metric tons	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	MnO (%)	TiO_2 (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)
2,673,000	98.52	0.12	0.42	0.02	0.10	0.00	0.06	0.01	0.10	0.00
B) Zone covered with waste **Metric tons**	**SiO_2 (%)**	**Fe_2O_3 (%)**	**Al_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**MnO (%)**	**TiO_2 (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**
822,000	98.73	0.12	0.38	0.04	0.09	0.00	0.05	0.02	0.06	0.00
Total deposit										
Metric tons	**SiO_2 (%)**	**Fe_2O_3 (%)**	**Al_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**MnO (%)**	**TiO_2 (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**
3,495,000	98.57	0.12	0.41	0.03	0.10	0.00	0.05	0.01	0.09	0.00

Source: Consultations Géo-Logic

1.4.2 Indicated Resources

The indicated resources have been subdivided into two categories, 1 and 2. Both indicated resource categories are located in the immediate continuity of the measured resource. In this case, the 25-meter horizontal influence used for the measured resource was increased to 50 meters. The indicated resource is therefore composed of the 25-50 meters in addition to the measured resource where the drilling pattern is 50 meters, and 0-50 meters from a hole where the drilling pattern is 100 meters (e.g., between Sections 283E and 386E). Any indicated resource (1 or 2) must consist of blocks contiguous to either the measured resource or other indicated resource blocks. No isolated block should exist. Horizontally, the indicated resource may be limited by faults. These general criteria apply to all indicated resource. The difference made between indicated-1 and 2 is the cover of waste material. If overlying waste reaches the equivalent of one mining bench, or 12 meters, then the indicated-1 becomes 2 to better show areas where the criteria are met but where an additional constraint is present. The indicated-2 resource is concentrated along the southeast margin of the deposit where the Lower sandstones are covered by gradually thickening red bedded sandstones and Intermediate sandstones.

Table 2: Indicated-1 resources – Langis deposit

Section	Item or Block	Hole	Surface (m^2)	Thickness (m)	Volume (m^3)	Tonnage (mt)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	MnO (%)	TiO_2 (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)
0/61	0/61-1	12	2363.0	18.50	43,716	109,289	98.34	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.09	0.00
61/115	61/115-1	12,13	438.7	22.00	9,651	24,129	98.37	0.12	0.36	0.02	0.08	0.00	0.06	0.01	0.07	0.00
	61/115-2	16	1310.4	19.00	24,898	62,244	98.44	0.15	0.47	0.02	0.11	0.01	0.06	0.01	0.14	0.00
	61/115-3	17	1315.5	9.80	12,892	32,230	97.41	0.21	0.77	0.04	0.13	0.01	0.08	0.01	0.28	0.00
	61/115-4	18	2592.3	11.75	30,460	76,149	98.06	0.19	0.58	0.02	0.11	0.00	0.06	0.01	0.23	0.00
115/171	115/171-1	26	466.5	26.35	12,292	30,731	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
	115/171-2	18	700.2	11.75	8,227	20,568	98.06	0.19	0.58	0.02	0.11	0.00	0.06	0.01	0.23	0.00
	115/171-3	7	695.6	19.60	13,634	34,084	98.28	0.13	0.51	0.02	0.07	0.00	0.05	0.00	0.20	0.00
171/226	171/226-1	26	1600.4	26.35	42,171	105,426	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
	171/226-2	1	961.9	30.28	29,126	72,816	98.65	0.15	0.44	0.11	0.09	0.01	0.05	0.06	0.07	0.01
	171/226-3	7	715.2	19.60	14,018	35,045	98.28	0.13	0.51	0.02	0.07	0.00	0.05	0.01	0.20	0.00
	171/226-4	23	651.4	7.20	4,690	11,725	98.34	0.18	0.51	0.02	0.08	0.01	0.06	0.00	0.18	0.00
226/283	226/283-1	25	722.4	33.00	23,839	56,598	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
	226/283-2	2	715.9	24.00	17,182	42,954	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	226/283-3	23	711.4	7.20	5,122	12,805	98.34	0.18	0.51	0.02	0.08	0.01	0.06	0.01	0.18	0.00
	226/283-4	8	718.4	16.80	12,069	30,173	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00
283/376	283/376-1	2	657.1	24.00	15,770	39,426	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	283/376-2	2	1079.4	24.00	25,906	64,764	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	283/376-3	24	1084.9	29.85	32,384	80,961	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	283/376-4	3	4175.2	21.00	87,679	219,198	98.67	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.12	0.00
	283/376-5	8	1625.7	16.80	27,132	68,279	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00
	283/376-6	8	580.0	16.80	9,744	24,360	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00
376/ext	376/ext-1	3	4644.2	21.00	97,528	243,821	98.67	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.12	0.00
Total:						**1,501,000**	**98.52**	**0.13**	**0.40**	**0.02**	**0.09**	**0.00**	**0.05**	**0.01**	**0.11**	**0.00**

Source: Consultations Géo-Logic

Table 3: Indicated-2 resources – Langis deposit

Section	Item or Block	Hole	Surface (m^2)	Thickness (m)	Volume (m^3)	Tonnage (mt)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	MnO (%)	TiO_2 (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)
61/115	61/115-5	10	2,131	26.5	56,472	141,179	99.03	0.10	0.36	0.02	0.09	0.00	0.05	0.00	0.04	0.00
115/171	115/171-4	15	1,339	29.3	39,233	98,082	98.64	0.09	0.39	0.02	0.11	0.00	0.05	0.00	0.08	0.00
171/226	171/226-5	26	1,380	26.4	36,432	91,080	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
226/283	226/283-5	09, 26	2,891	24.3	70,251	175,628	98.67	0.11	0.37	0.02	0.11	0.00	0.04	0.01	0.03	0.00
283/376	283/376-7	09	6,791	22.2	150,760	376,901	98.78	0.09	0.34	0.02	0.10	0.01	0.04	0.01	0.03	0.00
	283/376-8	02	556	24.0	13,344	33,360	99.07	0.08	0.30	0.02	0.04	0.01	0.04	0.03	0.06	0.00
376	376-1	05	8,818	24.3	214,277	535,694	99.03	0.08	0.35	0.05	0.08	0.01	0.04	0.06	0.04	0.01
	376-2	04	9,333	25.0	233,325	583,313	99.07	0.11	0.32	0.02	0.06	0.00	0.05	0.01	0.09	0.00
Total:						**2,035,000**	**98.92**	**0.10**	**0.34**	**0.03**	**0.08**	**0.00**	**0.04**	**0.02**	**0.05**	**0.00**

Source: Consultations Géo-Logic

1.5 Mining Methods

The Langis site will be operated as a traditional cone-shaped excavation, commonly called an open pit mine or quarry. The cone will advance in a top-down direction, maximizing the NPV (net present value). This excavation will be conducted with rope or hydraulic shovels with trucks carrying both silica and waste. Waste will be dumped outside the mined-out area since no room is available within the pit. Waste will be placed as close to the edge of the pit as possible, to minimize transportation costs.

Recovery of the deposit will be conducted in compliance with good practices of quarrying operations, according to the standards established in Mining Regulatory Standards, with special attention to safety conditions of the people involved, and with minimal negative impact to the environment.

Before actual production starts, there will be a stage of quarry preparation or development. At this stage the quarry will be prepared to insure the continuity of sufficient silica production to feedstock the smelter without interruption. This step must precede the start of smelter operations. Quarry preparation consists of removing the vegetation cover, if any, of the entire area planned for development. Then the organic soil will be removed and stockpiled in a location already prepared, for future use in the reclamation of degraded areas. This removal can be conducted with bulldozers, hydraulic excavators, wheel loaders, and dump trucks equipped with tipper buckets.

Initially, a wheel loader will scrape off the topsoil layer, forming piles in places accessible to trucks. Then a wheel loader or an excavator will load the material in the trucks that will transport it to storage sites where it will be unloaded. Once the topsoil is removed, the removal of waste material covering the silica can occur. This removal will be planned to allow a sufficient volume of exposed silica to feedstock the smelter.

No time or expense was considered for this initial operation since only a small quantity of overburden material exists. The waste material removed to expose the silica will be disposed as described in Section 16.3.6, Waste Disposal. The operations of vegetation removal, organic soil removal and overburden removal will need to be repeated throughout the life of the quarry as the pit is being expanded.

During the preparation phase of the quarry, some usable silica will be removed and stockpiled separately, to be used when the smelter is in operation. This silica can be transported to an area near the smelter to serve as stockpile in the event of a shortage of silica transported directly from the quarry.

1.5.1 Geological Model

The database used to generate the geological model and to estimate Langis resources is summarized in Table 4.

Table 4: Descriptive grid characteristics

Description	Quantity
Drill Holes	27
Total Drill Holes	1,157.6 meters
Drill Holes Depth Average	47 meters
Vertical Sections	6
Deviation Tests	31
Grid Spacing	50 meters x 50 meters

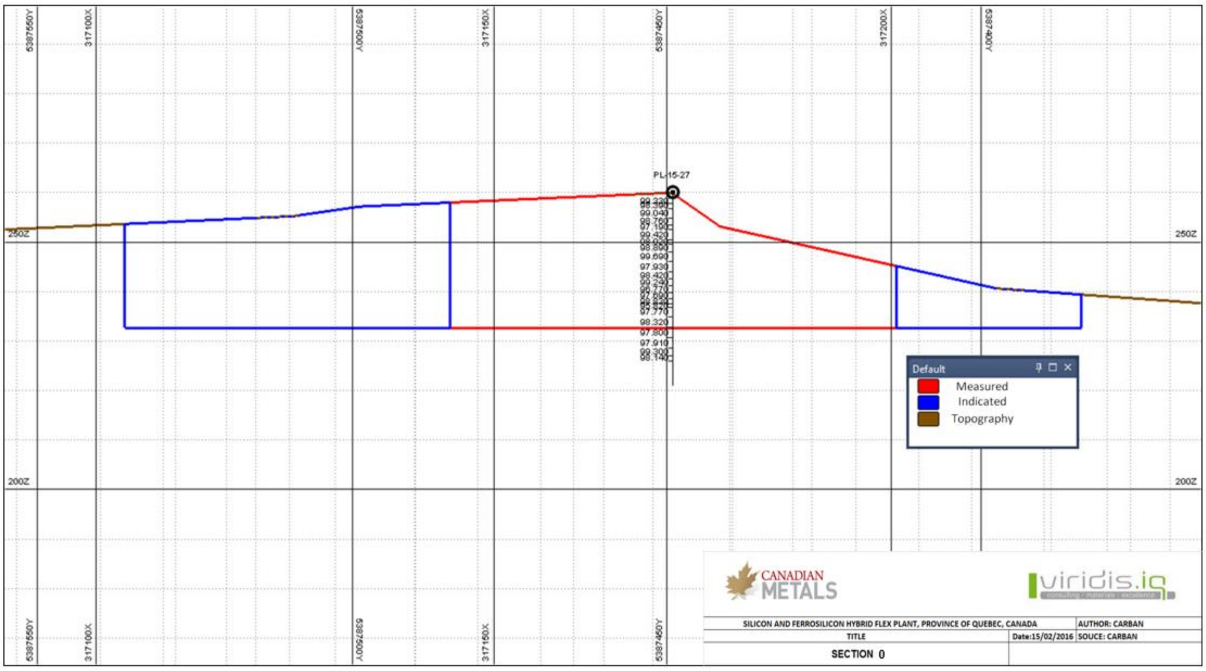
Source: Caban Geoservices, Viridis.iQ GmbH

For the Langis project, there were 35 drill holes available, but only those with the prefix PL (27 in total) have information about grades and lithology. Consequently, these were the ones used for the development of the geologic model and an estimated block model. With all this data available the following steps were executed in order to perform the geologic and block modelling.

- For the estimate of the blocks it was necessary to use samples with the same support, and to establish composites from drill hole samples. To determine the size of the composite in this project a statistical analysis was performed for the size of the samples in the original drilling database. A value 2 was adopted, which corresponds to the integer value nearest to the mode of the sizes (2.05);
- In order to better understand the behavior of the elements, apply this knowledge, and assess the grade estimation of the geological model a classic statistical analysis was used to assess the need for separate populations of grades, if more than one population exists and determine the grade distribution.
- Vertical geological sections (distributed in the region of interest for the Langis quarry) were used to develop geologic and block models. These sections were georeferenced based on the grid and the drill-hole collar

One of the sections used to build the geologic model is shown in the figure that follows:

Figure 5: Section 0 of the model



1.5.2 Block Model

A 3D block model was developed, based on the vertical sections, to estimate the resources and to define the open pit for the Langis project. The information necessary to develop the block model was received from Géo-Logic, including all the vertical sections, databases, and assumptions. The database and sections received were not modified in any way. Due to the low precision of the topography, it has been fitted with the drill-hole collars in the project area. The resources were already classified as measured and indicated in the information received, and the geological solids where generated to develop the block model based on this information. All the material classified by Géo-Logic as measured and indicated resources were respected in the development of the block model, and the economical definitions for exploration were included in the pit optimization phase of the study. The interpreted sections did not report inferred resources; therefore this type of resource was not included in the block model.

Following the NI 43-101 standard, all measured and indicated resources were considered as likely to turn into mineable ore, thereby determining the mineral reserves. All economical process and geotechnical parameters provided were used during the pit optimization phase for the definition of the blocks that should be part of the project reserves.

The definition of the optimal pit was developed with software that uses the Lersch - Three-dimensional Grossmann algorithm, an algorithm well known and widely used in the mining industry. This simulation took into consideration all the previously defined economical parameters.

The dimensions of the blocks are 15m x 15m x 10m, with sub blocks having maximum dimensions of 5m x 5m x 5m, such that in the x and y directions the parents blocks had a size equal to a quarter of the average distance between the drill holes (50 m), as dictated by standard practices. Table 5 below presents the main characteristics of the block model based on MTM system.

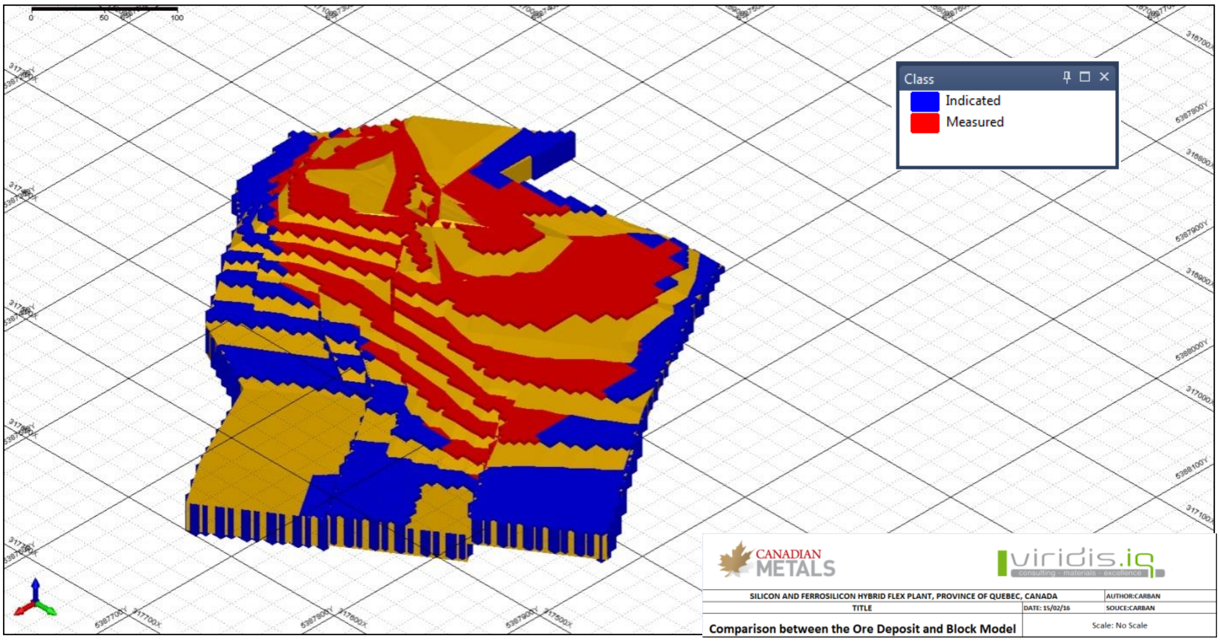
Table 5: Main characteristics of block model

Item	Main Characteristics of Block Model based on MTM System		
	X	Y	Z
Minimum	317,000.00	5,387,300.00	180
Maximum	317,690.00	5,387,990.00	260
Number of blocks	47	47	9
Blocks Size (meters)	15	15	10

Source: Caban Geoservices, Viridis.iQ GmbH

A comparison between the silica deposit solid generated in the block model and the original silica deposit solid from the wireframes provided shows a good level of accuracy in the resource estimate for the Langis project. Figure 6 below show this comparison, with the silica deposit surface in brown and the block model in blue and red.

Figure 6: Comparison between the silica deposit and block model



Geological testing performed by Consultations Géo-Logic and outlined in Section 14.2.5.1, Measured Resources, of this report indicated that the measured density of the deposit is reported by the ALS Chemex laboratory to be 2.75 g/ cm^3 (grams/cubic centimetre). Due to the minimal number of samples taken during the course of this work and the lack of statistical robustness, as well as the author's experience in mining silica, a conservative density assumption of 2.5 g/cm^3 has been adopted for the mining plan in this report, following the geologic Qualified Person recommendation, versus the 2.75 g/cm^3 presented by ALS data. Further testing at later stages may increase the accuracy of the density measurements by providing statistically relevant data concerning density, and, therefore, future mining plans may be modified.

The grade tonnage report below, from the block model, shows the total measured and indicated resources of the Langis quarry, with SiO_2 content.

Table 6: Grade tonnage table for the Langis quarry

Material	Resource	Volume (m^3)	Density (t/m^3)	SiO_2 (%)	Tons
Silica	Indicated	1,260,000	2.5	98.59	3,160,000
	Measured	1,470,000	2.5	98.44	3,670,000
	Total	2,730,000	2.5	98.51	6,830,000

Source: Caban Geoservices, Viridis.iQ GmbH

1.5.3 Mining Studies

The mining studies were conducted with the measured and indicated resources with the block model.

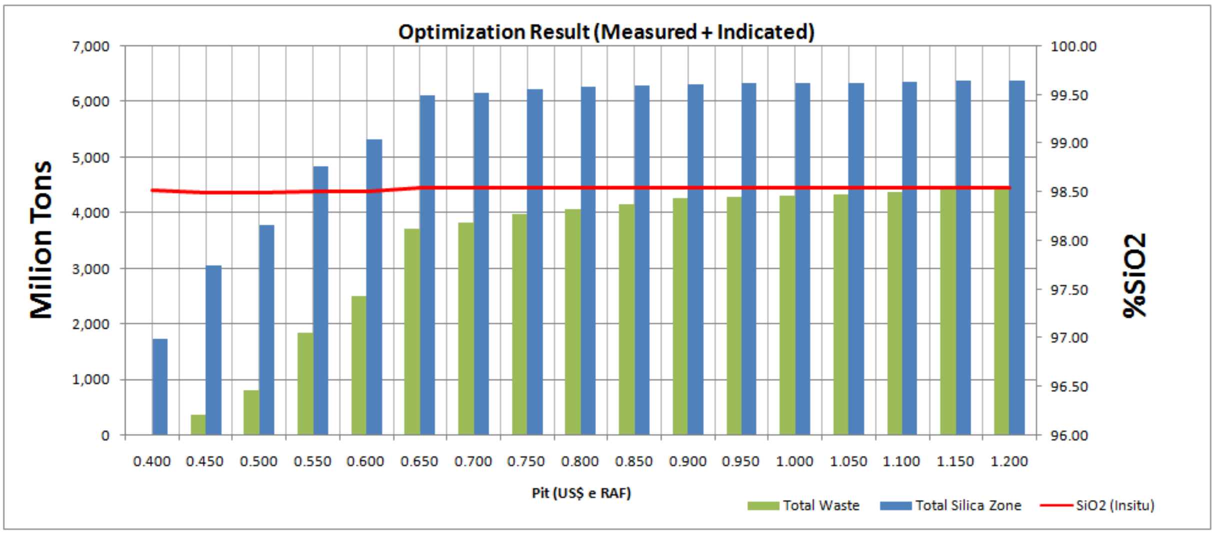
With all premises for the open pit optimization calculated, the optimization process results were obtained through the development of a RAF (Revenue Adjustment Factor) study as indicated by specialists in quarry pit optimization. This study aims to analyze the sensibility of the final pit by permitting the choice of a scenario with the best ratio between the variables of waste tonnage, silica zone tonnage and grades. The best results for optimization of the group, including measured and indicated resources are shown in the next Table 7 and Figure 7.

Table 7: Optimization results for the Langis quarry (measured + indicated)

RAF	Million Tons					% SiO_2 (in situ)	Strip Ratio
	Total Silica	Measured Silica	Indicated Silica	Total Waste	Product		
0.550	4.834	3.347	1.487	1.848	3.867	98.51	0.38

Source: Caban Geoservices, Viridis.iQ GmbH

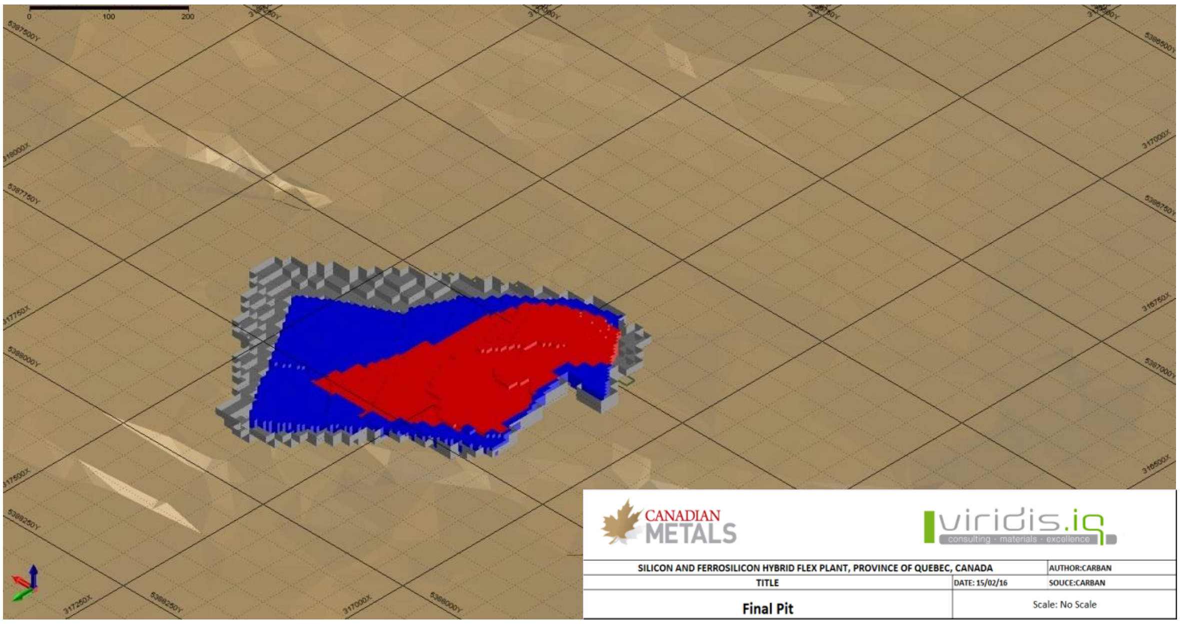
Figure 7: Optimization result (measured + indicated)



Source: Caban Geoservices, Viridis.iQ GmbH

The selected scenario was RAF 0.550 due to the satisfactory ratio between waste and silica. The optimized final pit obtained through the study is shown in Figure 8.

Figure 8: Final pit



1.5.4 Minerals Processing and Metallurgical Testing

Various chemical and physical analyses were performed on the samples, as the goal was to establish the characteristics of the Val-Brillant sandstone in relation to various potential commercial uses.

Based on the preliminary test work by GENIVAR, basic chemical, physical and thermal properties of the Langis sandstone indicates it has potential to be a usable source of silica. The impurities contained in the core samples are about 1% with a silica grade on the order of 98.55% SiO_2 and a loss on ignition ranging from 0.3% to 0.5%. When corrected for loss on ignition incurred during high temperature lump silica applications, the silica averages 98.95% SiO_2, 0.14% Fe_2O_3, 0.48% Al_2O_3 and 0.05% TiO_2.

Based on the chemical, physical and thermal properties observed from the test work at GENIVAR, by crushing and screening to -120/+20 mm lump particles, the Langis silica deposit may be a potential source for the production of ferrosilicon. Further crushing to -25/+5 mm particles will also make it a potential source as a flux agent for base metal smelting. The chemical composition of this material, however, does not meet the requirements for the production of silicon metal.

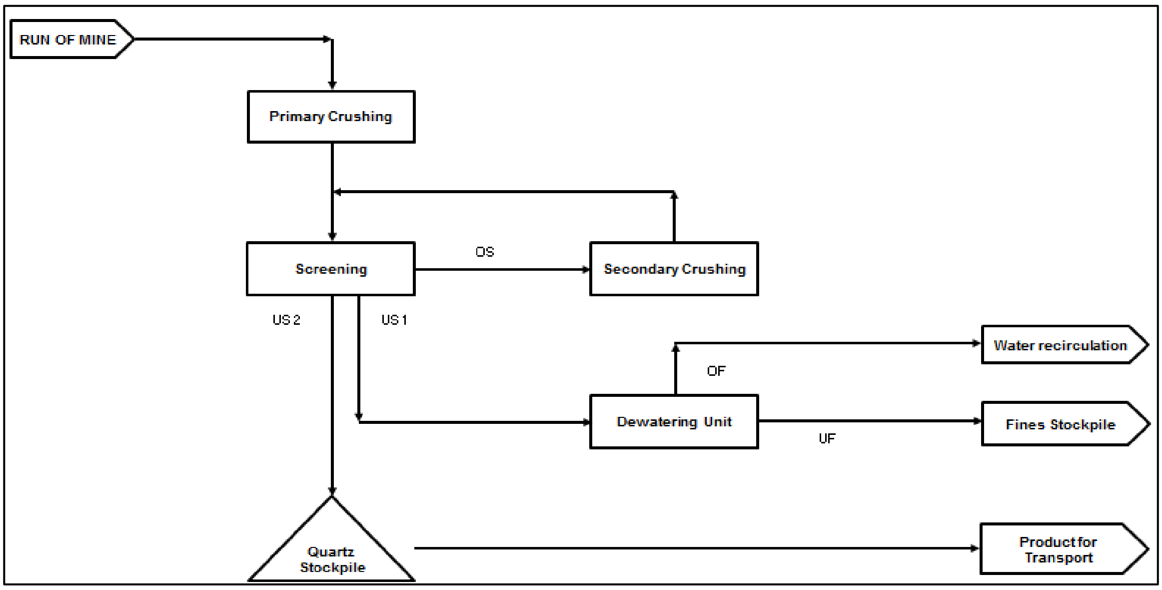
Crushing to -600 microns and desliming the -100 microns fines as well as attrition, size classification, dewatering and drying can be considered to provide a potential source of glass sand, foundry sand and other uses like abrasive sand, sodium silicate, and silicon carbide.

The material was also tested for frac sand applications, and based on this initial evaluation, the presence of many clusters as well as the issue with the grain's roundness should be considered a stumbling block for its potential as a source of frac sand. Further tests are recommended to better evaluate this product by a specialized frac sand laboratory.

Considering the results described above, and the intention to produce just lump material for metallurgical industry, a process route for Langis silica was developed in order to achieve this goal.

Basically, this process consists of primary crushing with a jaw crusher, secondary crushing with a cone crusher; triple deck wet screening, a dewatering system for fines, and stockpiles for fines and final product. A block flow diagram of the process is presented in Figure 9 below.

Figure 9: Quarry process-flow block diagram



Source: Viridis.iQ, Caban Geoservices

1.5.5 Water Management

The uses of water at the Langis quarry are preliminarily summarized below:

- Human consumption;
- Road wetting and dust suppression inside the quarry;
- Cleaning of vehicles, equipment and installations;
- Processing plant operation (wet screening)

The table below summarizes the volumes of water required for the project and the destinations after use.

Table 8: Water uses and destination

Water Use	Water Source	Reference Flow rate	Destination after use
Human Consumption	Potable water – from water treatment companies	4.8 m³ per day	Sewage treatment and reuse
Road Wetting and Dust Suppression	Raw Water – from natural water source	40 m³ per day	Sedimentation pond and then natural water course
Cleaning of Vehicles, equipment and installations	Raw Water – from natural water source	20 m³ per day	Oil and water separator station and then natural water course
Processing Plant Operation	Raw Water – from natural water source	5.12 m³/h as make up water	This value is based on the losses in the process.

Source: Viridis.iQ GmbH

1.5.6 Quarry Closure and Reclamation

The complete CRP (Closure and Reclamation Plan) for the Langis quarry will take the following situations into consideration:

- Revegetation of the degraded areas: this point is related to the revegetation of all areas affected by quarrying activities;
- Physical stability of quarry components: this point is related to the design and analysis of quarry components and rock properties such as: compressive strength, shear strength, durability, hydraulic conductivity and others;
- Open pit workings: this point is related to pit reclamation including quarries, open cuts, and major trenches in areas where activity has occurred;
- Waste rock and overburden piles: this point is related to waste rock, overburden, and low-grade silica material that may be extracted in developing and operating the quarry and supporting infrastructure;
- Buildings and equipment: this point is related to all the required infrastructure to operate the quarry, such as the processing plant, fuel station and others;
- Infrastructure: this point is related to road care, electrical power supply systems, silica handling facilities and others;
- Landfill and waste disposal areas and;

  Water management systems: this point is related to components of a water management system including embankments, ditches and culverts, pipelines, and storage tanks associated with fresh water supply, diversion of uncontaminated water, and collection/treatment and discharge of non-compliant water.

1.6 Recovery Methods

1.6.1 Recovery Process

The Langis silica deposit will be quarried and recovered for use as a feedstock into a downstream silicon and ferrosilicon smelter in nearby Matane. For production of premium silicon grades, the Langis feedstock will most likely need to be blended with higher-purity silica obtained from an external source, while no blending is anticipated for the production of ferrosilicon. A more detailed discussion on expected silica blending requirements for the production of silicon is provided in Section 13.2.

When the smelter is operatonal, the targeted output for product quality should be driven by company strategy (such market entrance), the profitability of the production process for each specific product quality level, and the availability of raw materials to produce different grades of metallurgical silicon.

Based on the actual project phase and the information and assumptions of the PEA (Preliminary Economic Assessment), the final products from the smelter are projected to be:

Table 9: Typical product output matrix

Product	% of Targeted Output	Feasibility
1101 mgSi	None	Difficult, would require using 100% high-quality, externally sourced silica.
2202 mgSi	Some	Best target zone, but 2202 may require a higher ratio of externally sourced silica to Langis silica.
3303 mgSi	Majority	
441 mgSi	None	Not target outputs, but likely to be main products during “learning curve” period. Once operators are proficient, 441 and 553 output is generally due to process upsets.
553 mgSi		
Std. FeSi	Specialty FeSi grades such as “low Al” and “high purity” (low carbon) sell for a premium price and should be targeted over standard grade.	
Specialty FeSi		
Microsilica	Entire smelter output typically sold to Microsilica distributors.	

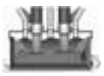
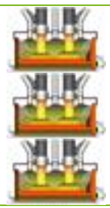
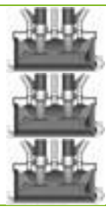
Source: Viridis.iQ GmbH

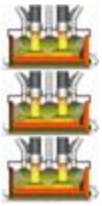
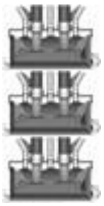
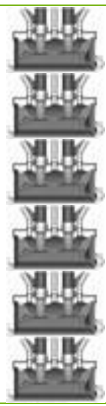
The current base-case for the project includes a flexible-furnace concept design named a Hybrid Flex Plant (HFP) by the authors. The HFP design principally means that the smelter is designed from the conceptual engineering stage with built-in capabilities to produce both silicon and ferrosilicon end products with any furnace. As both silicon and ferrosilicon end products have similar production process and raw materials, the added design parameters are not extensive and do not add significant costs from the equipment or process standpoint.

The HFP smelter is envisioned in two phases with the first phase of 3 Submerged Arc Electric Furnaces (SAFs) being installed at the identified site. The initial 3 furnace operation operating at 100% metallurgical silicon constitutes the underlying base-case for the PEA. The second phase would consist of an additional 3 SAFs.

The planned output of the HFP plant is described below, based on various production profiles:

Table 10: Phase 1 (3 SAF) versus Phase 2 (6 SAF)

	Flex Mix		**Flex MgSi (Base-case)**		**Flex FeSi**	
	mgSi	FeSi	mgSi	FeSi	mgSi	FeSi
Phase 1 only				none	none	
Annual output (primary)	mgSi	35,000	mgSi	50,000	mgSi	none
	FeSi	26,000	FeSi	none	FeSi	75,000
Annual output (secondary)	Silica fume	27,500	Silica fume	24,000	Silica fume	30,000

	Flex Mix		**Flex MgSi (Base-case)**		**Flex FeSi**	
	mgSi	FeSi	mgSi	FeSi	mgSi	FeSi
Phase 1 & 2				none	none	
Annual output (primary)	mgSi	70,000	mgSi	100,000	mgSi	none
	FeSi	52,000	FeSi	none	FeSi	150,000
Annual output (secondary)	Silica fume	55,000	Silica fume	48,000	Silica fume	60,000

Source: Viridis.iQ GmbH estimates

The smelter in Matane can produce silicon and ferrosilicon by a pyrometallurgical process that combines silica from the Langis quarry with a carbon source, iron ore (for ferrosilicon production only) and wood chips in a SAF (submerged arc furnace [1] or simply "furnace") in which these raw materials are smelted into silicon or ferrosilicon. Molten silicon or ferrosilicon

1 Schei, A. Tuset, J.K. and Tveit, H. Production of high silicon alloys. Trondheim: Tapir Forlag, 1998, pp. 13-20

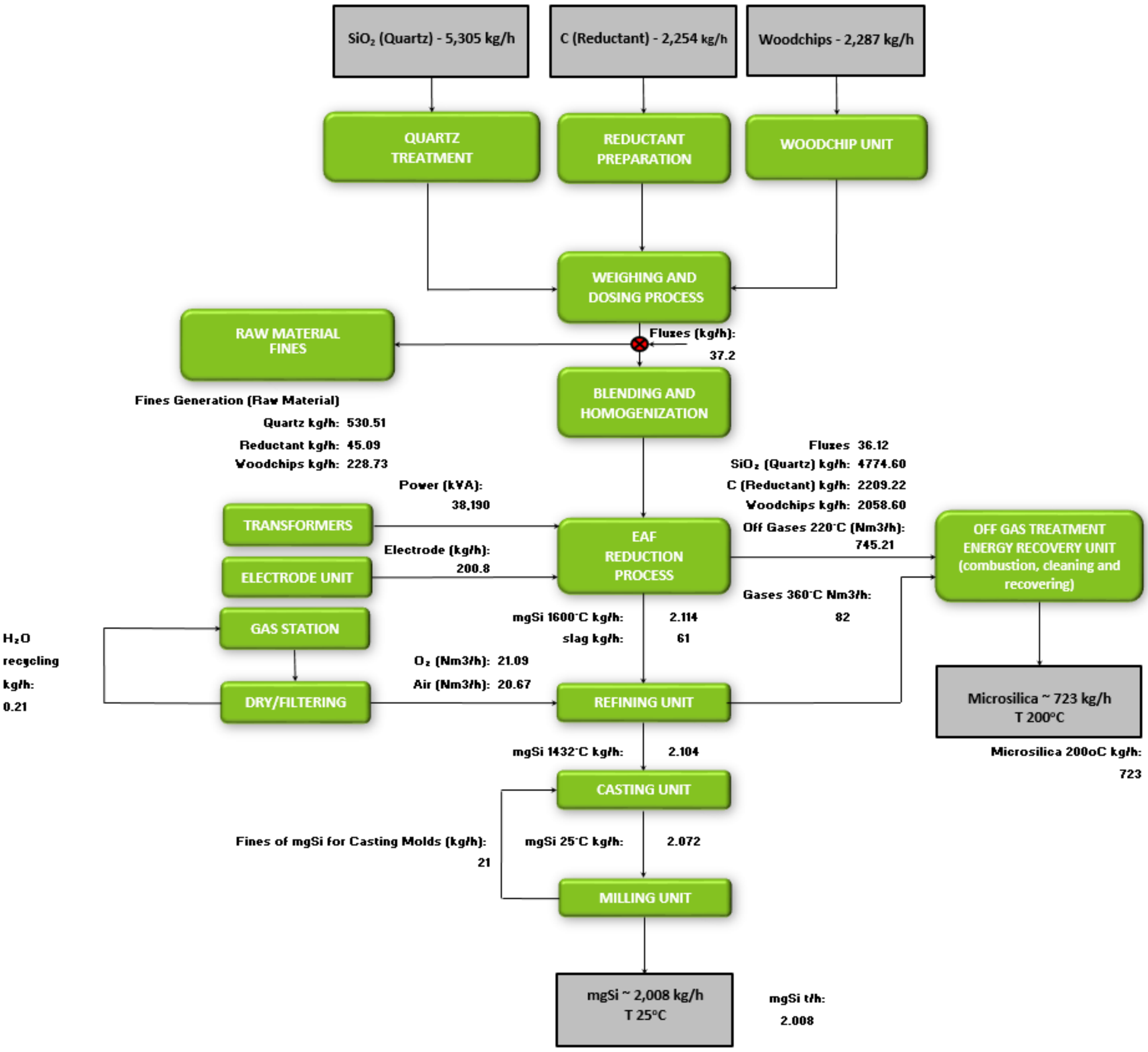
is tapped from the furnace into ladles, refined as necessary, and then poured into iron molds to cool and solidify into large ingots. After the ingots have cooled sufficiently they are removed from the mold and crushed into chunks or powder for sale.

The overall concept for the recovery plant for the Langis silica is showing below.

Figure 10: Silicon and ferrosilicon smelter for the recovery of Langis silica (Phase 1)

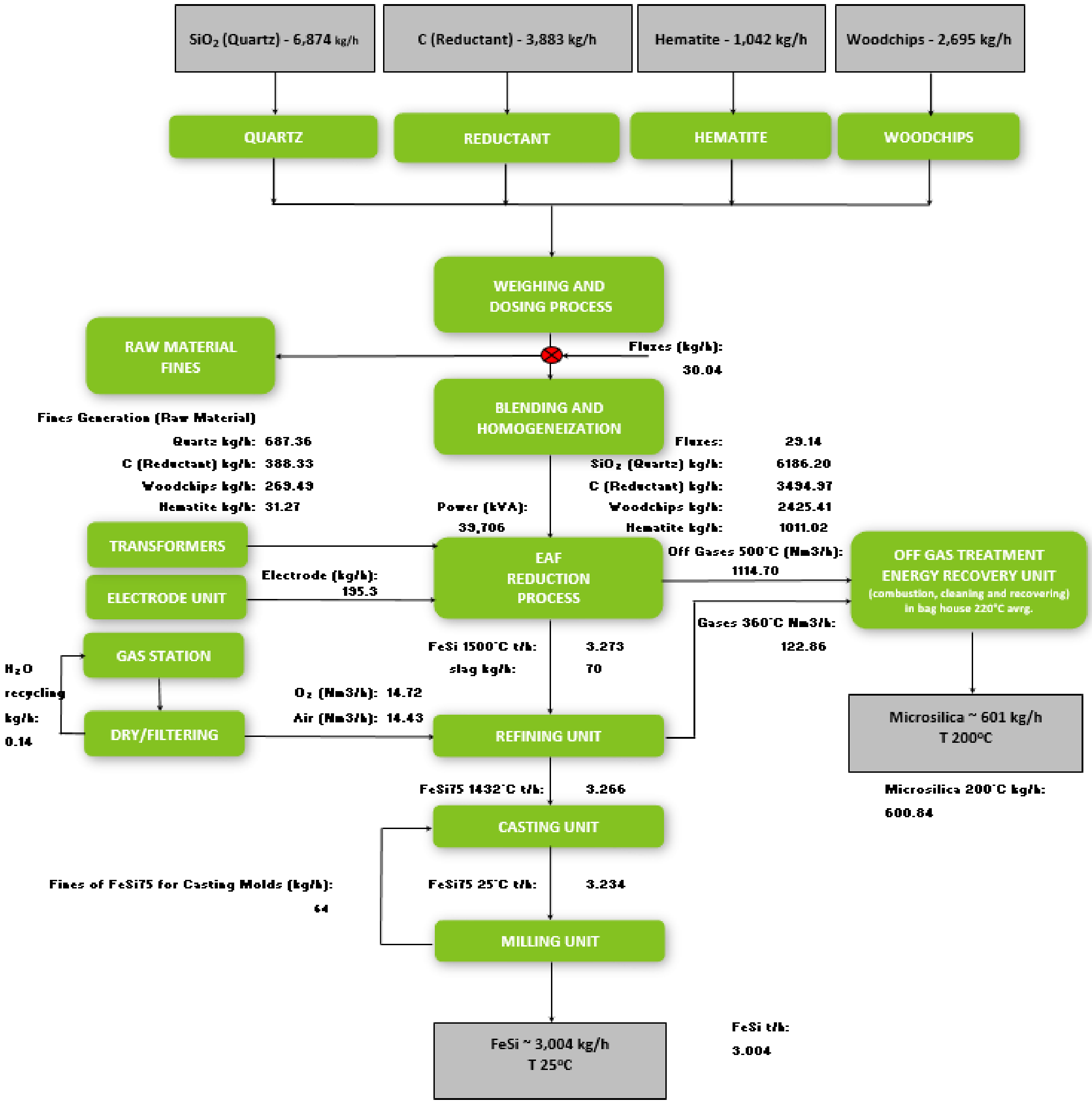
The following process flow charts are shown for both mgSi and FeSi production, including the respective mass flows, for each individual furnace.

Figure 11: mgSi process and mass flows on a "per furnace" basis



Source: Viridis.iQ GmbH estimates

Figure 12: FeSi process and mass flows on a "per furnace" basis



Source: Viridis.iQ GmbH estimates

1.6.2 Raw Materials

A variety of raw materials are used for the production of mgSi and FeSi.

To summarize the major raw-material requirements for mgSi:

- Carbon-containing reducing agents (coal and/or charcoal), also called as reductants
- Silicon dioxide (a.k.a. silica, quartz or quartzite)
- Wood chips (also a minor carbon source)
- Pre-baked electrodes
- Limestone
- Electricity

And for FeSi:

- Carbon-containing reducing agents (coal, charcoal or coke), also called as reductants
- Silicon dioxide (a.k.a. silica, quartz or quartzite)
- Iron source (hematite or scrap iron)
- Wood chips (also a minor carbon source)
- Self-baking electrode paste
- Limestone
- Electricity

1.6.3 Labor Resources

Year-round operation of the quarry was assumed in this Technical Report for the sake of simplicity. Other operating models such as seasonal operation and outsourcing to third parties are possible and should be explored at later project stages, however, these other models will not be considered in this work.

Table 11: Quarry labor plan

Qualification	Total
Quarry Manager	1
Mining Engineer	1
Geologist	1
Mining/Geology Technician	1
Safety Technician	1
Mechanical Technician	1
Electrical Technician	1
Electrical/Mechanical Maintenance	1
Operators	3
Drivers	3
Operation Auxiliars	1
Others	1
Total (Phase 1)	**16**

Source: Viridis.iQ GmbH

The smelter will require approx. 204 employees (Phase 1) of varying disciplines and skill sets. The overall labor plan for the smelter is shown in Table 12:

Table 12: Smelter labor plan

Qualification	Total
Management	3
General & Administration	6
Sales	4
Operator	136
Technician	36
Engineer	12
Administration	7
Total (Phase 1)	**204**

Source: Viridis.iQ GmbH

The smelter will work on a 4 shift model with 8 hours per shift. The main working hours are:

Management/Admin: Monday – Friday, 40 hours per week, 8am – 5pm
Production: Monday – Sunday, 40 hours per week, according to shift roster

No guarantee is given herein as to the number of permanent jobs that will be created either at the Langis quarry or the smelter. All labor and headcount assumptions are indicative only. Local labor regulation should be revisited in further project phases.

1.6.4 Power Requirements

The main power requirements (Phase 1) for the project are estimated in Table 13.

Table 13: Estimates of power requirement – Phase 1

Process	Transformer	Total Apparent Power (MVA)
Furnace 1	3 x 13.5 MVA	40.5
Furnace 2	3 x 13.5 MVA	40.5
Furnace 3	3 x 13.5 MVA	40.5
Auxiliary Equipment		3.0
Main Dust Collectors		8.5
Secondary Dust Collectors		1.0
Tapping and Casting Dust Collectors		1.5
Crushing and Handling		1.5
Cooling System		1.5
Raw Material System		2.0
Auxiliary Equipment		1.5
Offices, Lab and Other Buildings		0.75
Other System Loads		0.75
Total Plant Load	143.5 MVA expected **before** capacitors and filters; 103.2 MVA expected **after** capacitors and filters; 101.5 MW (<107 MW max.) with expected 0.98 power factor	

Source: Viridis.iQ GmbH estimates

1.7 Market Studies and Contract

The ferrosilicon and metallurgical silicon markets are highly disparate with little to no overlap in their end market applications. Both markets are subject to their own distinct drivers and share only one key similarity, namely the existence of large, under-utilized production capacities in China. As a counter effect to this build-up of capacities in China, non-Chinese producers have evolved to combat this reality by improving cost and technology efficiencies, economies of scale and the installation of trade barriers to keep Chinese production exports in check. Regulatory, environmental and labour costs in China constantly push the production costs higher in that country.

The metallurgical silicon market is a trade protected market that can benefit CME's factory in Canada by making premium ASP markets available with lower transportation cost. Regional demand for silicon is strong in North America and is increasing due to increasing demand for consumer goods, which are silicon based. Another supporting factor is the ongoing decentralization and decarbonisation of the energy-supply infrastructure that has led to continuous strong-growth in the demand for silicon based PV applications. It should be noted that market forces in the North American market are subject to regulatory influence as trade barriers keep ASPs higher than in other markets.

The ferrosilicon market in North American is tied to the volatility of the steel industry, which is currently in a correction phase. The prospects for ferrosilicon production might therefore be regarded as less attractive than those for silicon. Further market related investigations should be commenced at later project stages to assess the situation at that time. In that respect the flexibility of the project to serve diverse end market segments seems to be an advantage.

The described market dynamics lead to the conclusion that the HFP should start as a single product smelter dedicated to the production of metallurgical silicon. As a consequence, the technical possibility to smoothly transfer parts or even the entire capacity to ferrosilicon production is an option that can be drawn upon in later operation phases. The allocation of production capacity to different end-markets is a discretionary operator decision that will ultimately be based on future changes in the relative attractiveness of each end-product segment. Since such changes in market forces cannot be predicted with any accuracy, the commercial base-case presumes that the plant will only serve metallurgical silicon end-markets.

The proposed HFP concept allows CME the potential to reach meaningful scales that are higher than the average silicon production profile and thus increases the likelihood of maintaining its competitiveness over smaller factories. The potential expansion phase would only increase the scaling benefits over the competition and aid project viability.

1.8 Environmental and Social

1.8.1 Project Scope

The project under study is based on two distinct but complementary components: an open quarry and an industrial complex with the process plant.

The quarry consists mainly of the development and recovery of a silica deposit on the Langis Property. Quarry operations will supply the industrial complex aimed at producing both relatively pure silicon (98.5 - 99.5% metallurgical grade – mgSi) and ferrosilicon (FeSi). For the production of premium mgSi grades, Langis silica will need to be blended with silica obtained from an external source, while no blending is anticipated for the production of FeSi. A more detailed discussion on expected blending requirements is provided in Section 13.2. The complex will consist mainly in an electric arc smelting plant where silica is mixed with other raw materials such as coal, wood chips and iron ore for the production of mgSi and FeSi.

The two main project components have different locations, both in eastern Québec. The quarry is located in the municipality of Saint-Vianney while the plant is located in Matane. Still, the two components are close to each other, separated by about 40 km.

The study area for the quarry encompasses an area of about 240 ha, so that human features are taken into consideration. The study area of the smelting process plant encompasses an area of about 30 ha located in an industrial park within the municipality of Matane, about 2 km west of the city centre.

1.8.2 Regulatory Context

Both project components (quarry and process plant) fall under the same regime, the Québec Environmental Quality Act. Permits under the Québec jurisdiction as well as municipal by-laws will also apply to the project.

The quarry is subject to the Québec Environmental Quality Act (EQA), section 22, which requires a certificate of authorization. For the smelting plant, in addition to section 22 of the Québec Environmental Quality Act (EQA), the process plant component is also subject to section 31.1 of the EQA which states that the procedure for the evaluation and examination of impacts to the environment must be applied to such type of project.

While the authorization process for section 22 takes usually a few months, the timeline to go through an EIA usually requires about 18 to 24 months.

1.8.3 Baseline Studies

Baseline studies for the quarry have consisted in a desktop review of existing information and data, mainly from governmental sources, and a field survey performed in July 2015. Baseline biophysical and human features have been identified and are dominated with terrestrial vegetation.

Baseline studies for the process plant have consisted in a desktop review of existing information and data, mainly from governmental sources, and a field survey performed in October 2015. The site is dominated by terrestrial vegetation and wetlands.

1.8.4 Social and Community engagement

Since the EIA has not started, no activities pertaining to community and stakeholder engagement have been initiated yet. However, activities are planned and will include consultations and public hearing.

1.8.5 Issues and Potential Impacts

The construction of the quarry and process plant components and infrastructure and its operation could be the source of physical, biological and human issues affecting the flora and fauna of the project area.

However, in the case of the quarry, the remote location of the quarry contributes to the low level of impacts. Access roads are already in place. There are no residential or intensive human activities in the area that could interfere with the quarry location or operations. Measures will also be identified to control potential sources of disturbance and contamination.

For the smelting plant, since the environmental impact assessment is yet to be initiated, the analysis of issues and impacts is still to come. For such projects, environmental and social issues are mainly related to site location, project footprint, atmospheric emissions of contaminants and notably particulates, greenhouse gases emissions, water source location and consumption and regional economic spinoffs.

Mitigation measures will be identified to ensure that impacts are dealt with in order to minimize as much as possible their intensity, spread and duration. For key impacts that cannot be mitigated properly, compensation measures will be identified. Finally, monitoring and follow-up programs will be set up.

1.9 Commercial Analysis

1.9.1 Capital Budget

The preliminary assessment of the consolidated capital requirements for CME's integrated Hybrid Flex Plant project, which encompasses the development of the Langis silica deposit as well as the proposed first phase of the downstream smelter operation in Matane, is expected to amount to approximately US$278.8m within a range of +/-30%. Included in this budget is an estimated provision of US$31.4m for project management and non-capitalized development costs.

The working capital needs are not part of this budget estimate and are expected to be in an order of magnitude of US$23.8m under the steady-state base-case scenario. Some of the considered assumptions to estimate the Working Capital for the project were: the years 1 – 3 is the time period needed for the project construction, commissioning, ramp-up; the initial revenue are being generated during the 2nd semester of year 2 with ramp-up continuation to end of year 3; working capital based on 60 day cash conversion cycled as disclosed in the Section 22; calculations based on year 5 revenues as reference base-year in order to be flexible to model financial impacts of ramp-up delays into year 4 (in steady-state base-case revenues of years 4 and 5 are equal). These assumptions were considered in the Viridis.iQ financial model (Financing Planning tool). Hence, the overall capital requirements sum-up to a total project related capital need of approximately US$302.6 m (Table 14).

The capital requirements need to be provided in stages to fund further project development expenses with the lion's share expected to become due over a three year period once construction has been commenced at the two sites.

Table 14: Consolidated capital budget of CME's integrated quarry and HFP concept

Total capital budget estimate for CME's quarry and smelting operation	
Item	**Amount**
Quarry Equipment - upstream	848,478 USD
Smelter Equipment - downstream	74,340,959 USD
Total Equipment related Invest	**75,189,437 USD**
Quarry Infrastructure + Administrative Buildings - upstream	672,100 USD
Beneficiation Plant - upstream	2,607,000 USD
Building, Plant, Facility, Infrastructure & Auxiliaries - downstream	111,434,775 USD
Contingency	27,866,360 USD
IFC eligible as fixed investment	29,662,754 USD
Consolidated Balance-of-Plant excl. Furnace Technology Package	**172,242,990 USD**
Project management, non-capitalized development costs & insurances	31,386,153 USD
Total - Fixed Capital plus development expenses	**278,818,579 USD**
Working Capital Assumption (60 day cash conversion cycle)	23,758,003 USD
Total	**302,576,582 USD**

Source: Viridis.iQ GmbH estimates

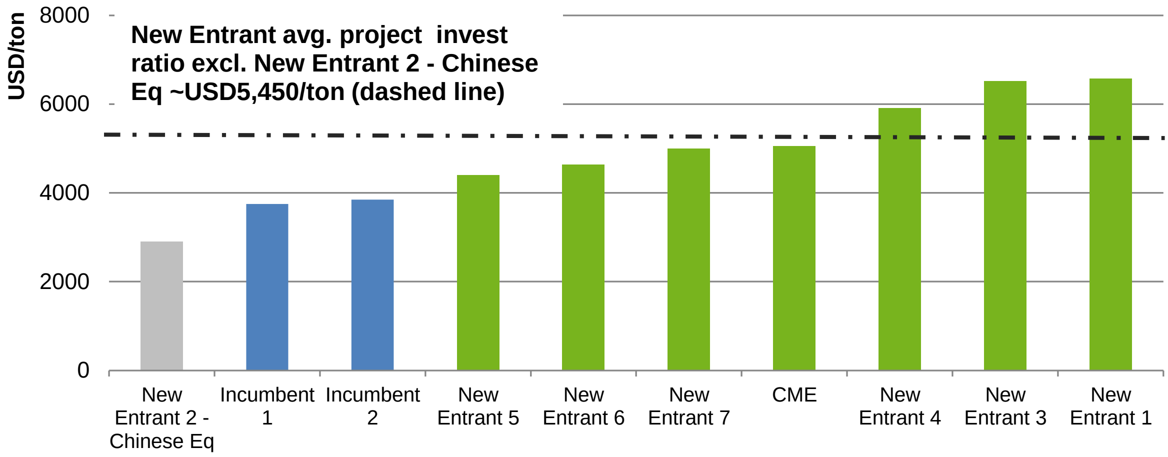
The upstream capital requirements for the development of the Langis quarry are expected to amount to approximately US$4.2m and thereby comprise only a minor part or about 1.5% of the total projected capital budget for fixed assets.

The vast majority of the capital will be invested in the proposed first phase 3 furnace HFP operation in Matane. Therefore, project chances and risks are clearly related to the silicon and ferrosilicon production part of the integrated project.

A relative comparison of the underlying investment coefficient for the development of the Greenfield HFP smelter in Matane with other new entrant Greenfield project announcements reveals that the potential site seems to exhibit some budgetary benefits. The investment coefficient is computed by a simple division of the projected investment budget by the plant's annualized production capacity.

The investment coefficient for the proposed CME smelter is estimated to come in at approximately US$5,050/ton, approximately 7% below the average investment coefficient from a peer-group of recently announced new entrant Greenfield silicon smelter projects of US$5,450/ton.

Figure 13: Greenfield project investment comparison by high-level project characteristics



Source: public announcements, Viridis.iQ GmbH[2]

The relative higher importance of the downstream silica processing operation is also reflected in the expected distribution of the human resource headcount. The upstream quarry operation is expected to deploy roughly 16 full-time employees while the downstream smelter is expected to operate with 204 full-time employees in the initial base-case.

1.9.2 Extraction and Production Costs

The initial, all-in extraction cost estimate for Langis silica is projected to be US$20.83/ton. This cost basis helps to improve downstream processing costs at the planned smelter site in Matane, as silica is planned to be provided on a cost-basis.

The benefit of this integrative aspect of the project set-up becomes clear when the expected transfer price of US$21.00/ton is compared to the quote for externally sourced silica, which stands at US$59.30/ton.[3]

The 100% mgSi base-case presumes a blending-ratio of 67% Langis silica with 33% external silica. The cost breakdown for Langis silica is depicted below:

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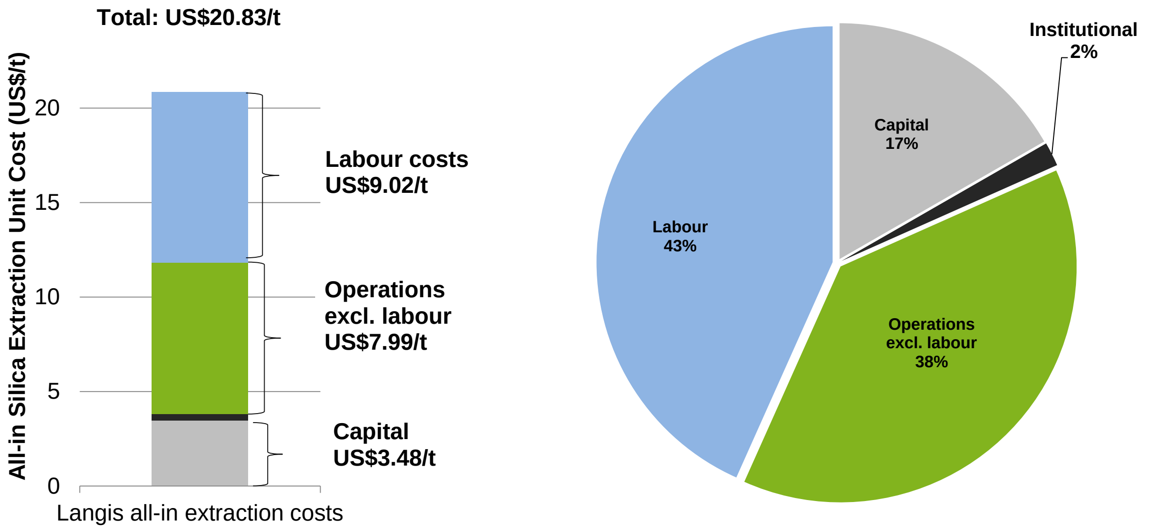
2 The data point "New Entrant 2 – Chinese Equipment" is an estimate done by Viridis.iQ GmbH. The QP signing for this part of the report has no access to the reference data base used for this value and assumes Viridis.iQ GmbH as responsible for this data point.

3 The internal transfer price does not take into account capital depreciation charges on fixed-assets and is therefore below the projected all-in extraction cost.

Figure 14: All-in unit extraction cost-breakdown - Langis silica

Absolute **Relative**

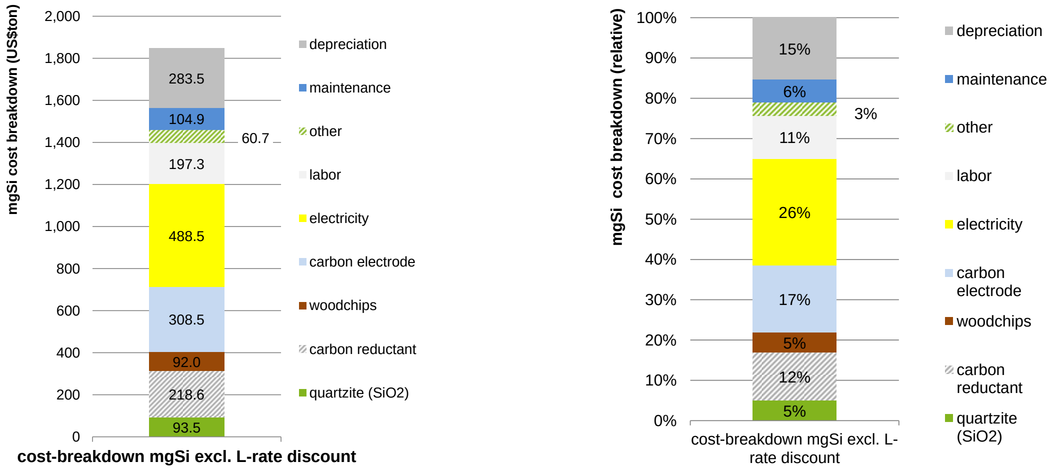


Source: Viridis.iQ GmbH estimates

The expected mgSi all-in production costs are US$1,847.50/ton once the smelter reaches full utilization and the L-rate discount has expired. An absolute and relative cost-breakdown for this case is provided below:

Figure 15: Absolute and relative cost-breakdown mgSi

Absolute cost-breakdown **Relative cost-breakdown**

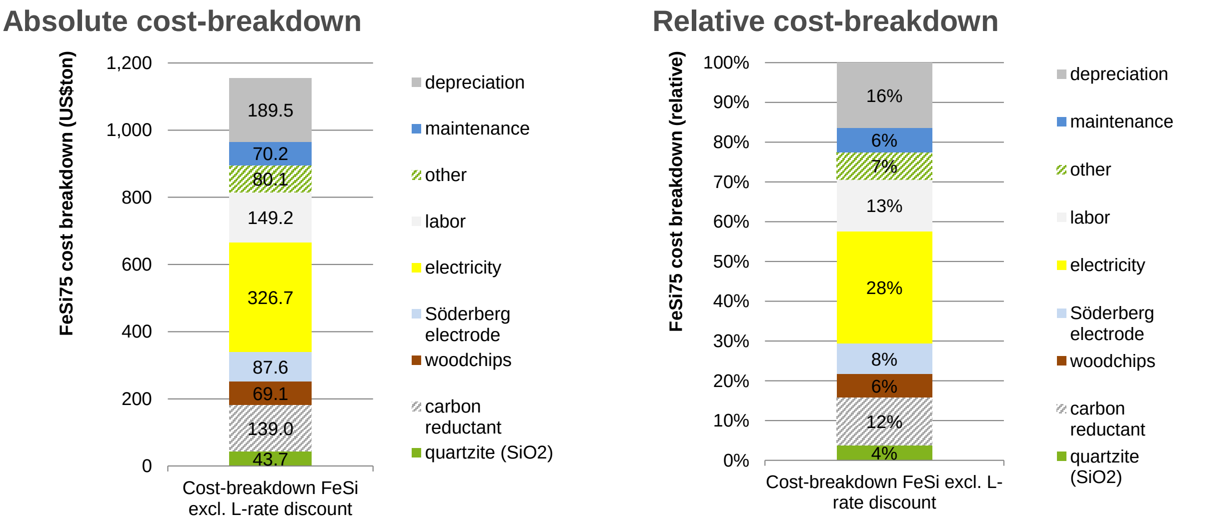


Source: Viridis.iQ GmbH estimates

For the case that the smelter will shift production to FeSi at a later-stage, a cost-breakdown is provided under the presumption that one furnace produces FeSi while the other two furnaces of the HFP plant continue with the production of metallurgical silicon.

The expected FeSi all-in production costs are US$1,155.10/ton once the smelter reaches full utilization and the L-rate discount has expired. An absolute and relative cost-breakdown for this case is provided below:

Figure 16: Absolute and relative cost-breakdown FeSi



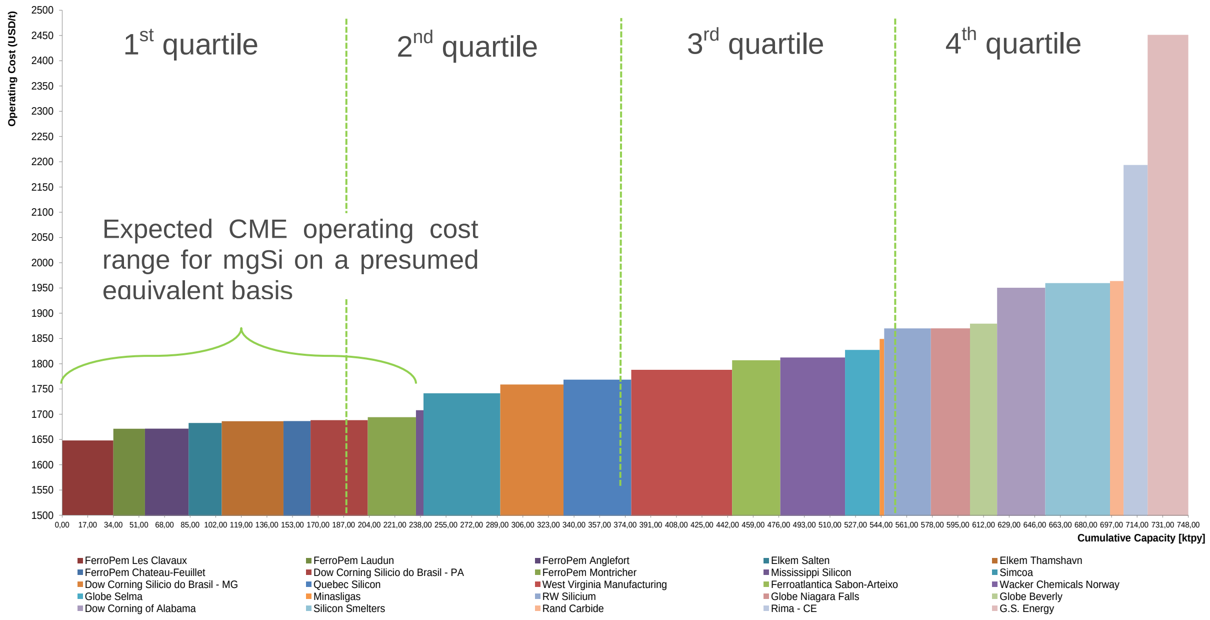
Source: Viridis.iQ GmbH estimates

Finding an equivalent basis for cash-production cost comparisons is not a straightforward scientific approach, as market research providers for industrial cost-stack curves use ambiguous cost definitions.

A comparison of the estimated mgSi cash-production cost of US$1,564.10/ton with a global peer-group of Western producers seems to indicate that the mgSi output of the HFP of CME would fall within the 1st to top 2nd quartile of this ranking.

A preliminary indication for both, mgSi and FeSi, with the latter having an estimated cash-production cost of US$965.60/ton, indicates that both estimated production costs for the smelter in Matane would have been well below the average ex-plant cash production costs for the respective product in the periods from 2007-2014. The utilized CRU cost-stack curve for comparison of mgSi cash-costs is shown below:

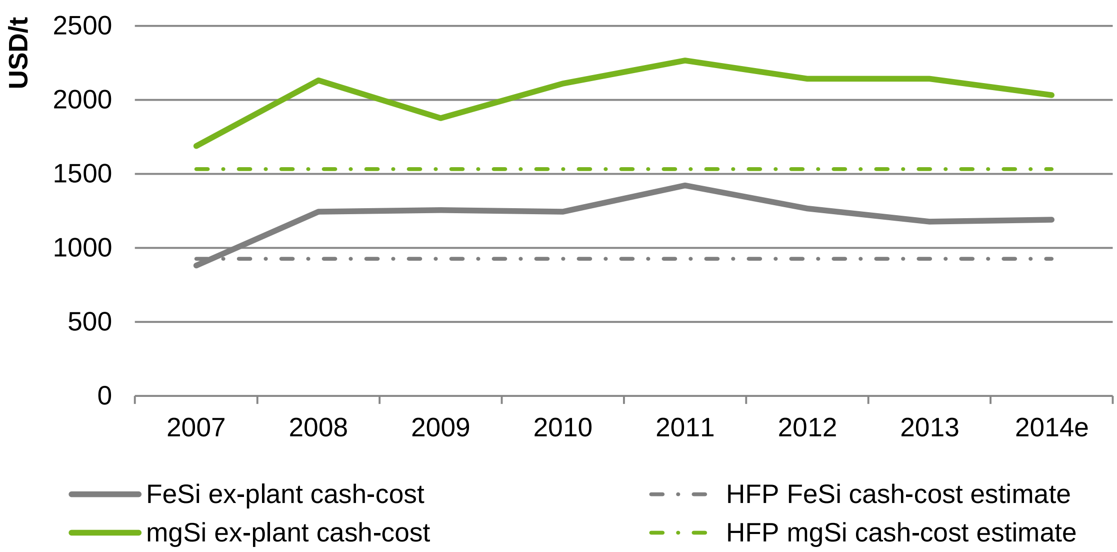
Figure 17: mgSi cost-stack curve – “operating costs”



Source: CRU (May 2015), Viridis.iQ GmbH estimates

The utilized Roskill average ex-plant cash-cost curve for the comparison of downstream cash-production costs for both, mgSi and FeSi is shown in the graph shown in Figure 18.

Figure 18: mgSi and FeSi cash-cost comparison



Source: Roskill 2014, Viridis.iQ GmbH estimates

1.9.3 Project Economics

The after-tax project IRR for the dynamic 100% mgSi base-case is 20.7% (NPV US$380.2m; wacc 7.3%), including a presumed terminal- or going-concern value. The expected project IRR can be classified as favourable for an industrial project in a mature and established industry.[4]

The project would benefit from existing trade barriers and a balanced North American mgSi market. In the event that trade barriers should not be extended at the next review the project would likely incur impairment charges if European prices remain at current levels. The dynamic base-case scenario presumes that North-American trade barriers will remain in-place for the foreseeable future.

The presented investment case is highly dependent on three major assumptions: First, that the current price levels for FeSi and mgSi constitute a good prediction for market prices in the USA once the smelter starts production. Second, that trade barriers will remain in place once the next round of regular duty reviews will be initiated by national trade authorities in target-markets. Third, that industry utilization levels in North America will remain high and therefore give a lower cost producer the chance to rapidly gain market shares. For further project phases, the market dynamics would also be revisited, in order to update values and assumptions.

The downstream part of the project benefits from low cost sourcing advantages achieved through the integration with the Langis silica deposit. The benefit from the integration of the silica quarry can be gauged by comparison of the expected internal transfer price of US$21.00/ton with the external silica price of US$59.30/ton.

The lower transfer price improves the integrated project IRR by approximately 100bps. An additional benefit comes from the low electricity rates and the L-rate discount offered by Hydro-Québec.

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4 For a more detailed review of the derivation of the dynamic base-case evaluation scenario and it's underlying assumptions based on the steady-state project evaluation, see Section 22.

The results of the three-case dynamic scenario analysis, which is further explained in Section 22, are presented in the table below:

Table 15: Results scenario analysis (after-tax)

	dynamic best-case	dynamic base-case	dynamic worst-case
NPV (USDk) excl. TV	364,488	260,847	-53,011
NPV (USDk) incl. TV	542,961	380,226	-39,349
wacc	7.3%	7.3%	7.3%
IRR excl. TV	22.3%	19.4%	4.5%
IRR incl. TV	23.6%	**20.7%**	5.9%
payback (yrs, mths)	6 yrs, 9 mths	7 yrs, 2 mths	13 yrs, 5 mths
- thereof investment period	months 0 - 36	months 0 - 36	months 0 - 36
- thereof recuperation period	months 18 - 81	months 18 - 86	months 18 - 161

Source: Viridis.iQ GmbH estimates

1.10 Recommendation

Detailed recommendations are provided in Section 26.

2 Introduction

The present work is a Technical Report, including a Pre Economic Assessment according to NI 43-101 standards, for the establishment of silica quarrying operation and a recovery operation in the St. Vianney Regional Municipality (MRC) of Matapedia, and in Matane, Québec, respectively.

2.1 Project Background

In 2013/14 Canadian Metals, Inc. (CSE: CME) began to characterize the Langis silica deposit with a drilling and testing campaign for the purposes of value-added transformation into silica-related downstream activities. This was then followed with further characterization activities, including metallurgical testing and environmental investigation to establish the foundation for a downstream silicon-based metals operation based in whole, or part, on the Langis deposit. CME began consideration of a ferrosilicon production facility on the scale of approximately 50,000 tons per annum, and then expanded the scope of the project to include production of metallurgical silicon as a diversification of risks. With the commencement in late 2015 of a Preliminary Economic Assessment (PEA) for a Mineral Reporting under NI 43-101 of the Langis deposit, the downstream value-added operation developed based on an integrated Hybrid Flex Plant concept, in which the recovery processing plant would be based on a flexible design to allow easier transitions between metallurgical silicon and ferrosilicon production. The current assumption is the smelter would commence with the 100% production of metallurgical silicon due to the more favorable market conditions with this project. However, since these two products (ferrosilicon and metallurgical silicon) are in distinct end markets the flexible concept allows for a balanced risk management approach based on the characteristics of the Langis deposit.

2.2 Project Description

The current base-case scenario is based on the model of using a blend of the silica recovered from the Langis deposit and externally sourced silica as a feedstock for the smelting production of metallurgical silicon, a key raw material for the production of silicones, photovoltaic devices and aluminum. A detailed discussion on expected silica blending requirements for the production of silicon is provided in Section 13.2.

The recovery process at the Langis quarry would consist of standard, open-pit quarrying techniques, including drilling, blasting, screening and washing processes to provide ready to use quartzite lump material to the smelting factory.

The Langis silica deposit would be a source of raw material for an industrial factory, located in Matane, Québec, for the downstream processing into these key materials. The quarry would supply approx. 97,000 tons per year of silica to be further processed, along with externally available silica, in the downstream recovery process.

The selected site for the base-case is a Greenfield site in Matane, Québec that would have rail and truck access to supply the factory with raw materials such as low-ash coal, wood chips, electrodes and other key materials. The location of the factory would allow for the distribution of the final products, ferrosilicon and metallurgical silicon, to the regional North American markets as well as the export market worldwide.

The current base-case for the project includes a flexible-furnace concept design named a Hybrid Flex Plant (HFP) by the authors. The HFP design principally means that the smelter is designed from the conceptual engineering stage with built-in capabilities to produce both silicon and ferrosilicon end products with any furnace. As both silicon and ferrosilicon end products have similar production process and raw materials, the added design parameters are not extensive and do not add significant costs from the equipment or process standpoint.

The HFP concept allows, from the initial design, the industrial infrastructure to permit an ease of transition from one product to another. The current base-case and flexible extremes to which the plant can be converted are shown in Table 51, as well as the end-product output that is associated with the various configurations.

Next to the principal authors employed with VIQ, this Technical Report and PEA integrated conclusions from the above-listed specialized reports. A complete and detailed list on the background of qualified persons contributing either directly or indirectly to the present assessment is given in Appendix XI.

2.3 Main PEA Findings

The Langis silica deposit is currently believed to be of sufficient quality and quantity to serve as a feedstock material for the downstream production of ferrosilicon and, in conjunction with externally available higher quality silica, for the production of metallurgical silicon. The quarry near the village of St-Vianney, established previously as a silica source, can adequately be used to supply the downstream metallurgical silicon and/or ferrosilicon smelter in Matane, Québec with measured resources of over 3.0 million tons. The industrial site in Matane selected for the base-case scenario is sufficient in size and infrastructure to serve as the location for the initial 3 submerged arc electric furnaces for the conversion of the silica to silicon based alloys. The site also is sufficient for a theoretical expansion phase of equal proportions and geographically located for favorable incoming and outgoing shipments of raw materials and end products. Specifically, end-product shipments to regional markets in the USA and Canada and export markets around the world. A comprehensive description of the main findings of the Preliminary Economic Assessment is presented in Section 25 (Interpretations and Conclusions) of this present document.

3 Reliance on Experts

Viridis.iQ GmbH (VIQ) has reviewed and considered data and information provided by Canadian Metals Inc, with respect to the Langis Property, and has used the data and information to develop conclusions for this Technical Report.

VIQ has also relied on data and information provided by the City of Matane, with respect to the base-case and Rock-Tenn alternative smelter sites, to draw conclusions regarding the development of those sites into a viable location for a silicon and ferrosilicon smelter.

VIQ has not carried out any independent geological work on either the Langis Property or potential smelter sites. VIQ has relied upon data and information provided by GENIVAR and Consultations Géo-Logic through Canadian Metals Inc to create relevant sections for the quarry operation of this Technical Report. QP Étienne Forbes of Geoforbes Services, retained by GENIVAR in the past and Canadian Metals Inc currently, has visited the Langis Property numerous times and was responsible for conducting both the 2013 and 2015 core-drilling programs. QP Alain Tremblay, with Consultations Géo-Logic, oversaw the preparation of geological sections of this Technical Report.

ViQ has not carried out any independent environmental assessments of the Langis Property or the base-case smelter site in the City of Matane, instead relying on data and information provided by Biofila and their QP, Caroline Lachance, through Canadian Metals Inc to create Section 20 of this Technical Report.

VIQ has not carried out any independent metallurgical evaluations of silica from the Langis Property, that information being provided by MINTEK through Canadian Metals Inc for use in this Technical Report.

VIQ has not verified any documents or agreements under which Canadian Metals Inc holds title to the Langis Property.

Caban Geoservices has provided ViQ with some data and information on the mining plan for the Langis Property. The quarry-related input has been used for the determination of the cost-based internal silica transfer price.

Certain interpretation on institutional aspects such as corporate tax treatments, possible tax benefit schemes and applicable state fees on quarry operation were provided by Canadian

Metals Inc to ViQ. A detailed tax due-diligence has not been conducted at this stage and is planned to be awarded to an accredited Canadian tax advisory firm in the next project development stages.

Some of the figures and tables for this report were reproduced or derived from current or historical reports written on the property and supplied to Viridis.iQ by Canadian Metals, Consultations Géo-Logic, Caban Geoservices and others. In cases where photographs, figures or tables were supplied by other entities, they are referenced below the inserted item.

All sections of this Technical Report that are not covered by a QP named above have been reviewed and approved by ViQ QP Valdiney Domingos.

4 Property Description and Location

4.1 Langis Silica Deposit

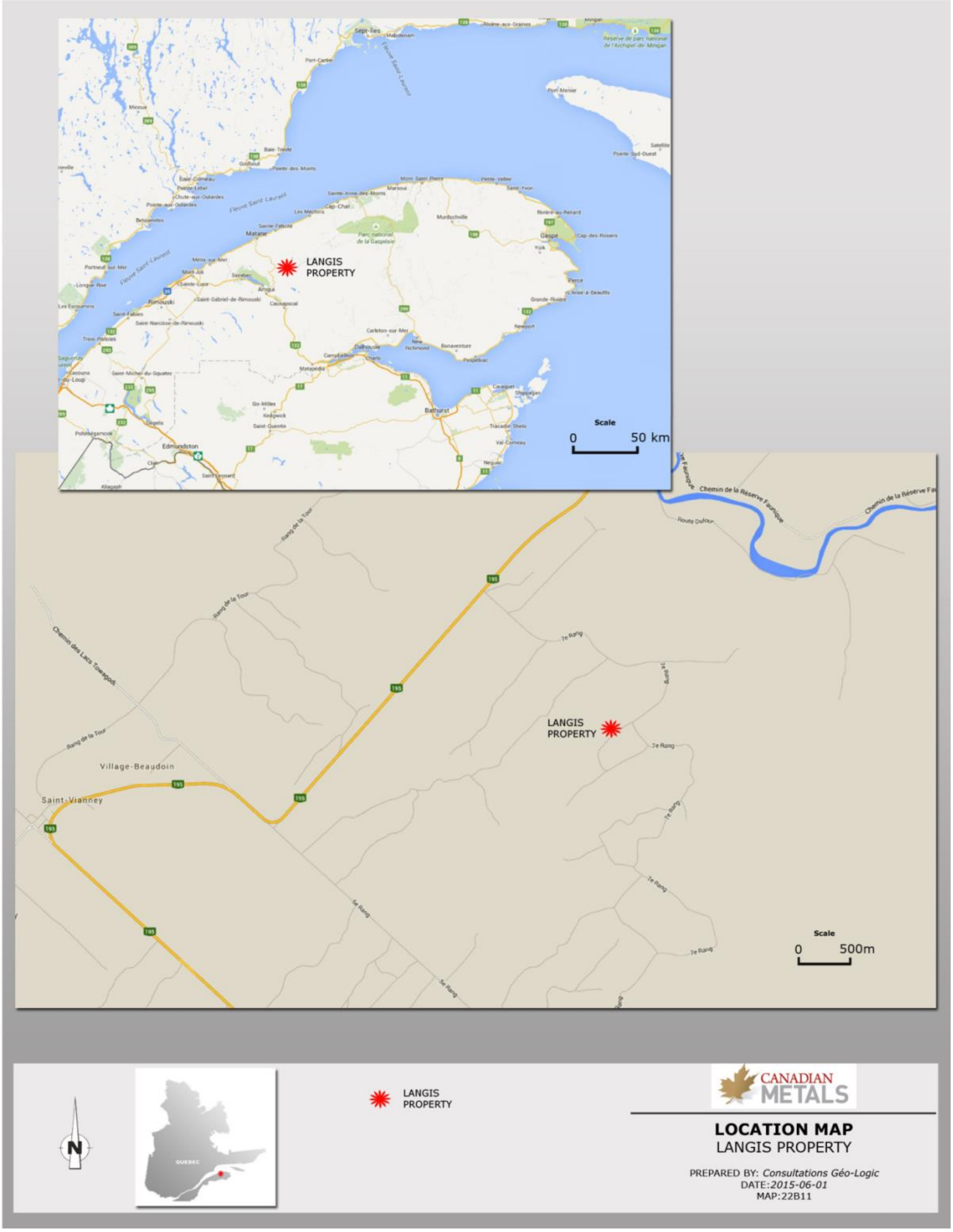
4.1.1 Area

The Langis Property is made up of four regular map designated claims, or MDC, totalling a surface area of 227.62 ha.

4.1.2 Location

The Property is located within NTS map sheet 22B11, in the Matapedia Region of the Gaspe Peninsula of Québec, within the Regional Municipality (MRC) of Matapedia (Figure 19). The geographic center of the Property is at approximately latitude 48° 37’ 30” N and longitude 67° 20’ 00” W or 5,387,200 N and 622,800 E in UTM zone 19. The Property covers parts of Ranges VI and VII of Langis Township.

Figure 19: Location map



4.1.3 Type of Mineral Tenure

The Langis claims are registered in the name of Canadian Metals Inc. (100%) and are currently valid till July 11, 2017, with plenty of accrued works for subsequent renewal. The claims are described in Table 16 and illustrated in Figure 20. The claims cover both private and crown lands. These are shown in Figure 20.

Table 16: Claims description

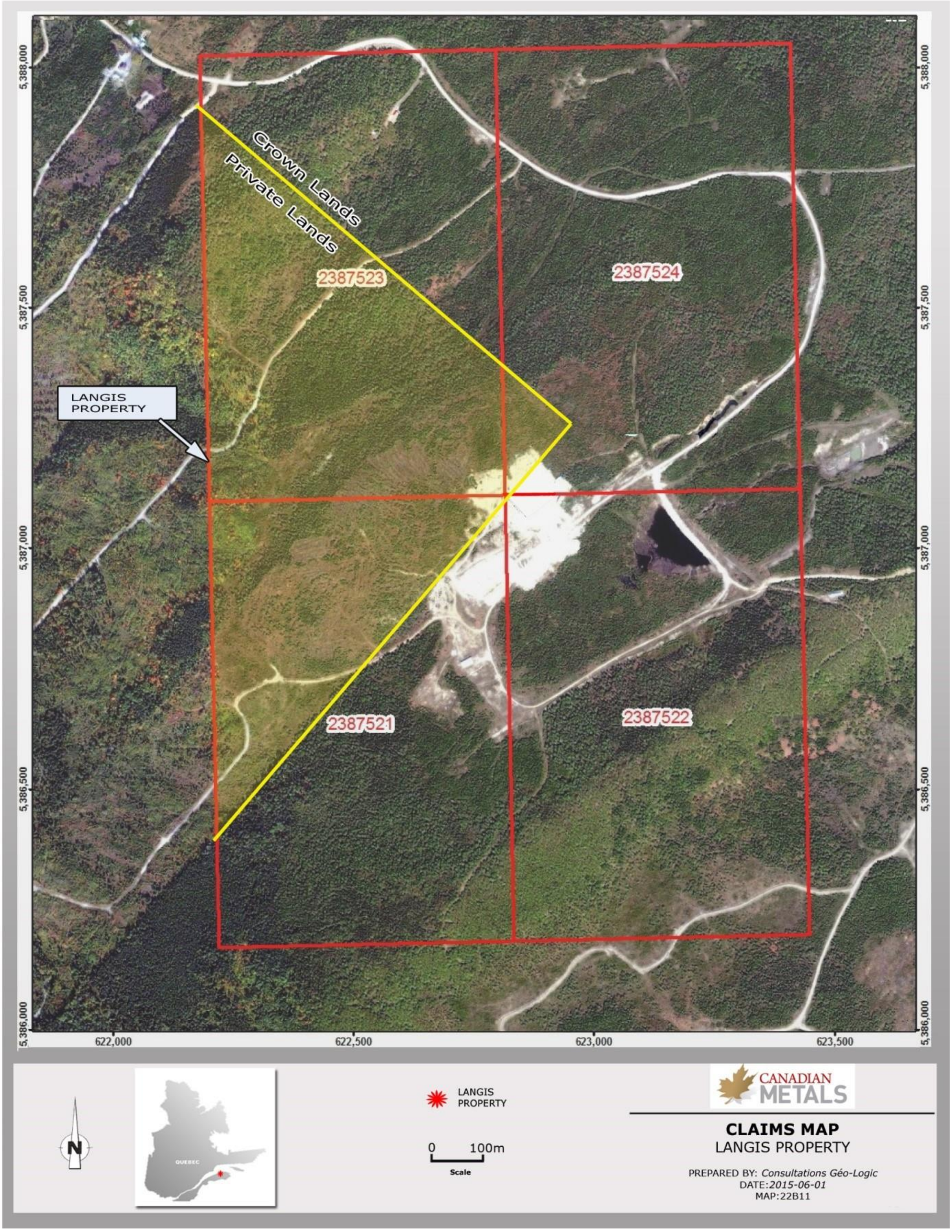
CDC number	Area (ha)	Registration Date	Expiration Date	Accrued work	Work required	Rights payable
2387521	56.91	July 12, 2013	July 11,2017	--	CAD 780.00	CAD 59.67
2387522	56.91	July 12, 2013	July 11,2017	--	CAD 780.00	CAD 59.67
2387523	56.90	July 12, 2013	July 11,2017	--	CAD 780.00	CAD 59.67
2387524	56.90	July 12, 2013	July 11,2017	CAD 153,075.62	CAD 780.00	CAD 59.67
Total:	227.62			CAD 153,075.62	CAD 3,120.00	CAD 238.68

Source: Consultations Géo-Logic

4.1.4 Nature and Extent of the Issuer’s Titles

The Property was bought from 9285-3696 Québec Inc. in September 2013 for 2,500,000 Canadian Metals Inc. warrants and the royalties describe below. Canadian Metals Inc. now holds 100% of the mining claims.

Figure 20: Claims map



4.1.5 Royalties

Production from the Property is subject to a 3% net smelter return (NSR) according to Canadian Metals Inc. This is a 3% surcharge on smelter EBIT in proportion to the Langis silica supply relative to the overall silica consumption. In the financial model this charge is treated as a cash operating expense. This contractual obligation by Canadian Metals Inc is payable to 9285-3696 Québec Inc.

4.1.6 Environmental Liabilities

To the knowledge of the authors, there are no environmental liabilities pertaining to the Langis property, as reported by Canadian Metals Inc.

4.1.7 Required Permits

The only permit required to carry out exploration work on the property is the usual permit for forestry management. The company must also respect all the environmental laws applicable to the type of work done. On private lands, if exploration activities need to be carried out, agreement must be negotiated with surface rights owners. The exploration activities completed to date and planned in the near future are on crown lands.

4.2 Proposed Greenfield Smelter Site in Matane (Base-case)

Various industrial sites for the proposed project are available in the Québec region and a total of 4 sites were reviewed previously by BBA, an independent Canadian consulting and engineering firm. These 4 sites were considered by the authors at this stage:

- The Langis silica deposit site located in St-Vianney
- An industrial zone site in the city of Matane
- A site in the Bécancour industrial park
- A site in the Baie-Comeau industrial park (a specific site was not identified)

The 4 sites were compared by BBA in terms of site infrastructure, logistics and electrical parameters. The chosen site for the base-case is the industrial site in Matane.

4.2.1 Location

The Municipality of Matane, with a population of about 14,500 inhabitants, is about 40 km northwest of the quarry site by Highway 195. The base-case site for the silicon and ferrosilicon smelter is located in Matane, Québec, along Highway 132 (Avenue du Phare) in the southwest part of the city.

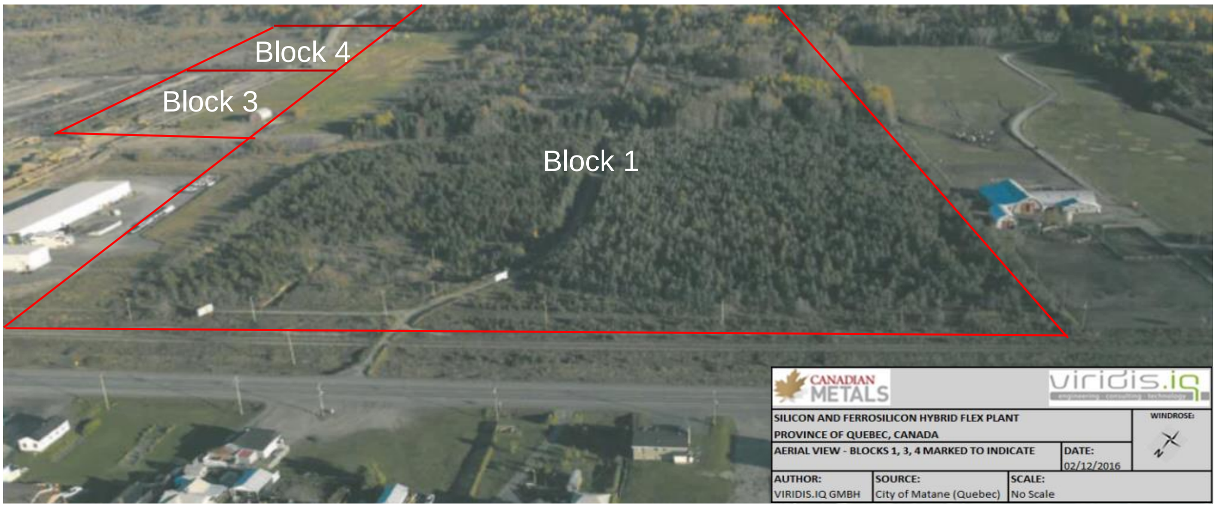
The selected site for the base-case is located 3 km from the port of Matane which can be used to transport some raw materials and end products.

Figure 21: Aerial view, City of Matane, Québec

4.2.2 Area

The site is an industrial zoned site and is virtually untouched in its natural form and heavily wooded with one gravel access road on the southwest side of the property. The main railway line crosses the site and power and sewer/water services are available.

Figure 22: Base-case site – Industrial zone, Matane



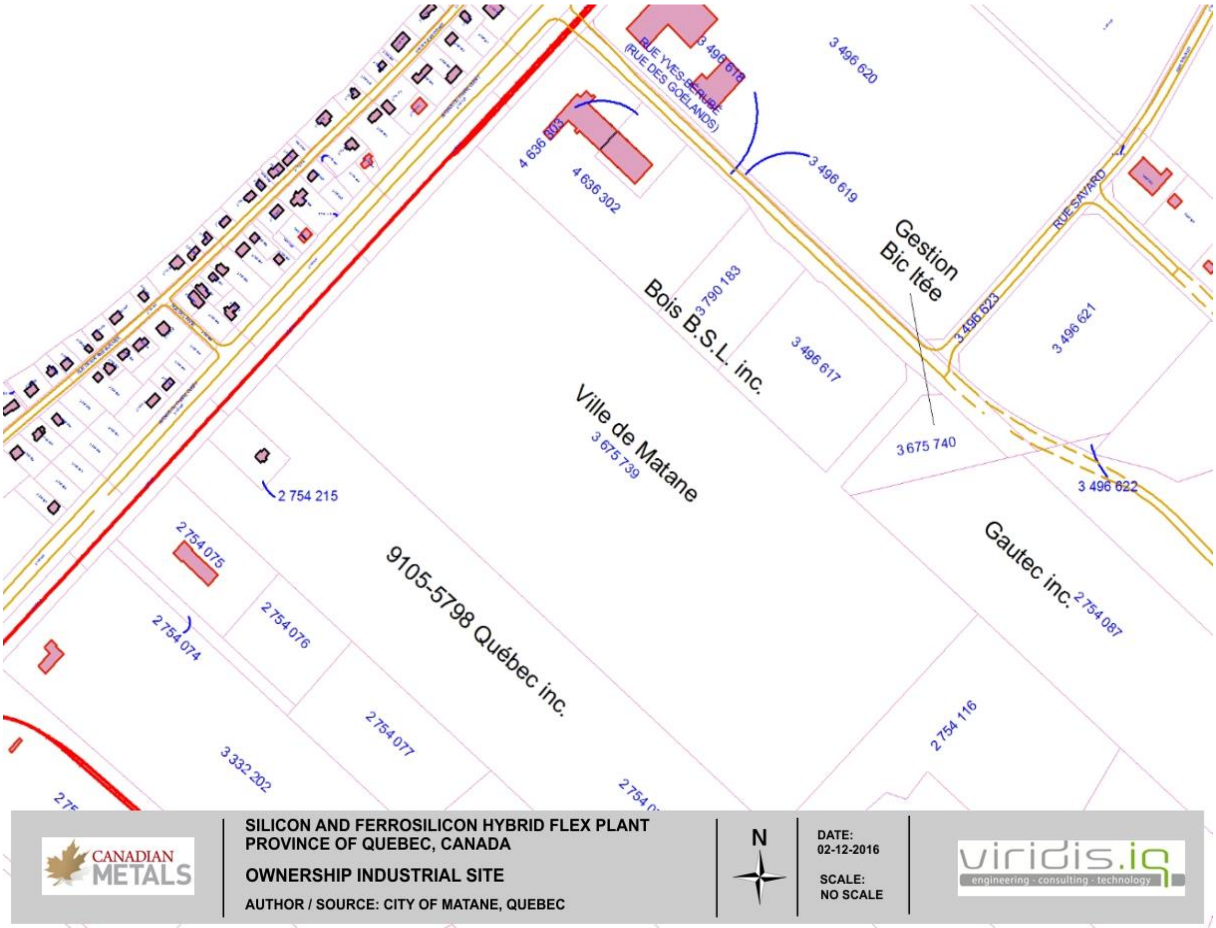
The site consists of 3 blocks of property (1, 3 & 4) that can be used for the project. Preliminary assessments indicate that the entire property is suitable for the proposed downstream project. The three blocks comprise an area of approximately 372,500 m^2, as shown in Figure 23:

Figure 23: Top view – industrial site, Matane

4.2.3 Description and Ownership

The main block 1 of the industrial site is currently owned by the municipality of Matane and is situated between various other private and industrial lots along the bank of the St Lawrence River. Blocks 3 and 4 need to be acquired from private owners which, according to City officials, are not likely to be a show-stopper as the relevant plots has been idled or not been developed at all.

Figure 24: Ownership of industrial site



4.2.4 License, Permits and Environment

The site is listed in the “Grille des spécifications” of the municipality of Matane as “21” and the activities permitted on the site are described under the “Zonage – Les usages et les Bâtiments principaux” as those of heavy industry (“Industrie manufacturière loured”) such as:

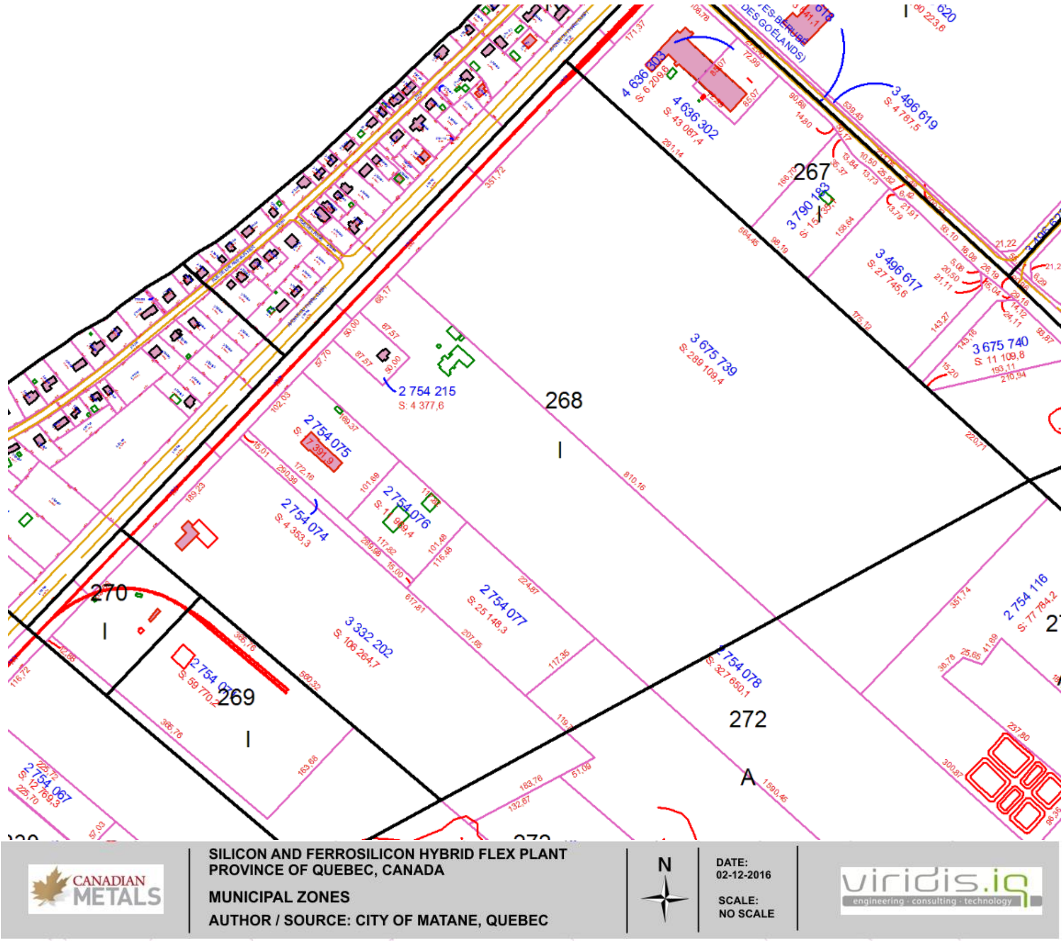
“The preparation of raw and semi-finished and for the manufacture and processing of raw, semi-finished or finished products that require large spaces, outdoor areas storage and a variety of infrastructure (water and sewer, railroad, seaport, etc.). The method of preparation, manufacturing or processing generates constraints (noise, odor, dust, etc.) and / or requires the use of dangerous substances and / or involves potentially dangerous treatment having environmental consequences. Included in this class the following uses:

(…) 2151. Industrie sidérurgiques[5]

Industrie du ferro-alliage”[6]

The various blocks of property considered in this work are listed in the municipality of Matane as zones 267 and 268.

Figure 25: Municipal zones



5 Generally meaning industries requiring the transformation of ores into metals

6 Ferroalloy industry

5 Accessibility, Climate, Local Resources, Infrastructure and Physiography

5.1 Topography, Elevation, Vegetation and Drainage

The Langis Property is located in gently rolling Appalachian terrain. A set of elongate hills oriented NNE dominates the topography. These are transected along the northeast by the valley of the Matane River. In the Property area and immediate surroundings elevations range from a high of 279 meters to a low of 90 meters along the river. In the area of interest around the quarry there is a gentle incline from the access road at 240 meters up to just over 250 meters proceeding across the hill toward the northwest.

The Property is largely forest covered. It is a mixed forest of hardwoods such as maple, poplar, and birch mixed with conifers such as white spruce, white pine, and cedar. Locally there are areas of second or third growth dominated by alders and other low bushes.

5.2 Accessibility

The Langis property is easily road accessible via paved provincial Highway 195 and a gravel road in good condition (Range VII road). The Property is 20 km by road (Highway 195) from the town of Amqui which is on Highway 132 and is the administrative center of the Matapedia Regional County Municipality (RCM). It is also accessible via Highway 195 from Highway 132 at the town of Matane, a distance of 40 km. The Langis gravel access road runs southeast from Highway 195, from a point 5 km to the east of the village of St.-Vianney. From this intersection it is 2.5 km to the existing quarry on the Langis Property.

Amqui is served by the CNR and has a train station with passenger services.

Access to the Property may be hampered by winter snow accumulation; but the Property can be accessed year-round if required.

5.3 Infrastructure

The Langis property is 20 km by paved road from Amqui. CN Rail passes through Amqui connecting it to the ports of Rimouski and Campbellton, New Brunswick. A rail siding would need to be permitted and built at Amqui in order to ship silica product by rail.

The Property is 40 km by paved road from the port of Matane. Matane is presently considered to be the most likely trans-shipment point for the potential silica product. These transportation alternatives will require research in the next phase of work. The road to the existing quarry area from the paved highway appears to be in good condition and may be capable of handling heavy truck traffic, although upgrading may be required.

The town of Amqui has a population of approximately 6,300, while the town of Matane has a population of approximately 14,500. There are several smaller villages in the area of the Property such as St.-Vianney, St.-Tharcisius, Saint-Rene-de-Matane, Lac-au-Saumon and Val-Brillant. There is an adequate skill set locally available for the operation of a silica quarry.

The nearest source of a continuous substantial flow of fresh water is a stream called Riviere Tamagodi 1.8 km to the east-southeast of the present Langis quarry. This stream flows northeastward into the Matane River. The Matane River flows northward into the St. Lawrence estuary. The Riviere Tamagodi can potentially be used as a source of raw water for activities such as pit wetting, car and equipment washing, workshops and fuel station washing, and for the processing plant, but this is a topic to be addressed in later project stages and the Environmental Impact Analysis (EIA). Since water from Riviere Tamagodi and the Matane River cannot be considered as potable for human consumption, the water demand for this purpose can be supplied by water trucks from the nearest water treatment company.

High voltage transmission lines cross the Property 300 meters south of the existing quarry. A transformer substation is already installed 400 meters southwest of the existing quarry.

At the southwest corner of the existing quarry, foundations for a loading and crushing facility, installed by an earlier operator, appear to be in good condition. About 400 meters southwest of the existing quarry there is a 25 meter X 12 meter finished concrete floor that might be suitable for a new building. There is adequate flat area for storage of waste rock from a quarrying operation.

5.4 Climate

The closest climate data collection site is the Mont-Joli airport, which is located 64 km straight west of the Property. Mont-Joli climate is somewhat modified due to the seashore location, the most obvious difference being stronger winds. Climate data for Mont Joli is shown in Figure 26.

Figure 26: Climatic data for Mont-Joli from Environment Canada

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Record high °C (°F)	13 (55)	12.4 (54.3)	20 (68)	29.1 (84.4)	31.4 (88.5)	33.3 (91.9)	35.9 (96.6)	33.3 (91.9)	32.2 (90)	26.7 (80.1)	21.8 (71.2)	16.7 (62.1)	35.9 (96.6)
Average high °C (°F)	−7.8 (18)	−6.5 (20.3)	−0.9 (30.4)	5.4 (41.7)	13.5 (56.3)	19.8 (67.6)	22.7 (72.9)	21.3 (70.3)	16 (61)	9.1 (48.4)	2.4 (36.3)	−4.6 (23.7)	7.5 (45.5)
Daily mean °C (°F)	−12.3 (9.9)	−10.9 (12.4)	−5 (23)	1.6 (34.9)	8.5 (47.3)	14.4 (57.9)	17.5 (63.5)	16.2 (61.2)	11.4 (52.5)	5.3 (41.5)	−0.7 (30.7)	−8.3 (17.1)	3.1 (37.6)
Average low °C (°F)	−16.7 (1.9)	−15.2 (4.6)	−9 (16)	−2.3 (27.9)	3.4 (38.1)	9 (48)	12.2 (54)	11.1 (52)	6.7 (44.1)	1.5 (34.7)	−3.8 (25.2)	−12 (10)	−1.3 (29.7)
Record low °C (°F)	−33.3 (−27.9)	−31.1 (−24)	−29.4 (−20.9)	−19.9 (−3.8)	−12.2 (10)	−1.1 (30)	0.8 (33.4)	1.8 (35.2)	−5 (23)	−8.4 (16.9)	−18.3 (−0.9)	−30.6 (−23.1)	−33.3 (−27.9)
Precipitation mm (inches)	79.8 (3.142)	59.1 (2.327)	69.4 (2.732)	63.3 (2.492)	84 (3.31)	73.5 (2.894)	84.6 (3.331)	89.1 (3.508)	77.8 (3.063)	83.9 (3.303)	77.7 (3.059)	86.7 (3.413)	928.9 (36.571)

Source: Consultations Géo-Logic

The Property experiences a cool, humid, continental climate with warm summers and cold winters. Average July high temperature (Mont Joli) is 22.7°C, with an average low of 12.2°C. The average January high temperature (Mont Joli) is -7.8°C, with an average low of -16.7°C. The spring-summer-fall period begins in early May and ends in the latter part of October. Winter conditions normally endure from early November through to late April. Precipitation is moderate and is fairly evenly distributed throughout the year. Snowfall accumulations of up to 3 meters are common by mid-March.

6 History

6.1 General Geologic Survey

Geological mapping and exploration of the Langis area of the Matapedia Region by governmental institutions began with the investigations of Logan in 1844 and his assistant Murray in 1846. A.P. Low visited the area in 1884, followed by Ells in 1885, and by L. W. Bailey and W. McInnes in 1884-85, the latter work resulting in the first geological map of the region (1888). Later, during the period 1928-31 F. J Alcock and G. W. Crickney surveyed the area as part of a larger regional mapping effort. Following up on that work, J. W. Laverdière and L. G. Morin concentrated specifically on the Langis area. A general geological map of the Matapedia-Matane region was completed by E. Aubert de la Rue in 1941 (RG 009). Still later, H. W. McGerrigle completed geological work in the area as part of his compilation of the Geological Map of the Gaspé Peninsula (1953).

Mapping the Region Rimouski-Matapedia, J. Beland touched on the area in 1960 (RP 430). Subsequently detailed geological mapping of the Cuoq-Langis Area of Matane and Matapedia Counties was completed by N. C. Ollerenshaw in 1961 and 1967 (RG121). This is the most comprehensive geological mapping of the Property area. Synthesis of the area into Gaspe regional geology was completed by Slivitsky et al (1991). Stratigraphy was reinterpreted and integrated into the Appalachian geology by Brisebois and Morin (2003). Most pertinent publications are listed in Section 27 (References) herein.

6.2 Exploration Geological Work

The first known examination and comprehensive report on the sandstones of Langis and Tessier Townships was done by R. A. Marleau (1979) for Placement Appalaches Inc. (GM 36008). This work on the Val-Brillant Sandstone was entitled a “Comparative study in regard to other commercial silica/sands of north-eastern America”. At the time, the sandstone was seen as a possible source for high purity sands.

Uniquartz Inc. took over the project from Placement Appalaches Inc. in 1982. Between August and October of 1982 an extensive diamond drilling program was completed on Langis and neighbouring Tessier sandstone occurrences. A total of 4,102.5 feet (1,243.1 meters) was drilled in twenty-five drill holes, eight of which, totalling 1,568 feet (475.1 meters), were completed on the Langis Property. The drilling was supervised by R. A. Marleau of Services Geotechniques Shickshocks Inc (SGS) for Uniquartz Inc. (GM 40477).

Subsequently (1983) extensive physical and geochemical testing was completed on the drill core in order to determine the physical and geochemical characteristics of the sandstones of the Langis and Tessier deposits. This testing comprised over 3,000 feet (914.4 meters) of drill core in sample lengths of 10 feet (3.05 meters). Additionally two (2) bulk samples were taken, each weighing more than 2.5 tons.

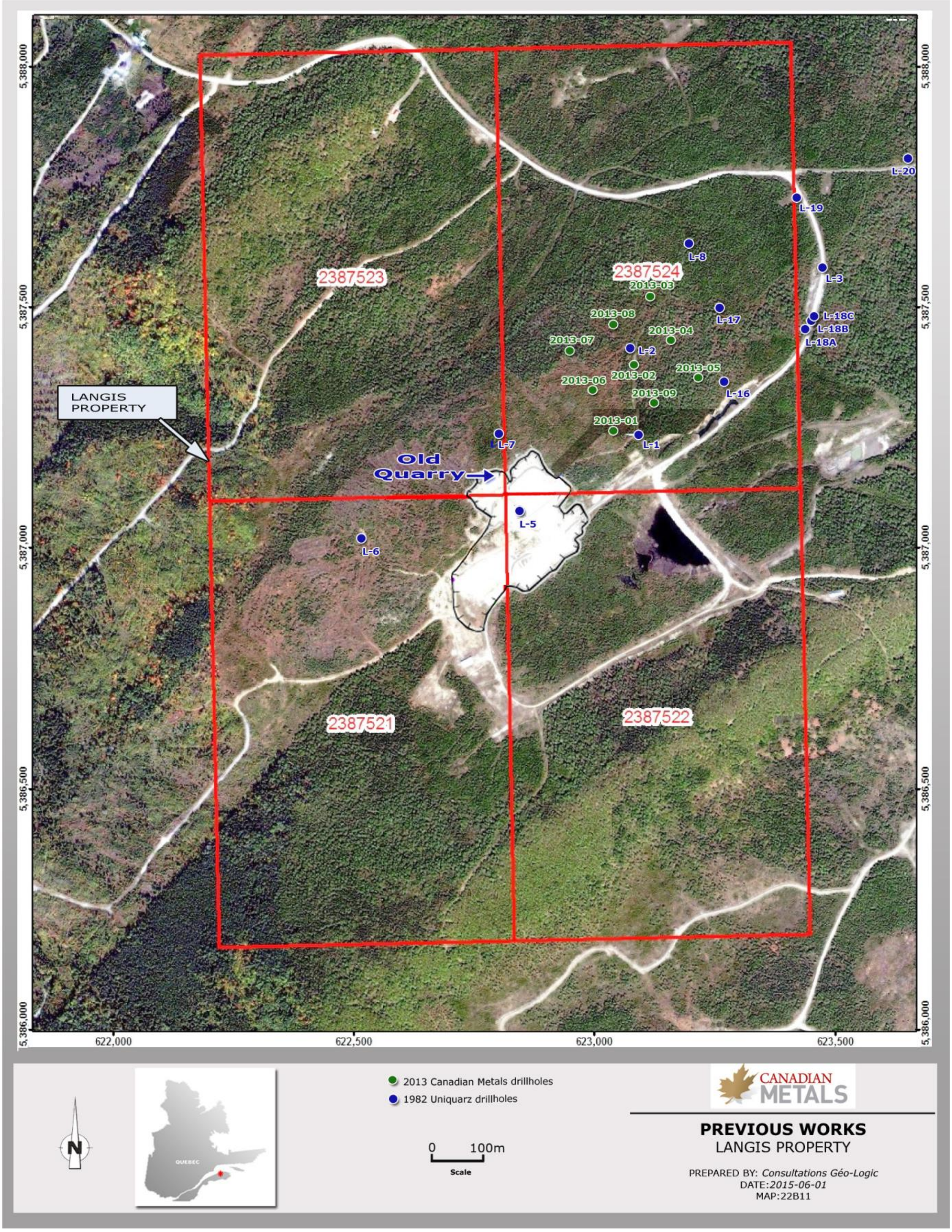
In 1984, historical tonnages published in the environmental study of the project (GM 42387) stand at 25.0 million tons at average grades of 0.11% Fe_2O_3 and 0.41% Al_2O_3, including 9.0 million tons at 0.11 Fe_2O_3 and 0.26 Al_2O_3 or 5.7 million tons at 0.05 Fe_2O_3 and 0.183 Al_2O_3. SiO_2 grade calculated from 750 feet (228.6 meters) of core is reported to be 99.25% but no details are given about this result. This was classified as an Indicated Reserve. *This resource is historic in nature and does not meet the requirements for Resource categorization as set out in NI 43-101.*

In 1985, Uniquartz obtained the Mining Lease no 741. In December 1985 and May 1986, a total of some 22,000 tons of lump silica was send to Norway and Iceland for testing into existing ferrosilicon facilities. The results were positive and 150,000 tons per year supply contract was signed. In 1988, start-up of the project was estimated at CAD 8.4 million. There are no records about difficulties encountered but the project never went into production.

In 1991, the site was visited by a geologist of the Québec ministry of Natural Resources during a quarries inventory. No activities were noted at the time but the site was identified as Aristide Brousseau & Fils. Apparently, material was extracted intermittently after 1991 for construction purposes. Several elongate piles of crushed waste rock remain to the west of the quarry. From the actual size of the quarry, it is estimated that around 400,000 tons have been extracted from the site over the years.

Figure 27 presents a compilation of historical works completed on the Langis property and Section 27 lists all private and public documents available for the Langis property.

Figure 27: Previous works on the Langis property



6.3 Historical Resources

Historical resources were calculated for the first time at the end of 1982, following a drilling program carried out by Uniquartz Inc. on the Langis Property and its northeastern extension in Tessier as both were part of the same property at the time. From early 1983, historical resources on the Langis portion of the Property were established (GM 42388) by Uniquartz at:

Millions short tons	% SiO_2	% Fe_2O_3	% Al_2O_3	
25.5	not specified	0.12	0.41	including
9.0	not specified	0.11	0.26	including
5.7	not specified	0.05	0.183	

In the public documents made available by Uniquartz, the only reference to the SiO_2% is from GM 42387 where an average grade of 99.25% has been calculated from 750 feet (228.6 meters) of core.

Authors have not done sufficient work to classify the historical estimates as current resources and the owner of the property is not treating the historical estimate as current mineral resources.

The historical resources were calculated with the following parameters (GM 42387 pp 20-26):

Tonnages (short tons) were estimated using interpreted vertical cross-sections. The silica was interpretd on one section from the drill results giving a surface in square feet. These surfaces were divided by the density which has been established at 13.3 cubic feet per short ton (2.46 g/cm^3); there is no record of how the density was calculated. This generated a tonnage per horizontal foot. Finally, the horizontal tonnage was multiplied by a width of 900 feet (274.3 meters) to produce the final tonnages for the deposit.

The notion of tonnage per vertical or horizontal foot is no longer in use to calculate resources. Moreover, in this particular case the limits of the deposit in a plane view form an elongate polygon that thins out gradually at both ends. The 900 feet (274.3 meters) width appears to correspond to the widest part of the deposit.

For all the categories of sandstone estimated and reported above, the thickness of the sandstone includes the overburden. Some tonnage must therefore be removed to account for this. For the 25.5Mt categories, 8% of the tonnage was removed from the estimate to take into consideration the worst parts of the sandstone, namely those showing a deep red hematization, as their distinctive colour would permit this material to be discarded in a selective mining approach. Comparing the data base, the Uniquartz resources calculation looks to be overestimated.

6.4 Production

Some 22,000 short tons are known to have been extracted in 1985-86 and sent to Europe to test the conformity of the material in ferrosilicon processes. Additional tonnages estimated at some 400,000 short tons were extracted from the site to produce aggregates for construction and concrete.

6.5 Historical Drilling

Historical drilling has been described in Section 6.2. The Uniquartz drilling program of 1982 was located on the actual Langis Property and its extension to the east. Table 17, presents the complete data about the 1982 program. Only the holes highlighted in green are located on the current Langis Property. All historical holes are shown in blue in Figure 27.

Table 17: Historical drilling

Hole	UTM zone 19			MTM zone 6		Hole data		
	North	East		North	East	Direction	Dip	Length (ft)
L-1	5 387 235	623 094		5 387 519	317 367	0	-80	410
L-2	5 387 411	623 078		5 387 695	317 355		-90	210
L-3	5 387 580	623 476		5 387 856	317 756		-90	178
L-4	5 387 801	624 143		5 388 064	318 427		-90	104
L-5	5 387 080	622 847		5 387 369	317 118		-90	118
L-6	5 387 024	622 514		5 387 319	316 783		-90	148
L-7	5 387 242	622 804		5 387 531	317 077		-90	151
L-8	5 387 628	623 200		5 387 910	317 481		-90	190
L-9	5 387 930	624 274		5 388 190	318 561		-90	188
L-10	5 388 018	624 396		5 388 276	318 684		-90	211,5
L-11	5 388 125	624 530		5 388 380	318 821		-90	230
L-12	5 388 239	624 651		5 388 492	318 944		-90	251
L-13	5 388 231	624 519		5 388 487	318 812	0	-75	127
L-14	5 388 142	624 415		5 388 400	318 706		-90	82
L-15	5 388 057	624 289		5 388 317	318 578	0	-75	199
L-16	5 387 348	623 275		5 387 628	317 550		-90	120
L-17	5 387 498	623 264		5 387 778	317 542		-90	230
L-18 A	5 387 454	623 445		5 387 731	317 722	0	-75	112
L-18 B	5 387 468	623 452		5 387 745	317 730		nd	24
L-18 C	5 387 478	623 457		5 387 755	317 735		nd	52
L-19	5 387 723	622 425		5 388 000	317 708		-90	233
L-20	5 387 803	623 657		5 388 076	317 941		-90	229
L-21	5 387 842	623 881		5 388 110	318 166		-90	87
L-22 A	5 388 416	624 881		5 388 664	319 177	293	-44	50
L-22 B	5 388 416	624 881		5 388 664	319 177	293	-44	253
Station A	5 387 247	622 946		5 387 534	317 219			

Holes located on the actual Langis Property

Source: Uniquartz

7 Geological Setting and Mineralization

7.1 General Geologic Setting

The Matapedia Region forms part of the Appalachian Geological Province, which stretches from Alabama, in the southeast USA, to Newfoundland. The portion of this Province that hosts the rocks pertinent to this Report is known as the Connecticut Valley – Gaspe Synclinorium (CVGS). These rocks were folded, faulted, intruded and weakly metamorphosed during what is generally known as the Appalachian Orogeny. In Matapedia, the Appalachian Orogeny is comprised of three main episodes of deformation:

- The Taconic Orogeny in late Ordovician time, when a volcanic island arc collided with the pre-existing Laurentia landmass as the Iapetus Ocean closed;
- The Acadian Orogeny of mid-Devonian time, whence the micro-continents Avalonia and Baltica abutted the accreted margins of the Laurentian continental mass;
- The Alleghenian Orogeny in the Permo-Carboniferous, when the continent of Gondwana accreted onto and joined with Laurentia to form Pangea.

The latter phase is of minor importance in Matapedia and Gaspe. However, a fourth phase, known as the Salinian (Silurian in age) is interpreted to have been a significant tectonic event in this region.

The CVGS rocks of Matapedia-Gaspe are of Ordovician-Silurian-Devonian ages (see Figure 28, below). They are comprised of wackes and conglomerates of the Cabano Group (Ordovician to Silurian in age), overlain by the Siluro-Devonian rocks of the Chaleurs Group, which are overlain concordantly to locally discordantly by Devonian limestones and sandstones of the Gaspe Group. The north contact of the CVGS is a discordant, tectonic contact with Cambro-Ordovician rocks to the north. Dominant structural features are kilometric, northeast-trending fold axes and major thrust faults.

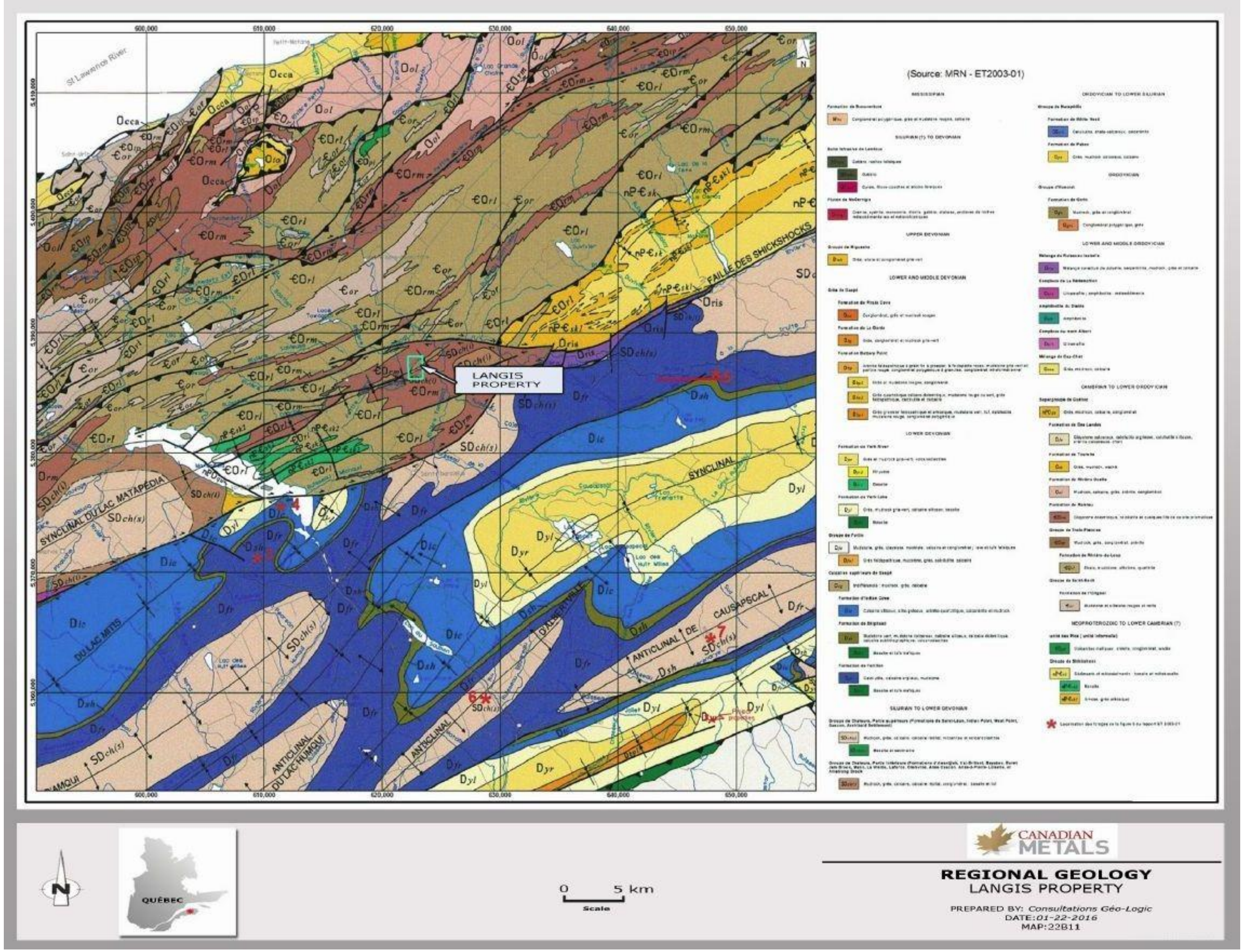
The stratigraphy of the Chaleurs Group is, from bottom to top, the green shales of the Awantjish Formation, the white to pink quartz arenites of the Val-Brillant Formation, the limestones of the Sayabec Formation, and the mudstones and siltstones of the Saint-Leon Formation.

The Val-Brillant Formation forms two distinct north and south arms. The north arm, in which the Langis Property is located, extends 97 km from Mont Comi, just south of Mont-Joli, to Lac

Matane. It is affected by thrust faulting and lateral faulting. The south arm is exposed along a 40 km strike length from Esprit-Saint and Grand Lac Neigette. NE-SW oriented synclines and anticlines characterize this area.

The quartz arenites of the Val-Brillant Formation are highly siliceous. It appears as thick (up to several meters) white layers, and locally, pink to mauve layers which result from hematite discoloration. The grains are medium-fine, well-rounded, and welded together with silica cement (GM 57849). Total thickness is usually 40 to 60 meters. These highly siliceous sandstones constitute the exploration target at the Langis Project.

Figure 28: Regional geology



7.2 Local Geology

In the area of the Property, the Siluro-Devonian Val-Brillant sandstones form a prominent remnant of a formerly more extensive sandstones cover. They average approximately 60 meters in thickness and sit conformably upon green shales of the Awantjish Formation, themselves overlying unconformably dolomitic claystones and calcilutites of the Ordovician Romieu Formation.

The Val-Brillant sandstone is conformably overlain by a 10 meters thick layer of arenaceous dolomites which transition into true dolomites at the top. These formations are interpreted to form the core of a shallow syncline that extends southeast to Lac Matapedia and is truncated to the northeast by the Shickshock Fault at the Matane River (ET 2003-01). The Val-Brillant sandstones are of multi-cyclic origins, having been derived from older sandstones situated to the north. They formed in a marine, well-oxygenated environment along an active but stable Silurian seashore.

Drilling by Uniquartz in 1982 and by Canadian Metals Inc. in 2013-15 defined a local stratigraphy of the Val-Brillant sandstones Formation in the Langis-Tessier area.

Formation	Unit	Average thickness	Sites
Sayabec	Dolomitic sandstone		Tessier
Val-Brillant	Upper Sandstone	13 meters	Tessier
	Intermediate Sandstone	20 meters	Tessier-Langis
	Red bedded Sandstone	15 meters	Tessier-Langis
	Lower Sandstone	20 meters	Tessier-Langis
	Transition Sandstone	10 meters	Tessier-Langis
Awantjish	Mudstone-argillite		Tessier-Langis

Upper, Intermediate and Lower sandstones are the most attractive units for industrial uses as they are all white to pale grey highly siliceous horizons with obviously low impurities. Descriptions from various Uniquartz and Canadian Metals drill logs and observations by Forbes, É. and Charlton, J. are as follows:

Upper Sandstone: is pale greyish-white with local pink patches. It is fine grained and forms thin beds (maximum 0.6 meter) that are characterized by laminae and cross-bedding. The grey colour signifies higher clay content than that of the Intermediate Sandstone. It is 10 – 15 meters thick, absent in the Langis area.

Intermediate Sandstone: is medium-grained, with well-rounded to sub-rounded grains and has a white sugary appearance. Finer grained layers are interstratified. Individual beds are up to 2 meters in thickness. Sporadic pink colouration is not necessarily indicative of an abundance of iron, but is normally caused by occurrences of particles of hematite. Bedding planes and fractures are commonly marked by paper-thin layers of hematite. It is a 12 – 20 meters thick unit that is locally present in the upper parts of the Langis area.

Lower White Sandstone: is generally fine-grained and exhibits less pink discolouration than the Intermediate Sandstone. It is comprised of sandstone beds from a few centimetres up to 0.5 meters in thickness. It is more compacted than the Upper and Intermediate Sandstones. In the Langis area, the Lower Sandstone is up generally around 20-22 meters but it is reported that locally, it may reach 60 meters in thickness where it abuts the east-west fault along the southern sandstone limit.

7.3 Geology of the Deposit

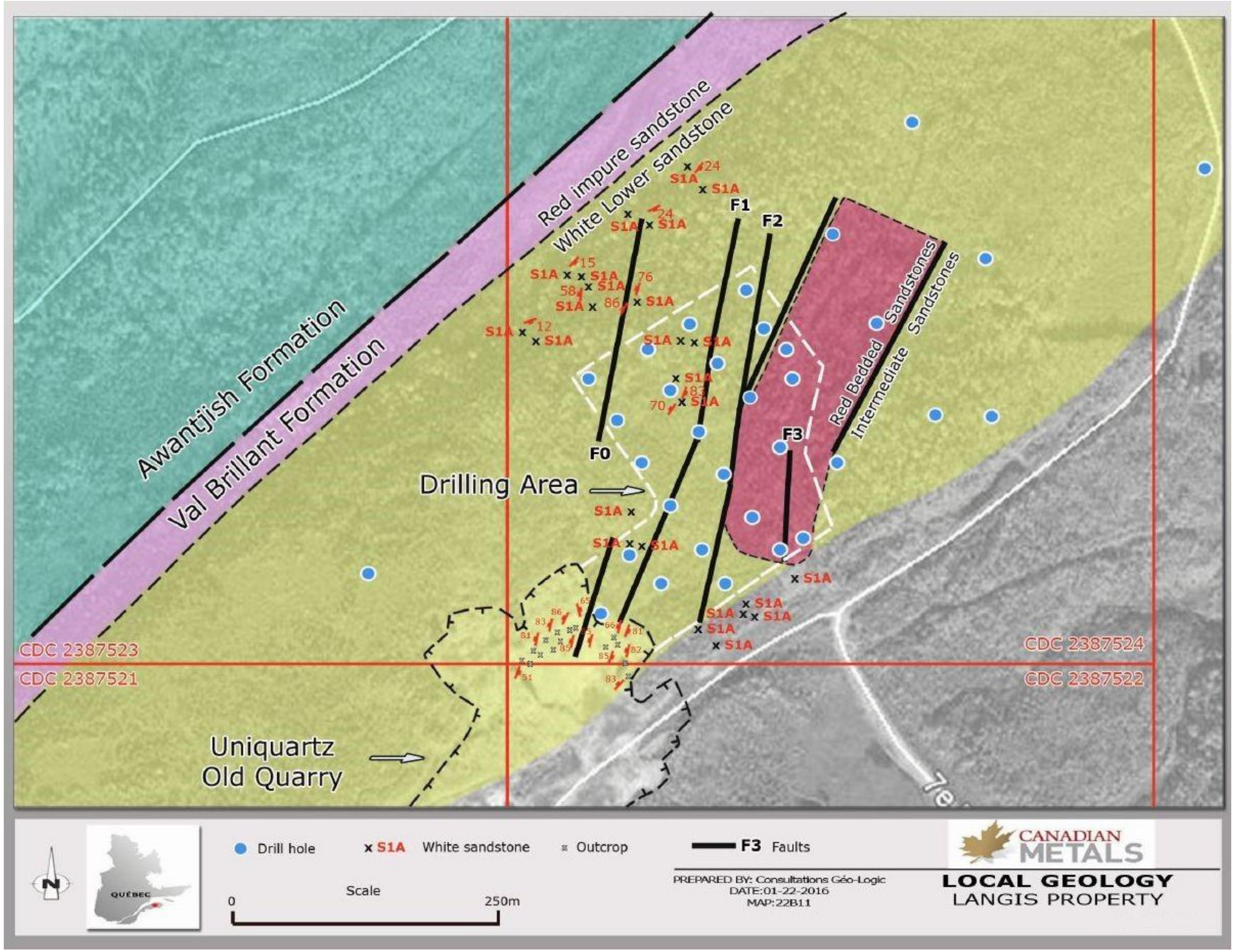
The Langis deposit is exposed in the contiguous Uniquartz quarry to the southwest. The quarry exposes a 20 to 30 meters thickness of Val-Brillant sandstones on its northeast wall forming a gently (-5° to -10°) south-dipping monocline. Sub-vertical faults cutting the sandstone strata oriented N-S and NE-SW, the latter exhibiting near-horizontal slickensides (strike-slip faults) were observed by Forbes, É. and Charlton, J. in 2013.

Drilling in 2013 and 2015 by Canadian Metal enabled the construction of a geological model for the Langis deposits (Figure 29).

Holes 13-01, 13-07, 15-12, 15-18 and 15-21 reached the underlying Awantjish shales which constitute a good marker horizon.

From the Awantjish shales, the first Val-Brillant units are composed of impure, gray sandstones that grade into reddish sandstones. These impure units usually form a transition zone some 5-10 meters thick. Above that transition zone begin the Lower White Sandstones, mostly white, with minor amount of pink to red horizons.

Figure 29: Local geology



Bedding observed in all holes indicate horizontal to gently dipping (5-10^0) units to the south. However, along any northwest-southeast section, one can see that the location of the location or elevation of the Awantjish Formation shales is not coherent with a regular 5-10^0 dip to the south. Irregularities observed in the trace of this marker horizon from the northwest to the southeast are explained by vertical displacement along thrust faults. These interpreted structural zones have been traced from one section to another and appear to be consistent. They are either single faults or closely spaced faults systems striking NNE and dipping steeply to the south. Movement along these fault zones is west block up relative to east block. The interpreted traces of these zone are shown on the local geological map (Figure 29) and labelled as F0, F1, F2 and F3. These structures were confirmed by field work (surface mapping by Forbes, É. in 2015).

The thickness of the Lower White Sandstone gradually increases from around 15 meters to the northwest to 30-35 meters to the southeast, a combination of the topography with the fact that dip of the unit is 5-10° to the south. In the southeast part of the deposit, the Lower White Sandstone becomes overlain by two younger sandstone units. First, the Red Bedded Sandstone forming a horizon between the Lower and Intermediate sandstones start to outcrop. Farther southeast, after gradually reaching some 15 meters thick, the Red Bedded Sandstone itself becomes overlain by the Intermediate Sandstone. Currrently, the Langis deposit is considered to be the part of the Lower Sandstone, which either outcrops or is covered by a relatively thin, removable Red Bedded Sandstone cover that is considered as waste material.

7.4 Mineralization

Mineralization at Langis is defined as sandstones that meet the chemical and physical specifications to produce lump silica suitable for a ferrosilicon plant. Physical tests done earlier by Uniquartz and more recently by Canadian Metals have confirmed that the Langis sandstones have the characteristics of an acceptable feed for a ferrosilicon plant.

The drilling program was therefore designed to assess and confirm that the Langis deposit could provide sufficient material for the long term and that this material meets the chemical specifications required for a ferrosilicon project.

The term “mineralization” at Langis will therefore be applicable to sandstone material whose chemical characteristics are within the specifications shown below:

Table 18: Preliminary specifications for the Langis sandstones

Preliminary Raw Material Specification

Quartz for FeSi

Parameter	Units	Typical	Range
Chemical Analysis (Dry Basis)			
SiO_2	wt%	98.4	> 97.7
Al_2O_3	wt%	0.45	< 1.00
Fe_2O_3	wt%	0.13	< 0.20
CaO	wt%	0.03	< 0.25
MgO	wt%	0.11	< 0.25
TiO_2	wt%	0.06	< 0.10
K_2O	wt%	0.10	< 0.40
Na_2O	wt%	< 0.01	< 0.20
MnO	wt%	< 0.01	< 0.02
P	wt%	< 0.01	< 0.02
LOI	wt%		< 0.25
Moisture	wt%	1	< 3
Physical Properties			
Specific Density	mt/m^3	2.6	
Bulk Density	mt/m^3		1.5 - 1.7
Angle of Repose	°		30 - 40
Particle Size Distribution			
Overall	mm	25 - 100 (> 98%)	
-25	%	Not determined	
+100	%	Not determined	
Stability			
Basic Mechanical	Must pass one of the commonly used test methods		
Thermal Shock	Must pass one of the commonly used test methods		

Revision: 0, Nov. 11, 2015 Project: 50047 Customer: 40031

Confidential

Source: Viridis.iQ GmbH estimates

8 Deposit Types

8.1 General

Siliceous sediments form on the shallow continental shelf and in inland seas or large lacustrine basins with a relatively low energy environment and a steady supply of well-sorted silica sand.

The source area has to be rich in siliceous sedimentary, igneous or metamorphic rocks to provide a steady supply of well-sorted and weathered clastic material to estuaries along the shoreline. Weathering conditions before and during transportation should be able to separate resistant silica from less stable feldspars, hornblende and pyroxenes, and transportation will separate the clay minerals and mica with heavy minerals from the silica particles. Silica-rich sediments typically have uniform grain size, may be well lithified or friable, and can be layered, cross bedded or massive beds. After deposition, the accumulated sediment will be cemented by compaction, a minor clay component, or introduced secondary silica. The siliceous sediments occur as meters thick beds that can extend more than tens of kilometers.

Each use has its very specific requirement for the particle size and shape, physical strength and permissible amounts of different impurities. For lump silica the concerns are purity, sizing of crushed rock (fracture and bedding density), thermal shock resistance and contamination by Ca, Fe, Mn, Ti, Al, Na and K minerals or graphite. Generally silica contents have to be 98% with significant impurities removable by processing.

8.2 Québec Deposits

In the province of Québec, silica deposits can be grouped in three categories; the sandstones, the quartzites and quartz veins. The Langis deposit belongs to the first category.

Four different sandstones formations have been recognized in Québec to meet the requirements for different uses in the silica industry.

8.2.1 The Cairnside Formation

The Cairnside Formation is a sandstone unit located in the upper part of the Cambrian Potsdam Group at the base of the St-Lawrence Lowlands formations. It outcrops both on the south and north shore of Montreal. It is composed of medium-sized quartz grains accumulated as massive beds totalling up to 30 meters thick. This pure quartzitic sandstone unit has been the source material particularly for the glass industry. A typical analysis of this formation gives 98.5-99.2% SiO_2, 0.30% Al_2O_3 and 0.10 Fe_2O_3 (ET 99-04).

Because of its proximity to the Montreal industry and markets, many quarries have been opened within the Cairnside Formation; Unimin and St-Scholastique on the north shore; Chromasco (ferrosilicon), Schink, Arcoite, E. Montpetit, Radius, Ste-Chlothilde and En-Ola on the south shore.

8.2.2 The Guigue Formation

The Guigue Formation is Ordovician sandstone located in western Québec and Ontario in the lake Temiscamingue area where it outcrops along the shore. The formation lies unconformably on the Precambrian rocks. It is composed of a 30 meter thick sequence that includes a conglomeratic unit at the base, fairly pure sandstone in the middle and calcitic-to-dolomitic sandstone at the top.

The median sandstone is a poorly consolidated unit composed of fine to large and rounded quartz grains with an argillaceous to dolomitic cement.

Two quarries have extracted material; the St-Bruno-de-Guigue quarry with a sandstone analysis of 97.0% SiO_2, 1.75% Al_2O_3 and 0.18 Fe_2O_3, and used in filtration, sandblasting and horticulture; and the Joannes quarry, with material analysed at 96.1% SiO_2, 2.67% Al_2O_3 and 0.34 Fe_2O_3, and used as flux for the Noranda foundry during the seventies.

8.2.3 The Kamouraska Formation

The Kamouraska Formation is an early Ordovician formation of the Trois-Pistoles Group that can be traced from Montmagny (east of Québec City) up to the Gaspe Peninsula. This pale grey quartzitic sandstone forms northeast-trending ridges that are well exposed, particularly east of Rimouski.

The sandstone is composed of mostly fine rounded quartz grains and silica cement. Layers are some five meters thick and the unit can reach a total thickness of some 60 meters. Sampling by Tifane (1975) indicated that the average composition of the formation was 95.5-98.5% SiO_2, 0.46-1.44% Al_2O_3 and 0.56 Fe_2O_3.

Quarries are known to have been developed in the Kamouraska Formation to extract material for aggregates and rock fill. The most important was the Grande-Vallee quarry in the Murdochville area, where the sandstone was used as flux for the Noranda smelter.

8.2.4 The Val-Brillant Formation

The Val-Brillant Formation has been described in Section 7 since it hosts the Langis Property. Over the years, exploration on the Val-Brillant Formation led to the discovery of many favorable areas for pure sandstones. These are referred as the Tessier, Colline de la Tortue, St-Tharcisius, Awantjish and Fleuriau deposits. No production is reported from these sites.

From the above, we can see that several of the province's deposits have the characteristics needed for uses in the silica industry. Substantial production has resulted when the quarry is directly linked to a major industrial project (e.g., flux agent for a foundry). The absence of a major industrial project in the Rimouski area is the main reason that the Val-Brillant deposits have never been mined.

9 Exploration

Canadian Metals Inc. has completed prospecting, mapping and sampling along with two drilling programs on the Langis Property. The first drilling program in 2013 (see Section 10) was a reconnaissance program designed to validate the Uniquartz global interpretation of the deposit and to collect material for metallurgical testing.

Nine whole core samples from the drill holes and three block samples collected from the wall of the quarry were provided for the thermal shock testing. The three block samples for thermal shock tests were located some 180 meters south-southwest from diamond drill hole PL-13-01. More details on the sampling and test results are available in the 2013 report for the Langis property. The conclusions of these tests are discussed in Section 13 of this report.

The second drilling program took place in June 2015 and is discussed in the next section. The objective of the 2015 drilling program was to increase the level of confidence in the deposit by infill holes in order to estimate measured resources.

Viridis strongly recommend, for further project phases to have a more accurate understanding of the exploration section and invest in further developments that would cover more details for the project such as the clearer description of the nature and extent of all relevant exploration information, work, and interpretation, including more results of surveys and investigations, and the procedures and parameters relating to the surveys and investigations. A new drilling survey is recommended to be done in further project phases, which will be sufficient to cover the higher accuracy level and understanding for the exploration and the project review.

10 Drilling

Since the historical drilling completed in 1982 by Uniquartz and described in Section 6 (History), two additional drilling programs were carried out, both by Canadian Metals Inc, in 2013 and in 2015. In the figure 54 are presented the image of the refereed drill holes.

10.1 The 2013 drilling program

The first drilling program by Canadian Metals Inc. conducted on the Property had one principal objective: to obtain a representative bulk sample of quartzitic sandstone for petrological and metallurgical characterization.

Les Forages Dibar Inc./André Roy from Ste-Anne-des-Monts, Québec, was commissioned to drill nine NQ diamond drill holes. This program was performed from September 16 to 20, 2013.

Drilling sites were first located with a handheld GPS with ± 5m accuracy and were more precisely surveyed at the end of the program. A total of nine diamond drill holes were drilled for 456 meters. The drill pattern consisted of three sections with three holes per section. The lines and holes were spaced at approximately 100 meters. The area tested consisted of a 200 x 200 meter square, or four hectares.

All holes were drilled vertically to allow intersection of the geological units at a high angle and thus obtaining sample length very close or equal to true thickness.

The 2013 holes locations are shown in Figure 27. The program successfully recovered core from the entire local stratigraphy. As discussed in Section 7.2, the local geology was found to be constituted, from bottom to top, by argillite/mudstone, followed by a 15-meter thick transitional zone comprising impure gray and pink to red sandstones. This is overlain by the pure white Lower Sandstones which ranges from 15 to 35 meters thick. This formation outcrops in some parts of the drilling area, for example around holes 13-06, 07 and 08. East of that area, a pinkish to red sandstone some 15 meters thick and the first layers of the Intermediate sandstone overlay the Lower Sandstone.

Only parts of the core were analyzed. Table 19 and Table 20 summarize the 2013 drilling program and the core sections analyzed.

Table 19: Summary of the 2013 drilling program

Hole number	UTM North (m)	UTM East (m)	Elevation (m)	Length (m)	Overburden (m)
PL-13-01	5,387,246.08	623,045.16	251.78	75.00	8.30
PL-13-02	5,387,384.72	623,083.70	244.29	56.08	3.26
PL-13-03	5,387,523.75	623,120.39	237.24	45.00	3.00
PL-13-04	5,387,434.02	623,160.38	238.58	53.65	3.90
PL-13-05	5,387,350.95	623,216.28	249.16	57.00	1.94
PL-13-06	5,387,331.62	622,994.85	251.50	39.00	1.84
PL-13-07	5,387,412.18	622,947.05	249.97	41.60	1.40
PL-13-08	5,387,464.86	623,039.24	243.58	30.00	2.23
PL-13-09	5,387,304.94	623,127.18	247.29	59.64	1.50
9 holes				456.97	

Source: Consultations Géo-Logic

Table 20: Core sections analyzed in the 2013 drilling program

Hole number	From (m)	To (m)	Length (m)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)
PL-13-01	12.10	41.05	28.95	98.69	0.15	0.42
incl.	14.30	32.00	17.70	99.05	0.12	0.28
Incl.	14.30	23.00	8.70	99.22	0.11	0.23
PL-13-02	10.80	51.00	40.20	98.72	0.13	0.48
incl.	10.80	33.00	22.20	99.15	0.08	0.29
PL-13-05	2.00	9.00	7.00	99.10	0.07	0.37
	32.00	53.30	21.30	99.09	0.08	0.32
incl.	32.00	44.00	12.00	99.33	0.06	0.24

Source: Consultations Géo-Logic

10.2 The 2015 drilling program

The second drilling program was completed between June 1 and 22, 2015. The drilling contract was again awarded to Forage Dibar-André Roy.

This time the objective was to reduce the drilling pattern and to concentrate on a promising part of the deposit in order to estimate the measured resources for at least a part of the drilling area.

NQ vertical holes were drilled on an approximately 50-meter grid. A total of 18 holes totalling 701.6 meters were drilled, adding to the nine previous 2013 nine holes (see Table 21 below).

Holes were located with a handheld GPS with ± 5 meter accuracy. The total area investigated is 350 meters by 400 meters and covers approximately 8.5 ha.

Table 21: Summary of the 2015 program

Hole number	UTM North (m)	UTM East (m)	Elevation (m)	Length (m)	Overburden (m)
PL-15-10	5,387,154	622,993	256	37.5	0.40
PL-15-11	5,387,190	622,960	258	41.5	1.30
PL-15-12	5.387.215	622,928	258	41.5	1.20
PL-15-13	5,387,262	622,966	258	38.5	1.50
PL-15-14	5,387,220	622,997	257	39.0	1.50
PL-15-15	5,387,188	623,023	254	42.0	0.75
PL-15-16	5,387,304	622,939	256	30.0	1.50
PL-15-17	5,387,345	622,916	252	24.0	2.25
PL-15-18	5,387,384	622,893	251	27.0	2.05
PL-15-19	5,387,373	622,967	251	33.0	1.20
PL-15-20	5,387,288	623,015	254	42.0	1.50
PL-15-21	5,387,361	623,036	248	51.0	1.40
PL-15-22	5,387,398	623,012	249	42.0	1.80
PL-15-23	5,387,434	622,985	248	26.0	1.80
PL-15-24	5,387,431	623,058	244	44.6	2.70
PL-15-25	5,387,318	623,070	247	54.0	2.30
PL-15-26	5,387,220	623,069	250	49.0	1.55
PL-15-27	5,387,161	622,900	260	39.0	1.15
18 holes				701.6	

Source: Consultations Géo-Logic

11 Sample Preparation, Analysis and Security

11.1 Sampling Approach and Methodology

All core logging was performed by Étienne Forbes, P. Geo., at the core shack located in Lac-au-Saumon following procedures further described herein.

At reception, all core boxes were opened and placed in order on the logging table. All meterage wood blocks were verified to control core box numbers and any possible mistakes made during drilling procedures.

Then, start and end intervals of core inside each core box were measured and recorded on a Microsoft Excel® sheet for future reference. All core boxes were tagged with an aluminum tape marked with the hole and box numbers with start and end intervals.

Logging procedures included a mineral description of geological units and sub-units in terms of color, grain size, bedding angle to core axis, alteration, accessory minerals and fracture angle to core axis. The recovery and Rock Quality Designation (RQD) were measured. These descriptive data were entered directly into the Geotic® Software at the core shack.

Finally, pictures of all the core boxes were taken by a geoscientist.

The sampling approach was discussed with Alain Tremblay, P. Geo, before and during the drilling program.

Sample length was based upon both geological contacts and on the whiteness of the quartzitic sandstone. Numbered sample tags were placed at the beginning of each sample, together with distinctive arrows on the core marking the beginning and end intervals. Sample lengths average 1.8 meters, with maximum of 3.3 meters and minimum of 0.5 meters.

No aspect of sample preparation was conducted by an employee, officer, director or associate of Canadian Metals.

11.2 Sample Preparation

All 2015 core samples received and the untouched core from the 2013 drill program were cut in half along the long axis by a hydraulic-powered core splitter. Half of the core sample was retained and placed back in the core box, respecting the original orientation and position. Sample tags were stapled to the bottom of the core tray at the start of each sample, so that each sample could be relocated following future handling, transportation and storage.

A total of 418 samples totalling 731.7 meters of core were prepared. This length represents 63.2% of the total core length from the two drill programs.

All samples were securely bagged and taped with adhesive tape before being placed in large Fabrene bags (rice bags) and tied with a security numbered plastic zip-tie before shipping. A list of sample numbers shipped was included in one of the rice bags for laboratory verification.

All rice bags were shipped by GoJit directly from the core shack to the ALS Chemex laboratory in Val-d'Or, Québec. All samples were received in good standing by the laboratory.

11.3 Analyses

Upon receipt of our samples, ALS Chemex Laboratory employees proceeded with the following preparations:

Bar code labels were attached to every sample bag. This bar code is used to compile information, from sample preparation to storage;

Samples were dried at a temperature range of 110°C to 120°C in gas-heated forced air furnaces. According to the laboratory, this method of drying does not affect the sample because volatile elements are not lost at this temperature;

Samples were crushed in a jaw crusher to obtain 70% of <2 mm particles. The jaw crusher is cleaned after every sample;

A fraction of the sample (up to 250 g) was split by a riffle splitter and pulverized to obtain >85% of <75 µm. Crushed samples are added to a tungsten carbide bowl and subjected to centrifugal force by mechanical action. The sample is subject to considerable grinding action by a puck and/or ring(s) that are free to move inside the bowl, resulting in a very fine sample; a tungsten carbide bowl was used instead of a ferrochromium bowl to avoid iron contamination during laboratory sample preparation. As the tungsten is absent from the primary rock sample, it is easy to demonstrate possible laboratory contamination.

Samples were dissolved in the presence of lithium borate;

Assays were performed by Inductively Coupled Plasma Emission Spectroscopy (ICP-AES). In plasma emission spectroscopy, a sample solution is introduced into the core of inductively coupled argon plasma (ICP) at a temperature of approximately 8,000°C. At this temperature, all elements become thermally excited and emit light at their characteristic wavelengths. This light is collected by the spectrometer and passes through a diffraction grating that serves to resolve the light into a spectrum of its constituent wavelengths. Within the spectrometer, this diffracted light is then collected by wavelength and amplified to yield an intensity measurement that can be converted to an elemental concentration by comparison with calibration standards. This measurement process is a form of atomic emission spectroscopy (AES). This analysis reports major and minor elements as oxides, together with the loss-on-ignition.

ALS Chemex is ISO 9001:2000 certified for its Val-d'Or laboratory. ISO 9001:2000 requires evidence of a quality management system covering all aspects of the organization. To ensure compliance with this system, regular internal audits are undertaken by staff members specially trained in auditing techniques.

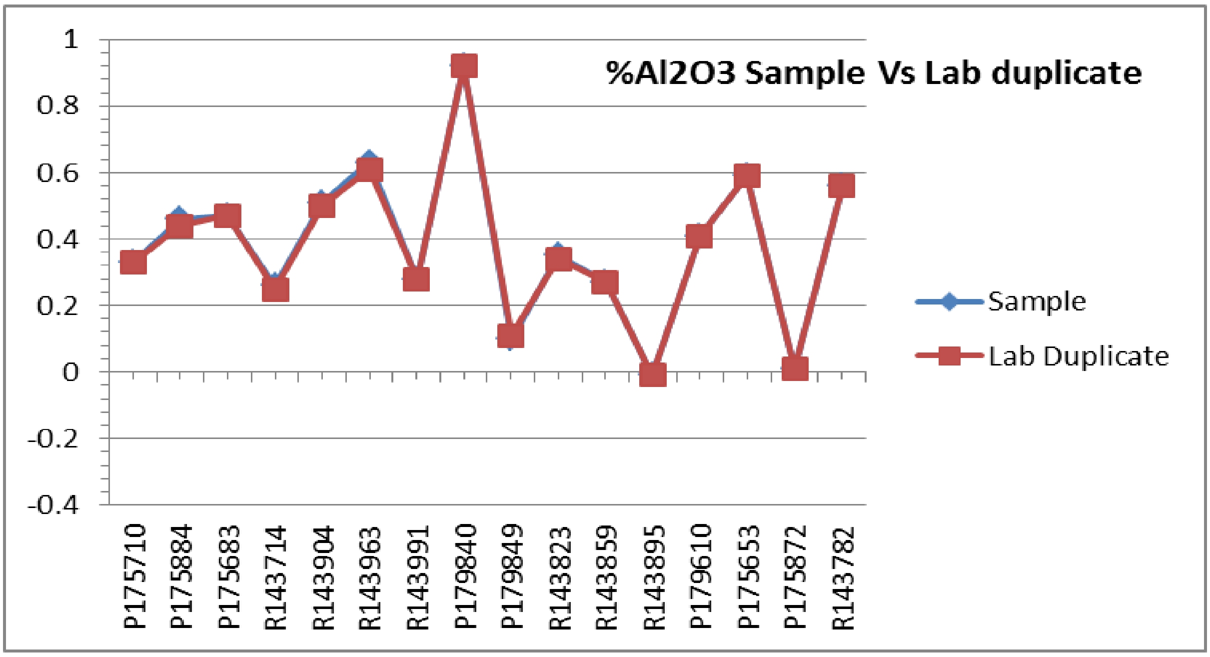
11.4 Laboratory QA/QC

ALS Chemex's analysis protocol includes inserting its own check samples in the assay batch. The check samples include re-assays (duplicates), blanks and standards.

11.4.1 Re-Assay (Duplicates)

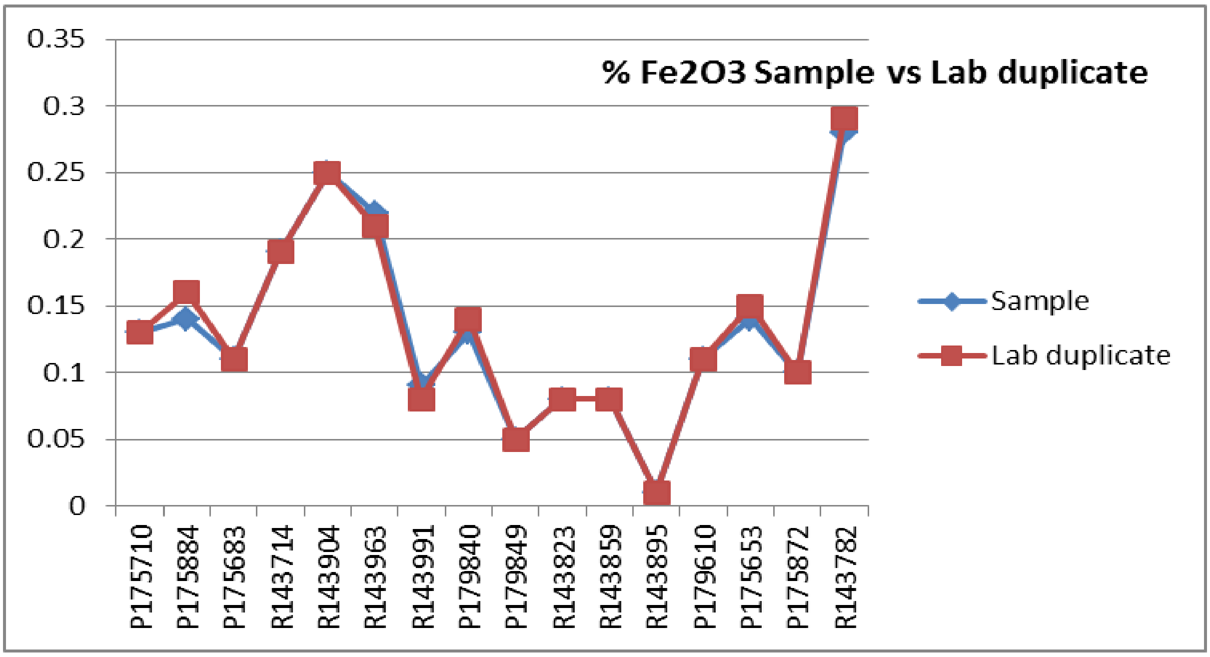
ALS Chemex protocols include reanalyzing samples at a regular interval. A total of 16 samples were thus analyzed twice. Figure 30 to Figure 33 indicate very weak variation of four different oxides in each sample (blue line) versus in the duplicates. The percentage of SiO_2 is the oxide that seems to be most variable, but it generally maintains the same pattern. These results can clearly be seen as reliable.

Figure 30: % Al_2O_3 sample vs lab duplicate



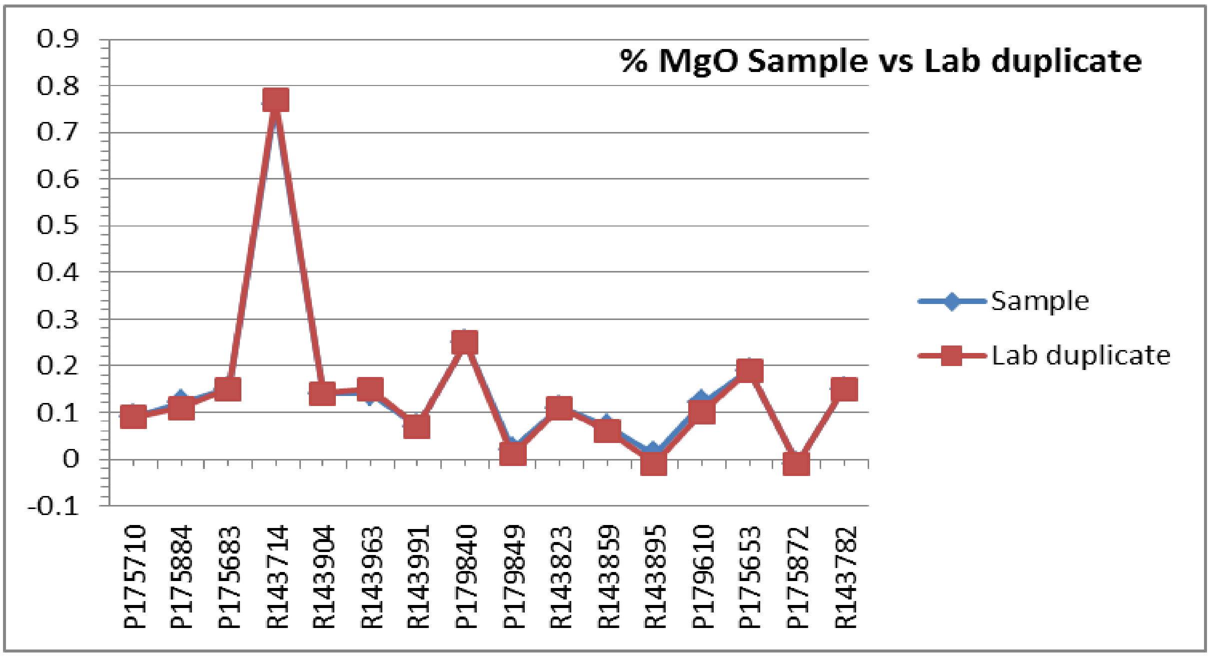
Source: Consultations Géo-Logic

Figure 31: % Fe_2O_3 sample vs lab duplicate



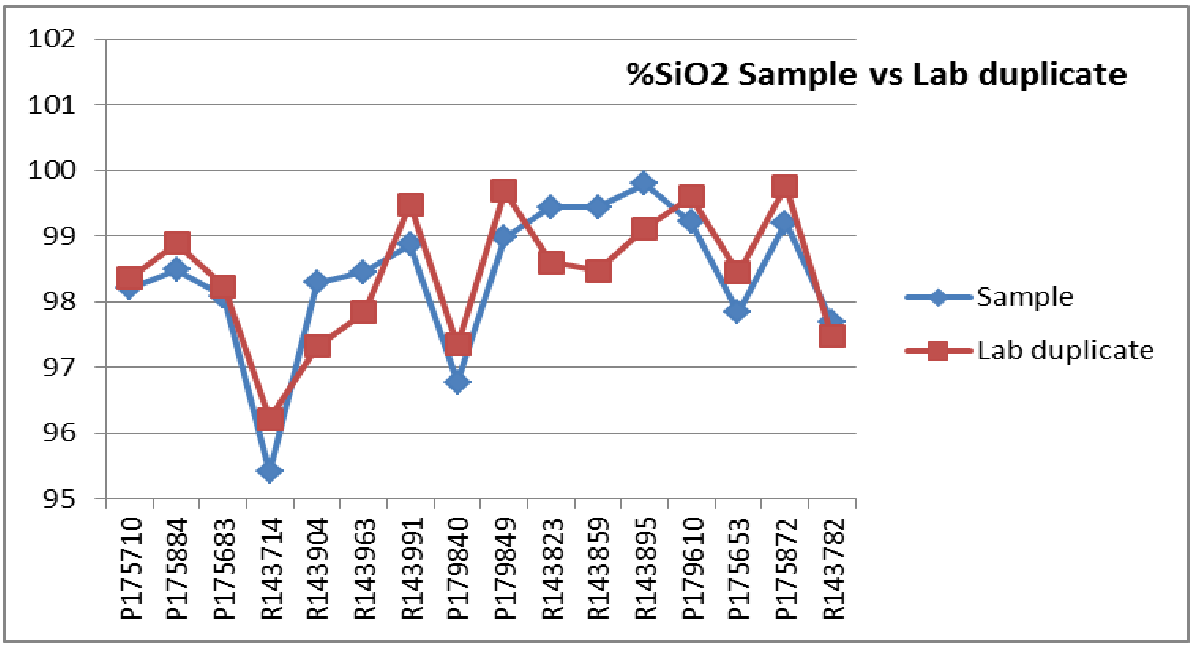
Source: Consultations Géo-Logic

Figure 32: % MgO sample vs lab duplicate



Source: Consultations Géo-Logic

Figure 33: % SiO_2 sample vs lab duplicate

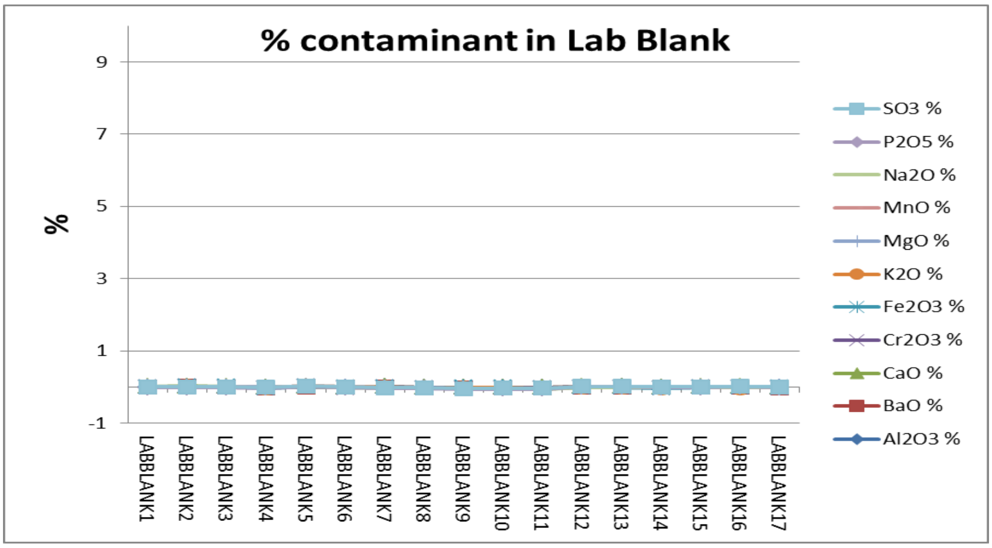


Source: Consultations Géo-Logic

11.4.2 Laboratory Blanks

ALS Chemex's protocols include analyzing blank samples at a regular interval. A total of 17 blank samples were analyzed. Blank samples consist of very pure silica. Figure 34 indicates other oxide content of between 0.02% and 0% in all samples. These results clearly confirm that no contamination occurred during any of the steps, from sample preparation to analysis, from the laboratory point of view.

Figure 34: % Contaminant in lab blank

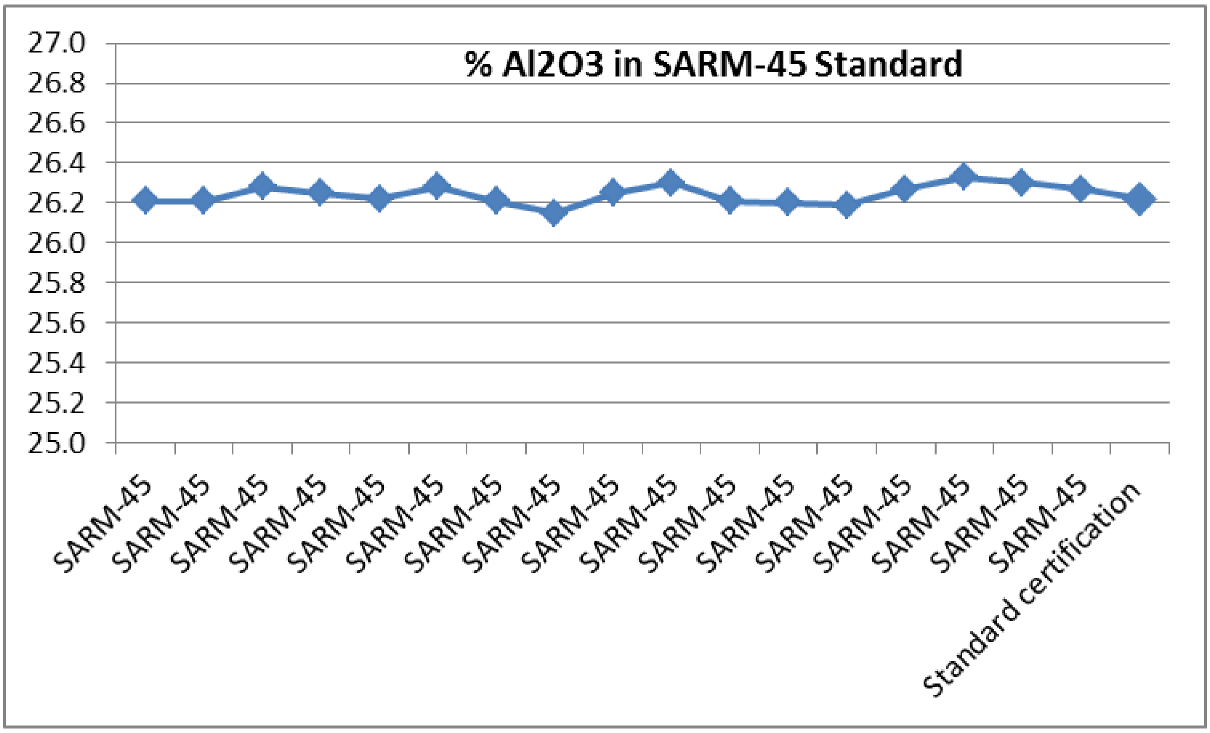


Source: Consultations Géo-Logic

11.4.3 Laboratory Standards

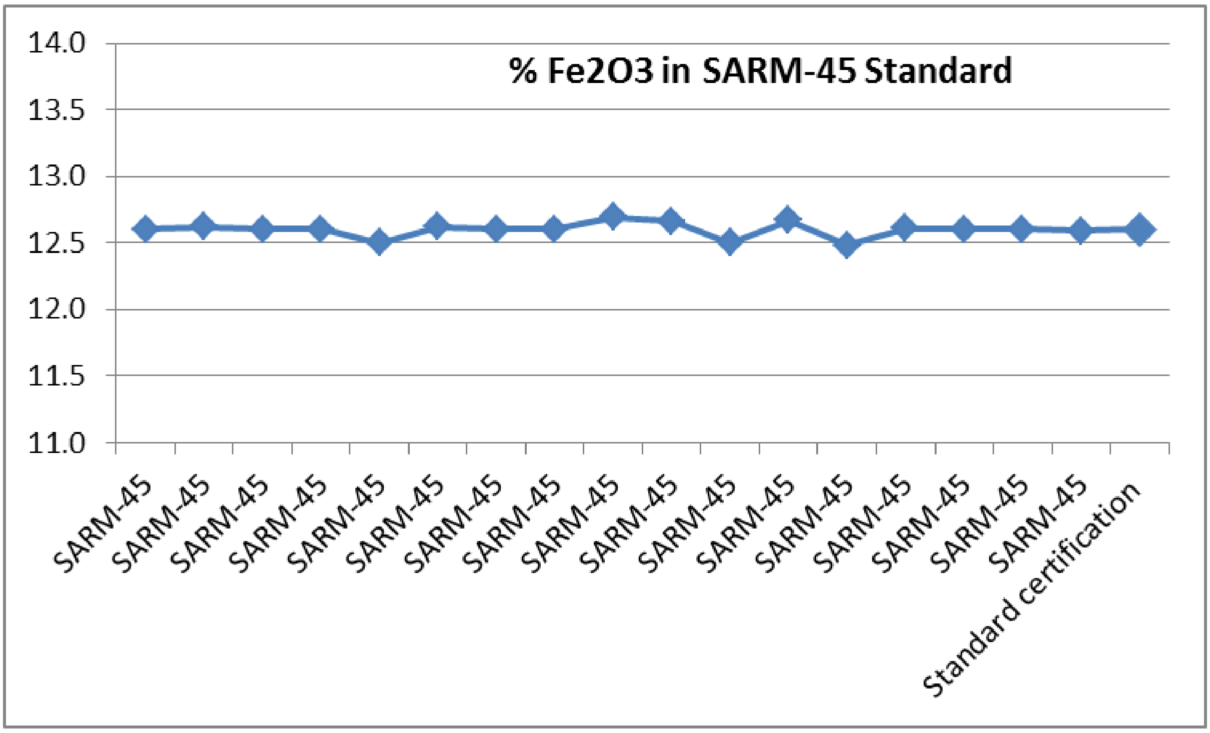
Laboratory protocols include analyzing standard samples at a regular interval. Three different standard samples were used by ALS Chemex. The most commonly used standard was SARM-45, consisting primarily of biotite, quartz, orthoclase, garnet, and accessory amounts of epidote, sillimanite, sericite, and chlorite. A total of 17 SARM-45 standard samples were analyzed. Figure 35 to Figure 38 indicate oxide content versus standard certification. These results clearly confirm assay method accuracy.

Figure 35: % Al_2O_3 in SARM-45 standard



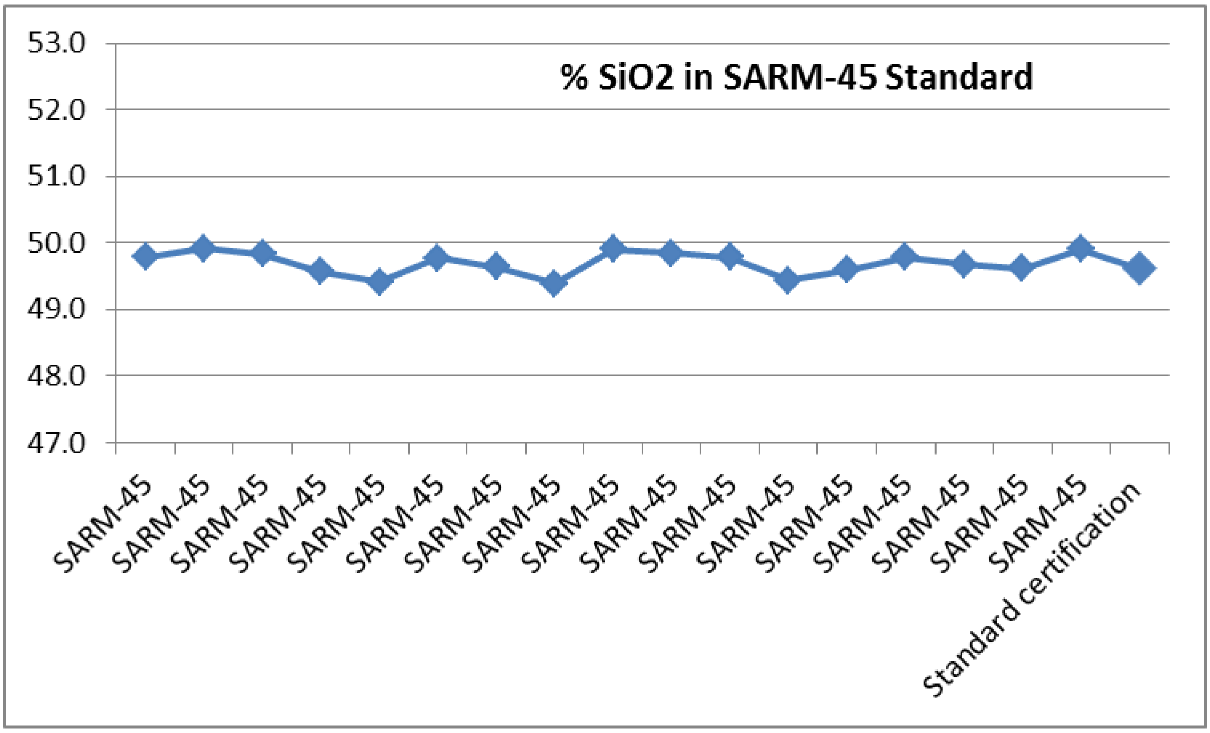
Source: Consultations Géo-Logic

Figure 36: % Fe_2O_3 in SARM-45 standard



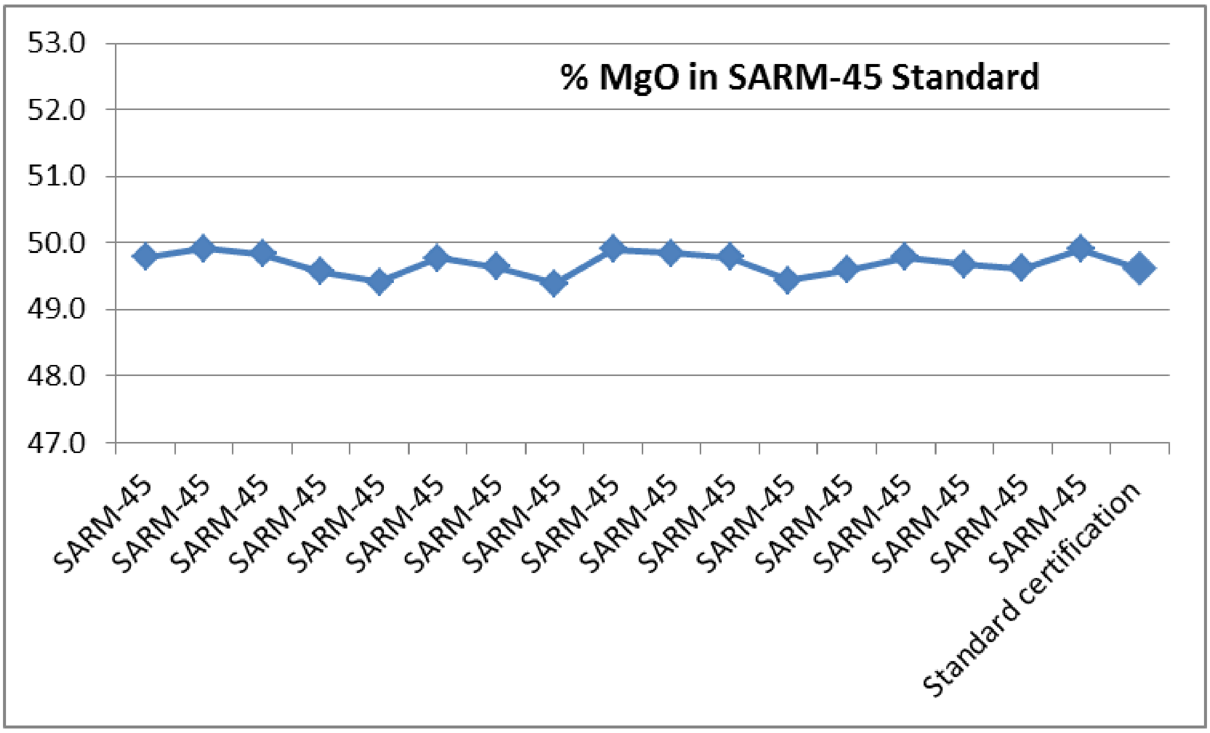
Source: Consultations Géo-Logic

Figure 37: % SiO_2 in SARM-45 standard



Source: Consultations Géo-Logic

Figure 38: % MgO in SARM-45 standard



Source: Consultations Géo-Logic

11.5 Independent QA/QC

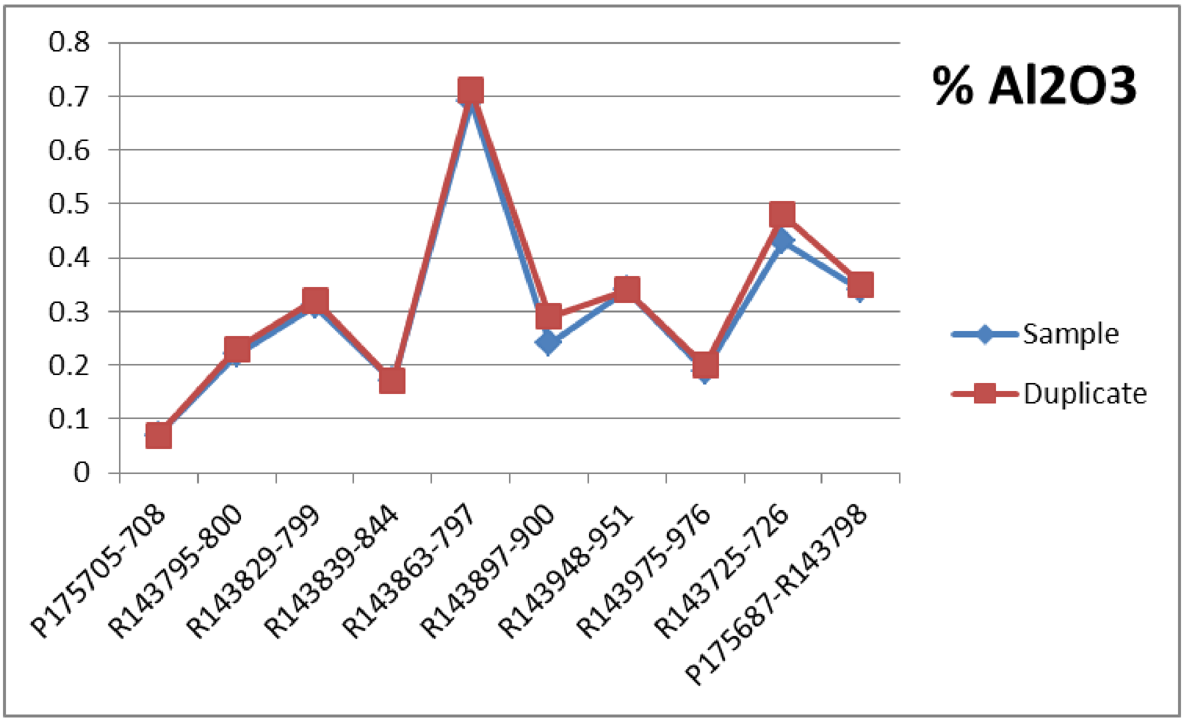
In addition to laboratory check samples, the author inserted three kinds of independent check samples. These included duplicates, blanks and standards. The following describes the results obtained from each of them.

11.5.1 Duplicates

A total of 10 duplicate samples were prepared in the core shack during core sampling and preparation. Core samples used for that purpose were first split in half to separate the sample from the core to be conserved in the box. Then, half samples were split into two quarter samples. Left samples were numbered following the previous sample number and different numbers were assigned to the right samples, considered as the duplicates. This kind of duplicate is intended to test the reliability of separation, as well as homogeneity of the rock units.

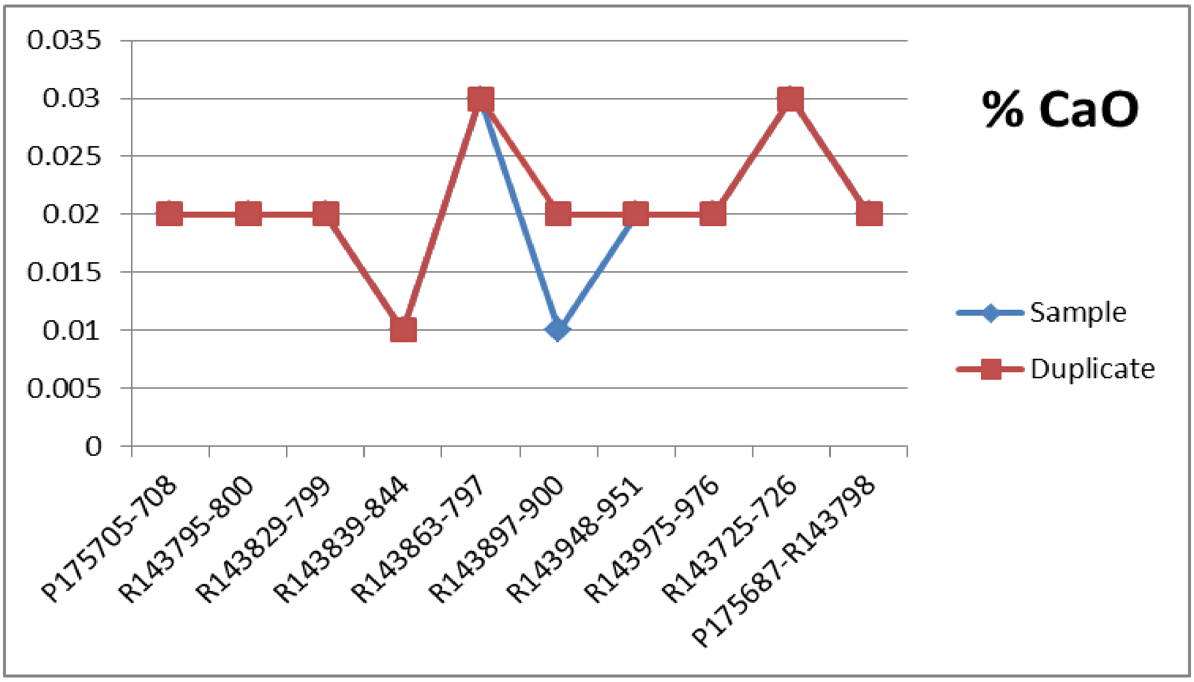
Figure 39 to Figure 44 report variations in six different oxides. These indicate slightly higher variation in the assay results than in the laboratory duplicates, but still very low and acceptable.

Figure 39: % Al_2O_3 in sample versus duplicate



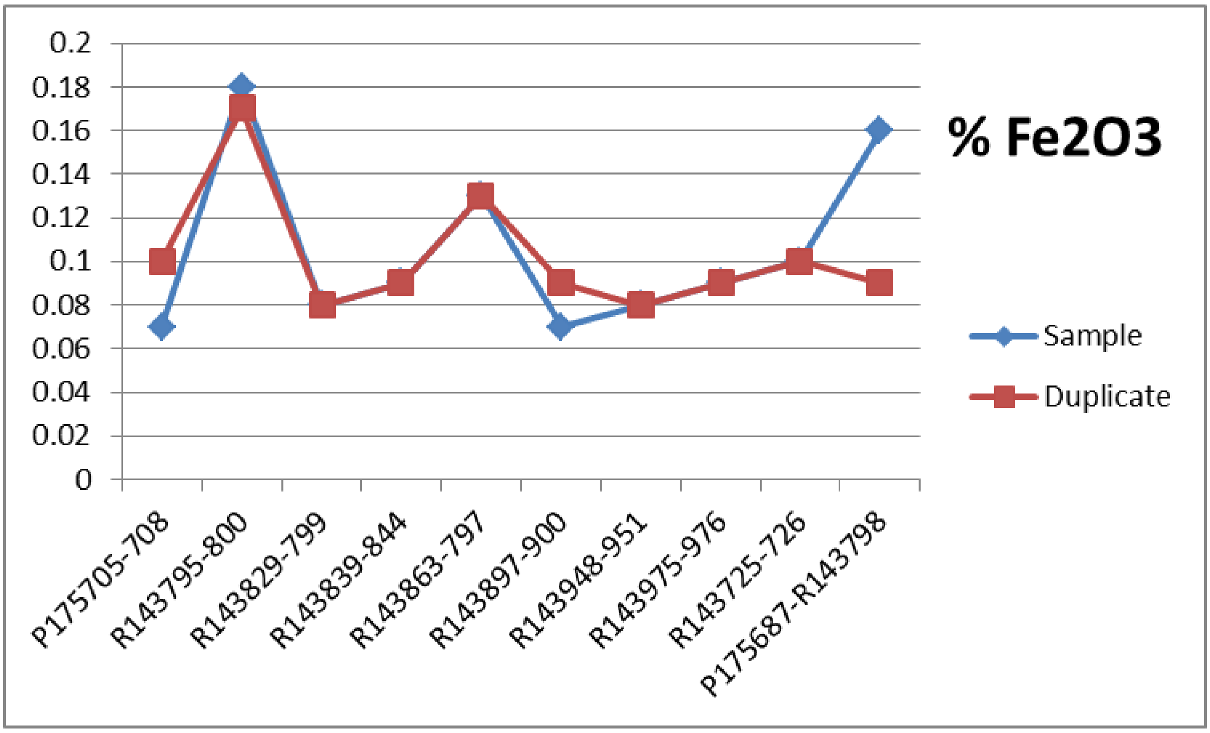
Source: Consultations Géo-Logic

Figure 40: % CaO in sample versus duplicate



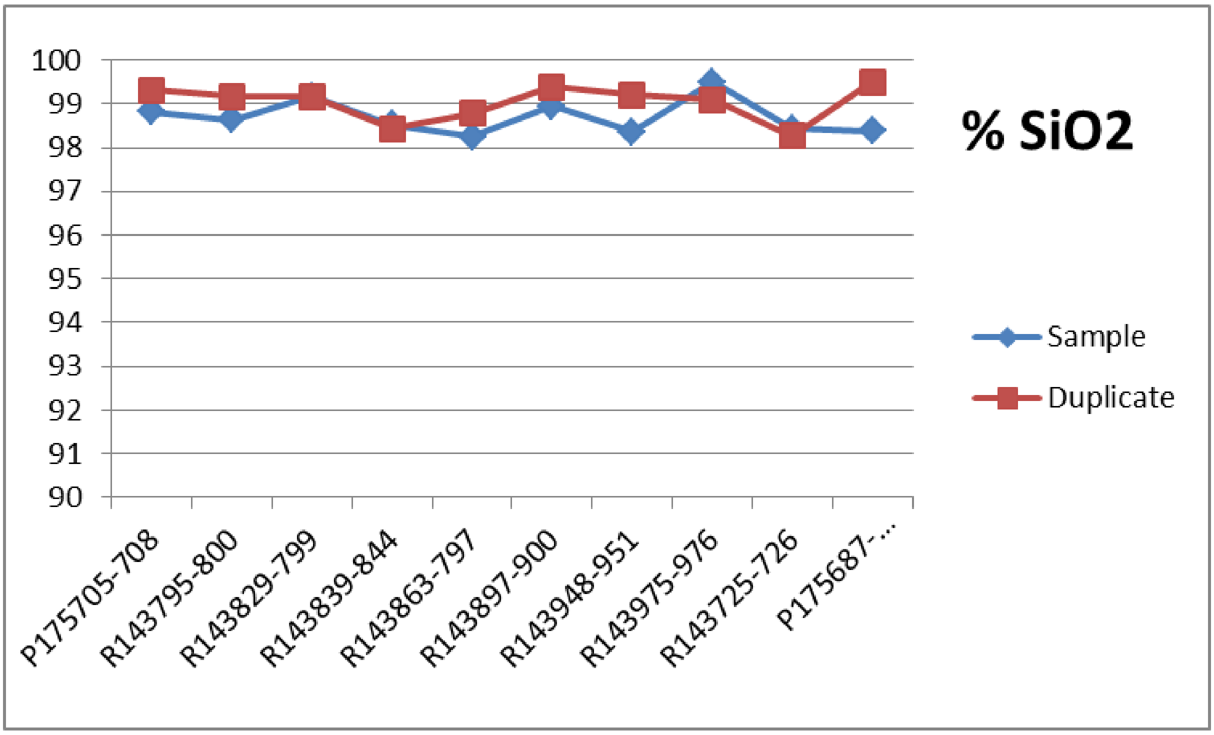
Source: Consultations Géo-Logic

Figure 41: % Fe_2O_3 in sample versus duplicate



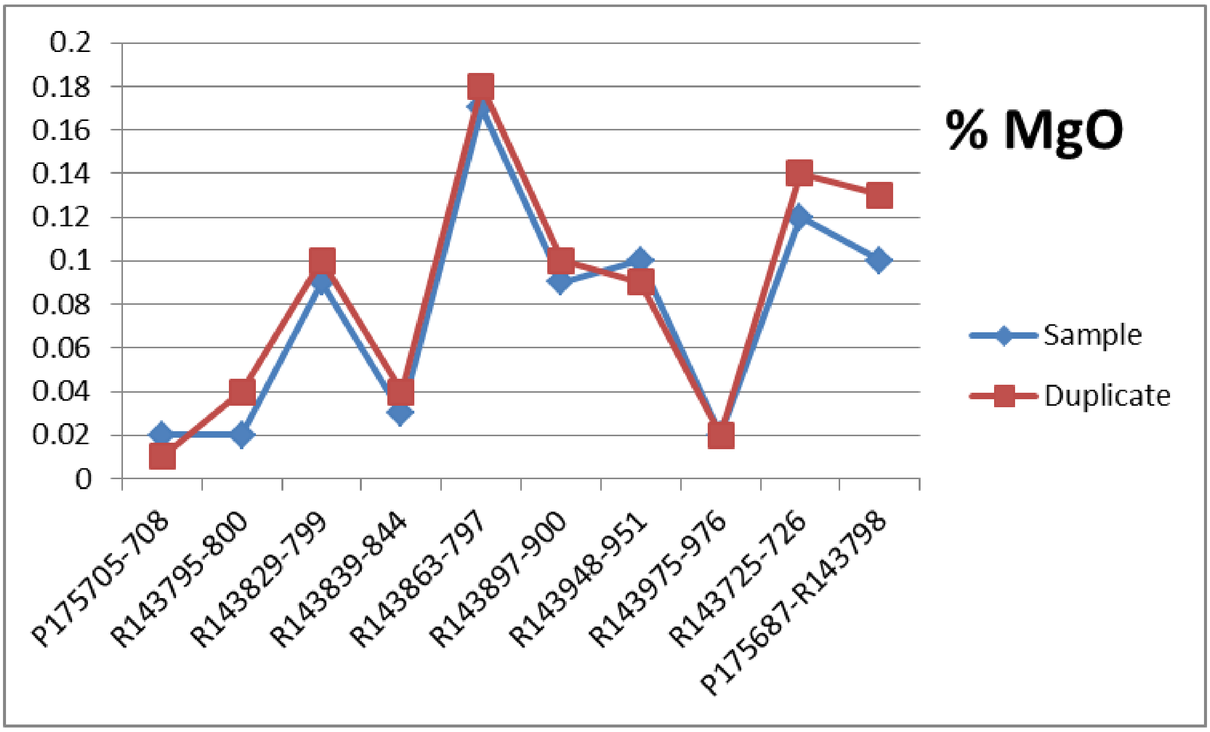
Source: Consultations Géo-Logic

Figure 42: % SiO_2 in sample versus duplicate



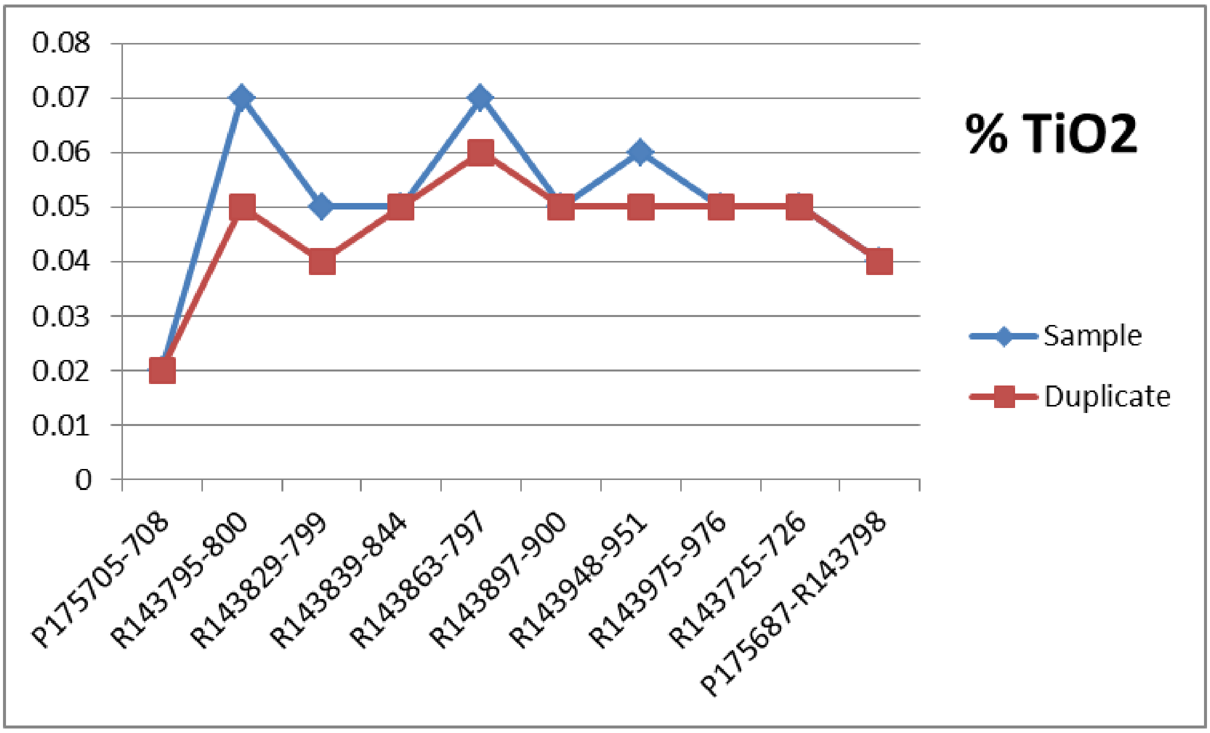
Source: Consultations Géo-Logic

Figure 43: % MgO in sample versus duplicate



Source: Consultations Géo-Logic

Figure 44: % TiO_2 in sample versus duplicate



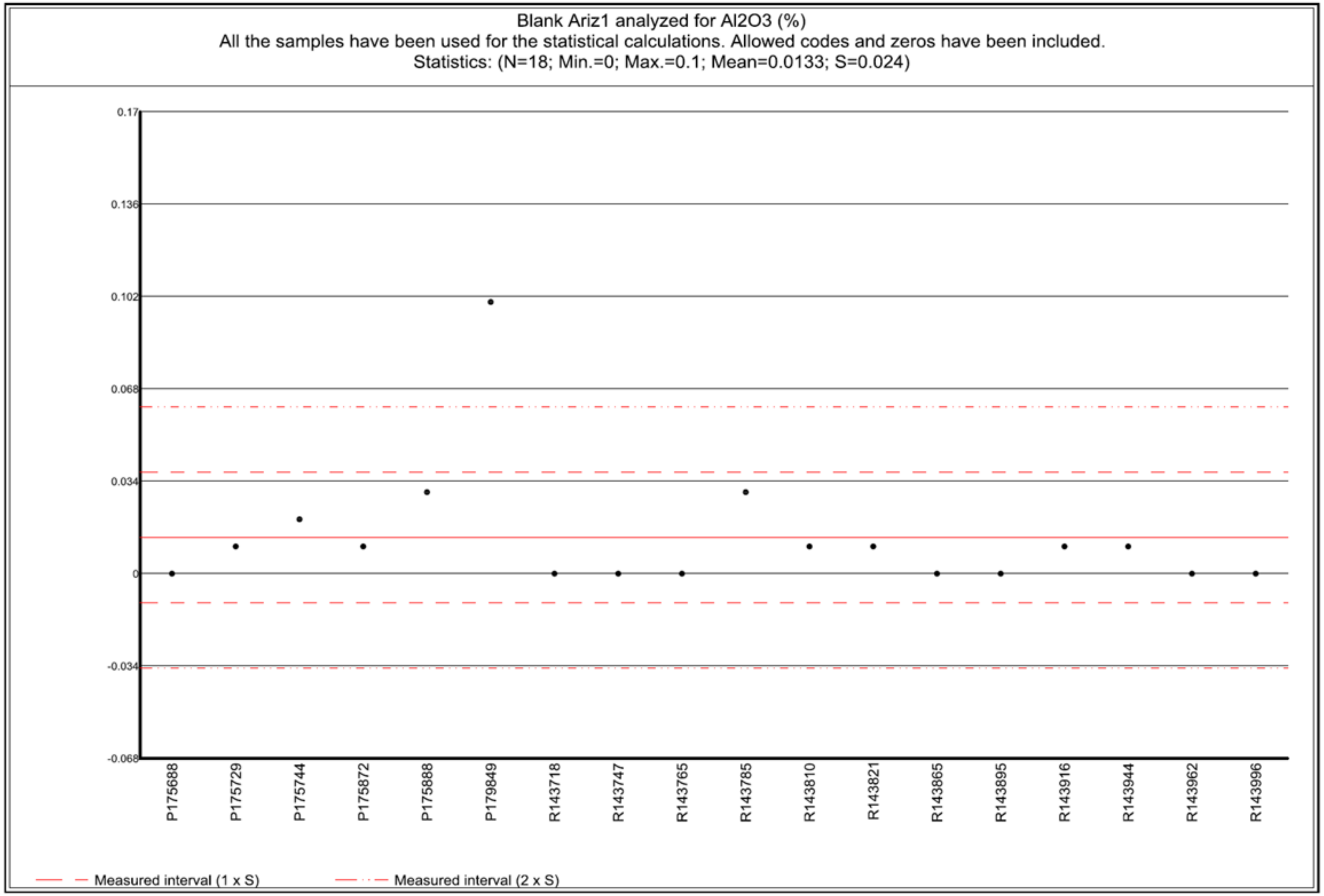
Source: Consultations Géo-Logic

11.5.2 Blanks

A total of 18 independent blank samples were inserted in the sample batch during core sampling and preparation. As in the case of ALS Chemex, the blank samples consisted of very pure quartz (silica). They were ordered from a mine located in Arizona, USA. Only white or milky quartz samples were used for this purpose. This type of sample is intended to test whether the laboratory's analytical devices were cleaned after each assay.

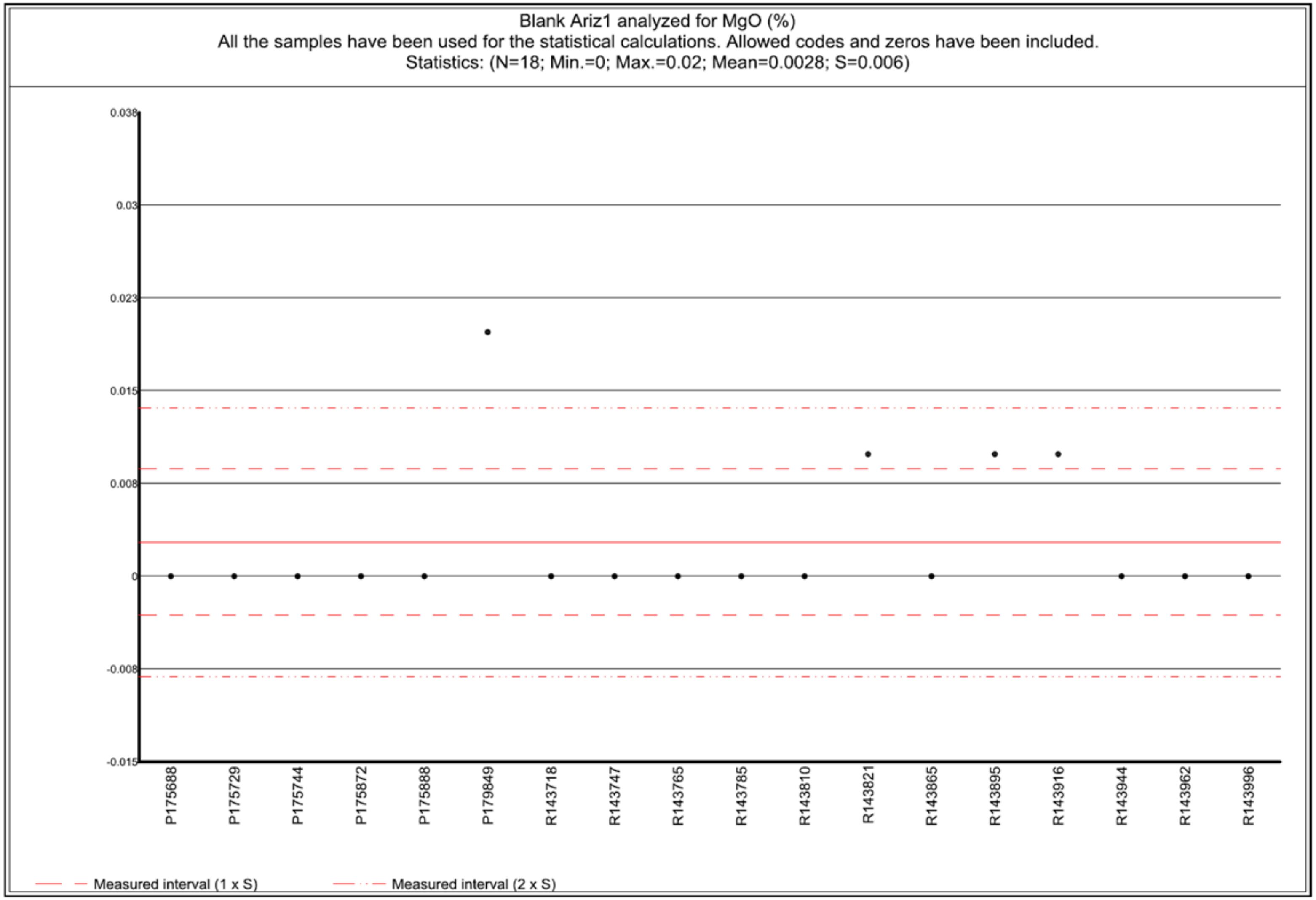
Figure 45 to Figure 47 report variation in three different oxides. Only two of the 18 samples (P17984-P179872) had oxide content (Al_2O_3-MgO and Fe_2O_3, respectively) of over the second standard deviation. This can be due to the presence of impurities in these particular samples.

Figure 45: % Al_2O_3 in the independent blank samples



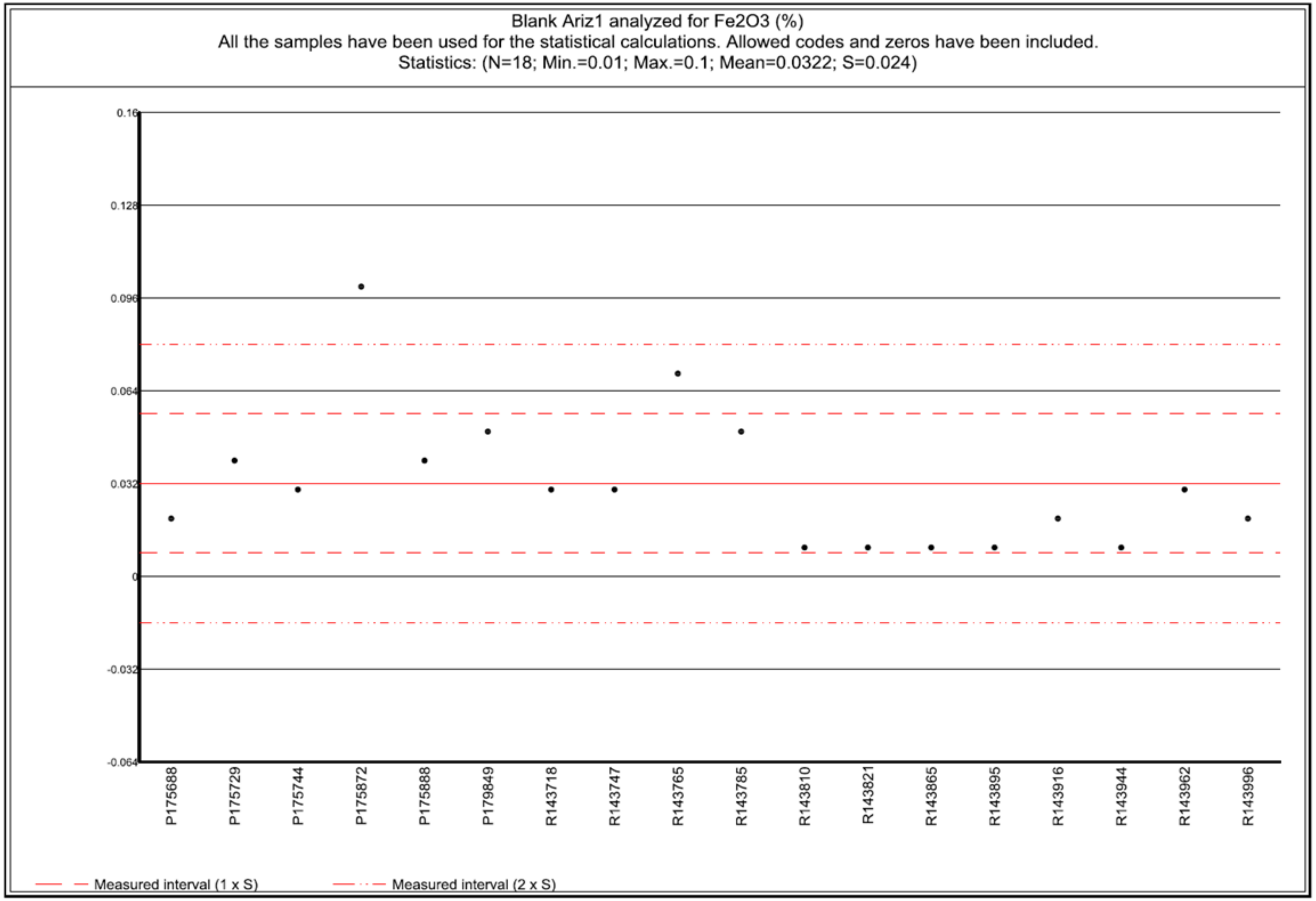
Source: Consultations Géo-Logic

Figure 46: % MgO in the independent blank samples



Source: Consultations Géo-Logic

Figure 47: % Fe_2O_3 in the independent blank samples



Source: Consultations Géo-Logic

11.5.3 Standard Samples

A total of 18 standard samples were inserted into the sample batch during core sampling and preparation. Standard samples consisted of fine-grained sand collected from a mound of silica located just beside the Langis quarry. This sand came from the Uniquartz operation back in the mid-1980s. This was the same mound of material that was used in 2013 for standard sample purposes.

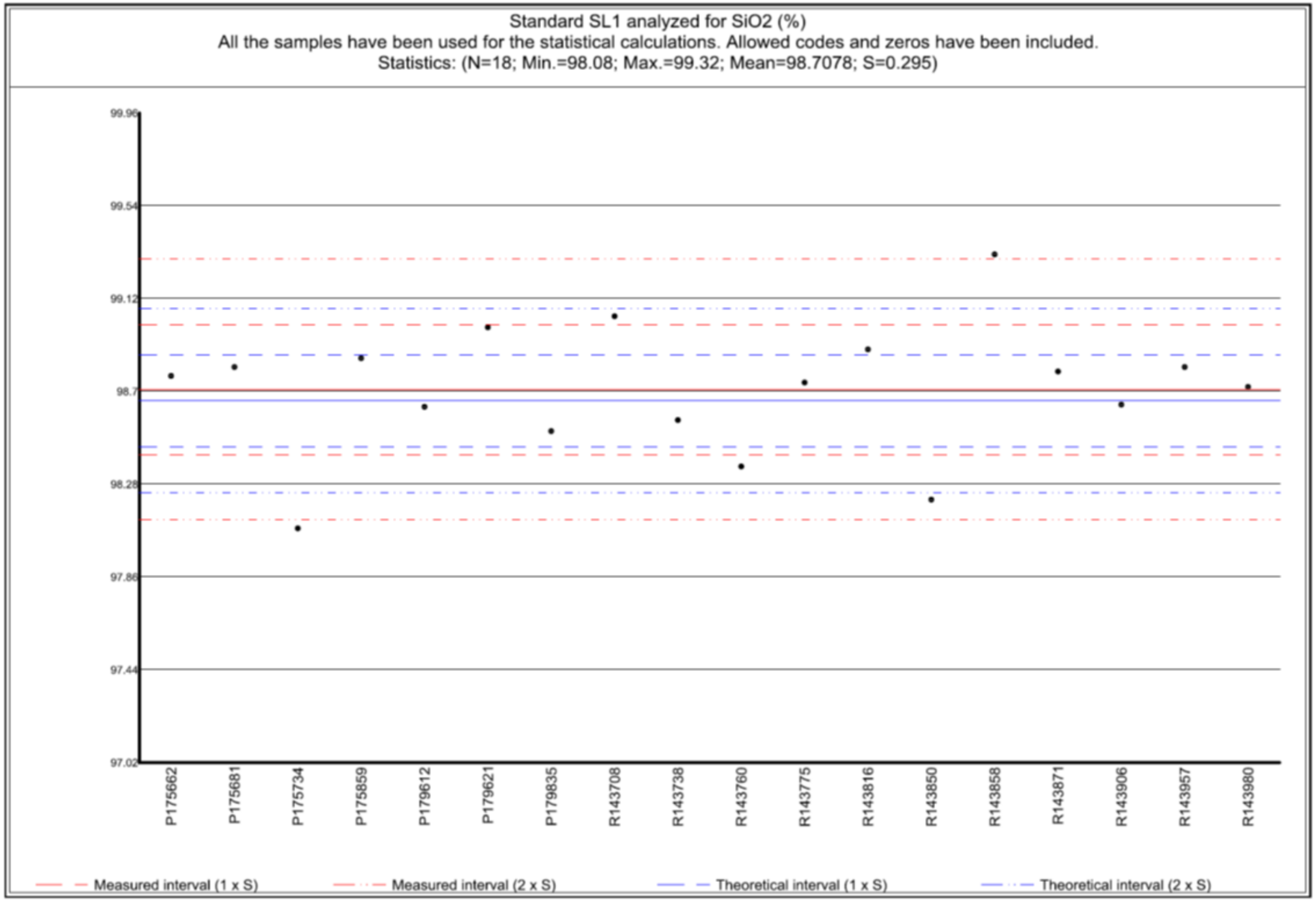
Figure 48 below reports the percentage of SiO_2 variation in the 18 samples. It can be observed on the chart that most of the samples are inside the second standard deviation, except two samples (R143858 and P175734), which are nevertheless very close to the second standard deviation.

Based on these results, it can be considered that ALS Chemex's assay method was accurate from the start to the end of the project.

11.6 Adequacy

According what was done at all stages of the program, I firmly believe that sampling preparation, security and analytical procedures meet industry standard and are therefore reliable.

Figure 48: % SiO_2 in the independent standard samples



Source: Consultations Géo-Logic

12 Data Verification

12.1 Controls and Verification Measures

All Canadian Metals 2013 and 2015 geological data was collected and verified by the author.

12.2 Limitation of Data Verification

Assays performed by CTMP Laboratory in 2013 on diamond drill holes PL-13-01, 02 and 05 were not reassayed by ALS Chemex. However, the standards used in the two programs were the same. Table 22, shows no to very minor discrepancies between assays from one laboratory to the other, which means that data from both programs can be used together in the present resource calculation.

12.3 Author's Opinion on the Adequacy of the Data

The authors are of the opinion that the 2015 and 2013 data is representative of the mineralization on the Langis property.

Table 22: Standards analyzed by CTMP and ALS Chemex

Lab.	DDH	Sample #	Name	Al2O3	CaO	Fe2O3	K2O	MgO	MnO	Na2O	SiO2	TiO2
				%	%	%	%	%	%	%	%	%
CTMP	PL-13-01	P179760	sil	0.42	0.02	0.16	0.05	0.08	0.01	0.03	98.83	0.06
CTMP	PL-13-02	P179784	sil	0.45	0.02	0.11	0.05	0.08	0.01	0.04	98.83	0.06
CTMP	PL-13-02	P179775	sil	0.44	0.03	0.09	0.05	0.09	0.01	0.04	98.70	0.06
CTMP	PL-13-05	P179791	sil	0.39	0.02	0.11	0.05	0.08	0.01	0.04	98.92	0.05
Avg				0.43	0.02	0.12	0.05	0.08	0.01	0.04	98.82	0.06
ALS	PL-13-06	P179612	SL1	0.41	0.01	0.13	0.05	0.11	0.01	0.01	98.63	0.06
ALS	PL-13-07	P175662	SL1	0.41	0.02	0.16	0.06	0.11	0.01	0.02	98.77	0.07
ALS	PL-13-08	P179621	SL1	0.45	0.02	0.15	0.06	0.11	0.01	0.01	98.99	0.07
ALS	PL-15-10	R143760	SL1	0.42	0.02	0.15	0.05	0.08	-0.01	0.02	98.36	0.06
ALS	PL-15-11	R143775	SL1	0.43	0.02	0.14	0.05	0.12	0.01	0.01	98.74	0.06
ALS	PL-15-13	R143816	SL1	0.44	0.02	0.16	0.06	0.12	-0.01	0.01	98.89	0.07
ALS	PL-15-15	R143858	SL1	0.42	0.02	0.14	0.06	0.13	0.01	-0.01	99.32	0.06
ALS	PL-15-15	R143850	SL1	0.45	0.03	0.15	0.06	0.14	0.01	0.01	98.21	0.07
ALS	PL-15-16	R143871	SL1	0.42	0.02	0.14	0.06	0.11	0.01	0.01	98.79	0.07
ALS	PL-15-19	R143906	SL1	0.43	0.02	0.14	0.06	0.11	0.01	0.01	98.64	0.06
ALS	PL-15-21	R143957	SL1	0.41	0.02	0.22	0.05	0.12	0.02	-0.01	98.81	0.06
ALS	PL-15-22	R143980	SL1	0.43	0.02	0.16	0.05	0.10	0.01	-0.01	98.72	0.06
ALS	PL-15-24	R143708	SL1	0.44	0.03	0.16	0.05	0.11	0.01	0.01	99.04	0.07
ALS	PL-15-24	P175734	SL1	0.44	0.02	0.16	0.06	0.09	-0.01	0.01	98.08	0.07
ALS	PL-15-25	R143738	SL1	0.43	0.03	0.15	0.05	0.10	0.01	0.02	98.57	0.07
ALS	PL-15-26	P175681	SL1	0.45	0.03	0.15	0.05	0.11	0.01	0.01	98.81	0.06
ALS	PL-15-27	P179835	SL1	0.43	0.03	0.16	0.05	0.11	-0.01	0.01	98.52	0.07
ALS	PL-13-04	P175859	SL1	0.41	0.02	0.13	0.05	0.10	-0.01	0.01	98.85	0.06
ALS	PL-13-05	P175884	SL1	0.46	0.02	0.14	0.05	0.12	-0.01	-0.01	98.48	0.06
Avg				0.43	0.02	0.15	0.05	0.11	0.01	0.01	98.70	0.07

Source: Consultations Géo-Logic

13 Mineral Processing and Metallurgical Testing

Following the 2013 drilling program, a number of samples were collected from three drill holes (PL-01, 02 and 5) and from surface. Detailed sampling procedures are described in Section 11: Samples Preparation, Analyses and Security of the 2013 report.[7]

Various chemical and physical analyses were performed on the samples, as the goal was to establish the characteristics of the Val-Brillant sandstone in relation to various potential commercial uses.

Again, a detailed description of the various tests performed is given in the 2013 report, and we refer the reader to Section 13.0 (Mineral Processing and Metallurgical Testing) of that report for the full results.[8] The conclusions of the 2013 tests, taken from that report, were as follows:

Based on the preliminary test work by CTMP, basic chemical, physical and thermal properties of the Langis sandstone indicates it has potential to be a usable source of silica. The impurities contained in the core samples are about 1% with a silica grade in the order of 98.55% SiO_2 and a loss on ignition ranging from 0.3% to 0.5%. When corrected for loss on ignition incurred during high temperature lump silica applications, the ore averages 98.95% SiO_2, 0.14% Fe_2O_3, 0.48% Al_2O_3 and 0.05% TiO_2.

Thermal shock tests on twelve representative lump samples reveal that this material has relatively strong cementation, making it a potential source for lump silica applications in high temperature furnaces.

For applications requiring silica sand grains it can be shown that a significant amount of impurities can be eliminated with the removal of fine sand below 100 microns. The residual sand then averages 99.44% SiO_2, 0.05% Fe_2O_3, 0.20% Al_2O_3 and 0.03% TiO_2.

7 GENIVAR, Characterization Study of the Langis Silica Deposit, p. 41-46
8 GENIVAR, Characterization Study of the Langis Silica Deposit, p. 49-64

With attrition, iron oxides and clays can be scrubbed from the surface of the sand grains thereby producing a cleaner silica sand averaging 99.56% SiO_2, 0.03% Fe_2O_3, 0.16% Al_2O_3 and 0.03% TiO_2.

High intensity magnetic separation removed a very small fraction of magnetic material with the objective of reducing the Fe_2O_3 content to below 0.03%, however the average impurities content in the sand product was left relatively unchanged.

Physical characteristics of the silica sand were evaluated with respect to particle size distribution; AFS grain fineness numbers, coefficient of uniformity, roundness, sphericity and crush resistance.

Based on the chemical, physical and thermal properties observed from the test work at CTMP, by crushing and screening to -120+20 mm lump particles, the Langis silica deposit may be a potential source for the production of ferrosilicon. Further crushing to -25+5 mm particles will also make it a potential source as a flux agent for base metal smelting. The chemical composition of this material, however, does not meet the requirements for the production of silicon metal.

Crushing to -600 microns and desliming the -100 microns fines as well as attrition, size classification, dewatering and drying can be considered to provide a potential source of glass sand, foundry sand and other uses like abrasive sand, sodium silicate, silicon carbide. The material was also tested for frac sand and based on an initial evaluation; the presence of many clusters as well as the issue with the grains' roundness should be considered a stumbling block for its potential as a source of frac sand. Further tests are recommended to better evaluate this product by a specialized frac sand laboratory.

From the above, Canadian Metals Inc. retained that the Langis Property sandstone can provide suitable material for ferrosilicon production. This conclusion tends to confirm historical information previously mentioned in Section 6, History, whereby some 22,000 tons of material is reported to have been shipped by Uniquartz to Norway and Iceland, leading to an agreement by which Uniquartz could supply 150,000 tons per year of lump material for ferrosilicon production. [9]

Additional testing of the Val-Brillant sandstone was conducted by Canadian Metals Inc. in 2015. Some 130 kg of sandstones were collected in the quarry contiguous to the Langis deposit as 100 mm pieces and sent to MINTEK in May 2015. MINTEK is a metallurgical consulting company with offices in South Africa.

The sandstone was crushed and screened in order to prepare four batches of 12 kg feed material that were used in MINTEK's test facility to produce ferrosilicon. Different proportions of additives were used in order to perform a preliminary evaluation of the optimal recipes for production of ferrosilicon with the Langis sandstone.

All tests succeeded in producing ferrosilicon of commercial quality.[10] Also, the thermal shock resistance of the sandstone, an essential criteria for a silica feed, was confirmed.[11] MINTEK's conclusion was that Langis sandstone would be an acceptable feedstock for ferrosilicon production, and they suggested testing on a larger scale be performed to better define the parameters for commercial-scale production of ferrosilicon.[12]

13.1 Comments on Previous Work

Commercial production of metallurgical-grade silicon, in place of or in addition to ferrosilicon, was not under consideration by Canadian Metals Inc when MINTEK was engaged to conduct testing of Langis silica in 2015. Consequently, Section 13 of this report is oriented more toward the production of ferrosilicon than metallurgical silicon. Nevertheless, MINTEK's conclusions regarding the thermal stability of Langis silica within a smelting furnace and the reduction of Langis silica to a silicon alloy are equally applicable to the metallurgical silicon base case, as is CTMP's determination of thermal shock resistance for the Langis material.

9 This report

10 MINTEK, Investigation on the Production of Ferrosilicon from Canadian Quartzite Using MINTEK's 100KVA DC Arc Facility, page 27-28

11 ibid

12 ibid

Thermal shock resistance is a critical factor when selecting a silica feedstock for silicon or ferrosilicon production. Silica with inadequate thermal shock resistance can fracture into smaller and smaller particles as the lumpy material travels through the raw material charge (burden) into the reaction zone of a submerged arc furnace. These fine particles decrease porosity in the furnace burden, which can result in poor furnace operation and reduced silicon recovery. Several minor variations of a test method to evaluate thermal shock resistance of potential silica sources exist today. One or another of these test methods is typically used in the silicon and ferrosilicon industry as a screening tool to qualify potential silica sources for full-scale production testing.

Chemical requirements for silica used to produce metallurgical silicon are more rigorous than those for ferrosilicon smelting. The content of Fe and other minor contaminants in the silica source must be held to very low levels to allow production of the best premium grades of metallurgical silicon. Silica from the Langis deposit, by itself, may not meet these requirements, based on analyses provided by Géo-Logic, GENIVAR and MINTEK. However, blending Langis silica with another silica source is an effective solution to this drawback. Blending opportunities are described below in Section 13.2.

Production of specialty, high-purity grades of ferrosilicon may also be precluded due to the high titanium content of Langis silica, but this cannot be confirmed without additional testing. Titanium cannot be effectively removed from molten alloys by post-taphole oxidative refining methods.

Production of a specialty, low-aluminum ferrosilicon grade would almost certainly require post tap-hole refining to reduce the aluminum content of the alloy.

13.1.1 Laboratory-scale, Langis Silica Smelting Test at MINTEK[13]

MINTEK conducted a series of four small-scale smelting tests utilizing Langis silica as the SiO_2 source. The objective of these tests was to determine suitability of the silica as a

13 MINTEK, Investigation on the Production of Ferrosilicon from Canadian Quartzite Using MINTEK's 100KVA DC Arc Facility

feedstock for commercial-scale ferrosilicon production. These tests clearly demonstrated that Langis silica can successfully be smelted into ferrosilicon in a laboratory setting. However, the raw material recipes used, mass balances calculated, and silicon yields obtained should not be taken as an indication of optimum commercial-scale recipes or results. This is due to MINTEK's use of a small, batch-process smelting furnace that does not approximate a commercial-scale ferrosilicon furnace and production environment.

MINTEK was well aware of the shortcomings in their initial testing protocol, which were duly noted in their report. Consequently, they proposed a follow-up evaluation of Langis silica in a larger smelting furnace at their facility, which more closely resembles a commercial-scale furnace and production environment. Comprehensive evaluation of different raw material recipes, mass balances and silicon yield in the larger furnace might then provide a more accurate starting point for selection of raw materials and recipes in commercial-scale ferrosilicon production.

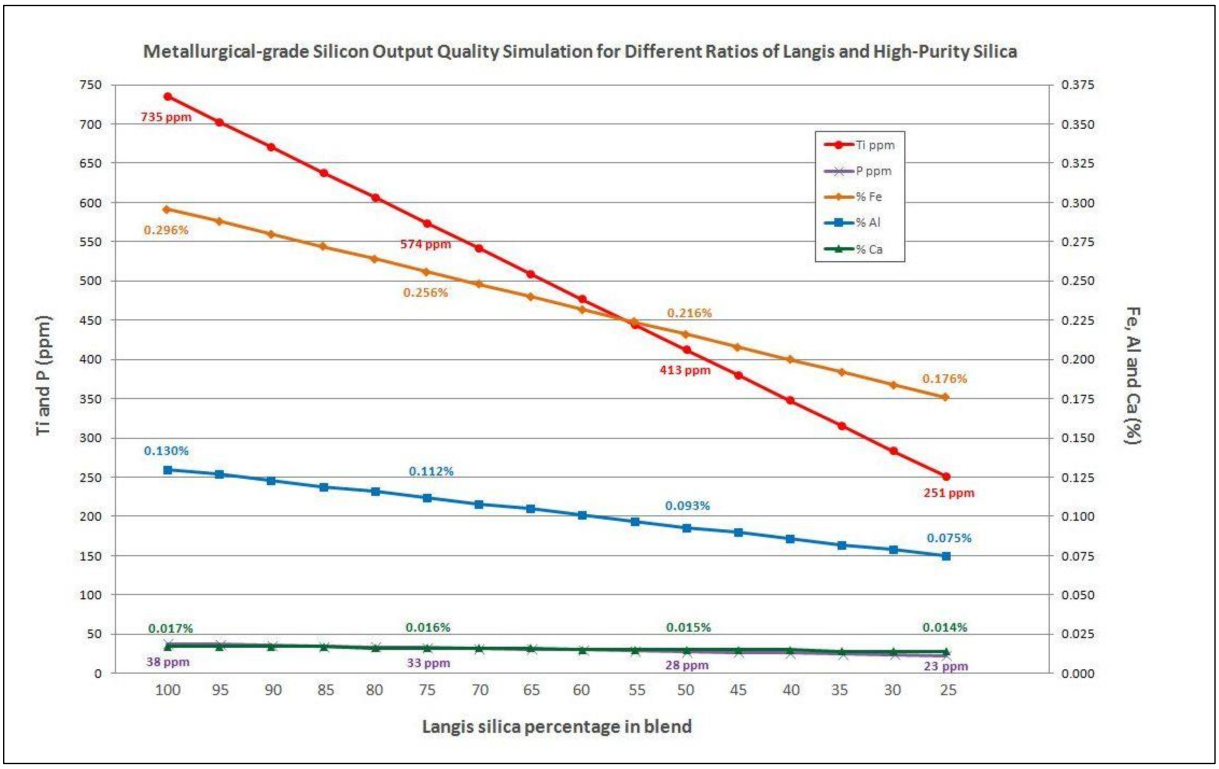
Nevertheless, MINTEK's work demonstrates:

- Thermal degradation of Langis silica in a laboratory smelting furnace was at acceptable levels and no explosive disintegration was observed during visual inspections
- FeSi alloy was formed during the test work, as evidenced from chemical, XRF and Scanning Electron Microscopy (SEM) analyses
- Langis silica can be reduced to silicon and normal furnace operation is possible

13.2 Blending Silica Sources for Metallurgical-grade Silicon Smelting

As mentioned in Section 13.1, using only Langis silica for smelting may not allow production of the best premium grades of metallurgical silicon due to its iron and minor contaminant content. This potential outcome must be verified by additional testing, but the drawback can easily be circumvented by blending Langis silica with a higher-purity silica supply in the smelter's raw material batching system, before the raw materials are charged to a smelting furnace. The supplemental silica would ideally contain <30 ppm TiO_2, <0.03% Fe_2O_3 and low quantities of other impurities commonly found in silica, such as Al_2O_3 and CaO. Silica meeting these requirements is readily available in the global marketplace. An output quality simulation for metallurgical silicon was generated using different blend ratios of Langis and supplemental silica to illustrate blending possibilities graphically. Typical chemical analyses of other raw materials necessary in the silicon production process, the average composition of Langis silica determined by Géo-Logic for this technical report, and a typical chemical analysis for high-purity, supplemental silica were used to generate the simulation shown in Figure 49. This graphic estimate should not be construed as a guarantee that specific results will be achieved in actual practice, as output quality depends highly on the raw materials actually selected for smelting, how smelting and refining processes are conducted, and the skill level (learning curve) of the operators responsible for the processes. In addition, a more detailed study and evaluation of external silica suppliers should be performed to provide a clearer picture on the blending ratios that can be used with Langis material. However, the graphic representation below is a clear indication that high-quality, metallurgical silicon can be manufactured from Langis silica when it is blended with a higher-purity, supplemental source. Note that aluminum and calcium levels shown below are estimated after oxidative refining of the molten silicon.

Figure 49: Simulation of Silicon Output Quality with Blended Silica Sources



Source: Viridis.iQ GmbH estimates

Figure 49 indicates that a blend of 25-35% high-purity, supplemental silica with Langis material, when using other typical raw materials for the production of metallurgical silicon, can shift silicon output quality into the premium grade regime. Using higher percentages of supplemental silica in the blend, on the order of 60%, appears to enable production of at least the 3303 silicon grade (a detailed explanation of metallurgical silicon grades can be found in Section 17.1.4). Since the smelter will have 3 furnaces, it is possible to have one furnace operating with a different silica blending ratio than the others, so that high quality grades can be produced in specific furnaces. Warrantying the use of silica from the Langis quarry is fundamental in further project phases. However, a comprehensive evaluation of Langis silica, including physical and chemical tests, designed experiments for smelting tests in the laboratory and pilot scale, and, if possible, an industrial test to have a very clear, accurate and more precise assessment on the process behavior of Langis silica to define the ideal production plan and calculate a precise blending plan is essential to any warranty.

14 Mineral Resource Estimate

14.1 Historical Resources

As discussed in Section 6.2, a historical resource was estimated by Uniquartz in 1982-84. The resources at the time were established at:

Millions short tons	% SiO_2	% Fe_2O_3	% Al_2O_3	
25.5	not specified	0.12	0.41	including
9.0	not specified	0.11	0.26	including
5.7	not specified	0.05	0.183	

(The authors have not done sufficient work to classify the historical estimates as current resources and the owner of the Property is not treating the historical estimate as current mineral resources.)

Efforts by Uniquartz to define resources with minimal iron and alumina content were driven by a different market outlook than the current work by Canadian Metals Inc. The resources calculated by Uniquartz were based on holes drilled on a fairly large, irregular drilling pattern with a spacing of around 200-250 meters. Some 12 holes covering almost 30 hectares were drilled to investigate the Val-Brillant Formation. With such a density of holes, the geological model presented was essentially conceptual. Done in the early 1980s, the Uniquartz estimate does not meet current NI 43-101 standards.

14.2 Canadian Metal Resource Estimate

Following the 2013-15 drilling programs completed by Canadian Metals Inc., the current resource estimate was prepared. This estimate is significantly different from the historical one described above, as 27 holes were drilled on an area of some 10 hectares. The drilling pattern of 100 meters in 2013 was reduced to 50 meters in 2015, which was deemed sufficient to construct a reliable geological model.

14.2.1 Database

The authors used the Geotic software for the Langis project. Data from the Uniquartz drill holes are incomplete. For example, no assays for silica were reported in the public documents filed by Uniquartz. The location of the drill holes was found to be acceptable as a landmark used by Uniquartz was identified during field work by Canadian Metals. Consequently, the historical hole collars are shown on our 2015 maps but the results obtained in these holes were not used for the interpretation.

The database used to estimate the Langis resource was therefore restricted to recent work by Canadian Metals, and included:

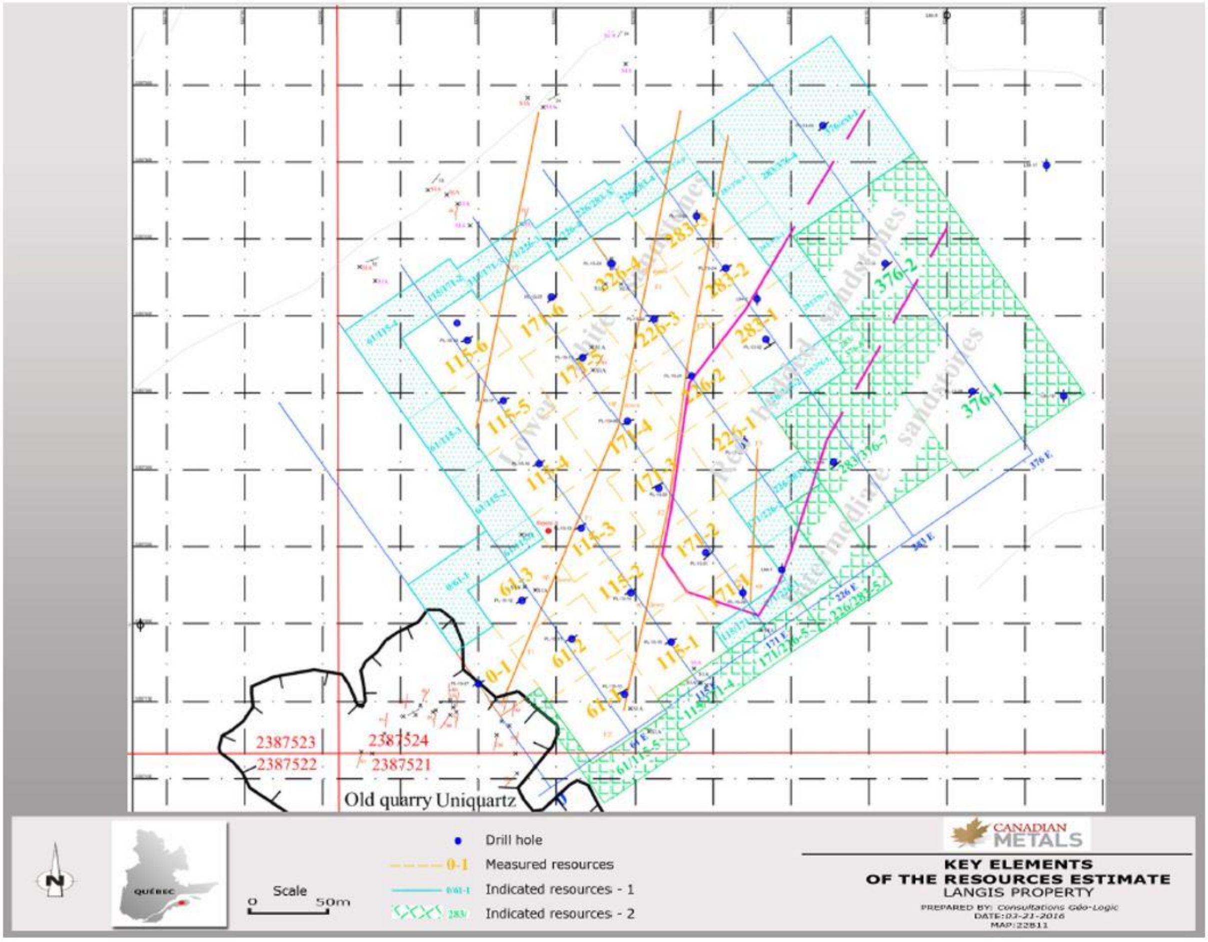
- 27 drill holes
- 1,157.6 meters
- 479 assays
- 31 deviation tests

14.2.2 Grid

The 2013 drilling program was put in place using GPS coordinates to implement a 100-meter drill grid. Nine holes were drilled in 2013 and surveyed at the end of the program.

In 2015, the base grid used on the project was established theoretically on a digitized map using the official government-source MTM NAD83 vector maps. After putting in the 2013 hole location, a base line oriented N240° was defined along the southeast part of the drilling area. From its southwest extremity, which corresponds to the northeast wall of the old Uniquartz quarry, the holes to be drilled were placed on perpendicular lines spaced 50 meters apart. On these lines, infill drill holes were placed between the 2013 holes to produce a final 50-meter drilling pattern. The hole coordinates were generated and located in the field by GPS. Once the program was completed, hole locations were surveyed. Due to field constraints and/or GPS precision, the N320° lines centered along drill holes lines are in fact at 0, 61E, 115E, 171E, 226E, 283E and 376E, the last being outside the 50-meter drill grid pattern. Figure 50 shows the grid, hole locations and other elements of the resource estimate.

Figure 50: Location of key elements for the resources estimate



14.2.3 General Key Assumptions of the Geological Model

The Langis deposit is composed of sedimentary rocks in which lateral variations of composition are gradual but vertical variations may be found to be important over short distances. The results obtained at a particular point are easier to extrapolate horizontally than vertically.

The Langis deposit is part the Val-Brillant Formation, and is located in an area where northwest-southeast tectonic compressive forces were active subsequent to the consolidation of the sandstones. As a result, the deposit is now on the north limb of an east-west regional structure. Locally, this means that the geological units dip to the south. Drilling and surface reconnaissance indicate that the general dip is around 5-10° to the south.

Compression also forced a horizontal shortening of the geological units. This was accommodated by vertical movements along NNE and NE north-dipping faults. These sets of faults have been identified in the walls of the old Uniquartz quarry.

A geological model must be stable from one section to another and consistent with the various structures (bedding, faults) identified in the core of the drill holes. The model was developed between Sections 0 and 283 E, where the drill grid is at a 50-meter spacing. These are the limits of the current model and therefore the location of the geological resources.

14.2.4 Geological Model

As described in Section 7, “Geology”, the Langis deposit is located at the base of the Val-Brillant Formation, just above the shales of the Awantjish Formation.

A couple of holes were deep enough to intersect the Awantjish Formation to make it possible to understand the detailed stratigraphy in the Langis deposit area. The distinctive shales constitute a reliable marker for interpretation.

The first units of the Val-Brillant Formation to overlay the Awantjish shales are heterogeneous and composed of impure gray, pink and red sandstones. This constitutes the transition between the shale units and the more homogeneous white sandstone of the so-called Val-Brillant Lower Sandstone. The top of the transition zone is a deep-red sandstone.

From that point, the Lower Sandstone is composed of mostly white horizons, but does include some pink and locally reddish sandstone horizons. The Lower Sandstone extends to the surface in the northwest portion of the Langis deposit. It is south dipping and thickens gradually to the southeast, where it reaches a total thickness of some 35 meters. There it starts being overlain by a sequence of impure pink-to-red sandstone some 15 meters thick. Locally, the lower contact of this impure sequence with the white underlying sandstones is a thin conglomeratic unit. This potential marker unit was found to lack lateral extension and was not found everywhere it should be.

The impure sequence currently indicates the southeastern edge of the Langis deposit, as thickening of this sequence going south gradually reduce the possibility of reaching the underlying Lower White Sandstone.

Farther south, the impure sequence is itself overlain by white sandstone that appears similar to the Lower White Sandstone. This sandstone is interpreted as being the lower part of the Intermediate Sandstone described in Section 7. Here, some 15 meters were intersected between the top of the impure sequence and surface.

As mentioned previously, all the units dip gently to the south. In-hole measurements indicate mostly sub-horizontal to 5-10° dips, and up to around 15-20° in a few cases.

Field observations indicate the presence of NNE-SSW and NE-SW faults dipping quite steeply to the north.

On-section interpretation suggests that the only way to reconcile the variation in the position of the contact between the Awantjish and Val-Brillant formations and the average dip of the units is vertical movement along the faults. Displacement along the faults is principally a thrust movement, with north blocks going up relative to south blocks. Three fault zones showing these characteristics were located in the model and found to be traceable from one section to the other.

A fourth fault, located on the southeast margin of the deposit, appears to show an inverse movement. It was reported previously by Uniquartz to be a complex structural zone where thicknesses and composition of the units may vary more significantly. Figure 51 is a typical section showing the geological model of the Langis deposit while Figure 52 is a longitudinal section across the central part of the deposit.

Figure 51: Typical cross-section of the Langis deposit

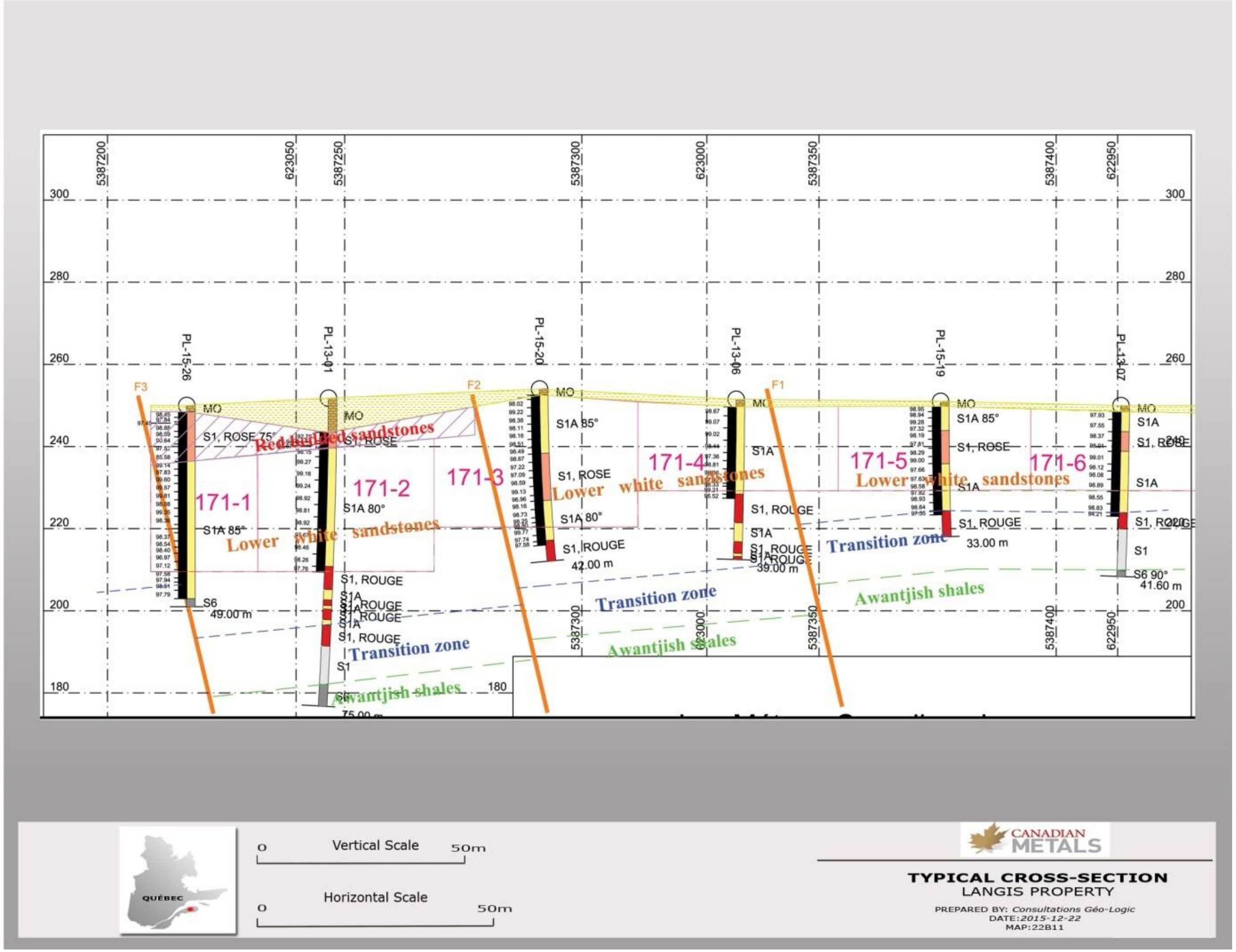
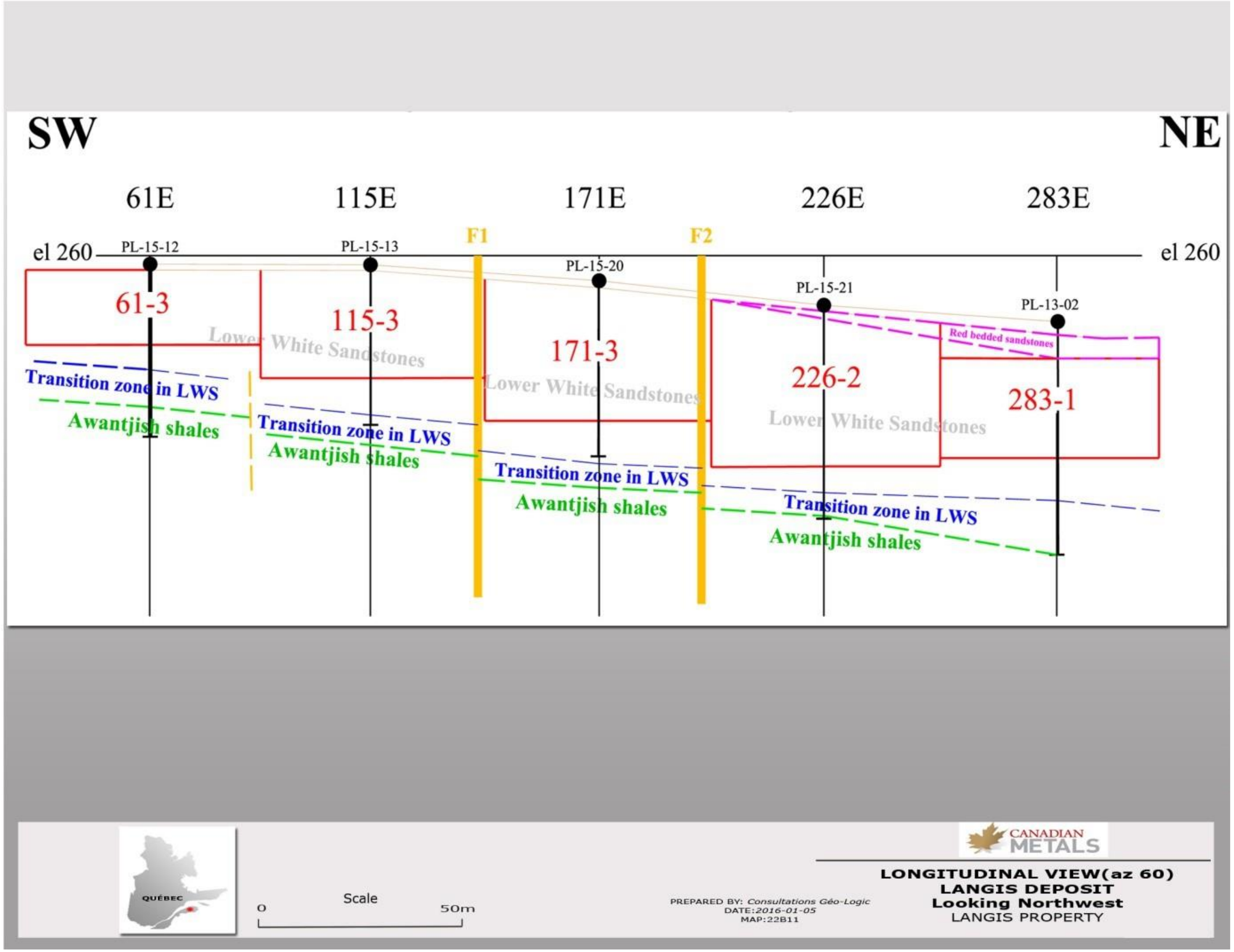


Figure 52: Longitudinal view – Langis deposit



14.2.5 Methodology and Parameters of the Resource Estimate

14.2.5.1 Measured Resources

Resources are considered measured within an area where a consistent geological model has been developed and where the density of information is considered sufficient to adequately characterize the resource. The measured resource must also form a continuous body without isolated blocks or areas. Here, the resource is located in the immediate continuity of a quarry that provides access to significant exposure of the geological units. In a sedimentary environment, given the 50-meter drill grid and the consistent results, the authors believe that the measured resource category is appropriate.

The measured resource was estimated using the polygons-on-section method. Sections were produced every 50 meters between 0 and 283E and included all the 2013-15 holes on these sections.

The first examination took into consideration a parameter established for the ferrosilicon plant, namely that a minimum of 97.7% SiO_2 content is needed for the feed. All the parameters for acceptable material (chemically) are presented in Table 18. A single, isolated sample not meeting these criteria can be included as long as the contiguous samples can compensate for the difference.

First, the mineralized envelope was defined on each section. The mineralized envelope was then divided into blocks.

A block is centered along the trace of one hole containing a vertical section (all holes being vertical) of sandstones meeting the minimum 97.7% SiO_2 criteria. The limits of a block may either be:

a) Vertically

- The mineralized envelope
- A vertical line located 25 meters (measured horizontally) from the hole if no other holes are present in that direction
- A vertical line located mid-way between two holes, if less than 25 meters
- A fault

- A vertical line located so that the overlying reddish impure sandstones is less than 12 meters thick, corresponding to one standard quarry bench

b) Horizontally

- The trace of the bedrock on surface (excluding overburden)
- The upper contact between the Lower Sandstone and the overlying reddish impure sandstone
- A horizontal line located 5-10 meters above the contact between the Lower Sandstone and the red sandstone of the transition zone
- The last samples analysed on a section, even if the core logs suggest that deeper material could very well be suitable

As one can see, even if the measured resource is normally based essentially on geology, some additional constraints were considered in this case, namely the limit of 12 meters of waste material on top of the resource and the loss of some resource at the bottom, in order to leave a safety margin between acceptable material and the beginning of the impure transition zone. These were considered essential to increase the level of confidence in the measured resource. Keeping a horizontal lower limit of the block also helps to maintain the tonnages when passing from measured resource to mineral reserves following pit design.

Once the block was defined, the area was measured, and this area was then multiplied by its influence on each side of the section concerned to calculate the block volume (cubic meters). The influence is the sum of half the distance to the next section on each side. If there was no section on one side, the influence was set at 25 meters.

Finally, tonnages were established by multiplying the volumes by a density of 2.50 g/cm^3 (see Section 14.2.8 below).

The chemistry of each block was then calculated from all assays forming the intersection in question, and is a weighted average of all the samples forming the intersection. This was applied to SiO_2 and to all other oxides analysed and considered as impurities. The results were all within the maximum impurity levels, so there was no need to discard any resource blocks or areas. In other words, no selective removal will be required within the block model.

Figure 50 is a surface view locating the measured resource blocks estimated (in orange), and Table 23 provides the details of each block per section, tonnage and chemistry by section, and the total for the Langis deposit.

Table 23 also shows the cubic meters of material to be removed to access the bedrock surface by section. The amount of waste rock to be removed in order to access the measured resource where the overlying red impure sandstone is present in the southeast part of the deposit should also be considered. Table 24 has been prepared to show the distribution of the measured resource and the chemistry of the resource covered or not covered by the red impure sandstone.

Table 23: Measured resources

Section	Item or Block	Hole	Surface (m^2)	Horiz. Influence (m)	Volume (m^3)	Tonnage (mt)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	MnO (%)	TiO_2 (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	Overbuden (m^3)	Waste (mt)
0	Overburden		106	30.5	3233												3233	
	Waste on top		0	30.5	0	0												0
	0-1	27	2521	30.5	76,891	192,226	98.43	0.11	0.40	0.03	0.09	0.00	0.05	0.01	0.08	0.00		
	Total section					192,226	98.43	0.11	0.40	0.03	0.09	0.00	0.05	0.01	0.08	0.00		
61	Overburden		132	57	7524												7524	
	Waste on top		0	57		0												0
	61-1	10	1323	57	75,411	188,528	99.03	0.10	0.36	0.02	0.09	0.00	0.05	0.00	0.04	0.00		
	61-2	11	1223	57	69,711	174,278	98.68	0.11	0.36	0.02	0.10	0.01	0.05	0.00	0.04	0.00		
	61-3	12	830	57	47,310	118,275	98.34	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.09	0.00		
	Total section					481,080	98.73	0.10	0.35	0.02	0.08	0.00	0.05	0.00	0.05	0.00		
115	Overburden		461	55	25,355												25,355	
	Waste on top		0	55		0												0
	115-1	15	1282	55	70,510	176,275	98.64	0.09	0.39	0.02	0.11	0.00	0.05	0.00	0.08	0.00		
	115-2	14	1437	55	79,035	197,588	98.69	0.09	0.39	0.02	0.11	0.00	0.06	0.00	0.08	0.00		
	115-3	13	1272	55	69,960	174,900	98.37	0.12	0.40	0.02	0.11	0.00	0.06	0.01	0.05	0.00		
	115-4	16	878	55	48,290	120,725	98.44	0.15	0.47	0.02	0.11	0.01	0.06	0.01	0.14	0.00		
	115-5	17	483	55	26,565	66,413	97.41	0.21	0.77	0.04	0.13	0.01	0.08	0.01	0.28	0.00		
	115-6	18	558	55	30,690	76,725	98.06	0.19	0.58	0.02	0.11	0.00	0.06	0.01	0.23	0.00		
	Total section					812,625	98.41	0.12	0.45	0.02	0.11	0.00	0.06	0.01	0.11	0.00		
171	Overburden		688	55.5	38,184												38,184	
	Waste on top		571	55.5	31,691	79,226												79,226
	171-1	26	709	55.5	39,350	98,374	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00		
	171-2	1	1305	55.5	72,428	181,069	98.65	0.15	0.44	0.11	0.09	0.01	0.05	0.06	0.07	0.01		
	171-3	20	1453	55.5	80,642	201,604	98.29	0.13	0.42	0.01	0.11	0.00	0.05	0.00	0.10	0.00		
	171-4	6	1014	55.5	56,277	140,693	98.56	0.13	0.44	0.01	0.14	0.00	0.06	0.01	0.05	0.00		
	171-5	19	953	55.5	52,892	132,229	98.31	0.16	0.56	0.02	0.15	0.00	0.07	0.00	0.15	0.00		
	171-6	7	905	55.5	50,228	125,569	98.36	0.13	0.47	0.02	0.07	0.00	0.05	0.00	0.20	0.00		
	Total section					879,536	98.45	0.14	0.45	0.04	0.11	0.00	0.05	0.02	0.10	0.00		
226	Overburden		359	56	20,104												20,104	
	Waste on top		357	56	19,992	49,980												49,980
	226-1	25	1743	56	97,608	244,020	98.85	0.11	0.37	0.02	0.10	0.00	0.05	0.01	0.04	0.00		
	226-2	21	1758	56	98,448	246,120	98.53	0.13	0.39	0.02	0.10	0.00	0.05	0.00	0.06	0.00		
	226-3	22	1003	56	56,168	140,420	98.84	0.13	0.35	0.02	0.04	0.00	0.05	0.00	0.13	0.00		
	226-4	23	339	56	18,984	47,460	98.34	0.18	0.51	0.02	0.08	0.01	0.06	0.01	0.18	0.00		
	Total section					678,020	98.70	0.13	0.38	0.02	0.09	0.00	0.05	0.00	0.08	0.00		
283	Overburden		379	53.5	20,277												20,277	
	Waste on top		276	53.5	14,766	36,915												36,915
	283-1	2	1251	53.5	66,929	167,321	99.07	0.08	0.30	0.02	0.04	0.01	0.04	0.03	0.06	0.00		
	283-2	24	1368	53.5	73,188	182,970	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00		
	283-3	8	757	53.5	40,500	101,249	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00		
	Total section					451,540	98.80	0.11	0.37	0.02	0.06	0.01	0.05	0.01	0.10	0.00		
Total:						3,495,000	98.57	0.12	0.41	0.03	0.10	0.00	0.05	0.01	0.09	0.00	114,677	166,121

Source: Consultations Géo-Logic

Table 24: Measured resource covered or not covered by waste material

A) Zone without waste coverage										
Metric tons	**SiO_2 (%)**	**Fe_2O_3 (%)**	**Al_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**MnO (%)**	**TiO_2 (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**
2,673,000	**98.52**	**0.12**	**0.42**	**0.02**	**0.10**	**0.00**	**0.06**	**0.01**	**0.10**	**0.00**
B) Zone covered with waste										
Metric tons	**SiO_2 (%)**	**Fe_2O_3 (%)**	**Al_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**MnO (%)**	**TiO_2 (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**
822,000	**98.73**	**0.12**	**0.38**	**0.04**	**0.09**	**0.00**	**0.05**	**0.02**	**0.06**	**0.00**
Total deposit										
Metric tons	**SiO_2 (%)**	**Fe_2O_3 (%)**	**Al_2O_3 (%)**	**CaO (%)**	**MgO (%)**	**MnO (%)**	**TiO_2 (%)**	**Na_2O (%)**	**K_2O (%)**	**P_2O_5 (%)**
3,495,000	**98.57**	**0.12**	**0.41**	**0.03**	**0.10**	**0.00**	**0.05**	**0.01**	**0.09**	**0.00**

Source: Consultations Géo-Logic

14.2.5.2 Indicated Resource

The indicated resource has been subdivided into two categories, 1 and 2. The indicated (both categories) is located typically in the immediate continuity of the measured resource. In this case, the 25-meter horizontal influence used for the measured resource was increased to 50 meters. The indicated resource is therefore composed of the 25-50 meters in addition to the measured resource where the drilling pattern is 50 meters, and 0-50 meters from a hole, where the drilling pattern is 100 meters (e.g., between Sections 283E and 386E). Any indicated resource (1 or 2) must consist of blocks contiguous to either the measured resource or other indicated resource blocks. No isolated block should exist. Horizontally, the indicated resource may be limited by faults. These general criteria apply to all indicated resources. The difference made between indicated-1 and 2 is the cover of waste material. If overlying waste reaches the equivalent of one mining bench, or 12 meters, then the indicated-1 becomes 2 to better show areas where the criteria are met but where an additional constraint is present. The indicated-2 resource is concentrated along the southeast margin of the deposit where the Lower Sandstones are covered by gradually thickening red bedded sandstones and Intermediate Sandstones.

Since the indicated resource is an extension of the measured resource, no on-section interpretation is required. The model constructed for the measured resource was simply extended to a greater distance from the sampling points. Therefore, the simplest way to visualize and calculate the indicated resource blocks (in blue for 1 and green for 2) was to use the plan view of the Langis deposit (Figure 50) to measure the surface of all the indicated blocks. The vertical influence is the length of the good material intersected in the hole(s) attached to the block.

An indicated resource must be drilled at 50-meter intervals in order to be upgraded to the measured category. Note that possible additional indicated tonnage under the measured resource blocks was not taken into consideration at this stage due to the structural complexity of this area.

14.2.6 Zonation of the Mineralization

Some work was done to see if there were obvious vertical or lateral variations in the chemical elements of the Langis deposit. As a general observation, slightly lower silica content corresponds to an increase in alumina, suggesting that some clay is present in these cases.

Examination of the sections did not reveal any tendency for one or more elements to be more abundant in relation to depth.

Table 23 indicates that laterally, the chemical composition calculated per section shows very slight variations from the southwest to the northeast. Similarly, for the northwest-southeast direction, we see that the composition of the material covered or not covered by the red impure sandstone is very similar. The average chemistry for each block and for the indicated resource as a whole is shown in the Table 25.

For the entire deposit, only one hole, namely Hole 2015-17 in Section 115E, returned average silica content under the 97.7% minimum value, with 97.41% SiO_2. This is an isolated case, and all the surrounding blocks will contribute to producing material within the desired specification.

14.2.7 Density

Ten pulp samples coming from the core analysed and stored at the ALS laboratory were used to determine the relative density by pycnometry. The density measured on pulp is reliable as long as the original rock is non-porous.

This method was used since the Lower Sandstone is compact and does not show an obvious porosity. The locations of the samples are indicated on sections 171E and 226E in Volume II of the references used in this report (see Section 27 for reference, the Géo-Logic, 2016 report). They are judged representative of the Lower Sandstone since this formation shows a very stable chemistry and mineralogy. The samples were taken in four holes and represent the upper, middle and lower part of the formation.

The results are quite stable and gave an average of 2.75 g/cm^3. Results obtained on standards tend to show a slight increase in the calibration of the measurements. Since the theoretical value expected from the chemical and mineral composition of the sandstone was in the 2.65 - 2.70 ranges, we retained 2.70 g/cm^3 as the more reliable number from these tests.

Further discussions about this issue resulted in the necessity of carrying out additional density determinations directly on the core to make sure that even if the rock looks non-porous, there could be some pores within the rock that would result in a slightly smaller density. This sampling program will include the overlying waste rock in the southeast part of the deposit, where mining is possible.

For the moment, in order to leave room for an eventual decrease of the final density, the author applied a density of 2.5 g/cm^3 for tonnage calculation. This is considered as a very conservative value by the author.

NOTE: The density issue has no implication on the development potential of the project. It will be useful however for the fine tuning of the subsequent mining plan.

Table 25: Indicated-1 resources

Section	Item or Block	Hole	Surface (m^2)	Thickness (m)	Volume (m^3)	Tonnage (mt)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	MnO (%)	TiO_2 (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)
0/61	0/61-1	12	2363.0	18.50	43,716	109,289	98.34	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.09	0.00
61/115	61/115-1	12,13	438.7	22.00	9,651	24,129	98.37	0.12	0.36	0.02	0.08	0.00	0.06	0.01	0.07	0.00
	61/115-2	16	1310.4	19.00	24,898	62,244	98.44	0.15	0.47	0.02	0.11	0.01	0.06	0.01	0.14	0.00
	61/115-3	17	1315.5	9.80	12,892	32,230	97.41	0.21	0.77	0.04	0.13	0.01	0.08	0.01	0.28	0.00
	61/115-4	18	2592.3	11.75	30,460	76,149	98.06	0.19	0.58	0.02	0.11	0.00	0.06	0.01	0.23	0.00
115/171	115/171-1	26	466.5	26.35	12,292	30,731	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
	115/171-2	18	700.2	11.75	8,227	20,568	98.06	0.19	0.58	0.02	0.11	0.00	0.06	0.01	0.23	0.00
	115/171-3	7	695.6	19.60	13,634	34,084	98.28	0.13	0.51	0.02	0.07	0.00	0.05	0.00	0.20	0.00
171/226	171/226-1	26	1600.4	26.35	42,171	105,426	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
	171/226-2	1	961.9	30.28	29,126	72,816	98.65	0.15	0.44	0.11	0.09	0.01	0.05	0.06	0.07	0.01
	171/226-3	7	715.2	19.60	14,018	35,045	98.28	0.13	0.51	0.02	0.07	0.00	0.05	0.01	0.20	0.00
	171/226-4	23	651.4	7.20	4,690	11,725	98.34	0.18	0.51	0.02	0.08	0.01	0.06	0.00	0.18	0.00
226/283	226/283-1	25	722.4	33.00	23,839	56,598	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
	226/283-2	2	715.9	24.00	17,182	42,954	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	226/283-3	23	711.4	7.20	5,122	12,805	98.34	0.18	0.51	0.02	0.08	0.01	0.06	0.01	0.18	0.00
	226/283-4	8	718.4	16.80	12,069	30,173	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00
283/376	283/376-1	2	657.1	24.00	15,770	39,426	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	283/376-2	2	1079.4	24.00	25,906	64,764	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	283/376-3	24	1084.9	29.85	32,384	80,961	98.60	0.13	0.41	0.02	0.08	0.01	0.05	0.00	0.11	0.00
	283/376-4	3	4175.2	21.00	87,679	219,198	98.67	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.12	0.00
	283/376-5	8	1625.7	16.80	27,132	68,279	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00
	283/376-6	8	580.0	16.80	9,744	24,360	98.72	0.11	0.38	0.03	0.07	0.01	0.06	0.01	0.14	0.00
376/ext	376/ext-1	3	4644.2	21.00	97,528	243,821	98.67	0.10	0.32	0.02	0.06	0.00	0.05	0.01	0.12	0.00
Total:						**1,501,000**	**98.52**	**0.13**	**0.40**	**0.02**	**0.09**	**0.00**	**0.05**	**0.01**	**0.11**	**0.00**

Source: Consultations Géo-Logic

Table 26: Indicated-2 resources

Section	Item or Block	Hole	Surface (m^2)	Thickness (m)	Volume (m^3)	Tonnage (mt)	SiO_2 (%)	Fe_2O_3 (%)	Al_2O_3 (%)	CaO (%)	MgO (%)	MnO (%)	TiO_2 (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)
61/115	61/115-5	10	2,131	26.5	56,472	141,179	99.03	0.10	0.36	0.02	0.09	0.00	0.05	0.00	0.04	0.00
115/171	115/171-4	15	1,339	29.3	39,233	98,082	98.64	0.09	0.39	0.02	0.11	0.00	0.05	0.00	0.08	0.00
171/226	171/226-5	26	1,380	26.4	36,432	91,080	98.55	0.13	0.39	0.02	0.12	0.00	0.04	0.01	0.03	0.00
226/283	226/283-5	09, 26	2,891	24.3	70,251	175,628	98.67	0.11	0.37	0.02	0.11	0.00	0.04	0.01	0.03	0.00
283/376	283/376-7 283/376-8	09 02	6,791 556	22.2 24.0	150,760 13,344	376,901 33,360	98.78 99.07	0.09 0.08	0.34 0.30	0.02 0.02	0.10 0.04	0.01 0.01	0.04 0.04	0.01 0.03	0.03 0.06	0.00 0.00
376	376-1 376-2	05 04	8,818 9,333	24.3 25.0	214,277 233,325	535,694 583,313	99.03 99.07	0.08 0.11	0.35 0.32	0.05 0.02	0.08 0.06	0.01 0.00	0.04 0.05	0.06 0.01	0.04 0.09	0.01 0.00
Total:						**2,035,000**	**98.92**	**0.10**	**0.34**	**0.03**	**0.08**	**0.00**	**0.04**	**0.02**	**0.05**	**0.00**

Source: Consultations Géo-Logic

14.2.8 Additional Potential

It is important to note that the work done by Canadian Metals is concentrated in an area covering some 10 hectares. Previous work done by Uniquartz covered close to 30 hectares, in the center of which lies Canadian Metals' Langis deposit.

Results obtained at the time by Uniquartz confirmed the presence of the Lower Sandstone in the entire area explored. We will not estimate the inferred resource on the Canadian Metals property as the Uniquartz results are incomplete, but it should be noted that there is significant room to increase the resources estimated in this report.

14.2.9 Other Important Considerations

Globally, the morphology of the deposit is very favorable for the development of an open pit with no waste or a very low waste-to-silica ratio. Mining could be started quickly at the northeast end of the old quarry, extending north-northeast.

The overburden thickness averages approximately two meters. A thicker zone of overburden is located at the eastern edge of the deposit, where some waste material overlies the Lower White Sandstone, but this area is not being considered for quarrying in the short-medium term.

All the resources are located on Crown lands and do not require surface rights permitting.

15 Mineral Reserve Estimate

A mineral reserve estimate should be revisited and calculated in further project phases as required. Based on Canadian Metals Inc, this is not a requirement for the PEA.

16 Mining Methods

The Langis quarry will be operated as a traditional cone-shaped excavation, commonly used in the mining industry and normally called an open pit mine or quarry. The cone will advance in a top-down direction, maximizing the NPV (net present value). This excavation will be conducted with rope or hydraulic shovels with trucks carrying both silica and waste. Waste will be dumped outside the mined-out area since no room is available within the pit. Waste will be placed as close to the edge of the pit as possible, to minimize transportation costs.

Mining of the deposit will be conducted in compliance with good practices for mining operations, according to the standards established in Mining Regulatory Standards, with special attention to safety conditions of the people involved, and with minimal negative impact to the environment.

Before actual production starts, there will be a stage of quarry preparation or development. At this stage the quarry will be prepared to insure the continuity of sufficient silica production to feedstock the smelter without interruption. This step must precede the start of smelter operations.

Quarry preparation consists of removing the vegetation cover, if any, of the entire area planned for development. Then the organic soil will be removed and stockpiled in a location already prepared, for future use in the reclamation of degraded areas. This removal can be conducted with bulldozers, hydraulic excavators, wheel loaders, and dump trucks equipped with tipper buckets.

Initially, a wheel loader will scrape off the topsoil layer, forming piles in places accessible to trucks. Then a wheel loader or an excavator will load the material in the trucks that will transport it to storage sites where it will be unloaded. Once the topsoil is removed, the removal of waste material covering the silica can occur. This removal will be planned to allow a sufficient volume of exposed silica to feedstock the smelter.

Time and expense was not considered for this initial operation since only a small quantity of overburden material exists. The waste material removed to expose the silica will be disposed as described in Section 16.3.6, Waste Disposal.

The operations of vegetation removal, organic soil removal and overburden removal will need to be repeated throughout the life of the quarry as the pit is being expanded.

During the preparation phase of the quarry, some usable silica will be removed and stockpiled separately, to be used when the smelter is in operation. This silica can be transported to an area near the smelter to serve as stockpile in the event of shortage of silica transported directly from the quarry.

The next step is to prepare the quarrying fronts, with the opening of benches having sufficient length to form an initial silica stock for the first months of smelter operation, and to insure the continuity of production required to feed the beneficiation plant.

16.1 Geological Model

16.1.1 Database

The database used to generate the geological model and to estimate the Langis resource can be summarized in Table 27, Table 28, Table 29, and Figure 53 as follows:

Table 27: Descriptive grid characteristics

Description	Quantity
Drill Holes	27
Total Drill Holes	1,157.6 meters
Drill Holes Depth Average	47 meters
Vertical Sections	6
Deviation Tests	31
Grid Spacing	50 meters x 50 meters

Source: Caban Geoservices, Viridis.iQ GmbH

Table 28: Samples in database

Description	Quantity
Assay Samples	447
Lithology Samples	142

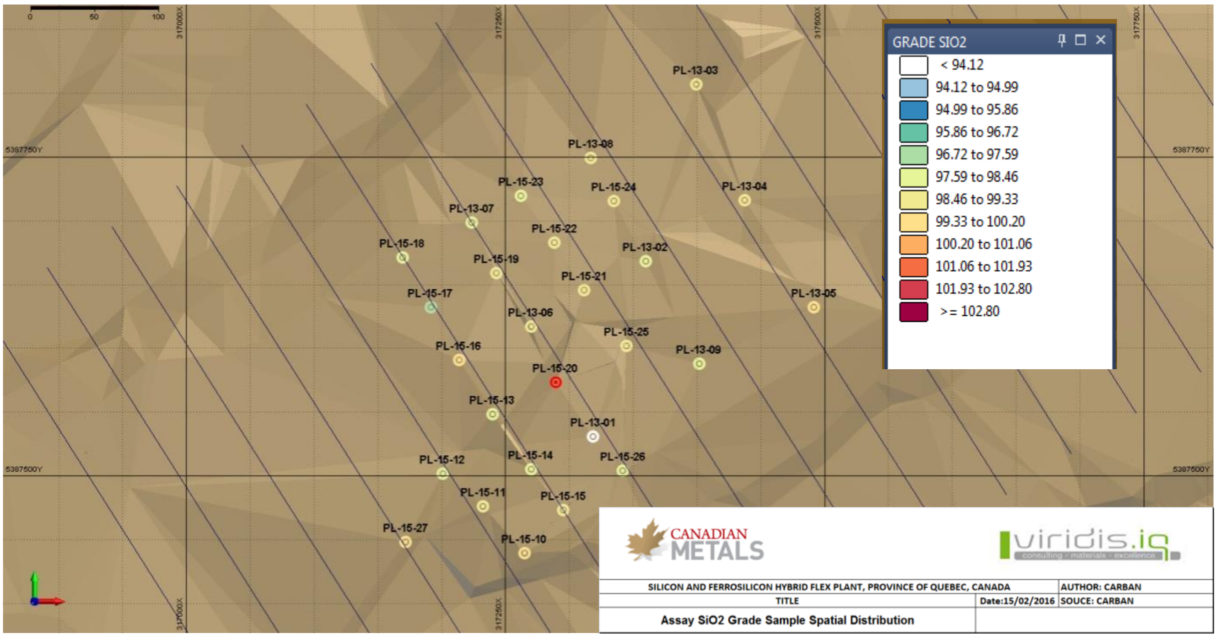
Source: Caban Geoservices, Viridis.iQ GmbH

Table 29: Assay descriptive statistics

Element	Minimum (%)	Maximum (%)	Mean (%)	Std Dev
SiO_2	49.84	99.87	97.49	4.69
Al_2O_3	0.07	3.05	0.47	0.33
Fe_2O_3	0.00	1.10	0.16	0.13
BaO	-0.01	0.02	0.00	0.01
CaO	0.01	15.65	0.32	1.43
Cr_2O_3	-0.01	0.03	0.01	0.01
K_2O	0.02	0.69	0.10	0.08
MgO	-0.01	10.25	0.31	0.95
MnO	-0.01	0.04	0.00	0.01
Na_2O	-0.01	0.19	0.01	0.02
P_2O_5	-0.01	0.02	-0.01	0.01
SO_3	-0.01	0.37	0.01	0.04
SrO	-0.01	0.01	-0.01	0.00
TiO_2	0.02	0.16	0.05	0.02
LOI	-0.05	24.05	0.64	2.19

Source: Caban Geoservices, Viridis.iQ GmbH

Figure 53: Assay SiO_2 grade sample spatial distribution



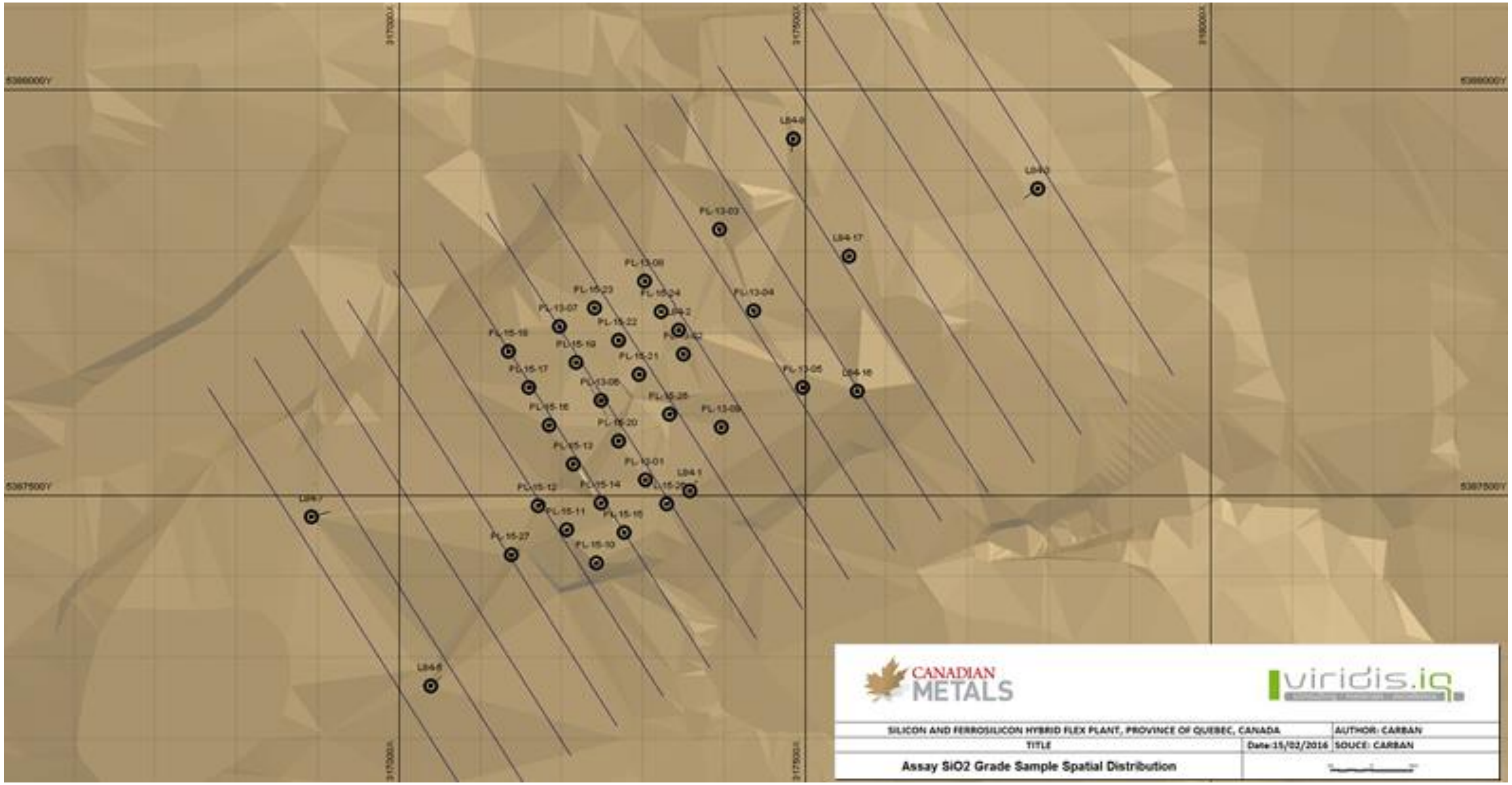
16.1.2 Grid

The 2013 drilling program was put in place using GPS coordinates to implement a 100-meter drilling grid. Nine holes were drilled in 2013 and surveyed at the end of the program.

In 2015, the base grid used on the project was established theoretically on a digitized map using the official MTM NAD 83 vectorial maps obtained from governmental sources. After adding the 2013 hole locations, a base line oriented N2400 was defined along the southeast part of the drilling area.

From its southwest extremity, which corresponds to the northeast wall of the old Uniquartz quarry, the holes to be completed were placed on perpendicular lines spaced 50 meters apart. On these lines, infilling drill holes were emplaced through the 2013 holes to produce a final 50 meter-spaced drilling pattern. The hole coordinates were generated and located in the field by GPS. Hole locations were surveyed once the program was completed. Due to field constraints and/or GPS precision it turned out that the N3200 line was actually 100 meters from its nearest neighbor. Figure 54 presents the grid, the holes locations and other elements of the resource estimate.

Figure 54: Grid, drill-hole locations and other elements for resource estimate



16.1.3 Drill Holes

The identification and other data related to the drill holes at the Langis quarry is shown in the Table 30. There were 35 drill holes available, but just those with the prefix PL (27 in total) have information about grades and lithology, consequently, they were the only holes used to generate the block model.

Table 30: Drill-hole database used for modeling

Project	Drill hole	UTM East (m)	UTM North (m)	Elevation (m)	Azimuth	Dip (º)	Length (m)
Silice Langis 2013	PL-13-01	623,045.16	5,387,246.08	251.78	0.00	-90.00	75.00
Silice Langis 2013	PL-13-02	623,083.70	5,387,384.72	244.29	0.00	-90.00	56.08
Silice Langis 2013	PL-13-03	623,120.39	5,387,523.75	237.24	0.00	-90.00	45.00
Silice Langis 2013	PL-13-04	623,160.38	5,387,434.02	238.58	0.00	-90.00	53.65
Silice Langis 2013	PL-13-05	623,216.28	5,387,350.95	249.16	0.00	-90.00	57.00
Silice Langis 2013	PL-13-06	622,994.85	5,387,331.62	251.50	0.00	-90.00	39.00
Silice Langis 2013	PL-13-07	622,947.05	5,387,412.18	249.97	0.00	-90.00	41.60
Silice Langis 2013	PL-13-08	623,039.24	5,387,464.86	243.58	0.00	-90.00	30.00
Silice Langis 2013	PL-13-09	623,127.18	5,387,304.94	247.29	0.00	-90.00	59.64
Silice Langis 2015	PL-15-10	622,993.00	5,387,154.00	256.00	330.00	-90.00	37.50
Silice Langis 2015	PL-15-11	622,960.00	5,387,190.00	258.00	330.00	-90.00	41.50
Silice Langis 2015	PL-15-12	622,928.00	5.387.215,00	258.00	330.00	-90.00	41.50
Silice Langis 2015	PL-15-13	622,966.00	5,387,262.00	258.00	330.00	-90.00	38.50
Silice Langis 2015	PL-15-14	622,997.00	5,387,220.00	257.00	330.00	-90.00	39.00
Silice Langis 2015	PL-15-15	623,023.00	5,387,188.00	254.00	330.00	-90.00	42.00
Silice Langis 2015	PL-15-16	622,939.00	5,387,304.00	256.00	330.00	-90.00	30.00
Silice Langis 2015	PL-15-17	622,916.00	5,387,345.00	252.00	330.00	-90.00	24.00
Silice Langis 2015	PL-15-18	622,893.00	5,387,384.00	251.00	330.00	-90.00	27.00
Silice Langis 2015	PL-15-19	622,967.00	5,387,373.00	251.00	330.00	-90.00	33.00
Silice Langis 2015	PL-15-20	623,015.00	5,387,288.00	254.00	330.00	-90.00	42.00

Project	Drill hole	UTM East (m)	UTM North (m)	Elevation (m)	Azimuth	Dip (º)	Length (m)
Silice Langis 2015	PL-15-21	623,036.00	5,387,361.00	248.00	330.00	-90.00	51.00
Silice Langis 2015	PL-15-22	623,012.00	5,387,398.00	249.00	330.00	-90.00	42.00
Silice Langis 2015	PL-15-23	622,985.00	5,387,434.00	248.00	330.00	-90.00	26.00
Silice Langis 2015	PL-15-24	623,058.00	5,387,431.00	244.00	330.00	-90.00	44.60
Silice Langis 2015	PL-15-25	623,070.00	5,387,318.00	247.00	330.00	-90.00	54.00
Silice Langis 2015	PL-15-26	623,069.00	5,387,220.00	250.00	330.00	-90.00	49.00
Silice Langis 2015	PL-15-27	622,900.00	5,387,161.00	260.00	330.00	-90.00	39.00

Source: Caban Geoservices, Viridis.iQ GmbH

16.1.4 Silica Solid

Interpreted sections were received with resources already classified as measured or indicated. Three-dimensional solids representing the geological model were then generated, as shown in Figure 55 and

Figure 56. Drill-hole collar information in the Langis Project area was fitted to the model due to the low precision of the topography (20-meter contours).

Figure 55: Indicated and measured silica solid

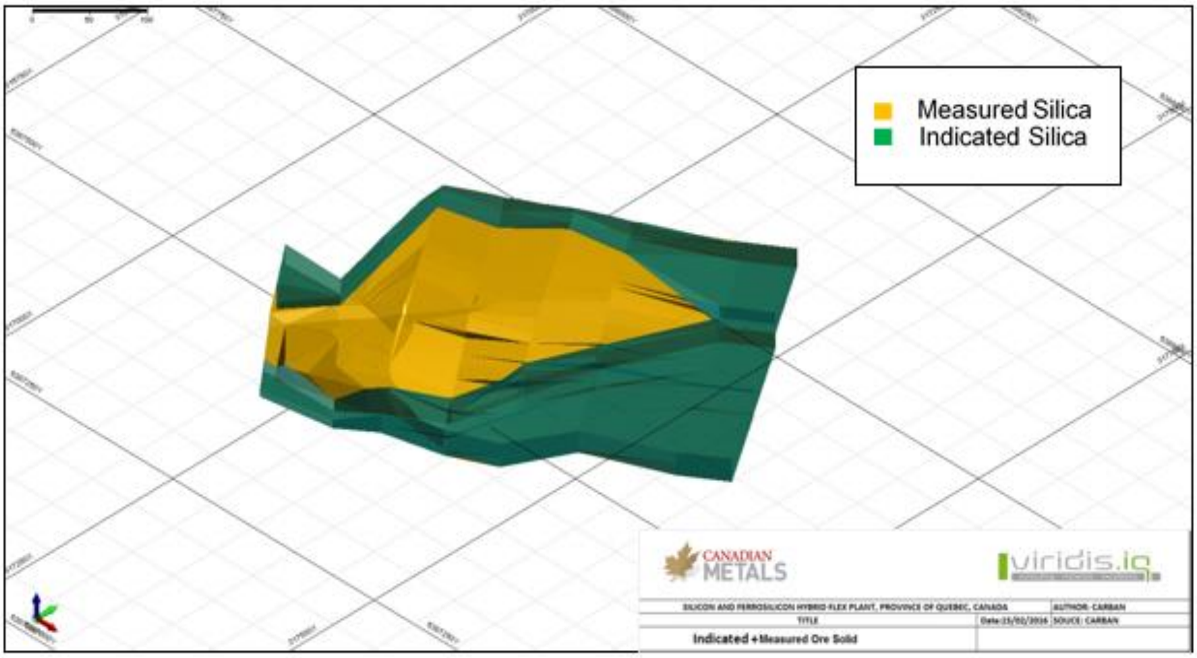
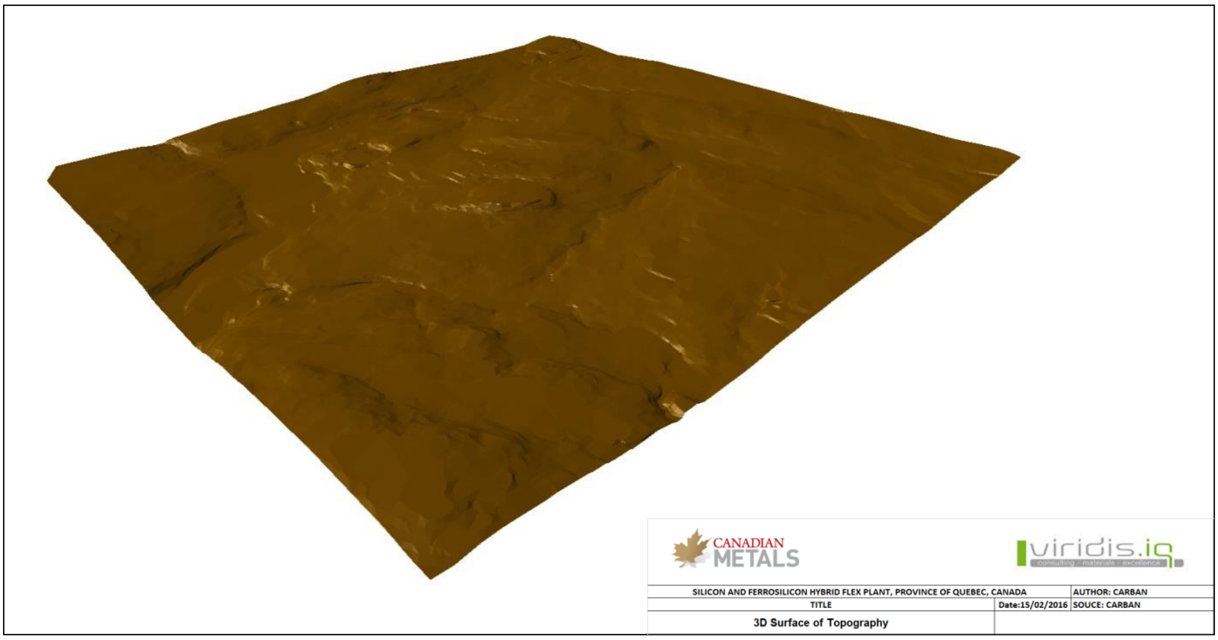


Figure 56: 3D surface of topography

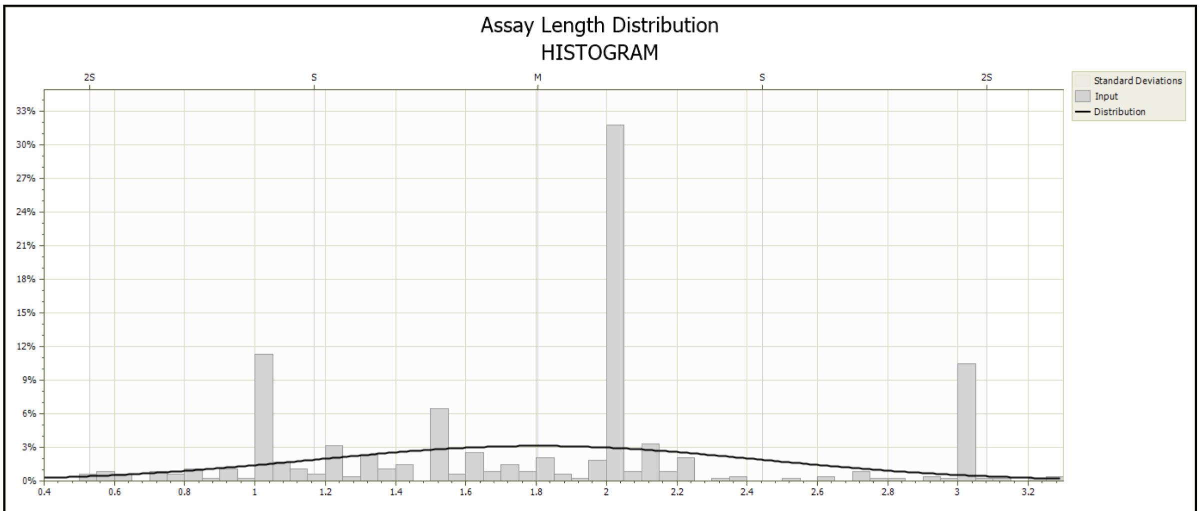


16.1.5 Compositing

Samples with the same support must be used to estimate the blocks, so it was necessary to establish the composites from the drill-hole samples. In order to determine the size of the composite in this project a statistical analysis for the size of the samples in the original drilling database was carried out. A value of 2 was adopted, which corresponds to the integer value nearest to the mode of the sizes (2.05), as shown in the Figure 57 and

Figure 58 below.

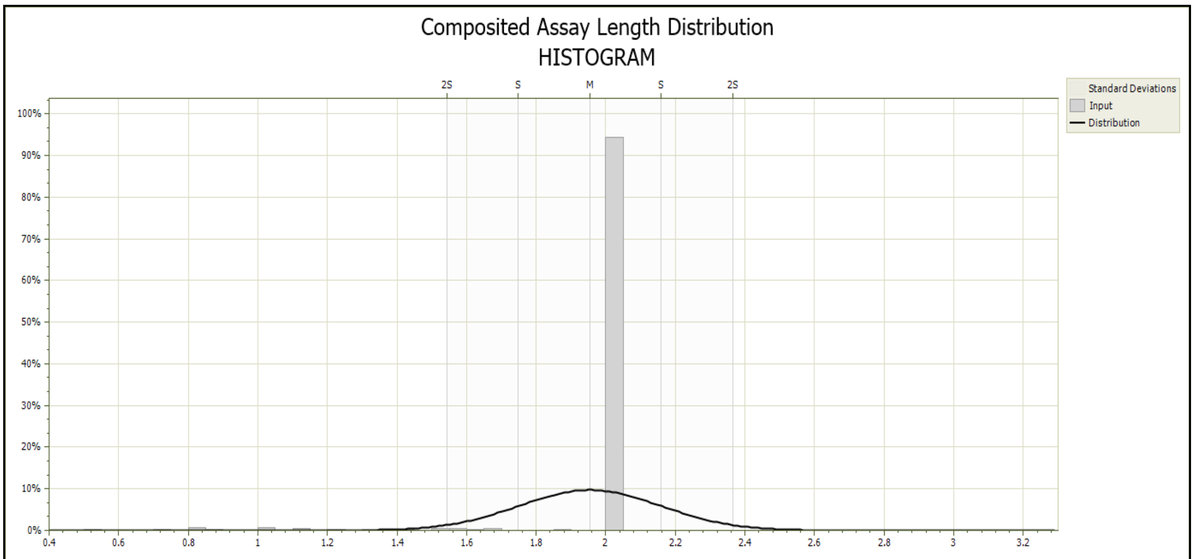
Figure 57: 3D assay length distribution



Minimum value	0.500000	N	479	Median	2.000000	Sichel's estimator	1.816513
Maximum value	3.300000	Mean	1.805219	Ln mean	0.520656	Sichel's V	0.152549
2nd highest	3.270000	Variance	0.406902	Ln std deviation	0.390575	Sichel's gamma	1.079246
3rd highest	3.200000	Standard deviation	0.637889	Geometric mean	1.683132	Chi-Square Test	2289.304076
4th highest	3.100000	Coeff. of variation	0.353358	Geometric std dev	1.477830	Degrees of freedom	47

Source: Caban Geoservices, Viridis.iQ GmbH

Figure 58: 3D composited assay length distribution



Minimum value	0.500000	N	384	Median	2.000000	Sichel's estimator	1.959476
Maximum value	2.000000	Mean	1.954219	Ln mean	0.660934	Sichel's V	0.023486
2nd highest	2.000000	Variance	0.042168	Ln std deviation	0.153252	Sichel's gamma	1.011812
3rd highest	2.000000	Standard deviation	0.205349	Geometric mean	1.936601	Chi-Square Test	3838.443225
4th highest	2.000000	Coeff. of variation	0.105080	Geometric std dev	1.165619	Degrees of freedom	20

Source: Caban Geoservices, Viridis.iQ GmbH

16.1.6 Statistical Analysis of Drilling Data Assay

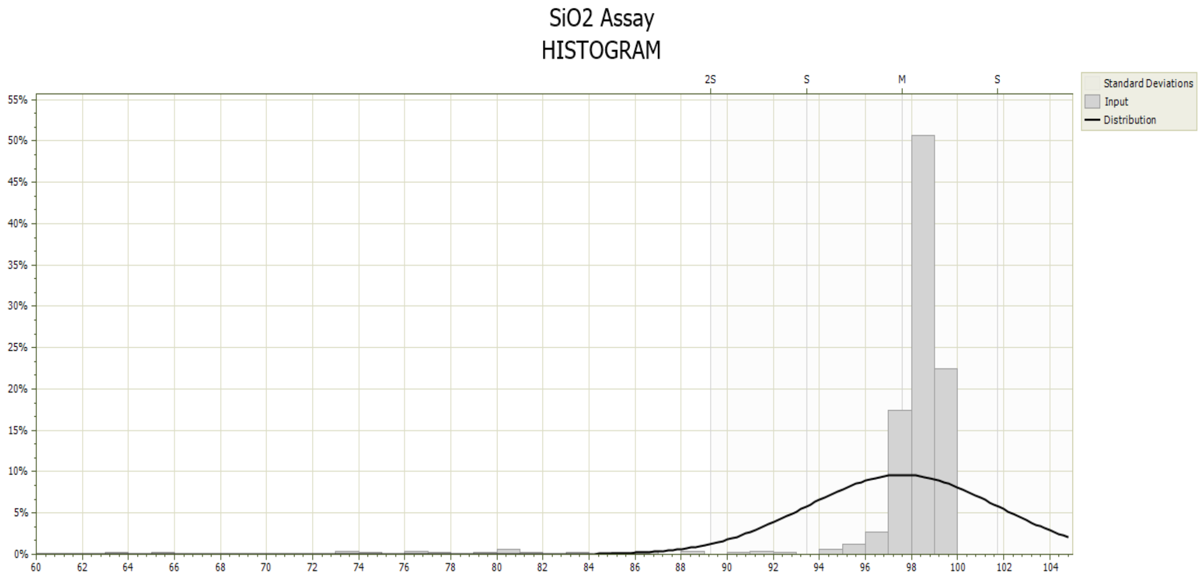
The resource model represents the silica-zone volume and tonnage, chemical grades of the element of interest and the contaminants.

To build this model we must understand the behavior of those grades in specific silica types and in three-dimensional space, by the application of appropriate statistical techniques to the data.

In order to better understand that behavior and to apply that knowledge and assess the grade estimation of the geological model, a classic statistical analysis was used to perform the following tasks:

- Assessing the need for separate populations of grades, if more than one population exists;
- Determining the grade distribution.

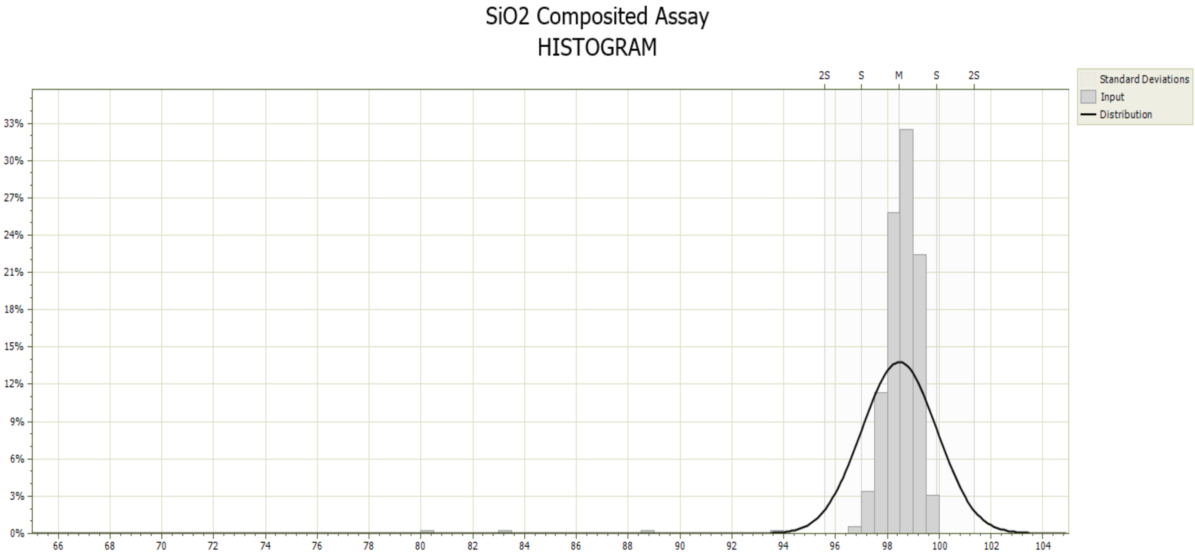
Figure 59: 3D assay SiO_2 grade distribution



Minimum value	63.130000	N	476	Median	98.500000	Sichel's estimator	97.603560
Maximum value	99.870000	Mean	97.594118	Ln mean	4.579746	Sichel's V	0.002336
2nd highest	99.840000	Variance	17.233699	Ln std deviation	0.048333	Sichel's gamma	1.001169
3rd highest	99.810000	Standard deviation	4.151349	Geometric mean	97.489622	Chi-Square Test	1465.978337
4th highest	99.770000	Coeff. of variation	0.042537	Geometric std dev	1.049520	Degrees of freedom	18

Source: Caban Geoservices, Viridis.iQ GmbH

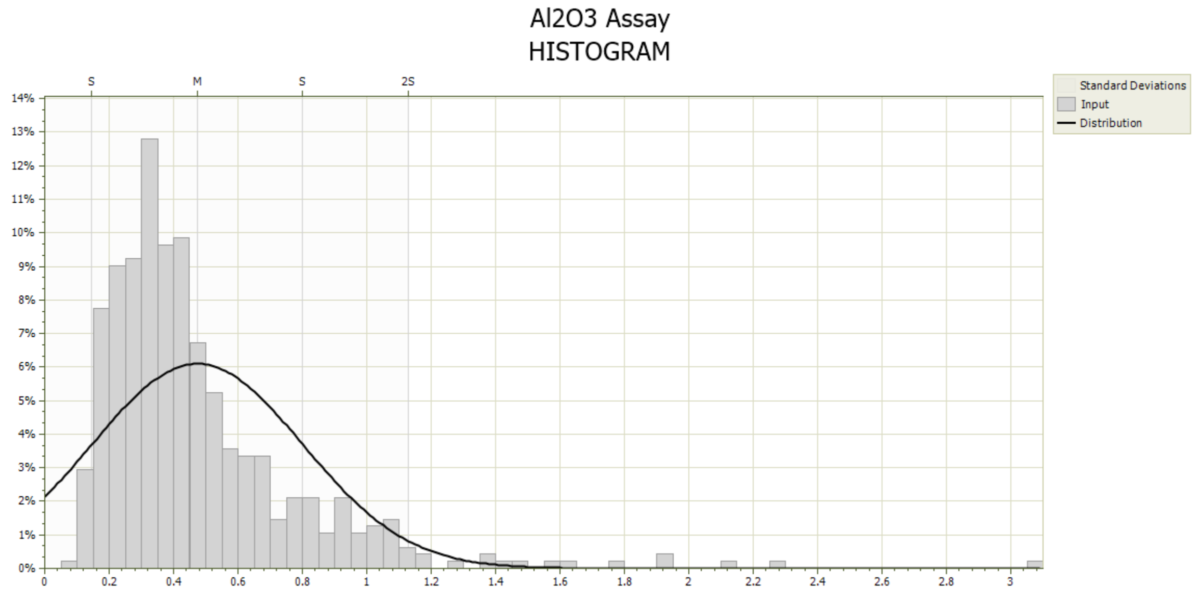
Figure 60: 3D composited assay SiO_2 grade distribution



Minimum value	80.147000	N	388	Median	98.642000	Sichel's estimator	98.459944
Maximum value	99.840000	Mean	98.459355	Ln mean	4.589525	Sichel's V	0.000249
2nd highest	99.770000	Variance	2.086383	Ln std deviation	0.015783	Sichel's gamma	1.000125
3rd highest	99.740000	Standard deviation	1.444432	Geometric mean	98.447681	Chi-Square Test	407.716754
4th highest	99.728500	Coeff. of variation	0.014670	Geometric std dev	1.015909	Degrees of freedom	14

Source: Caban Geoservices, Viridis.iQ GmbH

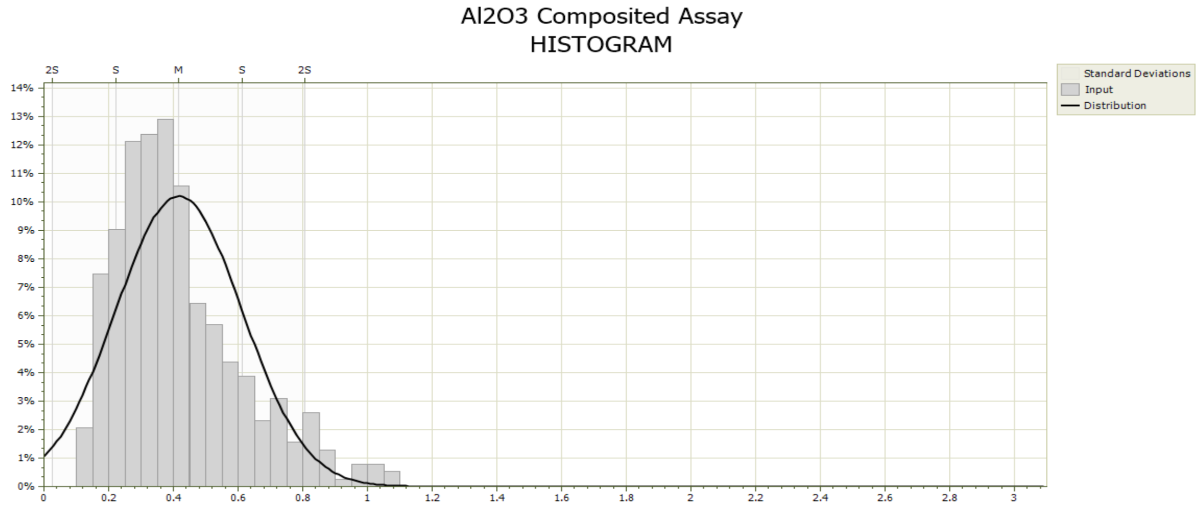
Figure 61: 3D assay Al_2O_3 grade distribution



Minimum value	0.070000	N	477	Median	0.380000	Sichel's estimator	0.469236
Maximum value	3.050000	Mean	0.473543	Ln mean	-0.923418	Sichel's V	0.333652
2nd highest	2.290000	Variance	0.107012	Ln std deviation	0.577626	Sichel's gamma	1.181480
3rd highest	2.120000	Standard deviation	0.327127	Geometric mean	0.397159	Chi-Square Test	605.457774
4th highest	1.910000	Coeff. of variation	0.690808	Geometric std dev	1.781803	Degrees of freedom	24

Source: Caban Geoservices, Viridis.iQ GmbH

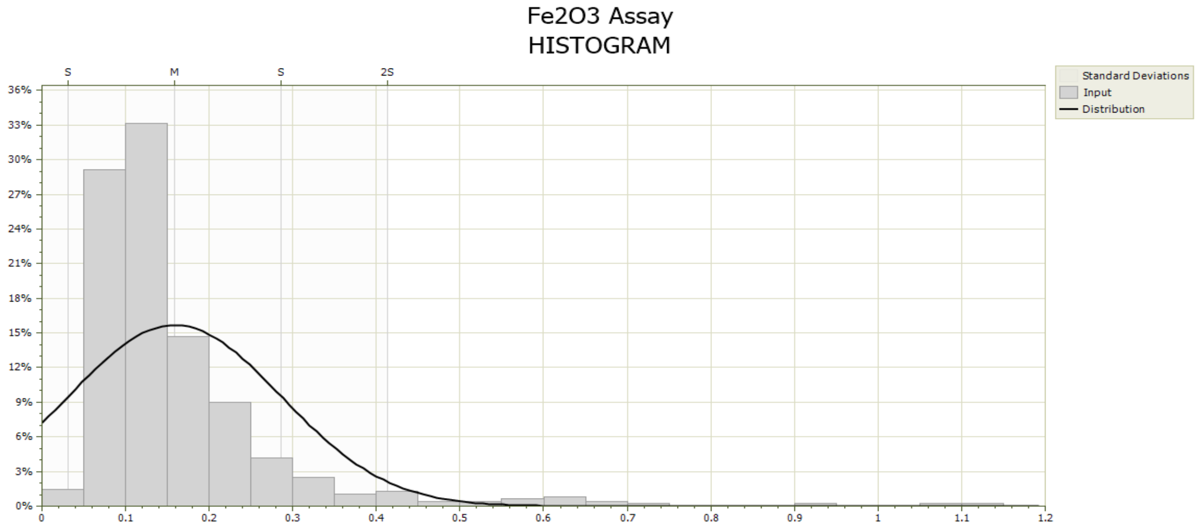
Figure 62: 3D composited assay Al_2O_3 grade distribution



Minimum value	0.110000	N	388	Median	0.374000	Sichel's estimator	0.417257
Maximum value	1.050000	Mean	0.416658	Ln mean	-0.981060	Sichel's V	0.214070
2nd highest	1.050000	Variance	0.038248	Ln std deviation	0.462677	Sichel's gamma	1.112940
3rd highest	1.047500	Standard deviation	0.195572	Geometric mean	0.374914	Chi-Square Test	175.486817
4th highest	1.039000	Coeff. of variation	0.469383	Geometric std dev	1.588320	Degrees of freedom	17

Source: Caban Geoservices, Viridis.iQ GmbH

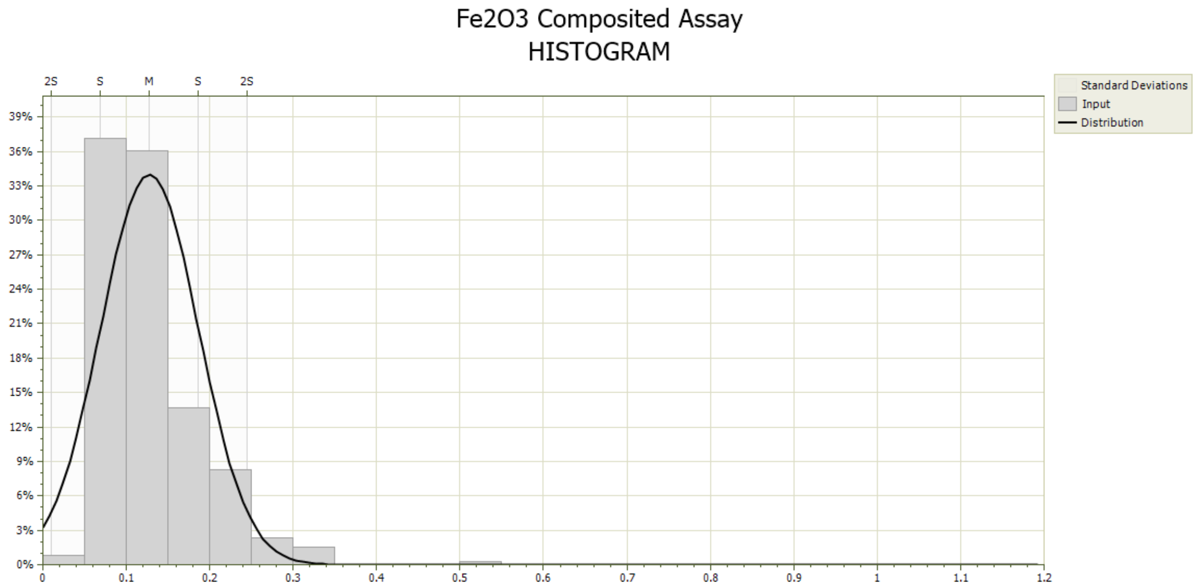
Figure 63: 3D assay Fe_2O_3 grade distribution



Minimum value	0.001000	N	477	Median	0.120000	Sichel's estimator	0.156897
Maximum value	1.100000	Mean	0.158744	Ln mean	-2.035163	Sichel's V	0.366141
2nd highest	1.080000	Variance	0.016178	Ln std deviation	0.605096	Sichel's gamma	1.200815
3rd highest	0.940000	Standard deviation	0.127193	Geometric mean	0.130659	Chi-Square Test	637.613507
4th highest	0.730000	Coeff. of variation	0.801245	Geometric std dev	1.831428	Degrees of freedom	9

Source: Caban Geoservices, Viridis.iQ GmbH

Figure 64: 3D composited assay Fe_2O_3 grade distribution



Minimum value	0.036400	N	388	Median	0.114250	Sichel's estimator	0.127173
Maximum value	0.512000	Mean	0.127659	Ln mean	-2.147080	Sichel's V	0.169782
2nd highest	0.347500	Variance	0.003446	Ln std deviation	0.412047	Sichel's gamma	1.088578
3rd highest	0.340000	Standard deviation	0.058700	Geometric mean	0.116825	Chi-Square Test	579.292226
4th highest	0.330000	Coeff. of variation	0.459820	Geometric std dev	1.509905	Degrees of freedom	5

Source: Caban Geoservices, Viridis.iQ GmbH

Table 31: Assay and composited assay values

Element	ASSAY				COMPOSITED ASSAY			
	Min (%)	Max (%)	Mean (%)	Std Dev	Min (%)	Max (%)	Mean (%)	Std Dev
SiO_2	49.84	99.87	97.49	4.69	80.15	99.84	98.46	1.44
Al_2O_3	0.07	3.05	0.47	0.33	0.11	1.05	0.42	0.20
Fe_2O_3	0.00	1.10	0.16	0.13	0.04	0.51	0.13	0.06
BaO	-0.01	0.02	0.00	0.01	-0.01	0.01	0.00	0.01
CaO	0.01	15.65	0.32	1.43	0.01	5.61	0.07	0.41
Cr_2O_3	-0.01	0.03	0.01	0.01	-0.01	0.03	0.01	0.00
K_2O	0.02	0.69	0.10	0.08	0.02	0.39	0.09	0.06
MgO	-0.01	10.25	0.31	0.95	-0.01	3.86	0.12	0.28
MnO	-0.01	0.04	0.00	0.01	-0.01	0.02	0.00	0.01
Na_2O	-0.01	0.19	0.01	0.02	-0.01	0.17	0.01	0.02
P_2O_5	-0.01	0.02	-0.01	0.01	-0.01	0.01	-0.01	0.01
SO_3	-0.01	0.37	0.01	0.04	-0.01	0.22	0.01	0.03
SrO	-0.01	0.01	-0.01	0.00	-0.01	0.01	-0.01	0.00
TiO_2	0.02	0.16	0.05	0.02	0.03	0.09	0.05	0.01
LOI	-0.05	24.05	0.64	2.19	-0.05	8.65	0.25	0.63

Source: Caban Geoservices, Viridis.iQ GmbH

16.1.7 Vertical Sections of Geologic Modeling

Seven vertical geological sections, distributed in the region of interest for the Langis quarry according to Figure 54, were used to develop a geologic model in 3D on Surpac software. These sections were georeferenced based on the grid and drill-hole collar information. The sections interpreted are shown in Figure 65, Figure 66, Figure 67, Figure 68, Figure 69, Figure 70 and Figure 71 as follows:

Figure 65: Section 0

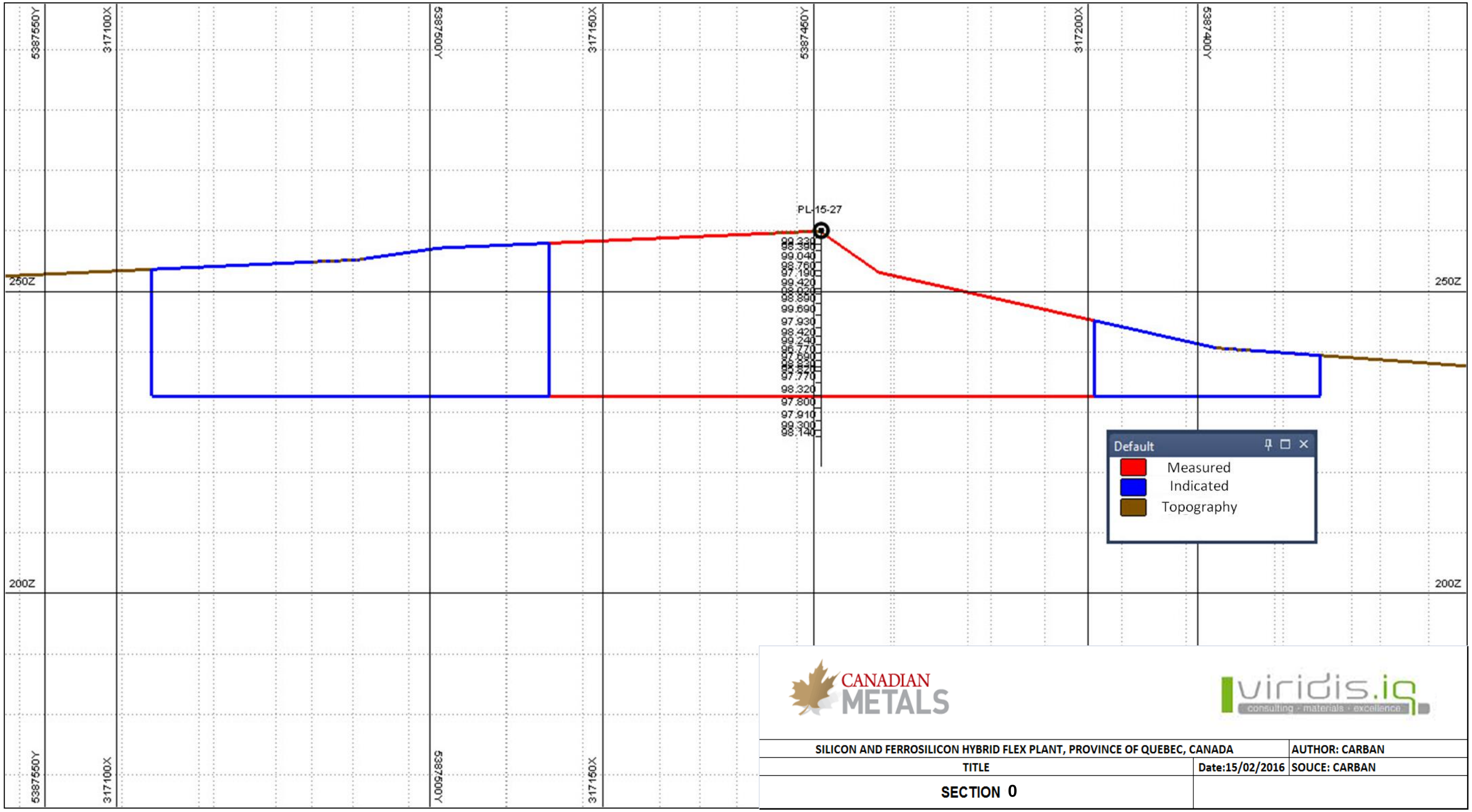


Figure 66: Section 61

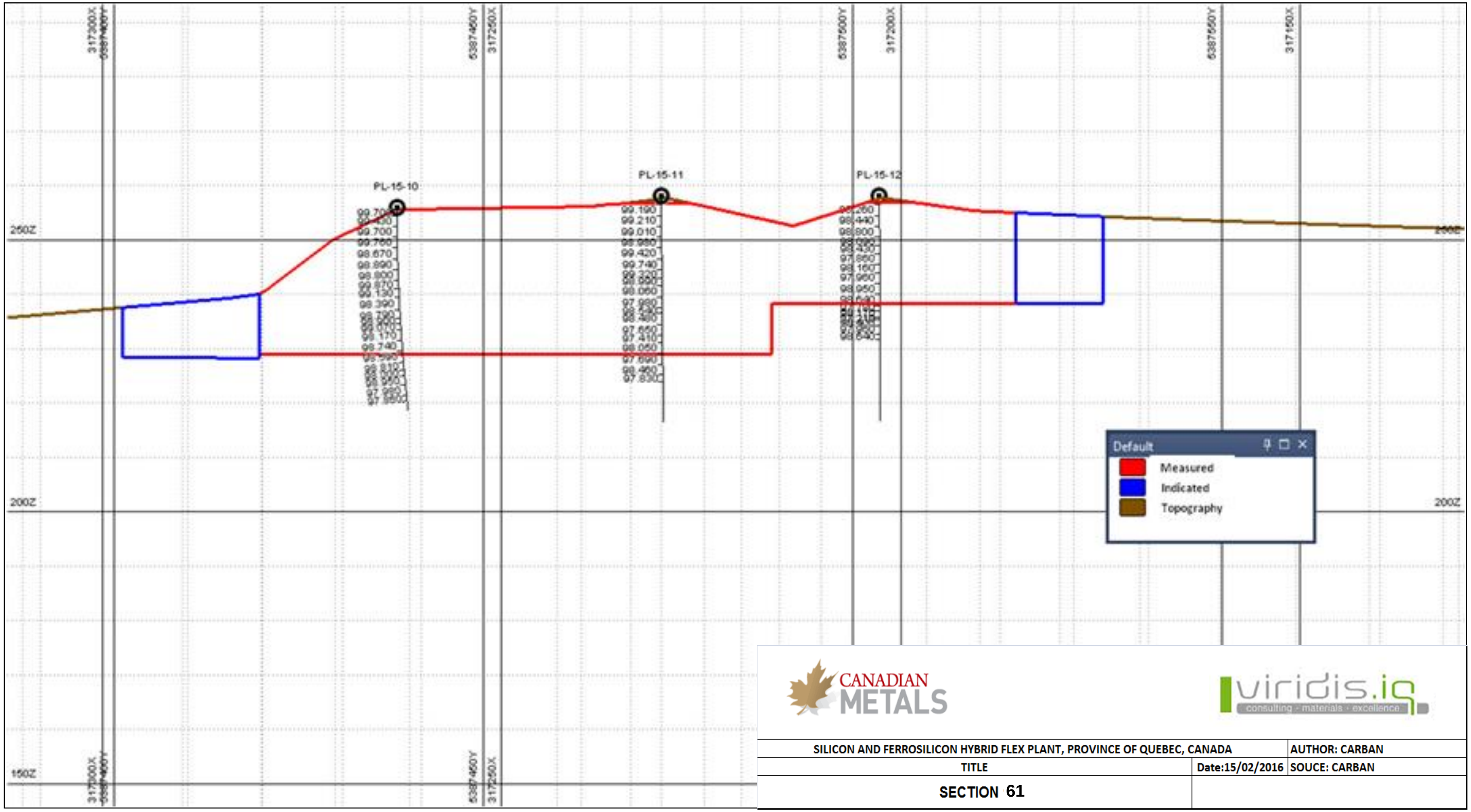


Figure 67: Section 115

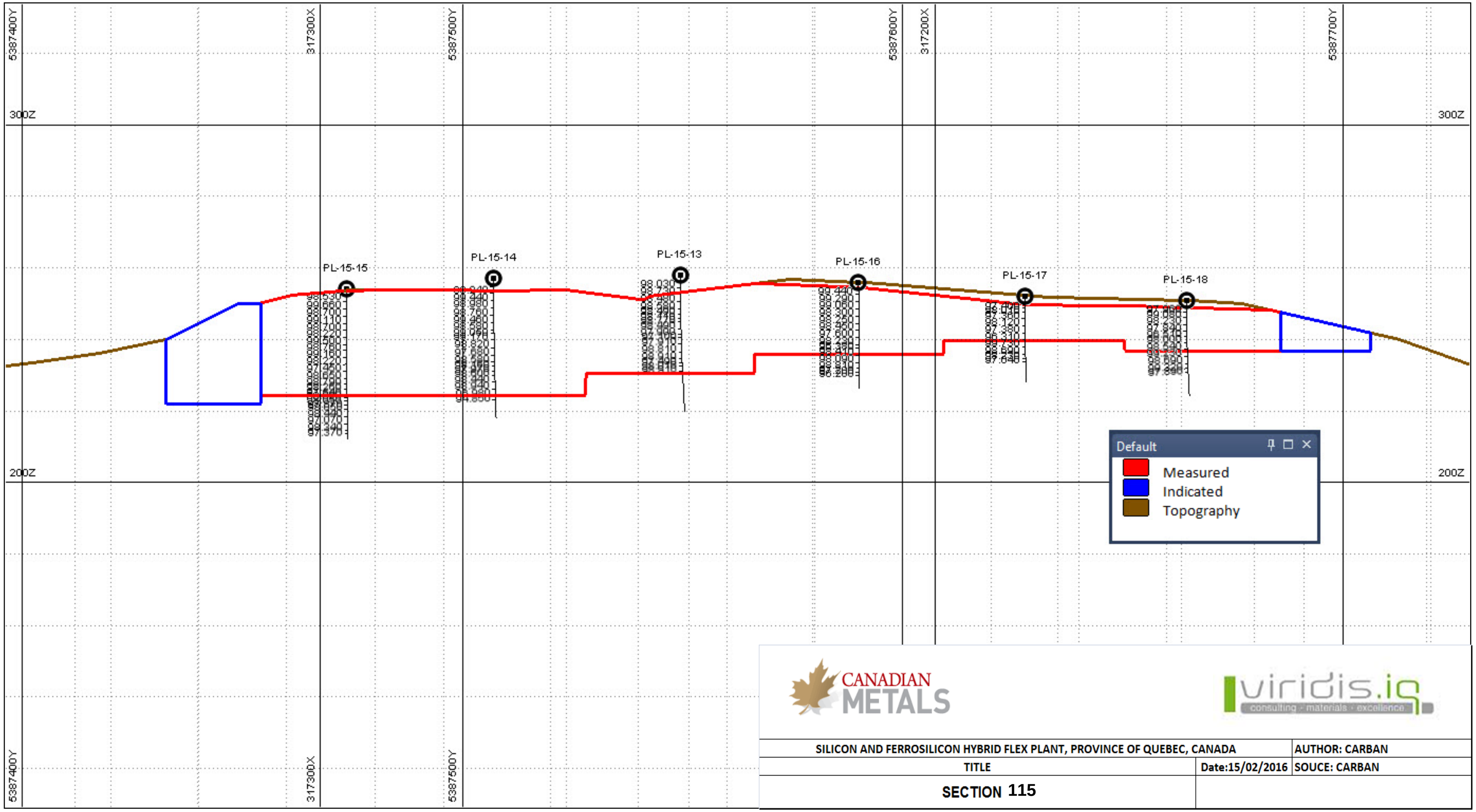


Figure 68: Section 171

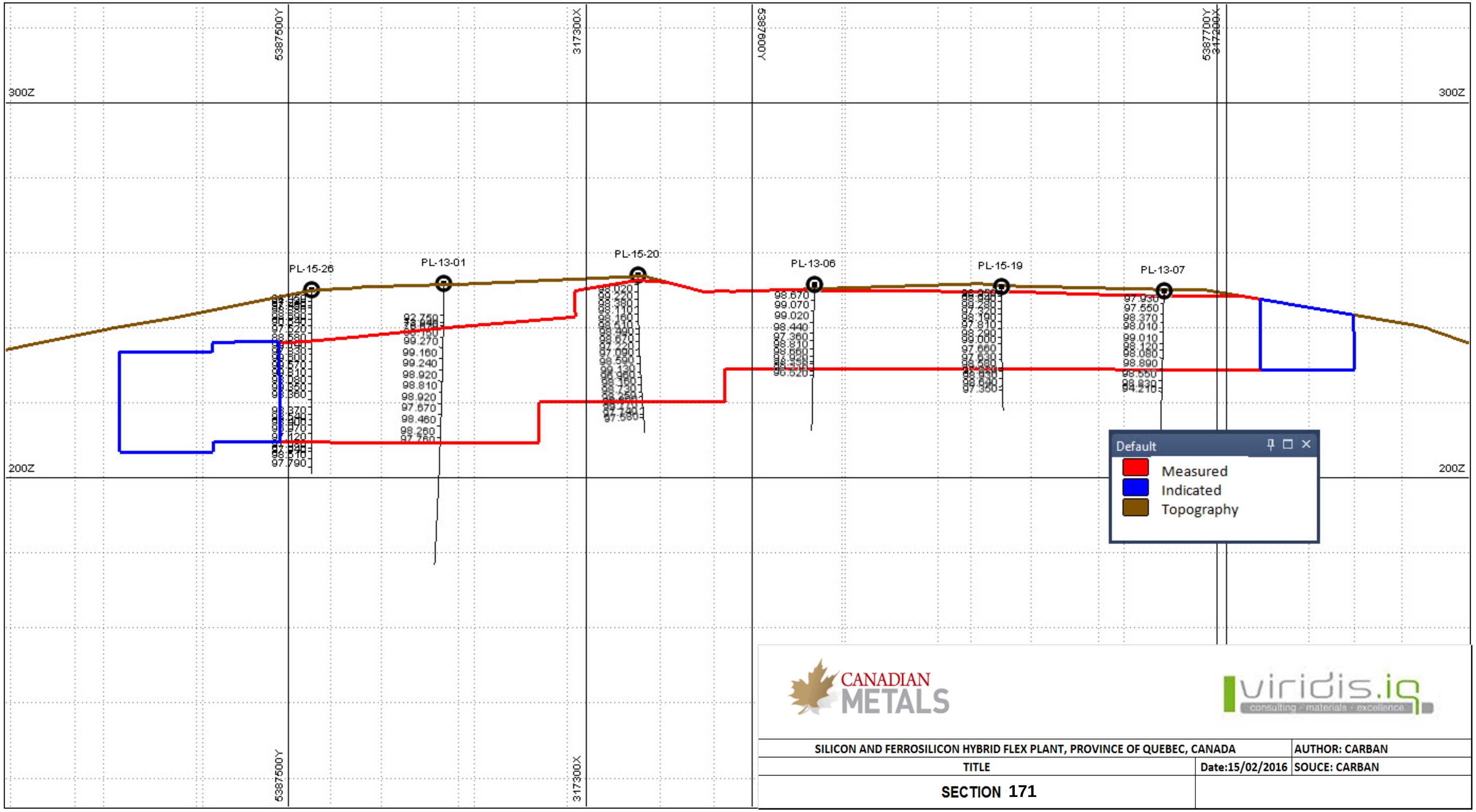


Figure 69: Section 226

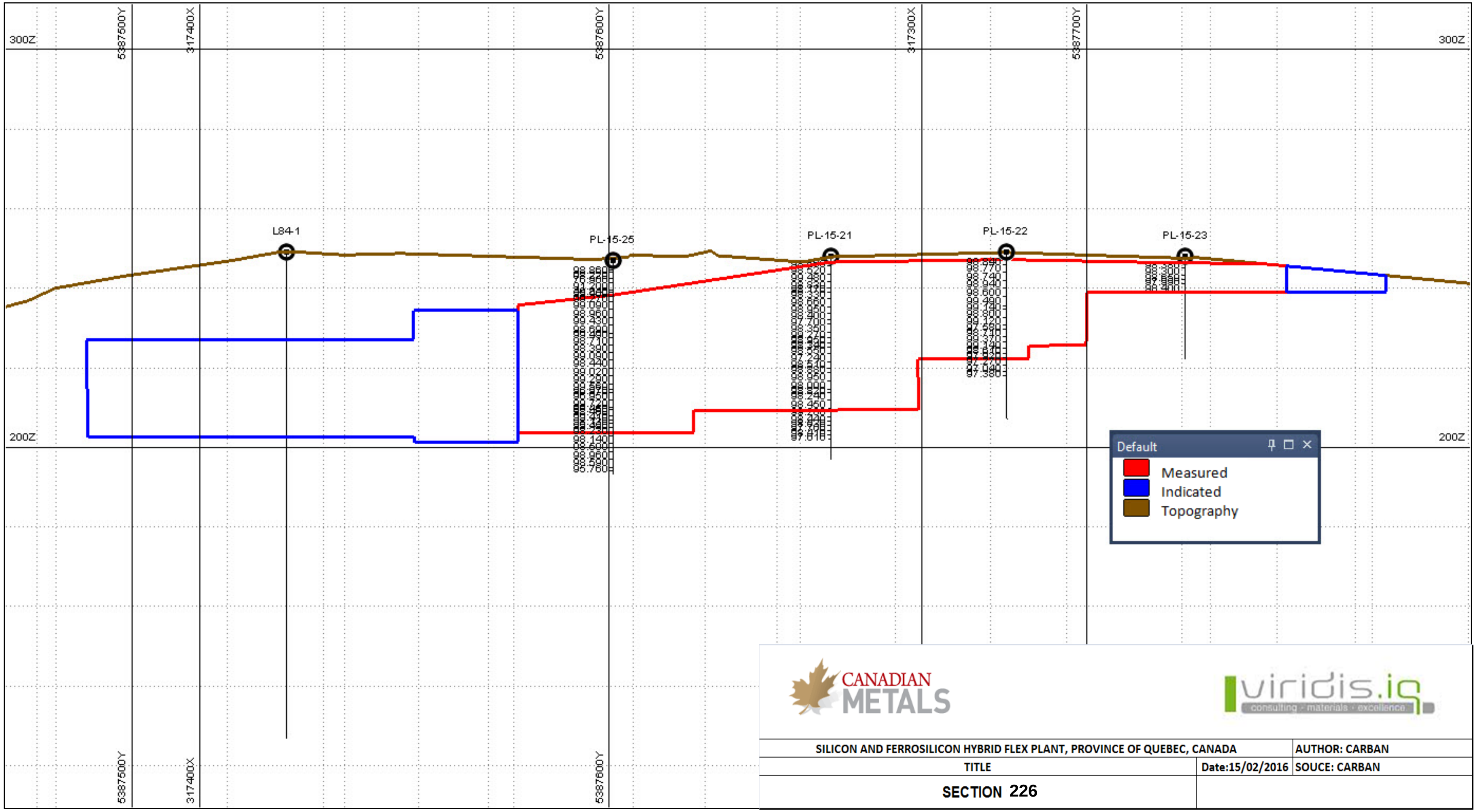


Figure 70: Section 283

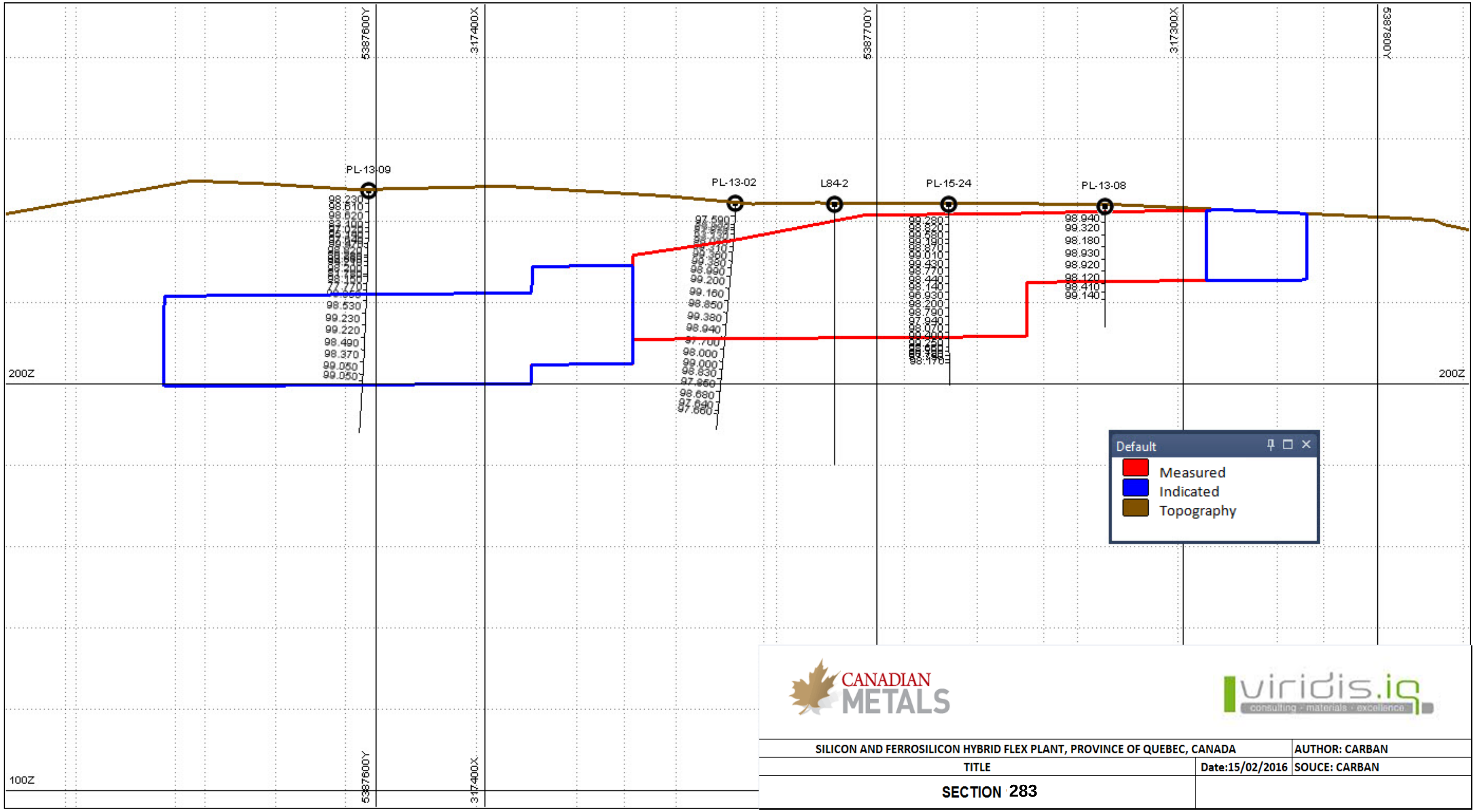
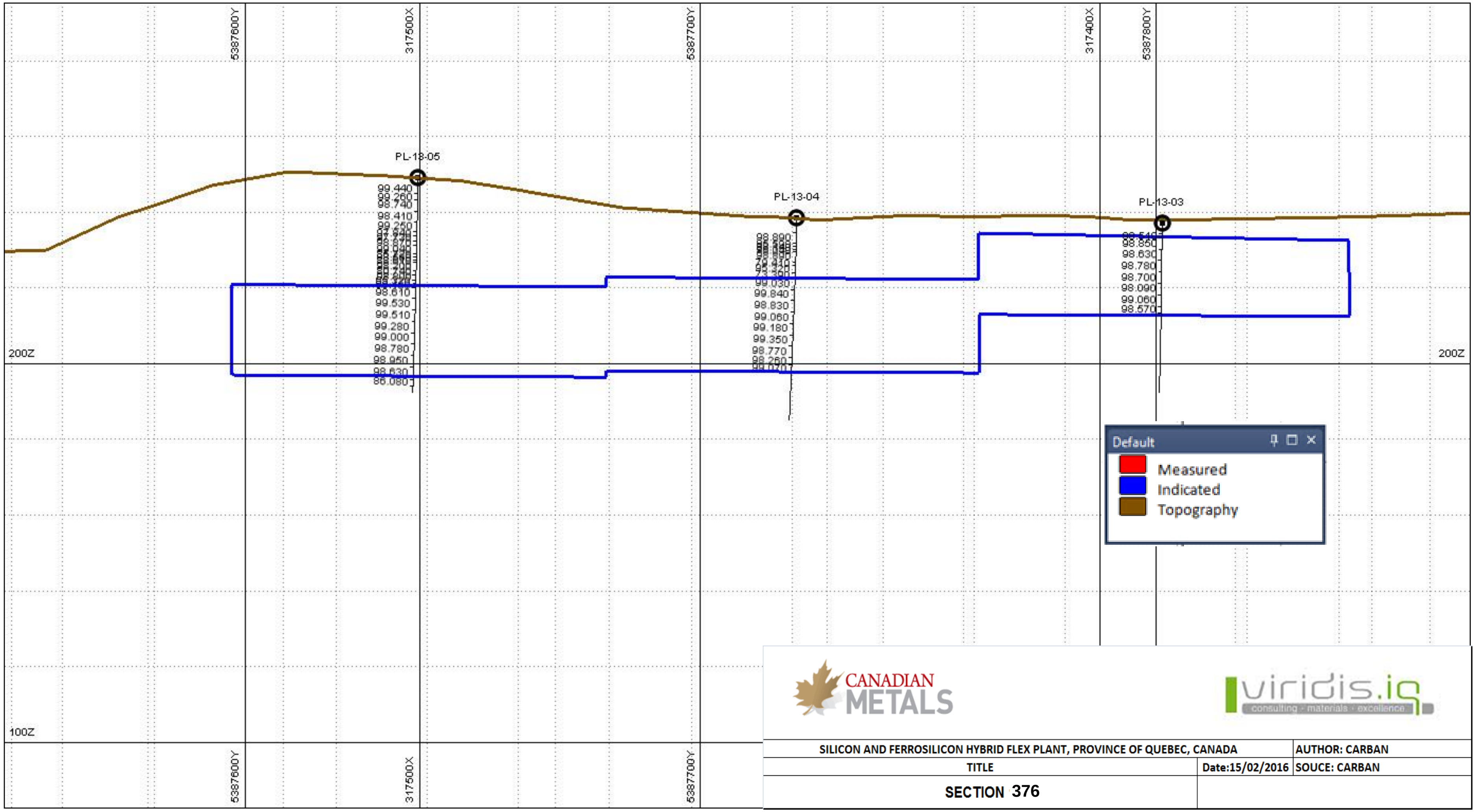


Figure 71: Section 376



16.2 Block Model

A 3D block model was developed, based on the vertical sections, to estimate the resources and to define the open pit for the Langis project. The information necessary to develop the block model was received from Géo-Logic, including all the vertical sections, databases, and assumptions. The database and sections received were not modified in any way. Due to the low precision of the topography, it has been fitted with the drill-hole collars in the project area. The resources were already classified as measured and indicated in the information received, and the geological solids where generated to develop the block model based on this information. All the material classified by Géo-Logic as measured and indicated resources were respected in the development of the block model, and the economical definitions for exploration were included in the pit optimization phase of the study. The interpreted sections did not report inferred resources; therefore this type of resource was not included in the block model.

Following the NI 43-101 standard, all measured and indicated resources were considered as likely to turn into mineable ore, thereby determining the mineral reserves. All economical process and geotechnical parameters provided were used during the pit optimization phase for the definition of the blocks that should be part of the project reserves.

The definition of the optimal pit was developed with software that uses the Lersch - Three-dimensional Grossmann algorithm, an algorithm well known and widely used in the mining industry. This simulation took into consideration all the previously defined economical parameters.

The dimensions of the blocks are 15 m x 15 m x 10 m, with sub blocks having maximum dimensions of 5 m x 5 m x 5 m, such that in the x and y directions the parents blocks had a size equal to a quarter of the average distance between the drill holes (50 m), as dictated by standard practices. Table 32 below presents the main characteristics of the block model based on MTM system.

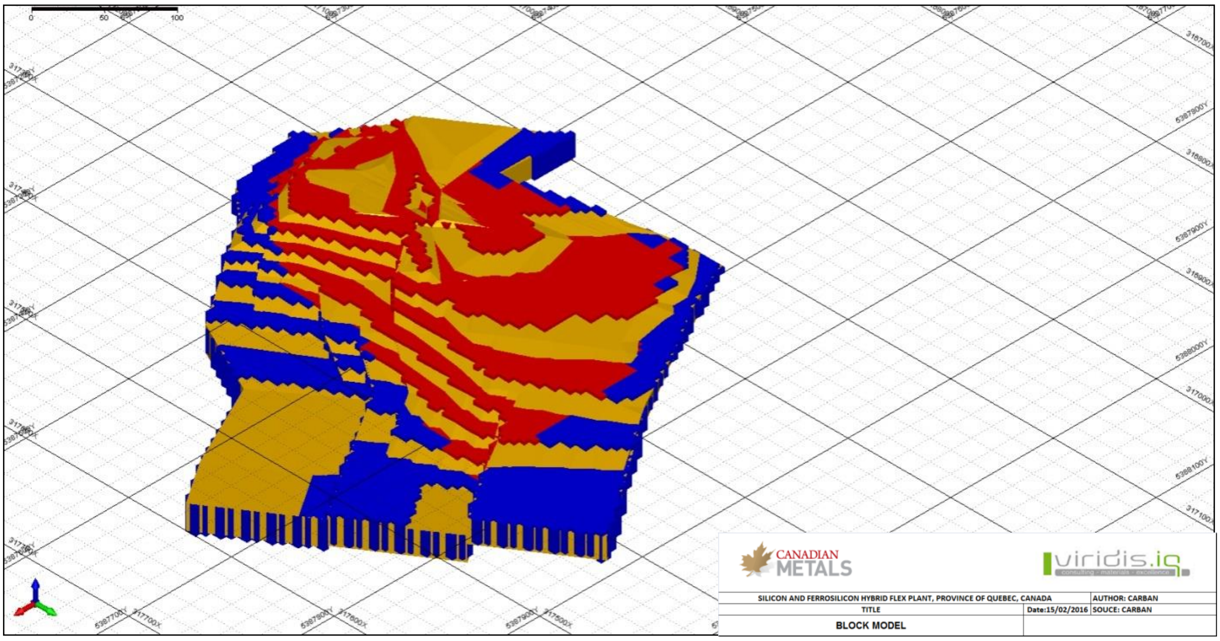
Table 32: Main characteristics of block model

Item	Main Characteristics of Block Model based on MTM System		
	X	Y	Z
Minimum	317,000.00	5,387,300.00	180
Maximum	317,690.00	5,387,990.00	260
Number of blocks	47	47	9
Blocks Size (meters)	15	15	10

Source: Caban Geoservices, Viridis.iQ GmbH

The block model developed for the Langis quarry is shown in Figure 72 below.

Figure 72: Block model



16.2.1 Visual Volumetric Block Model Validation

When compared with the total silica deposit (measured plus indicated) it is evident that the block model agrees well, with only a small difference in volume, as presented in Table 33 below.

Table 33: Comparison between volumes of silica deposit and the block model

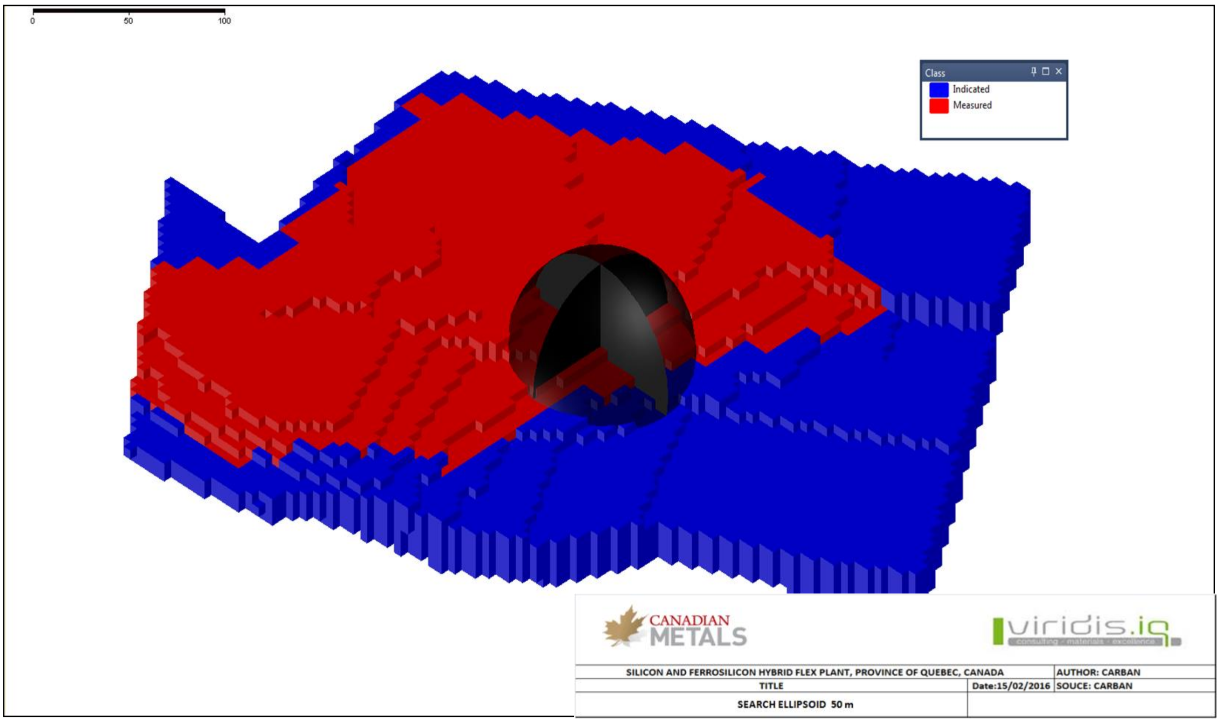
Item	Volume (m^3)
Silica deposit	2,740,000
Block model	2,730.000
Difference	-0.36%

Source: Caban Geoservices, Viridis.iQ GmbH

16.2.2 Grade Estimation

After creation of the composites and the block model, an estimate of the grades per block was then carried out using an inverse distance weighting (IDW) algorithm with a power of 2 (IDW 2). A spherical data search was used since the deposit can be considered homogeneous. Three runs were conducted for SiO_2 grade interpolation, using data search radii of 50 meters, 100 meters and 1000 meters. The results of the run with 50-meter search criteria are shown below.

Figure 73: Results of run with 50-meter search ellipsoid



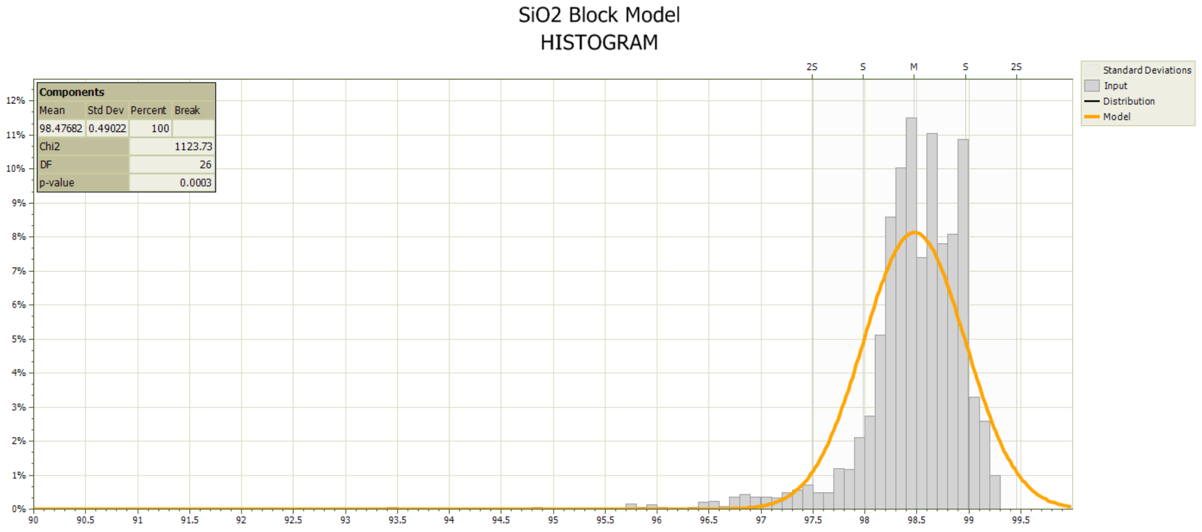
16.2.3 Density

Due to the simplicity of the deposit, it is important to highlight that the densities used for the block model where 2.5 t/m³ for silica blocks and 2.4 t/m³ for waste blocks. Other values used to develop the block model were obtained from the database.

16.2.4 Grade Check

The estimated block model was compared to composited assays to verify validity of the block model. A high correlation between the two is demonstrated by the histograms shown in Figure 74 and Figure 74 and the data presented in Table 34 and Table 35.

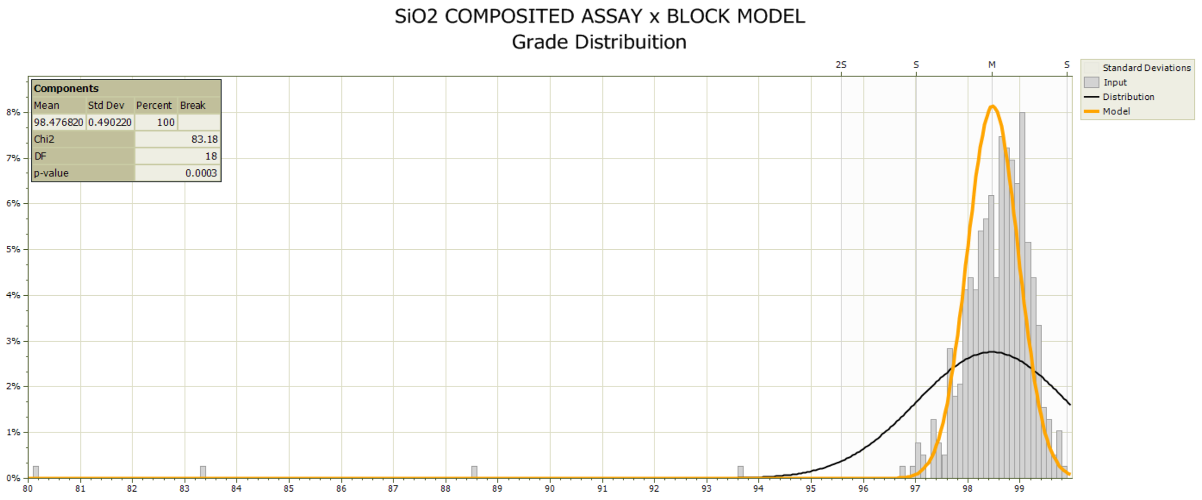
Figure 74: SiO_2 block model validation of estimation



Minimum value	93.49021	Variance	0.24032	Geometric std dev	1.00502
Maximum value	99.29413	Standard deviation	0.49022	Sichel's estimator	98.47683
2nd highest	99.29413	Coeff. of variation	0.00498	Sichel's V	0.00003
3rd highest	99.29413	Median	98.52689	Sichel's gamma	1.00001
4th highest	99.29413	Ln mean	4.58981	Chi-Square Test	1209.66121
N	2515	Ln std deviation	0.00501	Degrees of freedom	29
Mean	98.47682	Geometric mean	98.47559		

Source: Caban Geoservices, Viridis.iQ GmbH

Figure 75: SiO_2 block model x composited assay validation of estimation



Minimum value	80.147000	Variance	2.086383	Geometric std dev	1.015909
Maximum value	99.840000	Standard deviation	1.444432	Sichel's estimator	98.459944
2nd highest	99.770000	Coeff. of variation	0.014670	Sichel's V	0.000249
3rd highest	99.740000	Median	98.642000	Sichel's gamma	1.000125
4th highest	99.728500	Ln mean	4.589525	Chi-Square Test	339.382910
N	388	Ln std deviation	0.015783	Degrees of freedom	41
Mean	98.459355	Geometric mean	98.447681		

Source: Caban Geoservices, Viridis.iQ GmbH

Table 34: Grade estimation evolution of the Langis project

	Assay				Composite				Block Model			
	Min (%)	Max (%)	Mean (%)	Std Dev	Min (%)	Max (%)	Mean (%)	Std Dev	Min (%)	Max (%)	Mean (%)	Std Dev
SiO_2	49.84	99.87	**97.49**	4.69	80.15	99.84	**98.46**	1.44	93.49	99.29	**98.48**	0.49

Source: Caban Geoservices, Viridis.iQ GmbH

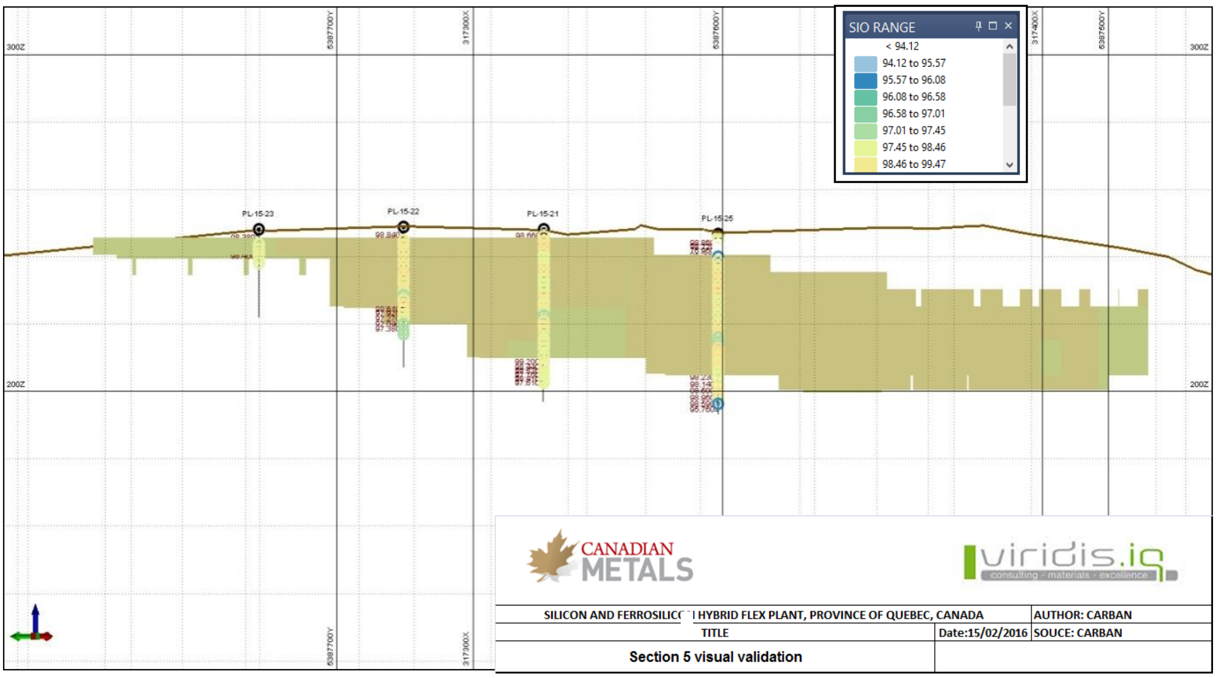
Table 35: Grade % comparison of Langis the project

	Assay (% Deviation)	Composite (% Deviation)	Block Model (% Deviation)
SiO_2	Reference	99.0	98.9

Source: Caban Geoservices, Viridis.iQ GmbH

Visual validation of the correlation between the estimated block model and composited assays is an important tool to validate the block model. The visual validation below confirms the estimated block model is in close agreement regionally with the composited assay for SiO_2.

Figure 76: Section visual validation



16.2.5 Grade Tonnage Report

Table 36 shows the total measured and indicated resources of the Langis quarry, with SiO_2 grades.

Table 36: Grade tonnage report for the Langis quarry

Material	Resource	Volume (m^3)	Density (t/m^3)	SiO_2 (%)	Tons
Silica	Indicated	1,260,000	2.5	98.59	3,160,000
	Measured	1,470,000	2.5	98.44	3,670,000
	Total	2,730,000	2.5	98.51	6,830,000

Source: Caban Geoservices, Viridis.iQ GmbH

16.3 Mineral Reserve Estimates

The mining studies were conducted with the resource model presented in this report, including the measured and indicated material. The reserves restrictions used in the optimization are shown in Table 37 below.

Table 37: Reserves restrictions used in the optimization

Parameter	Value	Unit
Silica Type	Measured/Indicated	----------
Cut Off	97	% of SiO_2
Spatial Restriction	None	----------

Source: Caban Geoservices, Viridis.iQ GmbH

The study described in this section aims to estimate reserves of the enterprise, considering the technological and economic constraints, in order to maximize the exploitation of the mineral deposit.

16.3.1 Basic Parameters and Assumptions for Optimization

The optimal limits were calculated using the Lersch - Three-dimensional Grossmann algorithm. The traditional methodology considers the development of the following main activities required:

- Review of the block model and topographic surfaces according to the information provided and required for optimization;
- Selection of technical and economic parameters for the design of optimal pits;

The parameters used for optimization of preliminary studies are described in Table 38 below.

Table 38: Key parameters - quarrying

Item	Value
Silica density (t/m^3)	2.50
Waste density (t/m^3)	2.40
Material moisture in situ (%)	6%
Quarrying cost (US$/t of ROM)	8.00
Waste cost (US$/t of ROM)	5.00
Quarrying dilution (%)	1
Quarrying recovery (%)	95
General angle - slope (°)	38
Silica cutoff grade (%)	97% SiO_2
Face angle (°)	52
Berm width (m)	5
Bank height (m)	10
Road length (m)	10
Road maximum inclination (%)	6
Production foreseen (t/year)	97,524
Processing cost (US$/t of ROM)	3.00
Mass recovery (%)	80.00
Specification - product grade (%)	98.5% SiO_2
G&A cost (US$/t)	2.00
Product loading cost (US$/t of product)	1.00
Product selling price (US$/t of product)	44.00

Source: Caban Geoservices, Viridis.iQ GmbH

To support the conceptual pit, the benefit function used was:

FB = t x R x SP – t x MC - t x PC, where:

- t = Block tonnage
- R = Mass recovery
- SP = Selling price
- MC = Mining costs
- PC = Processing and G&A costs

16.3.2 Optimization Result

The authors used a set of software, including Micromine, to develop the pit optimization based on the block model. All the parameters used in this optimization can be found in Table 38 (Key parameters – quarrying) above. The pit optimization was developed according to these parameters, resulting in the mathematical pit. The mathematical pit is the best exploration option for the quarry.

The optimization process results were developed by a RAF (Revenue Adjustment Factor) study as described by Professor W. Hustrulid. This study aims to analyze the sensibility of the final pit by permitting the choice of a scenario with best ratio between the variables waste tonnage, silica tonnage and silica grades. This method is indicated and used by most of the specialists in mine pit optimization, and the selected scenario was the RAF 0.550 due the satisfactory ratio between waste and silica.

The values obtained at this stage are lower than the estimated resources. With the pit optimization it is possible to determine the best pit option for the resources, but it is not possible to explore all the reported resources available.

The software considers a number of blocks for mathematical algorithms to divide and optimize the mathematical pit. After the establishment of the final mathematical pit, the authors developed the operational pit, considering the general angle of slope, batter slope, berm width, batter height, road width and road gradient.

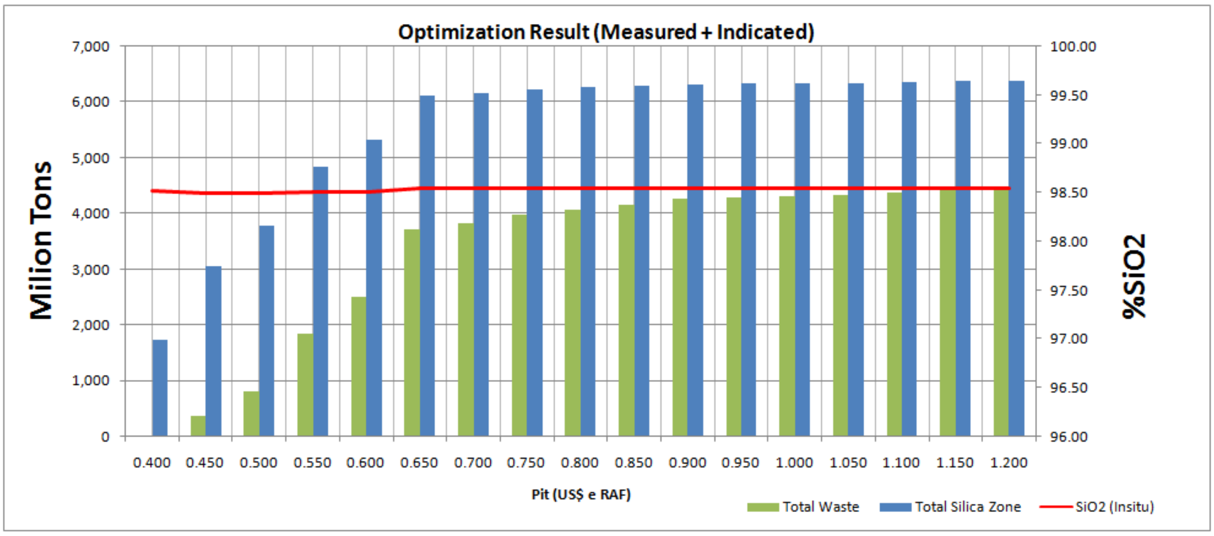
A summary of the generated set of pit shells is presented in Table 39 and Figure 77:

Table 39: Optimization results for the Langis quarry (measured plus indicated resources)

RAF	Million Tons					Percent	Strip Ratio
	Total Silica	Measured Silica	Indicated Silica	Total Waste	Product	SiO_2 (in situ)	
0.400	1.730	1.449	0.282	0.023	1.384	98.52	0.01
0.450	3.048	2.340	0.708	0.373	2.438	98.49	0.12
0.500	3.781	2.896	0.885	0.804	3.025	98.50	0.21
0.550	4.834	3.347	1.487	1.848	3.867	98.51	0.38
0.600	5.325	3.377	1.947	2.504	4.260	98.51	0.47
0.650	6.105	3.388	2.717	3.710	4.884	98.54	0.61
0.700	6.164	3.402	2.762	3.828	4.931	98.54	0.62
0.750	6.222	3.408	2.814	3.970	4.978	98.54	0.64
0.800	6.256	3.425	2.832	4.058	5.005	98.54	0.65
0.850	6.289	3.427	2.862	4.155	5.031	98.54	0.66
0.900	6.321	3.432	2.889	4.266	5.057	98.54	0.67
0.950	6.327	3.432	2.895	4.292	5.062	98.54	0.68
1.000	6.329	3.432	2.896	4.297	5.063	98.54	0.68
1.050	6.335	3.434	2.900	4.326	5.068	98.54	0.68
1.100	6.343	3.434	2.909	4.367	5.075	98.54	0.69
1.150	6.366	3.442	2.924	4.482	5.093	98.55	0.70
1.200	6.366	3.442	2.924	4.482	5.093	98.55	0.70

Source: Caban Geoservices, Viridis.iQ GmbH

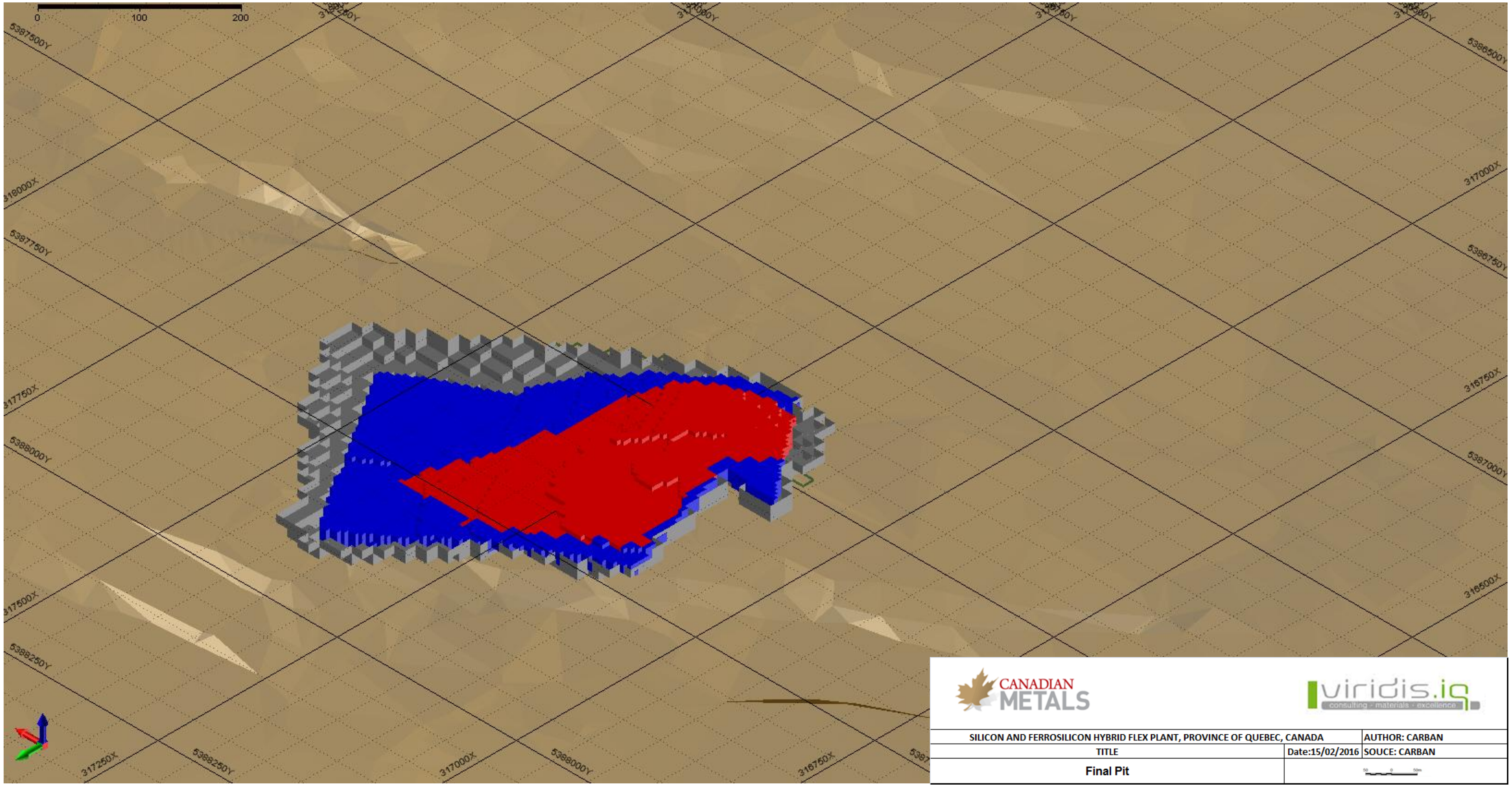
Figure 77: Optimization result (measured plus indicated resources)



Source: Caban Geoservices, Viridis.iQ GmbH

Figure 78, on the next page, shows a conceptual simulation of the final pit at the Langis quarry.

Figure 78: Final pit



16.3.3 Quarry Operations

In the operations cycle we can distinguish the main activities. The process of waste removal involves the material movement to expose the mineralized body, and the material movement with grade below the economic cut off (cut-off grade).

The same occurs for the silica recovery, but the objective is to move the materials that have a satisfactory economic grade. The unit operations involve: excavation, drilling, blasting, loading, and haulage. The silica destination will be the beneficiation plant and the waste destination will be the waste dump.

16.3.4 Quarry Layout

The final pit design was chosen respecting the parameters listed in Table 40, following the classic procedures based on crest, toe and benches, safety benches and work places, allowing the safe and efficient development of quarrying operations.

The quarrying activities will be developed in an open pit configuration to advance activities bench-by-bench. This operation will be planned and developed to satisfy the silica need at the smelter. The table below shows some parameters for this operationalization.

Table 40: Parameters for operationalization of the engineered pit

Parameter	Value
General angle of slope (°)	38.0
Batter slope(°)	52.0
Berm width (m)	5.0
Batter height (m)	10.0
Road width (m)	10.0
Road gradient (%)	6.0

Source: Caban Geoservices, Viridis.iQ GmbH

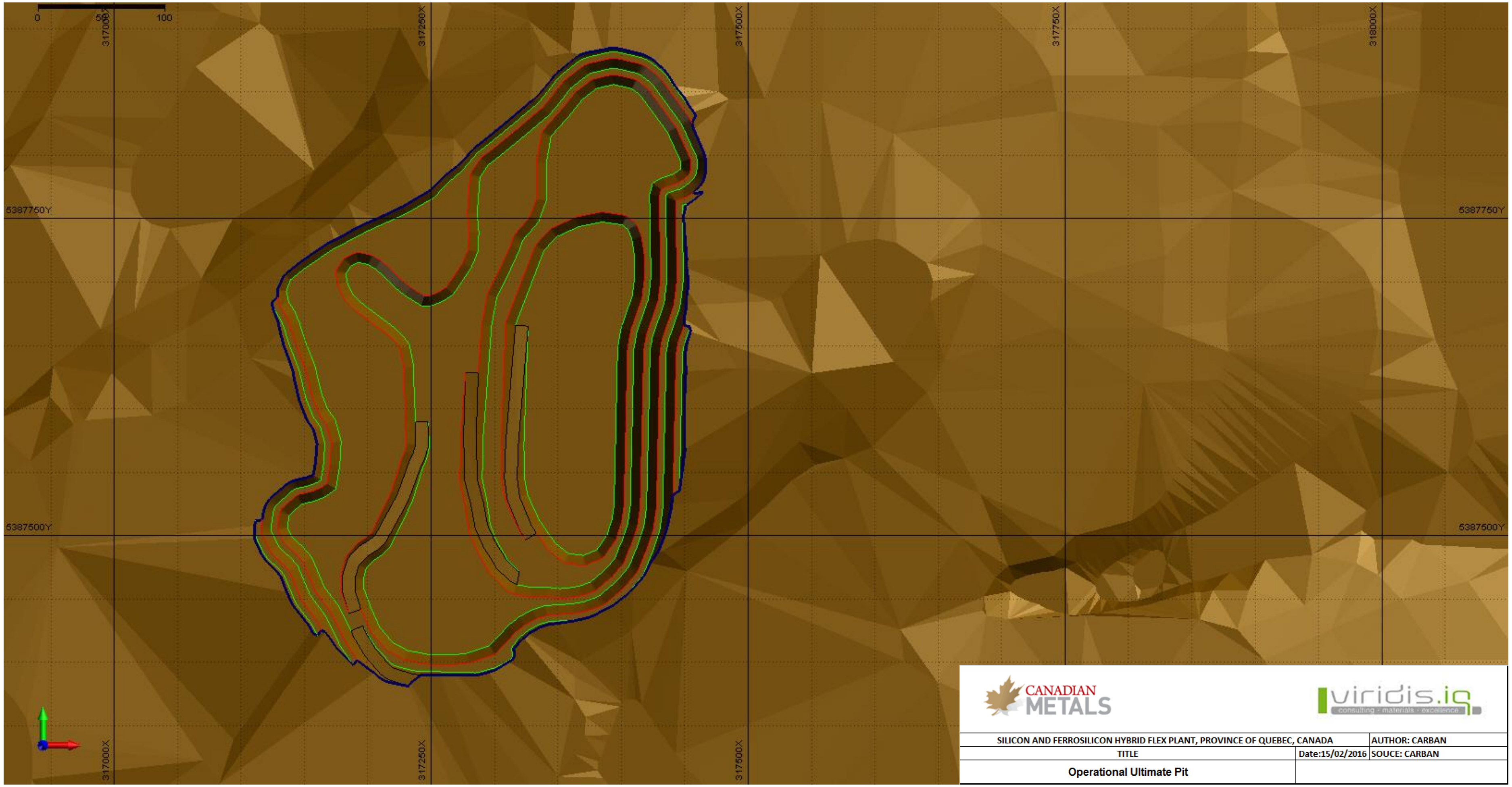
The final conceptual pit design is shown in Figure 79 and a summary of the results for it is presented in Table 41.

Table 41: Optimization results operationalized

	Million Tons				Grade	Million Tons	
	Measured Silica	Indicated Silica	Total Silica	Total Product	Total SiO_2 (%)	Total Waste	Strip Ratio
Operational pit	3.520	1.518	5.038	4.030	98.47	2.094	0.42
Mathematics pit	3.347	1.487	4.834	3.867	98.51	1.848	0.38
Difference	4.89%	2.07%	4.04%	4.04%	-0.03%	11.77%	8.05%

Source: Caban Geoservices, Viridis.iQ GmbH

Figure 79: Operational pit



16.3.5 Production Rates

A sequencing study was conducted to define the quarrying sequence for the silica zone blocks and waste throughout the quarry life to reach the final mineable pit.

For the development of the production program, areas have been defined to be quarried in order to optimize the flow of materials. Table 42 below shows the summary of results for the amounts of materials quarried per period in the annual sequencing.

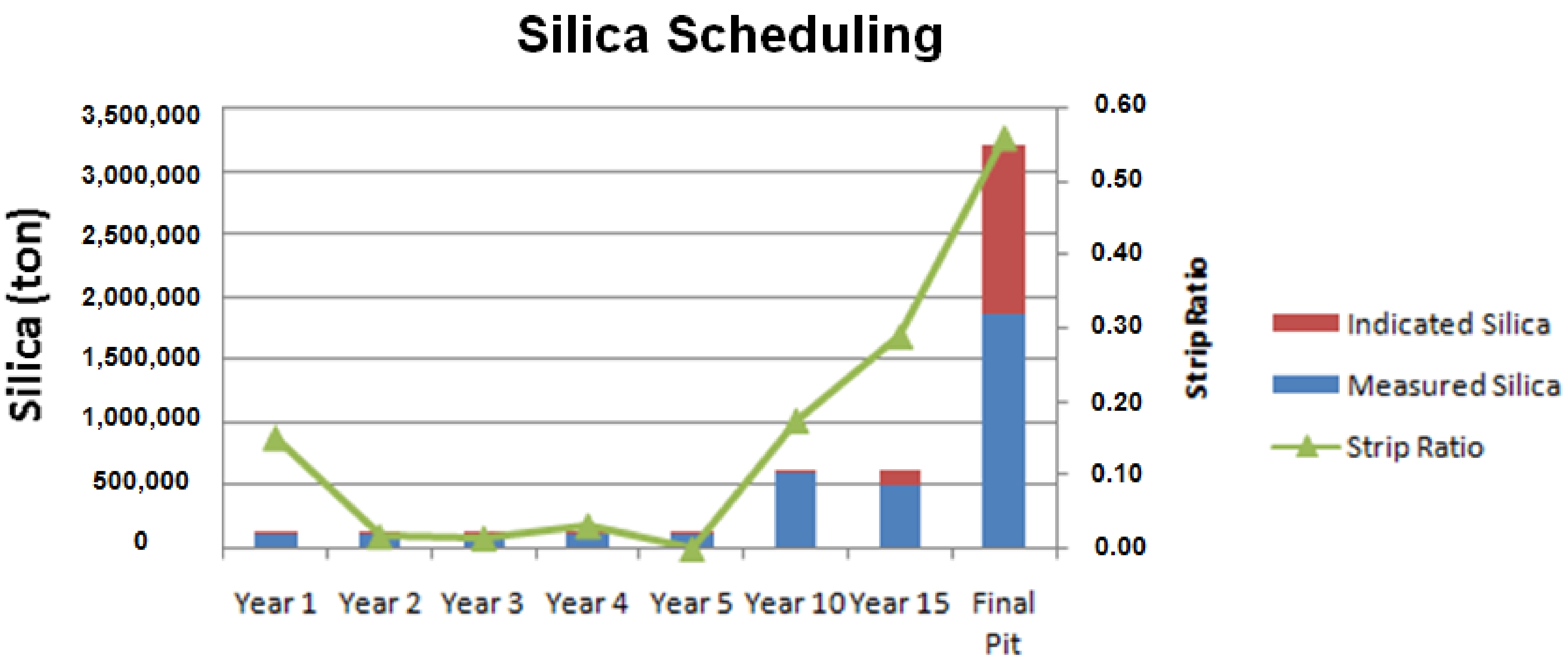
Table 42: Sequencing results

Years	Thousand Tons				SiO_2 Total (%)	Million Tons	
	Measured Silica	Indicated Silica	Total Silica	Total Product		Total Waste	Strip Ratio
Year 1	101.6	23.4	**125.0**	**100.0**	**98.81**	**18.9**	**0.15**
Year 2	122.8	1.3	**124.1**	**99.3**	**98.97**	**2.1**	**0.02**
Year 3	116.3	5.9	**122.2**	**97.8**	**98.63**	**1.8**	**0.01**
Year 4	115.0	10.0	**125.0**	**100.0**	**98.47**	**3.9**	**0.03**
Year 5	116.6	10.0	**126.6**	**101.3**	**98.71**	**0.0**	**0.00**
Year 6 to10	606.9	1.9	**608.8**	**487.0**	**98.39**	**106.2**	**0.17**
Year 11 to 15	496.3	113.8	**610.0**	**488.0**	**98.36**	**176.1**	**0.29**
Year 16 to 47	1,844.4	1,351.9	**3,196.3**	**2,557.0**	**98.46**	**1,785.2**	**0.56**

Source: Caban Geoservices, Viridis.iQ GmbH

The pit designs below represent the engineered pits according to the quarry schedule study and are aimed at presenting a plan view of the quarry evolution footprint for the years 1, 2, 3, 4, 5, 6 to 10, and 11 to 15:

Figure 80: Silica scheduling



Source: Caban Geoservices, Viridis.iQ GmbH

Figure 81: Pit year 1

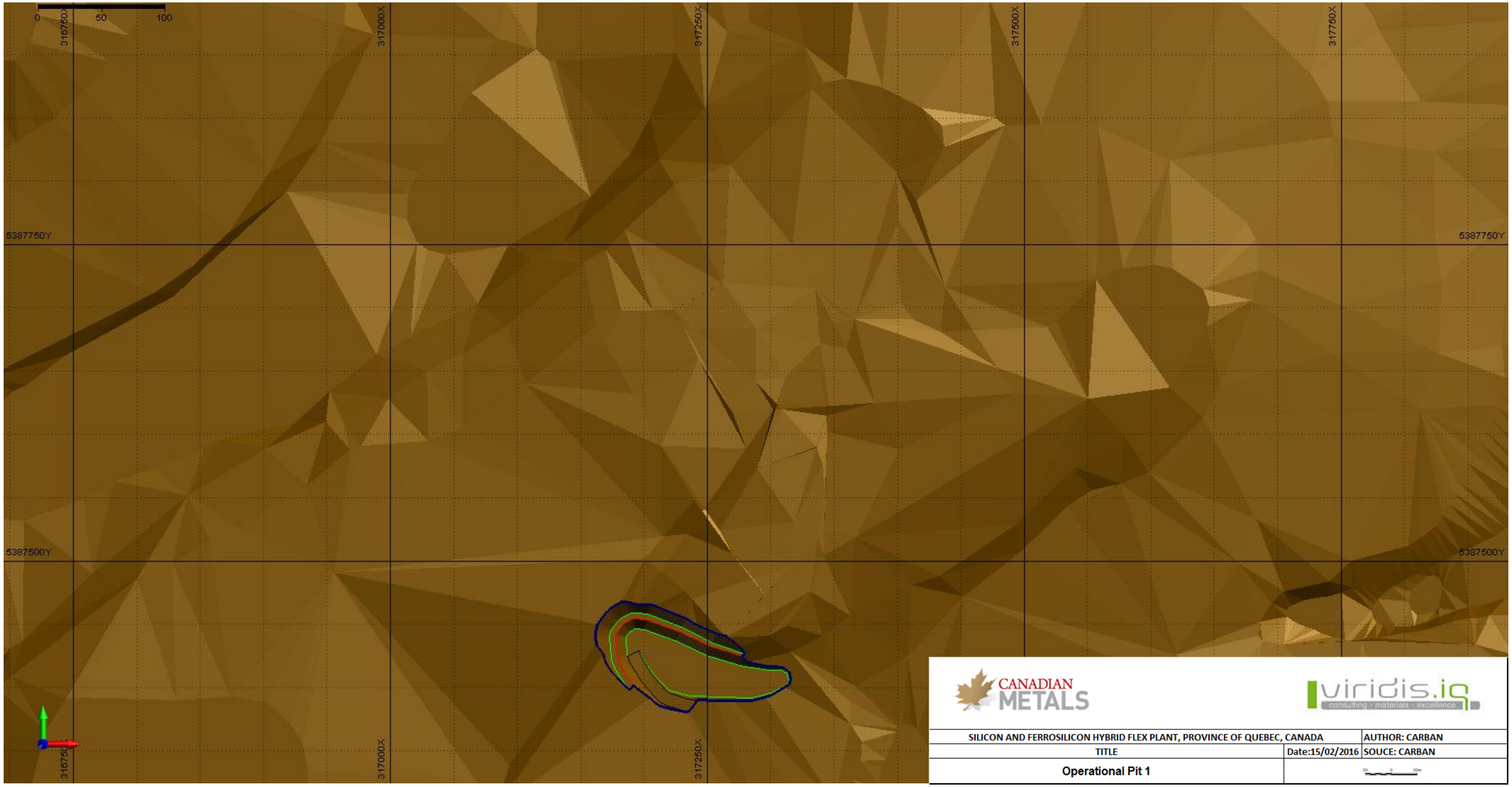


Figure 82: Pit year 2

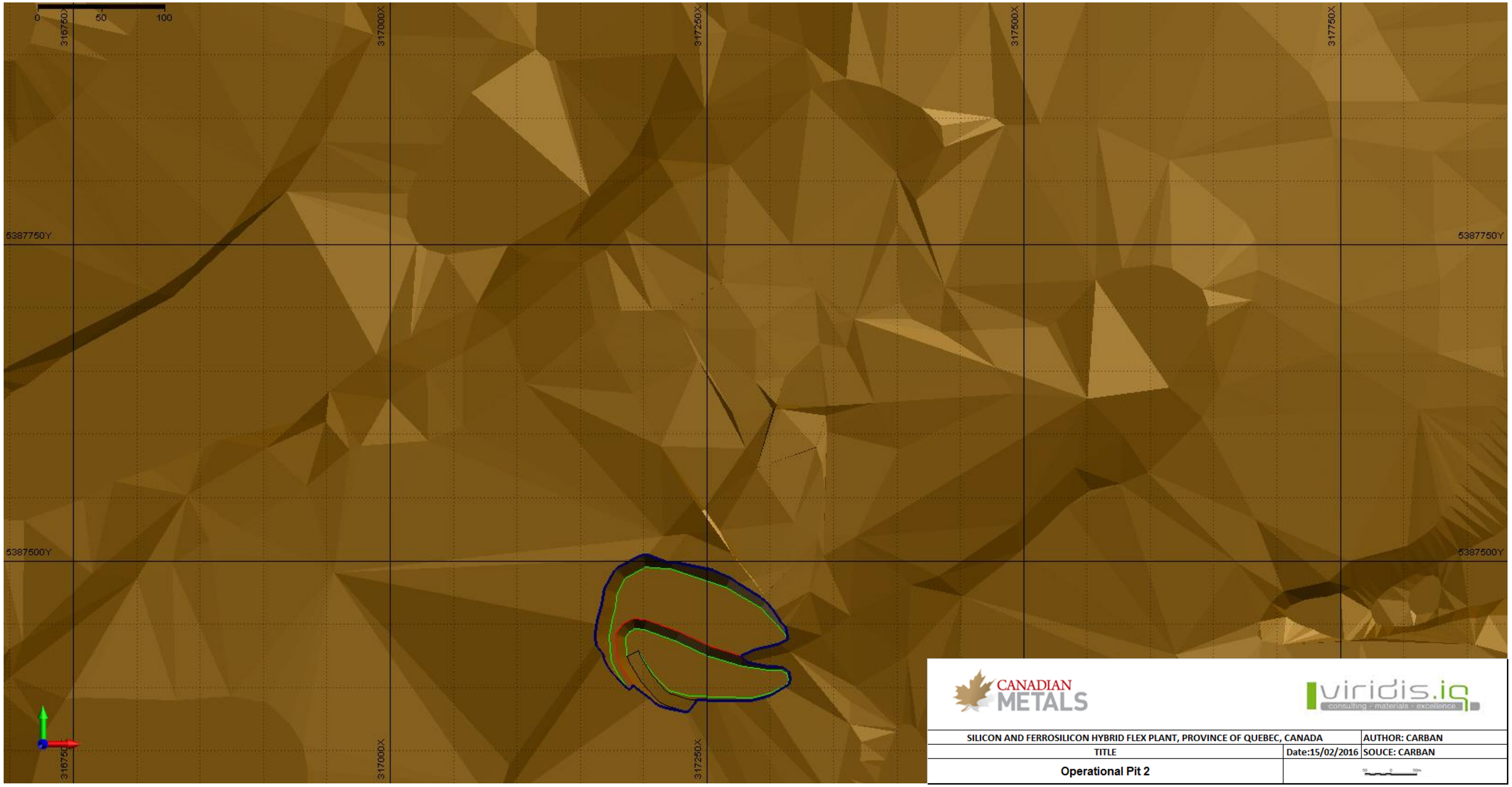


Figure 83: Pit year 3

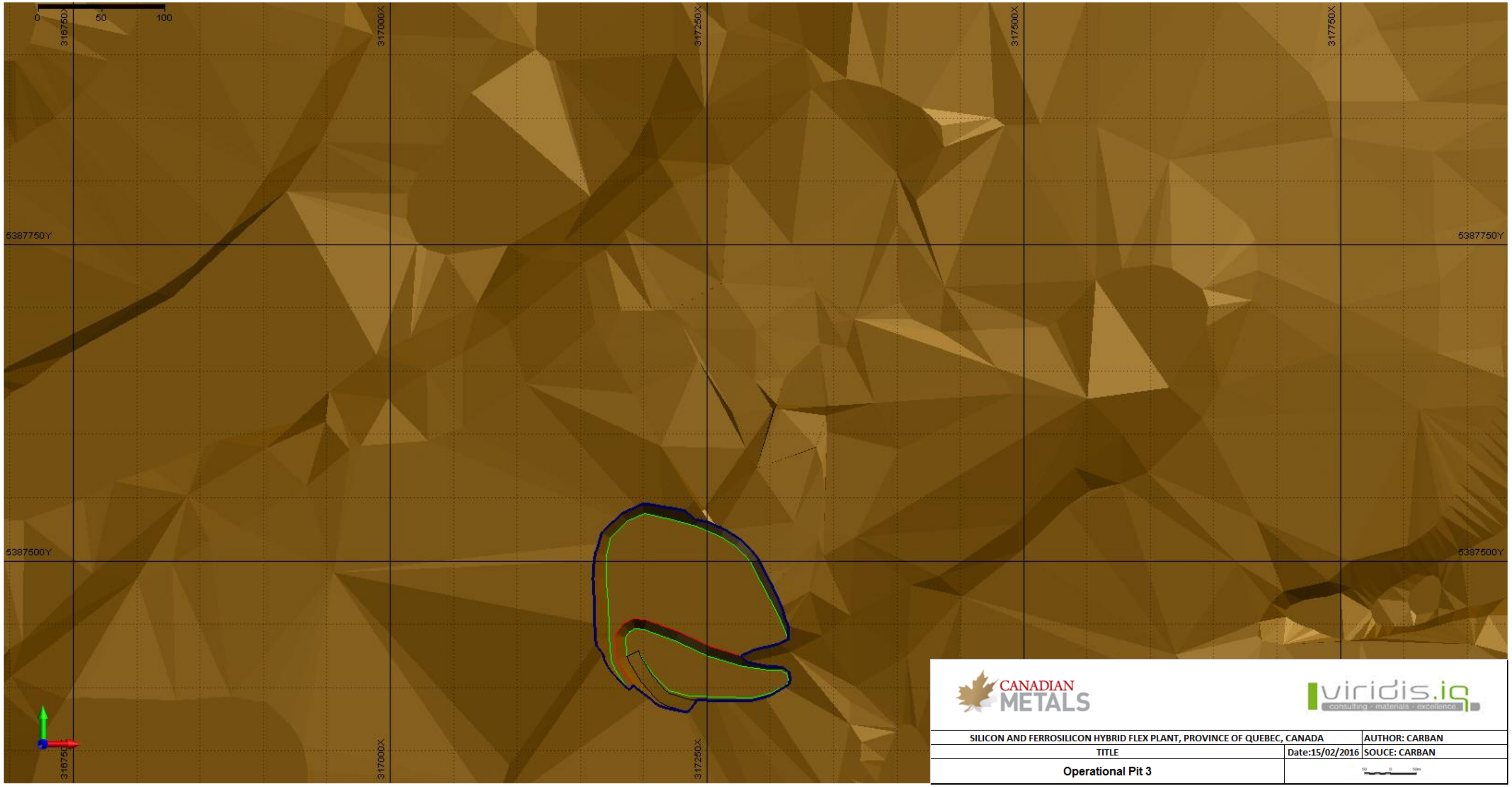


Figure 84: Pit year 4

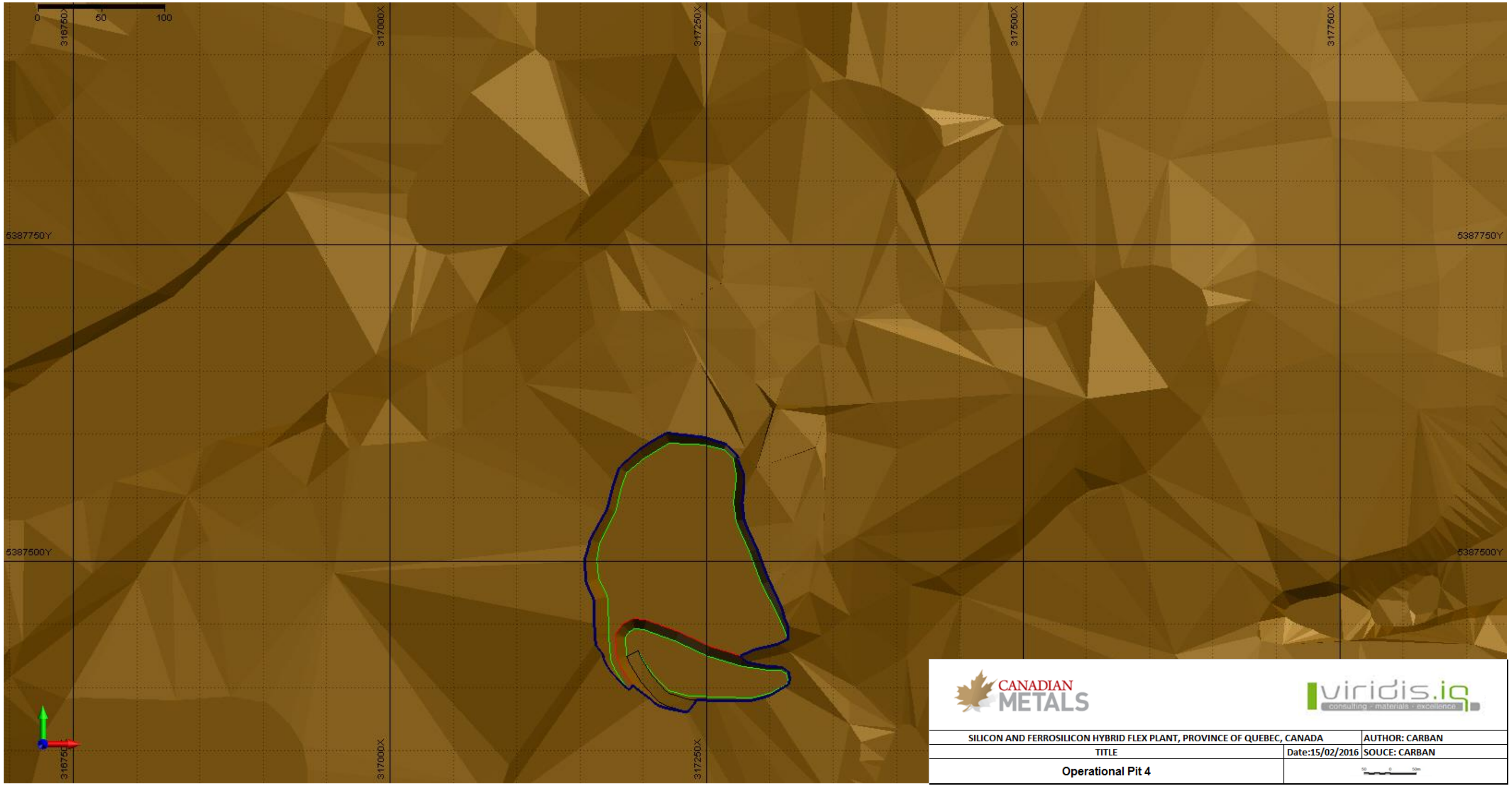


Figure 85: Pit year 5

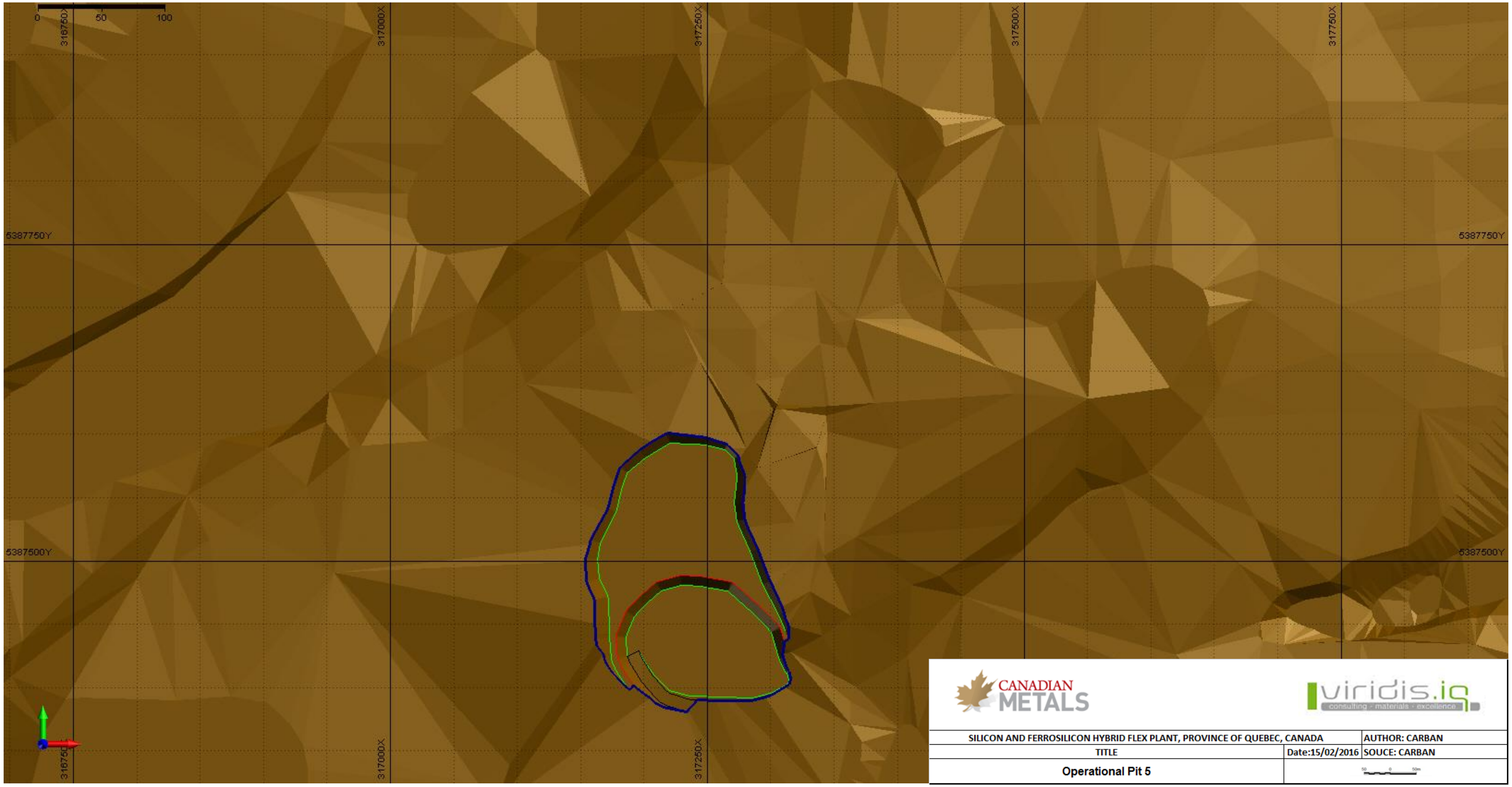


Figure 86: Pit year 10

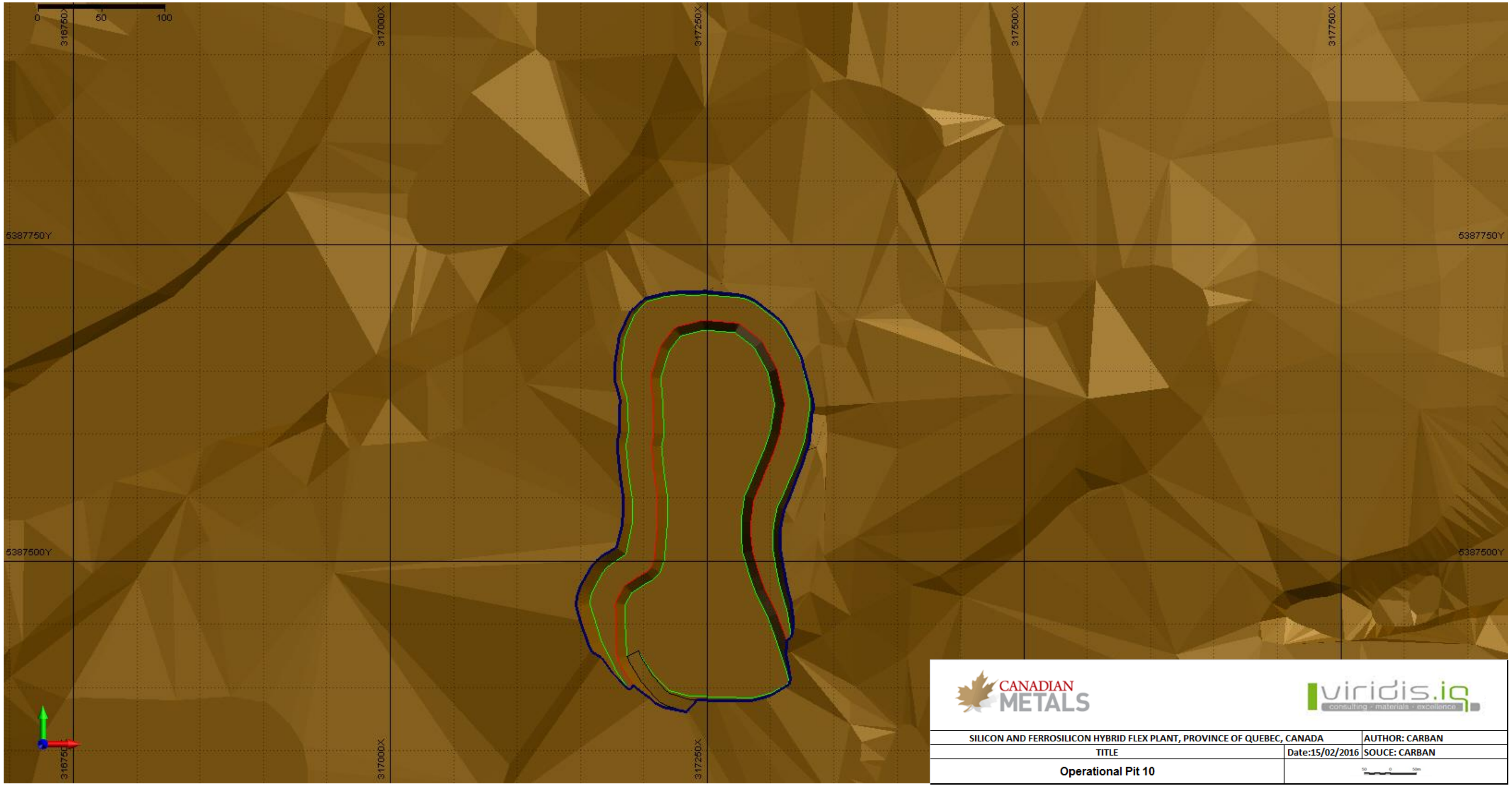
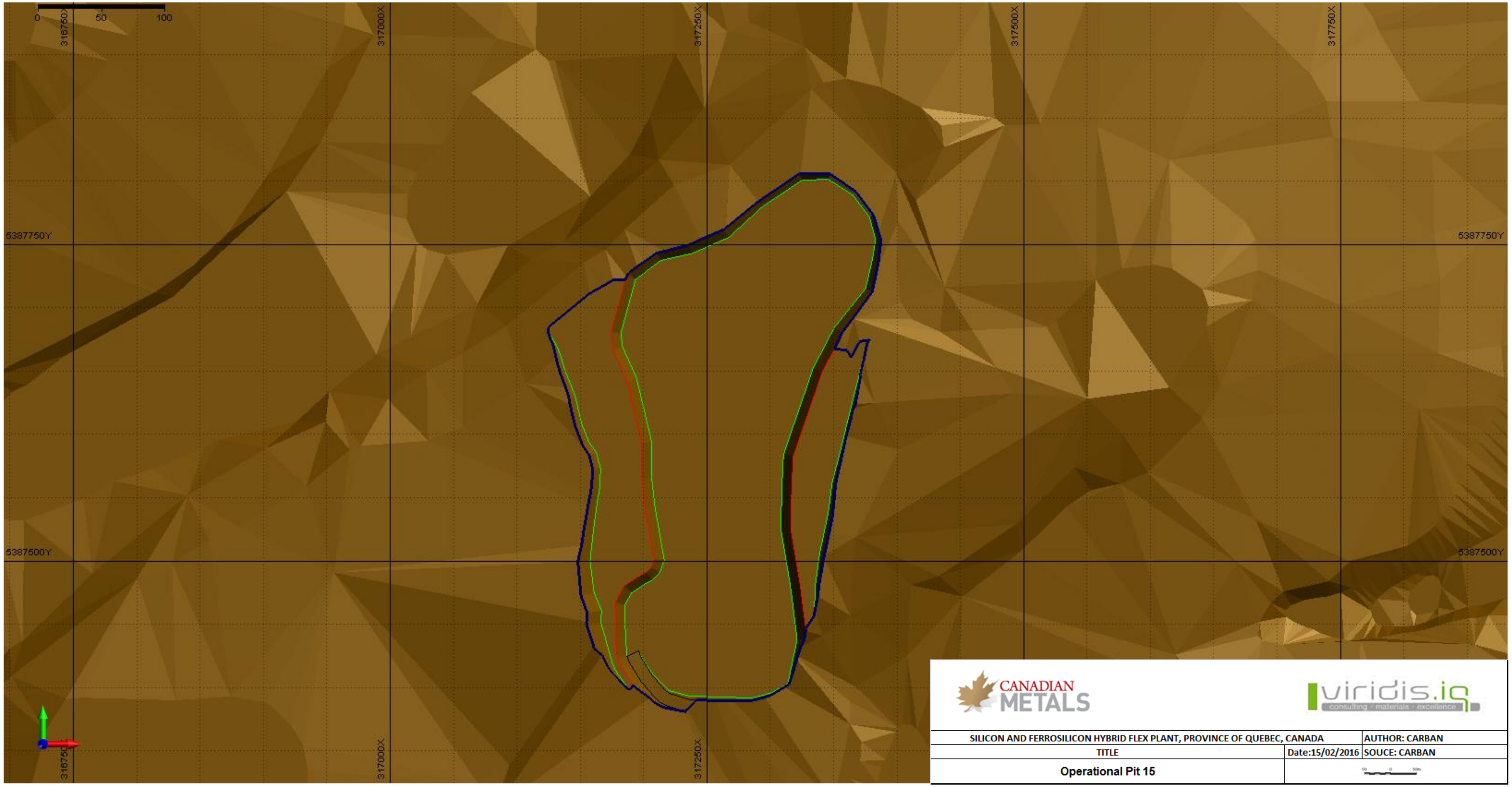


Figure 87: Pit year 15



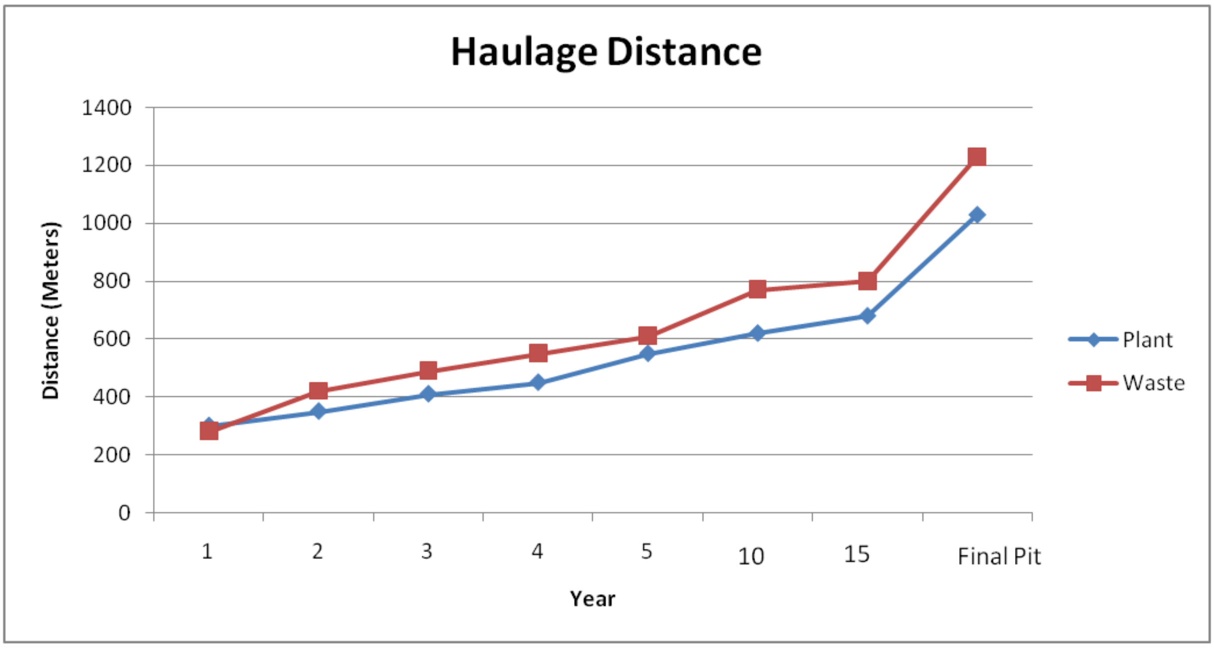
Average transportation distances were estimated years 1, 2, 3, 4, 5, 6 to 10 and 11 to 15 and are shown in Table 43 and Figure 88 below.

Table 43: Average haulage distance

Year	Silica (meters)	Waste (meters)
1	300	280
2	350	420
3	410	490
4	450	550
5	550	610
6 - 10	620	770
11 - 15	680	800
16 – 47	1030	1230

Source: Caban Geoservices, Viridis.iQ GmbH

Figure 88: Haulage distance



Source: Caban Geoservices, Viridis.iQ GmbH

An increase in the haulage distance is expected due to the increasing depth-of-work for each period.

The life time of the quarry in the planning design is 41 years, considering all the reserves calculated and the optimization parameters used for this project.

16.3.6 Waste Disposal

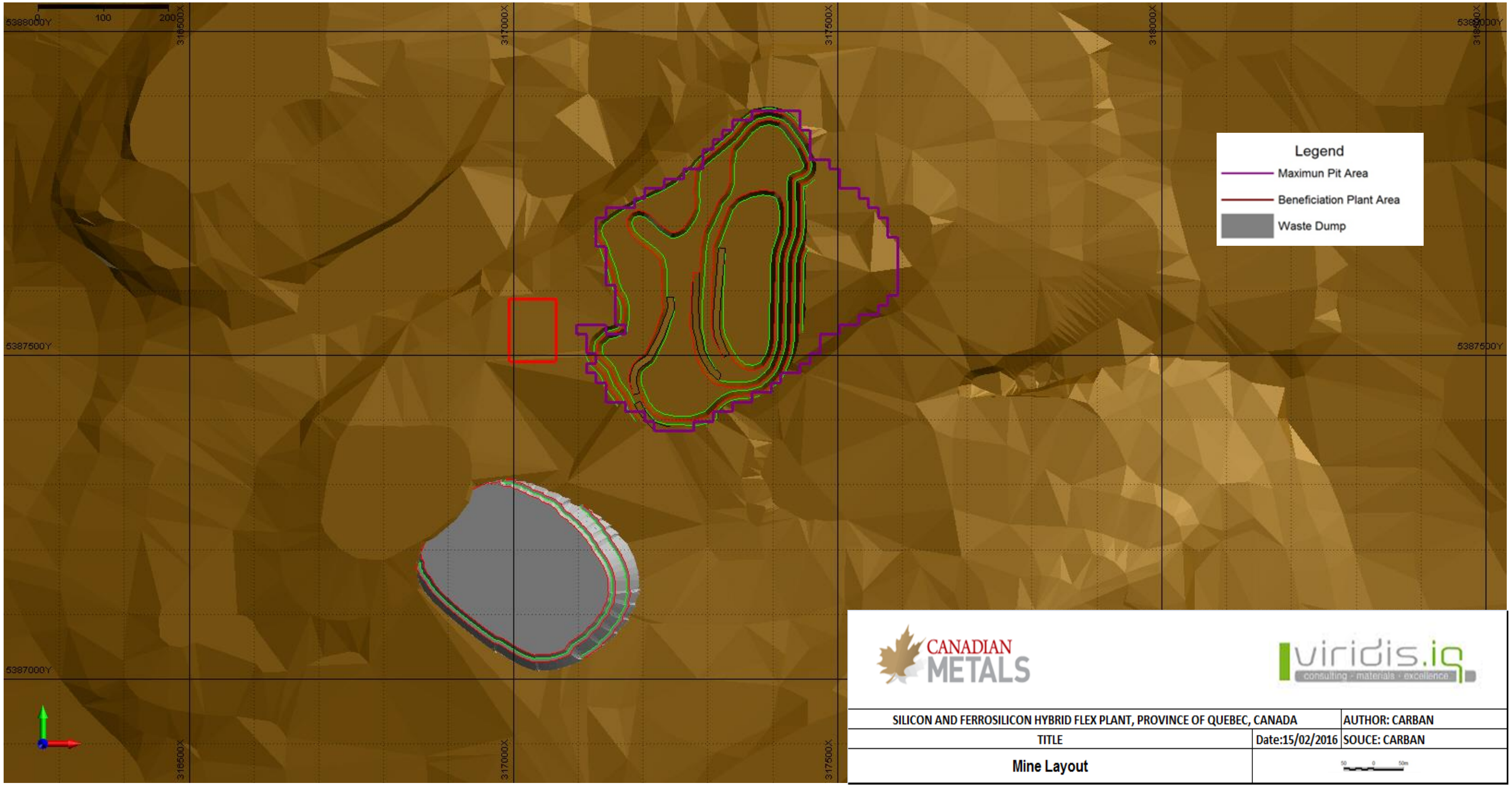
The disposal of waste should occur in a pile built in a controlled manner and following a sequence of ascending platforms, from bottom to top. This system will lead to better compression and stability of the pile, providing control of the geometrical characteristics and allowing greater efficiency in the application of security measures against incipient landslides. The waste disposal site must have the following characteristics:

- Location outside the limits of ultimate pit;
- Location on proven waste;
- Location on the ground with appropriate mechanical characteristics to support the weight of the material dumped;
- Location that allows, through appropriate measures, minimizing the environmental impact resulting from this disposal;
- Location in a place devoid of vegetation;
- Location large enough to contain the total volume to be generated during the depletion of quarrieable reserves.

The waste dump is designed with geometrical parameters selected properly in order to confer permanent stability. A conceptual design is shown in Figure 56. The projected parameters are:

- Face angle:, 30°;
- Berm height: 10 meters;
- Berm width: 5 meters;

Figure 89: Waste dump layout



Beyond compression that will be achieved by truck tires and tractor treads, the waste pile will be provided with a drainage system capable of removing rain water, to insure stability.

16.3.7 Equipment Sizing

Mining equipment sizing was carried out after the operationalization of the final optimized pit for the Langis quarry. The quarrying equipment list developed for the project is shown in the table below.

Table 44: Quarrying equipment list

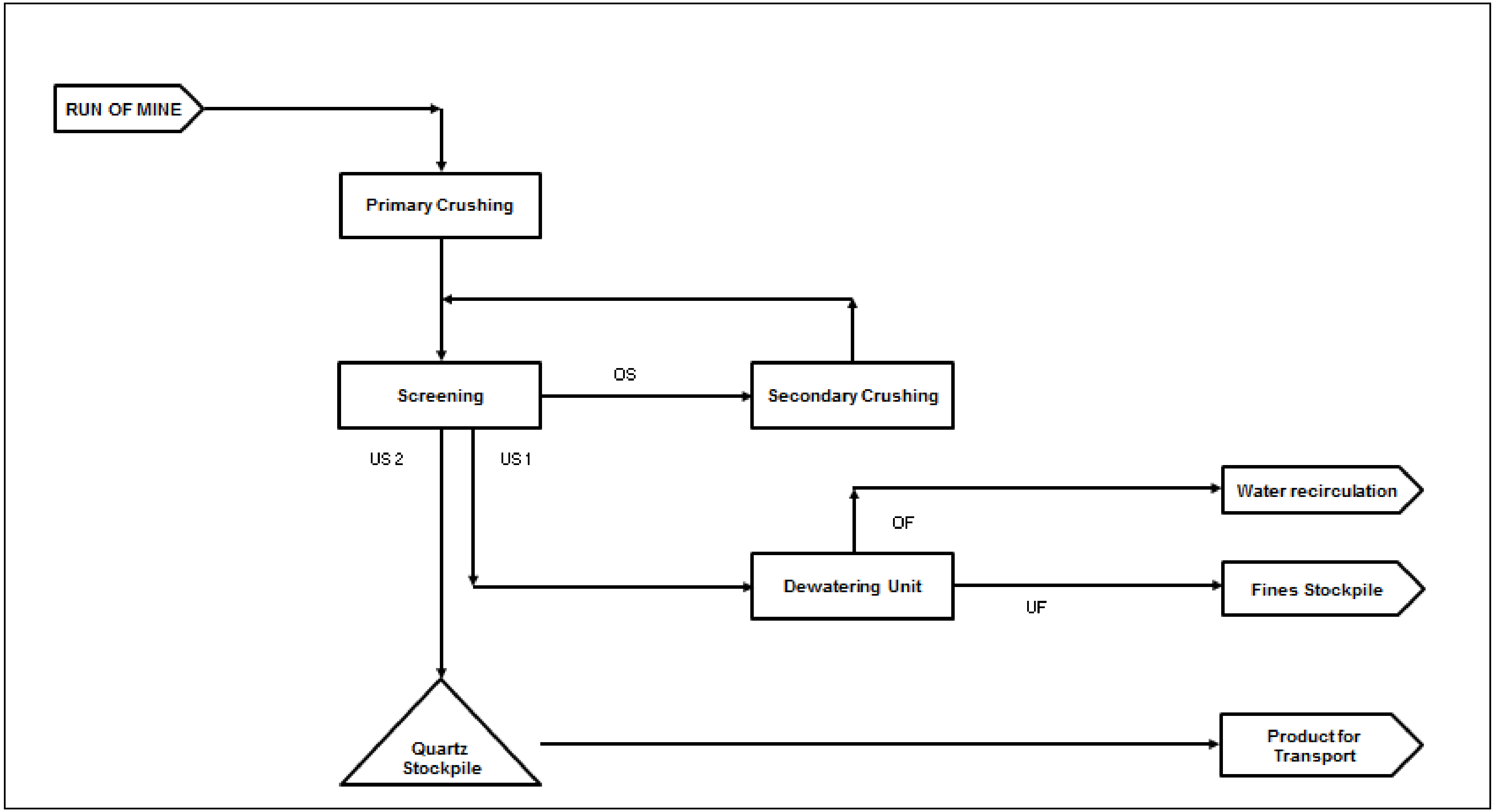
Equipment	Life Time (hours)	Life Time (years)	Capacity	Unit	Quantity
Main Equipment					
Truck Scania P 310 8X4	30,000	10	15	t	2
Hydraulic Excavator CATERPILLAR D-73	30,000	10	2	m^3	1
Group Truck (with drilling machine and accessories)	30,000	10	7.62	cm	1
Auxiliary Equipment					
Wheel loader CATERPILLAR 966C	20,000	10	3	m^3	1
Tractor	20,000	10	165	HP	1
Grader	20,000	10	125	HP	1
Air compressor	20,000	10	827	kPa	1
Manual drilling machine	20,000	10	700	kPa	1
Rollon adaptor for auxiliary truck	30,000	20	-	-	1
Water truck tank	60,000	20	25	m^3	3
Driving board	60,000	20	-	-	1
Train truck	30,000	10	-	-	1
Small trucks 4x4 (diesel)	15,000	5	-	-	4
Small cars (popular) (flex)	15,000	3	-	-	4
Total	-	-	-	-	23

Source: Caban Geoservices, Viridis.iQ GmbH

16.3.8 Block Flow Diagram of Langis Beneficiation Plant

Based on the information provided in the previous section, and the premise based on the production of Lump silica, the following block flow diagram has been developed. The figure below show the steps required for a beneficiation plant at the Langis quarry:

Figure 90: Quarry process-flow block diagram



Source: Caban Geoservices, Viridis.iQ GmbH

16.3.9 Process Description

The process at the quarry will consist of the following: The run-of-quarry arrives though trucks and is stockpiled near the processing plant. Then the material is fed to the primary crusher, through a vibrating feeder (VF-001). The primary crusher consists of a jaw crusher (JC-001) with an open side setting around 1000 mm. If big blocks become stuck in the feed opening, then a rock breaker can be used on the block and the process continues. The discharge of this crusher is directed to the primary wet screening (CS-001) through a belt conveyor (BC-001). This screening is formed by a triple deck screen (+120 mm, + 60 mm, + 20 mm), where the material is washed and then divided in three different flows in the plant.

- The material fraction + 120 mm is redirected to a secondary crusher that consists of a cone crusher (CC-001) with an open side setting around 150 mm. The discharge of this crusher is redirected to the feed of the screening unit with a belt conveyor (BC-003);
- The material fractions -120 mm + 60 mm and -60 mm + 20 mm are directed though a belt conveyor (BC-002) to a product bin (PB-001) outside the plant, and are then loaded into trucks for transportation to the smelter, and;
- The material fraction -20 mm is discharged into a dewatering unit, which consists of a dewatering screening (DS-001) and a 10-inch hydrocyclone (HC-001). In this dewatering unit, the slurry (-20 mm) feeds the dewatering screen, so the underflow of the screen with fines goes to a tank and then is pumped to the hydrocyclone through a slurry pump (SP-001). The underflow from the hydrocyclone, full of solids, again feeds the dewatering screening, and the overflow, practically free of solids is recirculated to the washing process. The overflow of the dewatering screening, with low moisture, goes directly to a fines stockpile by way of a belt conveyor (BC-003).

16.3.10 Mass and Water Balances

For the calculation of mass balance, the following assumptions were considered:

- Working hours per year: (8 hours/day) x (260 days/year) = 2080 hours per year;
- Production rate: 97,524 tons per year;
- Mass recovery of the plant: 75%;
- Run of mine (ROM) rate: ~133,333 tons per year;
- Production rate: 48.1 tons/hour;
- Run of Mine rate: 64.10 tons/hour;
- % of Moisture in the final product and ROM solids: 5%;

- % of solids (w/w) on screening feed: 65%.

Table 45 and Figure 91 below show the mass and water balances calculated for the project.

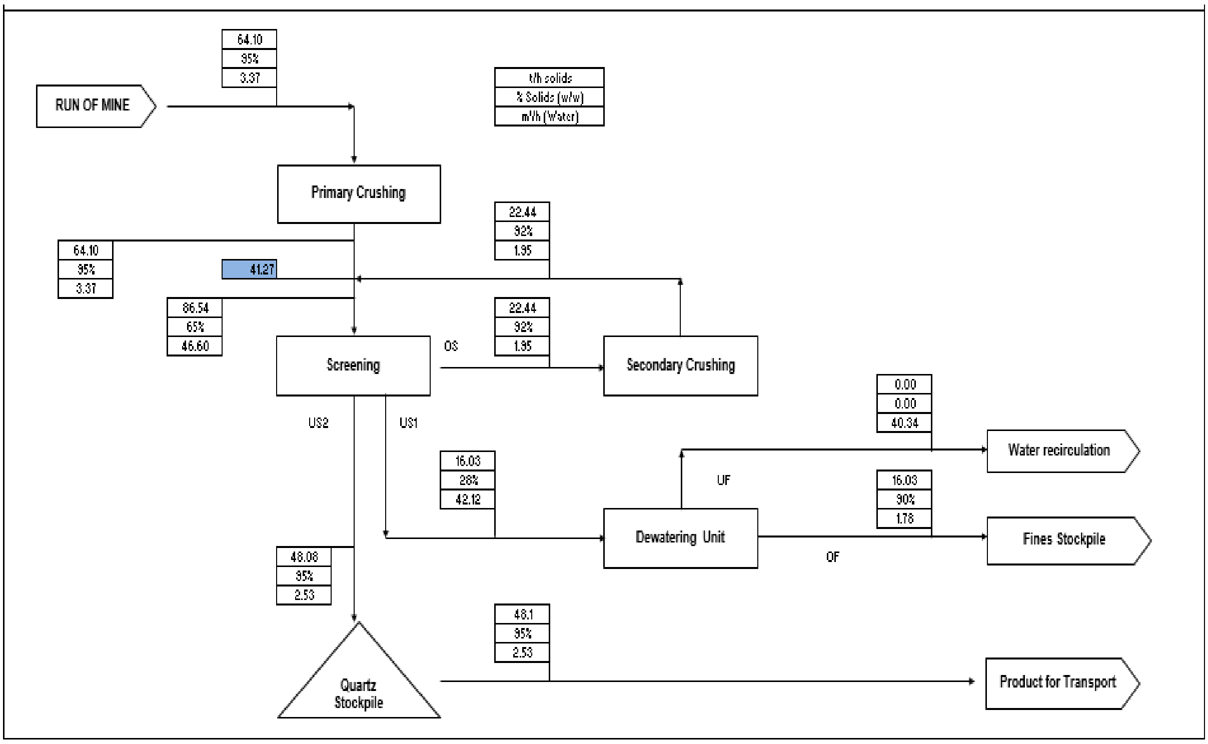
Table 45: Mass balance – Langis beneficiation plant

Stream Description	Solids	Solids (%w/w)	Water (m³/h)
Primary crushing feed	64.10	95	3.37
Primary crushing discharge	64.10	95	3.37
Screening total feed	86.54	65	46.60
Screening water addition	0.00	0	41.27
Screening oversize	22.44	92	1.95
Secondary crushing discharge	22.44	92	1.95
Screening US1	16.03	28	42.12
Dewatering unit UF	0.00	0	40.34
Dewatering unit OF	16.03	90	1.78
Screening US2	48.08	95	2.53
Final product for transport	48.10	95	2.53

Source: Caban Geoservices, Viridis.iQ GmbH

In order to validate these assumptions, more minerals processing and metallurgical tests must be carried out with this material.

Figure 91: Block flow diagram with mass and water balance



Source: Caban Geoservices, Viridis.iQ GmbH

16.4 Water Management

16.4.1 Location of Nearest Water Source

The nearest source of a continuous substantial flow of fresh water is a stream called Riviere Tamagodi 1.8 km to the east-southeast of the present Langis quarry. This stream flows northeastward into the Matane River. The Matane River flows northward into the St. Lawrence estuary. The Riviere Tamagodi can potentially be used as a source of raw water for activities such as pit wetting, car and equipment washing, workshops and fuel station washing, and for the processing plant, but this is a topic to be addressed in later project stages and the EIA.

Since water from Riviere Tamagodi and the Matane River cannot be considered as potable for human consumption, the water demand for this purpose can be supplied by water trucks from the nearest water treatment company.

16.4.2 Human Consumption

In terms of human consumption, according to statistics from the Canadian Government, the water consumption per person can be assumed as 0.3 m³ per person per day. Considering a team with 16 people, as shown in Table 46 below, human water consumption will be 4.8m³/day. Potable water for the quarry can be supplied by one water truck hauling 12 m³ per day, since there is no potable water source near the area of the project. A sewage treatment unit with 0.2 m³/h capacity must be sized in order to treat and reuse this water. This equipment sizing will be developed in the next phase of the project.

Figure 92: Sewage treatment system

Source: Caban Geoservices, Viridis.iQ GmbH

16.4.3 Raw Water for Quarrying Activities and Beneficiation Plant

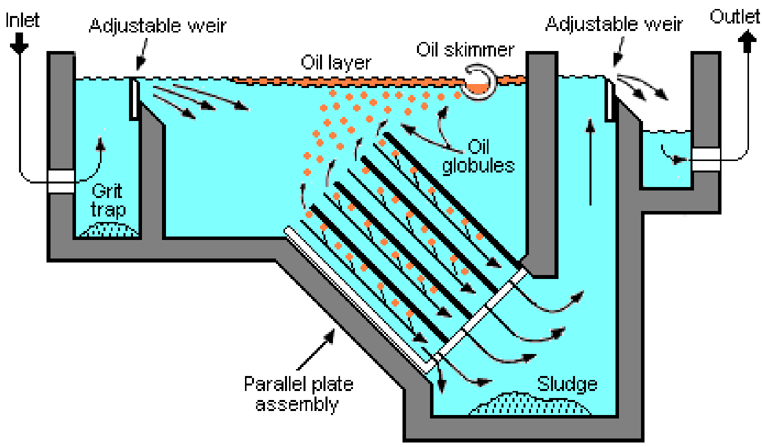
The use of raw water in the quarry is related basically to the wetting process for pit roads, workshops, fuel station and equipment cleaning, and for use in the wet screening on the beneficiation plant.

For the pit roads wetting process the reference value for quarries with this production scale (133,333 tons of ROM per year), is the use of 2 water trucks with 20 m³ capacity for the operation during the day, resulting in the use of 5 m³/h. The non-evaporated water from this process will be redirect to the sedimentation pond near the pit, and then directed to a natural water course.

Storm water in the region of the open pit will be directed to a sedimentation pond inside the pit. Then this water will be pumped to the natural water course, due to its low percentage of solids after sedimentation and its very low fraction of contaminants (diesel, lube oils and others). This sedimentation pond will be detailed in the next phase of the project.

For the calculation of the amount of water required for workshops, fuel stations and equipment cleaning, a cleaning frequency of once per day, at the end of the work-day, was assumed. Due to the small amount of equipment in the quarry and the small structures of the workshop and fuel station it should be sufficient to use one water truck with 20 m³ capacity per day for these purposes. After cleaning, the water drainage is directed to a water and oil separator station, and then the water goes to its natural course. The water and oil separator stations will be detailed in the next phase of the project. Figure 93 shows a scheme for the water and oil separation process, and Figure 94 shows an example of equipment for this process.

Figure 93: Scheme for water and oil separation system



Source: Caban Geoservices, Viridis.iQ GmbH

Figure 94: Examples of oil and water separator systems

Source: Caban Geoservices, Viridis.iQ GmbH

For the beneficiation plant, the block flow diagram shows the mass and water balances calculated for the process, considering 260 days per year and 8 working hours per day.

The make-up water required for the plant is 5.12 m^3/h, considering the water loss in the final product, the water loss in the fines pile, and some evaporation of recirculated water in the process plant (recirculated in wet screening) based on a 2% evaporation rate, due to conditions on site. The fines pile will be located near the beneficiation plant.

16.5 Labor Cost

The calculation of labor cost considers the technical team required to perform the works in the quarry, so that it is well operated.

The following data was used to calculate the annual costs for each type of professional on such a project. All taxes and benefits are already considered in this value.

The labor cost calculation is shown in the table 46.

Table 46: Labor cost

Team Member	Quantity	Per Employee (US$/year)	TOTAL (US$/year)
Quarry Manager	1	106,667.00	106,667.00
Mining Engineer	1	75,556.00	75,556.00
Geologist	1	75,556.00	75,556.00
Mining/Geology Technician	1	53,333.00	53,333.00
Safety Technician	1	53,333.00	53,333.00
Mechanical Technician	1	53,333.00	53,333.00
Electrical Technician	1	53,333.00	53,333.00
Electrical and Mechanical Maintenance	1	53,333.00	53,333.00
Operators	3	53,333.00	160,000.00
Drivers	3	35,556.00	106,667.00
Operation Auxiliars	1	53,333.00	53,333.00
Others	1	35,556.00	35,556.00
Total	**16**		**880,000.00**

Source: Caban Geoservices, Viridis.iQ GmbH

16.6 Langis Quarry Capital Costs (CAPEX)

Capital costs for the Langis quarry are divided into the following topics:

- Quarrying Equipment – US$ 848,478;
- Quarry Infrastructure and Administrative Buildings – US$ 672,100;
- Beneficiation Plant – US$ 2,607,000

This capital cost estimate is based on a database with similar projects and international indices. The precision of this CAPEX estimate is -/+ 30%.

16.6.1 Quarrying Equipment

This section of CAPEX covers all the required equipment to operate the quarry, such as trucks, excavators, drilling machines, tractors, graders and others auxiliary equipment.

The list of equipment sized for the quarry is shown with the respective capital cost in the table 47.

Table 47: CAPEX - quarrying equipment

Equipment	Quantity	Total (US$)
Main Equipment		
Truck Scania P 310 8X4	2	65,641.03
Hydraulic Excavator CATERPILLAR D-73	1	102,051.28
Group truck (with drilling machine and accessories)	1	139,743.59
Auxiliary Equipment		
Wheel loader CATERPILLAR 966C	1	75,018.32
Tractor	1	76,190.48
Grader	1	88,461.54
Air compressor	1	17,582.42
Manual drilling machine	1	3,515.49
Rollon adapter for auxiliary truck	1	5,860.81
Water truck tank	3	15,000.00
Driving board	1	21,794.87
Train truck	1	29,304.03
Small trucks 4x4 (diesel)	4	94,871.79
Small cars (popular) (flex)	4	36,307.69
Sub-total	23	771,343.33
Contingencies	10%	77,134.33
Total	**23**	**848,477.67**

source: Caban Geoservices, Viridis.iQ GmbH

16.6.2 Quarrying Facilities

This section describes the CAPEX for the infrastructure required at the quarry, such as maintenance shops, offices, fuel tanks, fuel tank farms, power substations, etc.

The total capital cost calculated for this section includes earthworks, civil construction, steel structure, piping and others necessary components.

The CAPEX for infrastructure and civil construction at site is shown in the Table 48.

Table 48: CAPEX for infrastructure and civil construction

Description	Quantity	Total (US$)
Power substation	2	36,000.00
Power substation buildings	2	40,000.00
Office (3 Rooms - adm., selling and expedition) and 2 Toilets	1	40,000.00
Male dressing room / toilets for 8 modules	1	82,000.00
Female dressing room / toilets for 2 modules	1	12,000.00
Quarry entrance - one room and toilet	2	145,000.00
Fuel tank - diesel + fuel station	1	110,000.00
Vehicle washing (recycled water)	2	96,000.00
Workshop for minor maintenance	1	50,000.00
Sub-Total	11	611,000.00
Contingencies	10%	61,100.00
Total	**11**	**672,100.00**

Source: Caban Geoservices, Viridis.iQ GmbH

16.6.3 Beneficiation Plant

The equipment and infrastructure related to a beneficiation plant for production of 97,524 tons per year of product is described in Table 49 below.

Table 49: CAPEX for beneficiation plant

Description	Total (US$)
Equipment	
Vibrating feeder	23,700.00
Jaw crusher	213,300.00
Belt conveyor (30")	94,800.00
Conventional triple deck screen	118,500.00
Cone crusher	225,150.00
Belt conveyor (30")	94,800.00
Belt conveyor (30")	94,800.00
Dewatering screen	106,650.00
Dewatering cyclone (10")	17,775.00
Slurry pump	41,475.00
Belt conveyor (30")	94,800.00
Product bin	177,750.00
Infrastructure + Building + Services	
Description	158,000.00
Earthworks	237,000.00
Civil construction	158,000.00
Steel structure	355,500.00
Engineering	79,000.00
Piping	39,500.00
Electrical	39,500.00
Others	39,500.00
Total CAPEX	
Sub-total	2,370,000.00
Contingencies - 10%	237,000.00
Total	**2,607,000.00**

Source: Caban Geoservices, Viridis.iQ GmbH

16.6.4 Total CAPEX for Quarrying the Langis Deposit

The total CAPEX for the project is summarized in Table 50 below:

Table 50: Total CAPEX for Langis quarry

CAPEX Item	Value (US$)
Quarrying equipment	848,477.67
Quarry infrastructure and administrative buildings	672,100.00
Beneficiation plant	2,607,000.00
Total CAPEX	**4,127,577.67**

Source: Caban Geoservices, Viridis.iQ GmbH

These values are included in the overal consolidated capital budget for the integrated quarry and smelter operation as disclosed in Section 21.1.

16.7 Quarry Closure and Reclamation

The complete CRP (Closure and Reclamation Plan) of Langis quarry will take the following situations into account:

- Revegetation of the degraded areas;
- Physical stability of the quarry components;
- Open pit quarry workings;
- Waste rock and overburden piles;
- Tailings impoundment and containment systems
- Buildings and equipment;
- Infrastructure;
- Landfill and waste disposal areas and;
- Water Management systems.

16.7.1 Revegetation

Revegetation of all areas affected by quarrying activities should be considered. This may involve the establishment of media to support vegetation growth.

16.7.1.1 Objectives

- Re-establish the pre-activity ground cover, which may involve encouraging self-sustainable, indigenous vegetation growth;
- Provide wildlife habitat where appropriate and feasible;
- Assist with providing physical stability of quarry components;

16.7.1.2 Pre-quarrying Planning Options

- Determine baseline ecological conditions prior to disturbance;
- Determine affinity for indigenous plants to uptake metals, determine if these metals are bioavailable and if they have synergetic/antagonistic effects;
- Conduct local soil assessments to determine whether organic supplements should be used (e.g. peat, biosolids);

- Include native plant collection and propagation methods, successional processes, and final plant communities that provide biodiversity and sustainability to reclaimed sites in the research plan;
- Conduct studies to characterize the local climate, temperature, precipitation, and wind as they relate to plant growth;
- Strip and stockpile organic and fine-grained soils from disturbed areas, such as open pits, waste rock piles, infrastructure and tailings facility footprints, consistent with the need to maintain permafrost and use during progressive reclamation;

16.7.1.3 Progressive and Post-closure Reclamation Options

- Begin revegetation efforts as soon as possible for quarry site areas/components (progressive reclamation);
- Contour, scarify, and seed area using native seed mixes to establish vegetative cover;
- Apply gravel barriers or other underlying cover systems where desired to control or limit the upward movement of acidic pore water or heavy metals that may inhibit plant growth or for moisture retention near the surface;
- Apply stripped/stockpiled soil or growth medium to a depth sufficient to maintain root growth and nutrient requirements;
- Incorporate organic materials, mulches, fertilizers, or other amendments based upon local soil assessment;
- Establish appropriate temporary or permanent wind breaks where necessary to establish vegetation;
- Transplant vegetation that would otherwise be lost to quarry disturbance where feasible;
- Select indigenous vegetation for reclaimed sites that has a low potential for metal accumulation;
- Revegetate with indigenous vegetation not used by wildlife or people if uptake of metals is a concern;
- Place a gravel or coarse cover to discourage vegetation growth where desired;

16.7.1.4 Northern Limitations and Considerations

- Revegetation success may be limited due to northern climatic conditions including mean daily temperature, frost-free period, growing season, amount and timing of precipitation and the prevailing wind;
- There may be a lack of viable/suitable soil and seed sources;

- Information resources on revegetation of quarry sites in the north (e.g. species, seed collection and availability, and soil development) may not be as readily available as southern sites;
- It is important to reestablish the site's indigenous species because there is a high reliance on native vegetation by humans and wildlife as a food source;

16.7.1.5 Post closure Monitoring

- Inspect revegetated areas periodically following initial planting until vegetation is successfully established and self-sustaining in accordance with the agreed criteria;
- Conduct soil analysis for nutrients and pH until the vegetation is successfully established and self-sustaining;
- Inspect vegetated areas that may be obscuring possible cracks and other problems on dams and embankments;
- Inspect for root systems that are penetrating protective covers or decaying/rotting providing tunnels for water to pass through protective covers;
- Identify excessive vegetation stress or poorly established areas and implement contingency measures if required;

16.7.2 Physical Stability

Design and analysis of quarry components requires knowledge of material properties such as compressive strength, shear strength, durability and hydraulic conductivity. Stability of earth and rock structures is also governed by the in situ pore water pressure and hydrogeological conditions. The geometry of earth and rock slopes is typically designed to optimize production costs. Construction methods must ensure that the structures are built according to the design requirements and will perform safely during operations.

16.7.2.1 Objectives

Ensure physical stability of residual earth structures for environmental, human, and wildlife safety;

Physical stability of remaining earth structures is compatible with, and will not be compromised by, the post-closure land use;

16.7.2.2 Pre-quarrying Planning Options

- Minimize the number of earth structures required at closure;
- In order to improve stability in open pits, rock piles, tailings embankments, and rock cuts, the following measures should be considered:
  - The presence or absence of permafrost;
  - Removal of weak or unstable materials from slopes and foundations;
  - Slope flattening (slope stepping results in overall slope flattening by creating intermediate berms);
  - Off-loading the crest of the slope;
  - Constructing toe berms such as a free draining stabilizing counterweight at the toe of the slope or to contain stockpiles of materials having low shear strength where permafrost does not exist (toe drainage must not be impeded);
  - Drainage measures including pumping from relief wells at the toe of a slope or installation of horizontal drains;
  - Biotechnical measures such as vegetation to prevent surface erosion and shallow failures;

16.7.2.3 Progressive and Post-closure Reclamation Options

- Implement construction control, including: surveys, grouting, foundation preparation, material quality control, compaction control, and instrumentation monitoring;
- Conduct reclamation risk assessments for design criteria of dams, spillways, and covers;
- Reclamation design criteria for dams, spillways, and covers should consider the following:
  - All stability analyses should be based upon conservative estimates of material strengths and seismic accelerations;
  - Stability analyses should consider the angle of friction and cohesion values obtained at critical moisture contents for the materials;
  - The character and shear strength of all structural components including rock, soil, liners, and sub-grade soils or rock should be presented in the site characterization and baseline data of the design report and all relevant test work should be fully documented;
  - Stability analyses should consider all kinematically possible failure modes and solifluction should be addressed for slope stability and cover designs where frost susceptible soils are involved;

- Consideration should be given to the potential for long-term changes in material strength due to weathering, frost action, degradation, seismic events and chemical changes;
- Maximum runoff should be the most critical runoff (precipitation plus snow melt);
- All dams and associated structures should be designed, constructed, and maintained as stated in the procedures and requirements set out in the “Dam Safety Guidelines” published by the Canadian Dam Association;
- Spillway design should include consideration of the effects of the failure of water diversion structures during the critical design events;
- Where there is risk of thawing in the long term, stability should be demonstrated for frozen, thawing and fully thawed conditions.

16.7.2.4 Northern Limitations and Considerations

- There is a large range of seismic conditions across the north that should be considered;
- There is a large range of thermal ground conditions across the north that should be considered;
- The effects of climate change could be more dramatic in permafrost regions;
- Remote quarry site locations and limited accessibility may be an additional consideration for designs; reliance on synthetic “man-made” materials such as geo-synthetic liners should be minimized.

16.7.2.5 Post-closure Monitoring

- A consistent monitoring record from a constant point of observation from pre-quarrying through post-closure should be maintained;
- Inspect to ensure there are no ongoing deformations that could lead to instability, unsafe conditions or compromise the post-closure land use;
- Trigger levels for monitoring and maintenance will be site-specific and consider designs and natural setting (this should be developed in the Closure and Reclamation Plan).

16.7.3 Open Pit Quarry Workings

Open pit reclamation also include quarries, open cuts, and major trenches in areas where quarrying has occurred. Sand and gravel quarries are not specifically addressed in these guidelines although some of the principles may also apply.

16.7.3.1 Objectives

Minimize access to protect human and wildlife safety;

- Allow emergency access and escape routes from flooded pits
- Implement water management strategies to minimize and control migration and discharge of contaminated drainage, and if required, collect and treat contaminated water
- Meet water quality objectives for any discharge from pits
- Stabilize slopes to minimize erosion and slumping
- Meet end land use target for resulting surface expression
- Establish original or desired new surface drainage patterns
- Establish in-pit water habitat where feasible for flooded pits

16.7.3.2 Pre-quarrying Planning Options

- Insulate stripped overburden with rock fill so that the exposed soil slopes can be immediately protected to avoid ongoing erosion, sedimentation and instability
- Excavate rock and soil slopes that will remain above final predicted pit water level to their final stable slopes prior to deepening pit
- In order to improve stability in open pits, consider removing weak or unstable materials from slopes and foundations, flattening slopes, and off-loading the crest of the slope
- Install thermistors to monitor thermal regime around pit, especially if pit is constructed adjacent to a water body or talik
- Have storage and treatment facilities in place prior to stripping of the open pit where overburden and/or overburden melt-water quality is poor
- Divert surface drainage to minimize pit water handling and treatment requirements until the pit water reaches acceptable standards for discharge to the environment after closure

16.7.3.3 Progressive and Post-closure Reclamation Options

- For multiple pits, sequentially backfill with waste rock and/or tailings as operations proceed
- Backfill open pits with appropriate materials (e.g. waste rock, tailings)
- Flood the pit (natural or accelerated)
- Allow gradual slope failure of pits involving rock masses, or slope pit walls
- Block open pit access routes with boulder fences, berms, and/or inukshuks (guidance from local communities and elders should be sought)
- Post warning signs (with visible symbols placed close enough so they are visible from one to another) and fences or berms around the perimeters for actively managed sites (not acceptable for remote sites into the long-term)
- Long-term fencing to prevent access may only be appropriate if the quarry site is located close to a community where regular access for maintenance is possible and where there is a higher risk of access by the general population
- Cover slopes with rip rap thick enough to provide insulation or stabilization to minimize erosion or permafrost degradation
- Stabilize exposed soil along the pit crest or underlying poor quality bedrock that threatens to undermine the soil slope above the final pit water level
- Backbrush area to improve visibility
- Plug drill holes
- Maintain an access/egress ramp down to water level for flooded pits
- Contour to discourage or encourage surface water drainage into pits where appropriate
- Cover exposed pit walls to control reactions where necessary
- Collect waters in pit that do not meet the discharge criteria and treat passively (active treatment is not acceptable for the long term) or passively treat waters in the pit
- Breach diversion ditches and establish new water drainage channel
- Establish aquatic life in flooded pits

16.7.3.4 Northern Limitations and Considerations

- Changes in the permafrost conditions, and groundwater regimes, may ultimately affect physical stability, the mitigation measures in place, and site water balance
- Thaw in permafrost regions is a critical consideration where slumping and sediment release could result in failure of upper pit slopes

- In permafrost areas, there is the potential for initiating permafrost degradation by excavating trenches or ditches if adequate thermal and erosion protection is not present
- Snow drifts in pits may alter the hydrology
- High evaporation rates may exceed input rates for reclaimed pit lakes
- Poor visibility of pits during winter conditions could be hazardous to travel in the north (mostly by snow machines)

16.7.3.5 Post-closure Monitoring

- Identify areas that are not stable
- Check ground conditions to confirm permafrost conditions are being re-established as predicted
- Sample surface water and profiles of flooded ponds/pits
- Ensure that there is sufficient water supplied to maintain an appropriate water depth for flooded pits
- Sample water quality and volume at controlled discharge points of pit lakes
- Sample quality of groundwater seeping from pit walls to assess potential for contamination of quarry water due to melting permafrost and ARD/ML from pit walls
- Identify and test water management points (including seepage) that were not anticipated
- Inspect barriers such as berms, fences, signs, and inukshuks
- Inspect fish habitat in flooded pits where applicable

16.7.4 Waste Rock and Overburden Piles

These piles are made up of waste rock, overburden, and low-grade silica that may be extracted in developing and operating the quarry and supporting infrastructure. Waste rock and overburden piles are typically placed in piles for permanent storage unless used in the construction, operation or closure of the site.

16.7.4.1 Objectives

- Minimize erosion, thaw settlement, slope failure, collapse or the release of contaminants or sediments
- Build to blend in with current topography, be compatible with wildlife use, and/or meet future land use targets

- Build to minimize the overall project footprint

16.7.4.2 Pre-quarrying Planning Options

- Select the location and design for waste rock, overburden, and silica stockpiles to complement the desired reclamation objectives and activities
- Segregate deleterious materials for controlled disposal or cellular pile construction
- Salvage overburden materials from stockpiles for use in reclamation
- Construct waste rock piles and overburden piles in lifts with slopes where individual lifts can be set back to provide long-term stability
- Construct rock fill toe berms to contain overburden stockpiles and maintain stability
- Select site that avoids low strength foundations and consider slope angle
- Construct sediment collection ponds for use during operation
- Construct waste rock and overburden piles such that they do not straddle a watershed divide or are not in the path of stream flows that drain to medium-large watersheds
- Select a site within the same drainage catchment as the proposed tailings containment area or alternatively, in the same drainage basin and upslope of the open pit, so runoff is captured and treated with pit water
- Locate waste rock piles in the upper portion of the watershed where runoff effects can be minimized
- Construct internal drains to prevent water table rise
- Manage waste rock by exploring options to control ARD/ML
- Design and construct rock piles to encourage and maintain permafrost

16.7.4.3 Progressive and Post-closure Reclamation Options

- Doze down crest if required or construct toe berm to flatten the overall slope
- Remove weak or unstable materials from slopes and foundations
- Off-load materials from the crest of the slope
- Leave waste piles composed of durable rock “as is” at the end of quarrying if there is no concern for deep-seated failure or erosion, and if the end land use targets can be achieved
- Cover to control reactions and/or migration (re-slope to allow for cover placement if necessary)
- Place riprap insulation/stabilizing layer
- Freeze waste into permafrost

- Place Potentially Acid Generating (PAG) rock underwater or underground if viable
- Place Potentially Acid Generating (PAG) rock within the center of the waste pile so it is encapsulated by permafrost if conditions permit and underwater or underground disposal are not viable options
- Construct collection systems to collect contaminated runoff or leachate
- Construct diversion ditches to divert uncontaminated runoff
- Install horizontal drains or pump leachate from relief wells at the toe of the slope
- Passively treat contaminated waters where necessary, active treatment is not acceptable for the long term
- Use benign waste rock as backfill in underground quarry workings, to seal portals, to fill open pits, or for construction material such as ramps or covers
- Revegetate using indigenous species or use other biotechnical measures (use of living organisms or other biological systems for environmental management) to reduce surface erosion
- Reslope, contour, and/or construct ramps to facilitate wildlife access
- Use inukshuks to deter wildlife where appropriate (guidance from local communities and Elders should be sought)
- Include records of construction drawings, as-built drawings, location of landfill sites, and potential ARD materials and other contaminated materials which are contained within the rock pile in the reclamation research plan

16.7.4.4 Northern Limitations and Considerations

- Permafrost aggradation into rock piles might occur in permafrost regions
- Ice and snow incorporation into rock piles may lead to instability if thawing occurs
- Foundation thawing may cause instability
- Long term aggradation of ice rich soils may be a problem that needs to be addressed in design
- Severe northern conditions (such as climate) may affect cover performance
- Piles may alter wildlife routes or mobility; actions to improve safe wildlife passage may be required

16.7.4.5 Post closure Monitoring

- Periodically inspect areas where stabilization measures may be required
- Periodic inspections by a geotechnical engineer to visually assess stability and performance of waste pile and cover(s)

- In the case of water covers, ensure that there is sufficient water supplied to maintain an appropriate water depth
- Periodically inspect ditches and diversion berms
- Examine ground conditions to confirm predicted permafrost conditions are being established as predicted
- Check thermistor data to determine thermal conditions within waste piles to confirm predicted permafrost aggradation/encapsulation where applicable
- Test water quality and measure volume from controlled discharge points of workings to confirm that drainage is performing as predicted and not adversely affecting the environment
- Identify water discharge areas (include volume and quality) that were not anticipated

Evaluate/confirm success of revegetation activities; meets technical needs (maintains physical stability) or aesthetic needs (blends with surroundings) and meets end land-use targets.

16.7.5 Buildings and Equipment

Quarry site buildings may include: a processing/concentrator plant, head frame, maintenance shops, offices, warehouses, fuel tanks, fuel tank farms, assay and analytical labs, process reagent and explosive storage, boiler houses, power generation plants, and camp facilities. Equipment may include: all surface and underground mobile equipment, shaft installations, distribution piping, and conveyors.

16.7.5.1 Objectives

- Ensure buildings and equipment do not become a source of contamination or a safety hazard to wildlife and humans
- Return area to its original state or to a condition compatible with the end land-use targets

16.7.5.2 Pre-quarrying Planning Options

- Locate buildings on bedrock or thaw stable soil foundations to minimize need for foundation preparation and disturbance of terrain
- Use inert waste rock pads placed on top of tundra surface for structures having low foundation loads, such as camp, offices, and warehouses

- Avoid stripping tundra surface where possible
- Locate heated structures such that the degradation of underlying permafrost is reduced or eliminated

16.7.5.3 Progressive and Post-closure Reclamation Options

- Dismantle all buildings that are not necessary to achieve the future land use target
- Raze/level all walls to the ground and remove foundations
- Cover remaining foundations with materials conducive to vegetation growth
- Remove buildings and equipment during the winter to minimize damage to the land where appropriate
- Remove floor structures over basements and cellars
- Remove and dispose concrete in an approved landfill if it contains contaminants such as hydrocarbons or PCBs that may pose a hazard over time
- Where approved, break or perforate concrete floor slabs and walls to create a free draining condition in order that vegetation can be established
- Backfill all excavations below final grade to achieve the final desired surface contours to restore the natural drainage or a new acceptable drainage
- Cover excavated sites which have exposed permafrost with a rock cap to prevent thermokarst erosion
- Reduce dust emission during demolition of buildings that contain or contained asbestos, hazardous chemicals or other deleterious material
- Remove buried tanks, where they already exist, to prevent subsidence
- Bury materials in the unsaturated zone or below the active layer
- Decontaminate equipment (free of any batteries, fuels, oils, or other deleterious substances) and reuse or sell (local communities may have interests in some of the materials)
- If sale or salvage of equipment is not possible, dispose of decontaminated equipment in an approved landfill or as recommended by the regulatory authorities
- Cut, shred or crush and break demolition debris to minimize the void volume during disposal
- Maintain photographic records of major items placed into landfills, as well as a plan showing the location of various classes of demolition debris (e.g. concrete, structural steel, piping, metal sheeting and cladding)
- Leave non-salvageable materials and equipment from underground operations in the underground quarry upon approval from the regulatory authorities

- Remove all hazardous materials and chemicals prior to demolition to national approved hazardous material treatment facilities, recycle, reuse, or dispose of in an appropriate manner upon approval from the regulatory authorities (check for PCBs in fluorescent light fixtures, lead-based paints, mercury switches or radioactive instrumentation controls)
- Backhaul materials for recycling or disposal to a southern location

16.7.5.4 Northern Limitations and Considerations

- Caution should be taken in permafrost zones where buried material can potentially be pushed to the surface years later
- Maintaining permafrost under buildings and roads may be important to ensure physical stability of the infrastructure (heat, from buildings and processing plant, may create enough heat to affect the underlying ground conditions)
- The breakdown of materials left on northern sites will be slow due to cold temperatures
- Remote sites are hampered by restrictive and perhaps seasonal factors such as transportation (ice roads, water access), climate, and hours of daylight; logistics such as timing activities and disposal options should be considered
- Local residents and communities may also identify a desire to maintain certain buildings for emergency, or community, purposes (ownership liability will need to be considered)

16.7.5.5 Post-closure Monitoring

- Maintain all buildings and equipment left onsite
- Inspect disposal areas periodically to establish if buried materials are being pushed to the surface as a result of frost heaving

16.7.6 Infrastructure

Infrastructure may include roads, airstrips, electrical power supply systems, bridges, culverts, railways, ports, barge landings, and silica handling facilities.

16.7.6.1 Objectives

- Ensure infrastructure does not become a source of contamination

- Return area to its original state or to a state compatible with the desired end use
- Restore natural drainage patterns where surface infrastructure has been removed
- Restore the natural use by wildlife

16.7.6.2 Pre-quarrying Planning Options

- Construct airstrips as part of site access roads to minimize the project footprint
- Evaluate alternative access road options such as winter roads and alternative alignments
- Evaluate terrain sensitivity along route alignments, potential environmental impacts and construction mitigation requirements
- Avoid or minimize bridge crossings
- Where possible, use gentle slopes in road verges to facilitate wildlife passage during operation and after closure

16.7.6.3 Progressive and Post-closure Reclamation Options

- Remove structures including bridges, culverts, pipes, buried wires and power lines and fill ditches in if no longer required and evaluate the area for potential contaminants
- Reclaim areas to the original topography and drainage or to a new topography or drainage compatible with end land use targets
- Scarify abandoned road/runway surfaces to promote revegetation of indigenous species
- Leave roads, airstrips, bridges, or railways intact if it is in the public interest to do so (ownership liability will need to be considered)
- Flatten berms and slopes at the side of roads to facilitate wildlife passage

16.7.6.4 Northern Limitations and Considerations

- The scheduling for dismantling infrastructure components should be carefully considered in the context of the need for their use during the reclamation and monitoring period
- Quarry sites in the north may result in opening up the area by providing access to other land users (e.g. tourists, hunters, prospectors)
- Maintaining permafrost under roads and pads may be important to ensure physical stability of the infrastructure

- Local residents and communities may also identify a desire to maintain certain infrastructure for emergency, or community, purposes (ownership liability will need to be considered)

16.7.6.5 Post-closure Monitoring

- Maintain access infrastructure to support on-going reclamation and closure monitoring
- Monitor wildlife/fish use of area to ensure mitigation measures are successful
- Monitor other land users access and activity in the area

Check stream crossing remediation and any degradation associated with decommissioned roads such as erosion or ponding of water.

16.7.7 Landfill and Waste Disposal

Landfills and other waste disposal areas may include industrial and domestic waste, sewage, chemicals, and water treatment sludge.

16.7.7.1 Objectives

- Control erosion and effects to the ground thermal regime
- Prevent inadvertent access
- Ensure waste disposal areas do not become a source of contamination
- Return area to its original state or to a state compatible with the desired end use

16.7.7.2 Pre-quarrying Planning Options

- Minimize the use of hazardous chemicals
- Take inventory of chemicals to be used
- Locate hazardous waste facilities and other waste storage areas away from waterways to minimize environmental impacts that could result from spills
- Do not excavate or cut ice-rich soils to construct a landfill
- Assess suitability of using abandoned quarries, borrow pits, underground quarry workings, and tailings impoundments for inert waste disposal to minimize footprint

16.7.7.3 Progressive and Post-closure Reclamation Options

- Some low level contaminated soil may be used progressively to cover landfills if the entire landfill is designed to be ultimately encapsulated in permafrost
- Remove hazardous waste to an approved hazardous material storage facility
- Dispose of wastes in quarries, borrow pits, underground mine workings, tailings impoundments, and waste rock piles
- Burn domestic waste in an incinerator during operation and at closure as part of camp maintenance
- Burn waste oils, solvents and other hydrocarbons on-site with an incinerator if approved (chlorinated substances should not be burned)
- Cover landfills and other waste disposal areas with erosion resistant material (e.g. soil, riprap, vegetation)
- Divert runoff with ditches or covers
- Ditch, berm, fence, or use alternative methods to limit access to waste storage areas
- Contour/blend to match the natural topography or a new desired topography and re-vegetate with indigenous species to meet the end use land targets
- Consider surface application of sewage for revegetation

16.7.7.4 Northern Limitations and Considerations

- Many northern sites do not have local sources of impervious soils to use as a landfill barrier and rely on permafrost as the barrier
- If permafrost is present within the landfill, the cap should sometimes be sloped to allow runoff where it is not necessary to prevent infiltration of precipitation
- Conventional landfill designs using an impervious liner may be more appropriate than utilizing frozen ground conditions to encapsulate the waste - especially for quarry sites located in the discontinuous permafrost area

16.7.7.5 Post-closure Monitoring

- Sample water treatment sludge periodically to determine the chemical characteristics, sludge stability, and leachability under the proposed long-term storage conditions
- Test water quality and quantity to measure the success of the mitigation measures for waste disposal areas
- Identify any unpredicted sources of potential contamination

- Check the ground thermal regime (by means of thermistors) and cover performance to check if permafrost has aggraded into the landfill and if the seasonal active zone remains within the cover

Check for cracking or slumping of the cover and for underlying waste material pushing its way up through the cover

16.7.8 Water Management System

The components of a water management system may include embankments, ditches and culverts, pipelines, and storage tanks associated with fresh water supply, diversion of uncontaminated water, and collection/treatment and discharge of non-compliant water.

16.7.8.1 Objectives

- Dismantle and remove/dispose of as much of the system as possible and restore natural or established new drainage patterns
- Stabilize and protect from erosion and failure for the long term
- Maintain controlled release from water dams, ditches and all points of water discharge to the environment
- Achieve approved water quality limits, and in the case of existing quarries, implement long term treatment only if necessary and ensure that minimal maintenance is required

16.7.8.2 Pre-quarrying Planning Options

- Minimize reliance on long-term diversion ditches
- Plans should be designed to be robust to address development plans of other quarry components and compatible with the long term end-use targets
- Construct pilot channels to assess ice buildup in water passage channels

16.7.8.3 Progressive and Post-closure Reclamation Options

- Water management facilities including ditches and settling ponds that are not required for long-term use should be treated and discharged, sediment should be removed and disposed of properly, and the embankments, dams and culverts should be breached if not required

- Use passive treatment systems as the preferred method for dealing with contaminated waters if it can be demonstrated to be effective
- Locate permanent spillways in competent rock
- Drain, dismantle and remove tanks and pipelines from the site or fill and cover them with appropriate materials if they are approved to remain
- Cover embankments, ditches, culverts, and other drainage channel slopes with erosion resistant material (e.g. soil, riprap, vegetation)

16.7.8.4 Northern Limitations and Considerations

- Designs should account for snowfall and snowdrifts that may accumulate in topographic lows
- The flow capacity of the water passages may be affected by ice buildup and debris in the channels
- May need to incorporate management of water under ice and snow conditions; this is particularly difficult during spring melt when flows can be large, ice and snow may obstruct flows, and visibility and access to those flows may be limited
- Long periods of snow or ice cover makes passive systems more difficult to implement
- Water in the north is considered pristine and aquatic organisms may be particularly sensitive to water quantity and quality changes
- Land and water are vital parts of the Aboriginal identity and culture and a traditional lifestyle is dependent on a healthy aquatic ecosystem

16.7.8.5 Post-closure Monitoring

- Periodic inspections are required in the post-closure period to assess the performance of the existing water management structures
- Check the performance of erosion protection on embankment structures such as rip rap or vegetation and the physical stability of water management systems including permafrost integrity where applicable
- Check water quality and flows to ensure system is working as predicted
- Conduct ongoing inspection and maintenance of passive or active water treatment facilities associated with non-compliant quarry water or runoff discharges
- Sample surface and groundwater if site specific conditions dictate
- Check the smell and taste of water and fish (guidance from local communities and elders should be sought)

17 Recovery Methods

The Langis silica deposit will be quarried and recovered for use as a feedstock into a downstream silicon and ferrosilicon smelter in nearby Matane.

Process steps at the quarry site will consist of blasting, crushing, sieving and washing the silica before transportation to the smelter by truck. Silica that is too small for use in the smelter can be marketed to local industries, while large chunks will be used directly in the smelter.

The smelter in Matane can produce silicon and/or ferrosilicon by a pyrometallurgical process that combines silica from the Langis quarry with a carbon source, iron ore (for ferrosilicon production only), limestone and wood chips in a SAF (submerged arc furnace [14] or simply "furnace") in which these raw materials are smelted into silicon or ferrosilicon. Molten silicon or ferrosilicon is tapped from the furnace into ladles, refined as necessary, and then poured into molds to cool and solidify into large ingots. The ingots are removed from the mold after they have cooled sufficiently, then crushed and classified into chunks or powder for sale.

17.1 Silicon and Ferrosilicon Production Process

Silicon (Si) is the second member in the Group IVA in the periodic system of elements and does not occur free in nature, but only in combination with oxygen. Most of the Earth's crust is made up of silica (quartzite, silicon dioxide, SiO_2) and miscellaneous silicates comprised of silicon, aluminum, magnesium, oxygen, and other elements. Silicon constitutes about 27% of the Earth's crust and is the second most abundant element by mass, after oxygen. Silicon is not a metal by strict definition because it does not conduct electricity. It is often called a metal due to its lustrous, metallic appearance, but metalloid or semi-metal are the correct terms.

Ferrosilicon (FeSi also called FeSi75 std) is a shiny, gray metalloid that is used as a key raw material in many important industrial processes. It is typically an alloy comprised of about 75% silicon and 25% iron, however, the composition can vary depending on the end-user's requirements.

14 Schei, A. Tuset, J.K. and Tveit, H. Production of high silicon alloys. Trondheim: Tapir Forlag, 1998, pp. 13-20

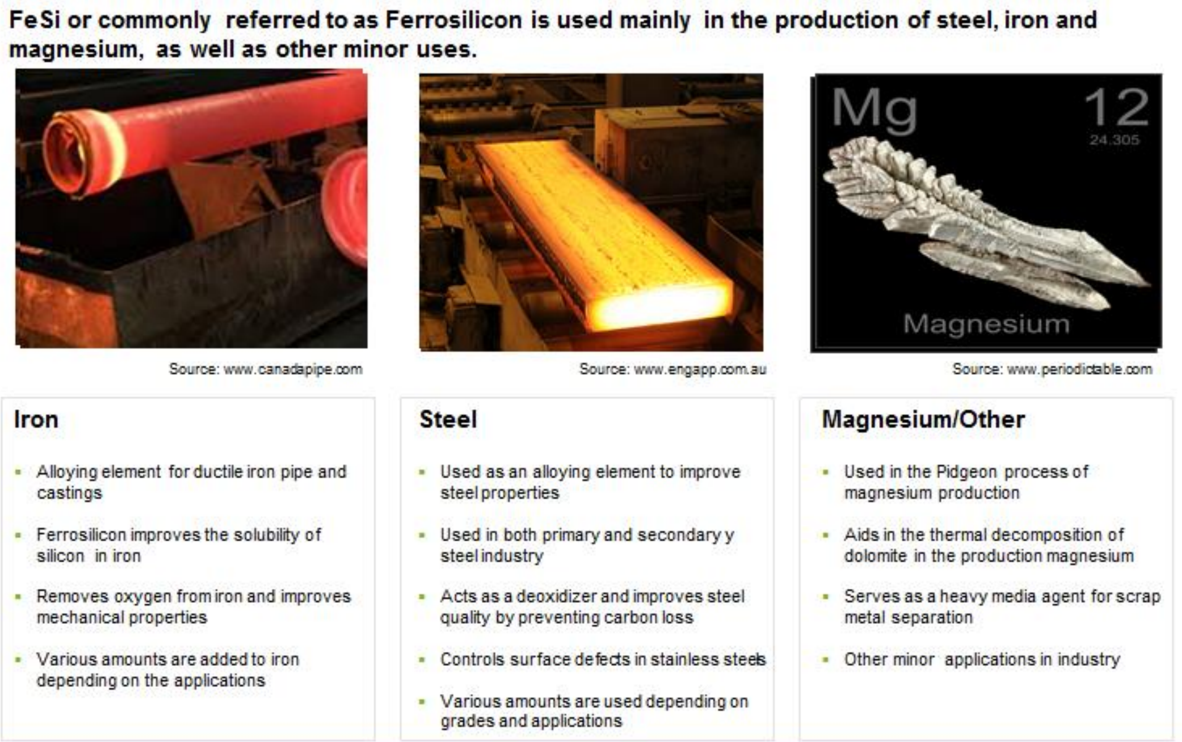
The production processes for metallurgical-grade silicon (mgSi) and ferrosilicon and are very similar in principle and involve the reduction of silica—a chemical change to remove the oxygen from SiO_2—with a carbon source in a SAF. The major difference between the production processes is that iron, in the form of iron ore or scrap steel, is also added to the furnace charge mixture for ferrosilicon production.

Figure 95: Concept art for an mgSi or FeSi smelter

The production of silicon and ferrosilicon is a widespread and proven technology with a history of well over 100 years. Quantities produced globally have increased over recent decades due to the broad spectrum of end uses, especially for silicon.

Ferrosilicon is a key raw material for the production of several types of steel. For example, it is used to deoxidize carbon steel in the molten state to prevent the loss of carbon, in the production of cast iron to control silicon content, as an alloy with magnesium to nodulize ductile iron, in “silicon steel” used for electric motors and transformer cores, and in stainless steel to control surface defects. It is also used as a raw material in one of the main process routes to produce magnesium metal.

Figure 96: End use markets for FeSi



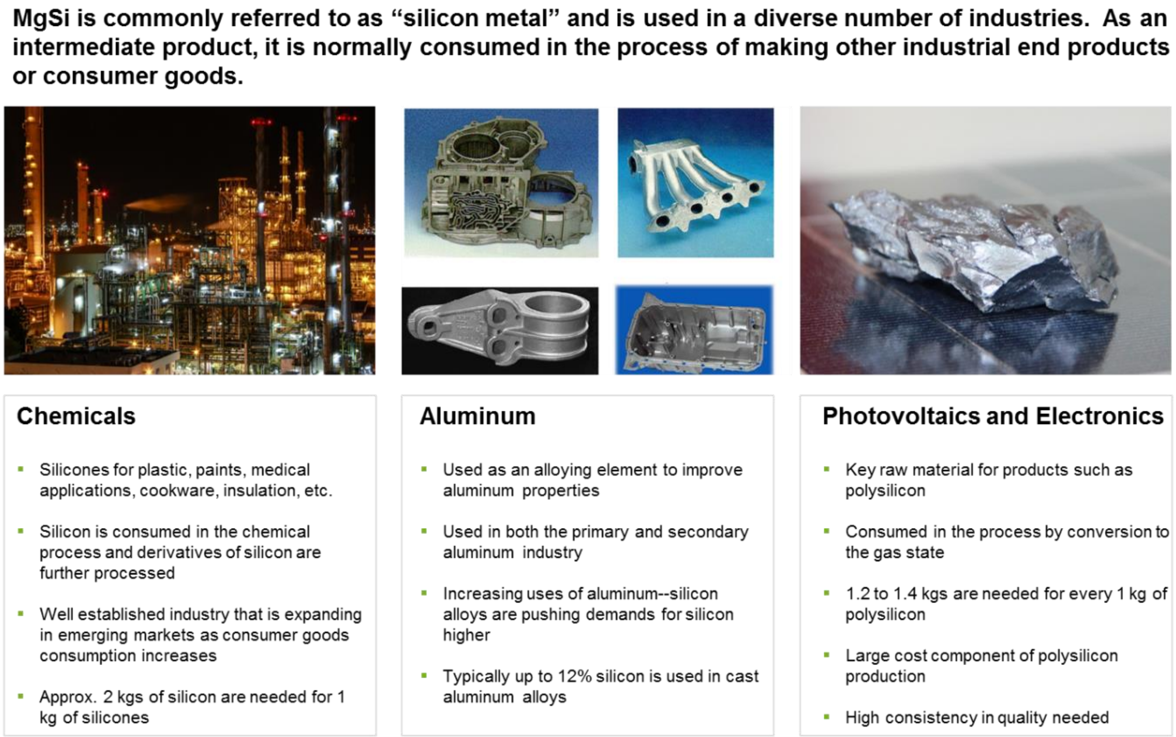
Source: Viridis.iQ GmbH

Silicon lies at the heart of much of the modern industrial metals sector of bulk commodities such as aluminum, steel, concrete, clays and ceramics; and through more chemically modified systems in such applications as soluble silicates, glasses and glazes. The more recent industries based on silicone polymers and solid-state electronic devices have also played a large role in the industrialization of silicon and silicon chemicals production. The different grades of silicon are related to its purity and the contaminants present in the product. The refining technology for ultrapure, single-crystal silicon is perhaps the most elegant example of the close relation between chemistry and solid-state physics, which has led to numerous developments such as the transistor and modern microelectronic devices.

Three major applications have greatly stimulated the production and purification of silicon, that is, as an alloying element for aluminum, chemicals (or mainly silicones) and solid-state electronics. Silicon carbide and silicon nitride ceramics, manufactured from mgSi, have also found a broad range of applications taking advantage of their hardness and chemically non-reactive character.

The photovoltaic (PV, “solar cell”) industry has been experiencing a strong economic growth globally over the past 15 years. This expansion is due to an increasing demand for silicon photovoltaic modules, which is expected to continue for many years. The dominant semiconductor material used in photovoltaic cells and modules is solar-grade silicon ("polysilicon") and the need for high-quality mgSi as a feedstock for the purification process to solar-grade silicon is expected to increase tremendously during the next few decades.

Figure 97: End-use markets for mgSi



Source: Viridis.iQ GmbH

17.1.1 Industrial Basics

The production of mgSi and FeSi takes place in large, open, submerged arc furnaces (SAF) using alternating current and three large, carbon-based electrodes. The production process has been industrialized over the last century and the basic process has not changed significantly over time. It is a function of the specific conditions in which silicon dioxide "rocks" transform into silicon monoxide gas (SiO) and combine with carbon, which is reproducible in the unique furnace environment. The process takes place in an industrial environment and is highly energy intensive, on the order 7 to 9 MWh per ton of FeSi or 11 to 14 MWh per ton of mgSi output. This energy consumption is concentrated mainly in the smelting step ("furnacing") in the SAF, due to the need to disassociate highly stable silicon dioxide, in the form of silica or quartzite, into the final product.

The smelting process is accompanied by an intense emission of gases with a high content of carbon monoxide (CO) and entrained particulates that can cause severe air pollution, and which also represents a high loss of energy. This off gas must be captured by a dust removal system before being released into the air. The captured dust can be sold as a by-product called "silica fume" for use in high-strength and other specialty concrete production. The waste heat from the process can be captured and reused for pre-heating of ladles and other equipment or to generate electricity.

The overall global reaction for the production of silicon in a SAF can be shown as follows:

$SiO_2 + 2C \rightarrow Si + 2CO$ $T_{reaction} \sim 2{,}000°C$

However, this is a vast simplification of the complex set of reactions occurring in a SAF.

The raw materials charged to a furnace for silicon smelting are silica, carbon (low-ash coal and/or charcoal) and wood chips. Limestone may also be added to adjust the content of calcium (Ca) in the molten alloy for proper refining conditions.

Ferrosilicon production can use petroleum coke in place of coal or charcoal, depending on cost and availability at the smelter location, but coke is not the most desirable carbon source from an operations and product-quality perspective. Of course iron must be added to a ferrosilicon furnace somehow, and iron ore (hematite) or unalloyed, scrap steel are the typical raw materials used. In the case of ferrosilicon production using iron ore in the charge mixture, the oxide iron ore will also be reduced to metallic iron by a global reaction similar to the one shown above for silicon production:

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$

In this case carbon monoxide, which is readily available in the furnace environment, is the carbon source. Silica and iron ore reduction to Si and Fe, respectively, occur simultaneously in a ferrosilicon furnace.

Adding scrap steel to a ferrosilicon furnace charge mixture, instead of iron ore, may appear to be a more attractive answer to the question of how iron should be introduced to a smelting furnace. However, the reduction of iron ore to metallic iron is exothermic and significantly lowers the energy requirement for ferrosilicon smelting. Additionally, the use of scrap steel can be difficult to manage operationally, and may give rise to product quality problems if the scrap contains extraneous material or alloyed steel has inadvertently been included by the supplier.

The different temperature zones in a SAF have different, on-going chemical reactions occurring in them. The actual conversion of the SiC (silicon carbide) intermediate species to silicon itself takes place in the lowest zone of the furnace and is a continuous process. As such, the furnace is designed to allow constant removal (tapping) of the molten alloy produced. The use of wood chips in the furnace charge or “burden”—the raw material mixture undergoing smelting—is crucial as it promotes the distribution of gasses within the charge to help prevent losses of the critical SiO intermediate species. The main gas species formed in the furnace are SiO and CO, which are converted to SiO_2 and CO_2 when exposed to the atmosphere. Since the furnace is open and exposed to the atmosphere at the top of the charge, a major responsibility of the furnace operator is to keep these reactive gases inside the charge mixture to promote reaction with fresh raw materials.

Molten silicon is collected in large, refractory-lined, steel ladles when it begins flowing from the furnace. During collection in the ladle, the molten material is refined with pure oxygen or an oxygen-air mixture injected into the ladle to reduce the content of unwanted metallic elements, primarily aluminum and calcium. A synthetic slag made of silica sand or alumina may also be added to the ladle as a refining aid. The refining process takes place without external heating, therefore the superheat—the difference between the melting point of silicon and the actual temperature of the ladle contents—is a crucial operating parameter for the refining process. After refining, the molten silicon is poured into molds to solidify, then mechanically crushed or milled to customer requirements after it has cooled.

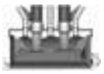
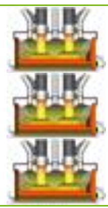
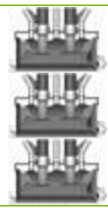
Molten ferrosilicon is collected in ladles similarly, but may or may not be refined depending on the particular grade being produced and customer requirements. It is poured, cooled and crushed using the same equipment and methods as for silicon.

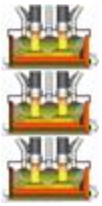
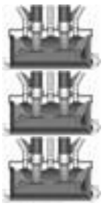
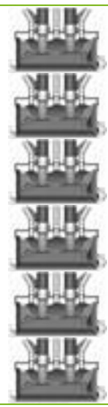
17.1.2 Hybrid Flex Plant

The current base-case for the project includes a flexible-furnace concept design named a Hybrid Flex Plant (HFP) by the authors. The HFP design principally means that the smelter is designed from the conceptual engineering stage with built-in capabilities to produce both silicon and ferrosilicon end products with any furnace. As both silicon and ferrosilicon end products have similar production process and raw materials, the added design parameters are not extensive and do not add significant costs from the equipment or process standpoint.

The HFP concept allows, from the initial design, the industrial infrastructure to permit an ease of transition from one product to another. The current base-case and flexible extremes to which the plant can be converted are shown in Table 51 as well as the end product output that is associated with the various configurations.

Table 51: Phase 1 (3 SAF) versus Phase 2 (6 SAF)

	Flex Mix		**Flex MgSi (Base-case)**		**Flex FeSi**	
	mgSi	FeSi	mgSi	FeSi	mgSi	FeSi
Phase 1 only				none	none	
Annual output (primary)	mgSi	35,000	mgSi	50,000	mgSi	none
	FeSi	26,000	FeSi	none	FeSi	75,000
Annual output (secondary)	Silica fume	27,500	Silica fume	24,000	Silica fume	30,000

	Flex Mix		**Flex MgSi (Base-case)**		**Flex FeSi**	
	mgSi	FeSi	mgSi	FeSi	mgSi	FeSi
Phase 1 & 2				none	none	
Annual output (primary)	mgSi	70,000	mgSi	100,000	mgSi	none
	FeSi	52,000	FeSi	none	FeSi	150,000
Annual output (secondary)	Silica fume	55,000	Silica fume	48,000	Silica fume	60,000

mgSi =  FeSi = 

Source: Viridis.iQ GmbH

The HFP concept is not unusual in the ferroalloy industry as many silicon and ferrosilicon producers can, and often do, switch between the products based on market and other boundary conditions. However, given the fact that few Greenfield silicon smelters have been built in recent decades, the HFP concept is relatively new in that foresight into the possible transitions between the products can be built into the design and thus a cost savings and competitive advantage can be realized.

The estimated costs savings will not be detailed herein; however, there are several main areas of competitive advantage that the concept brings into play:

- Reduced transition down time (furnace downtime, process reformulation, etc.)
- Infrastructure capabilities for additional raw materials for both products
- Flexible electrode column design for transition between electrode technologies
- Increased depth of knowledge on processes for both products for ease of transition
- Increase procurement leverage with overall increased depth of the supply chain
- Diversified risk profile as both end product markets are disparate and do not overlap

17.1.3 Smelting Process

The industrial production process for mgSi and FeSi is based on the reduction of silica with carbon in a SAF. The furnace is typically a large, open, semi-closed or closed-roof, alternating current (AC) furnace with large, carbon-based electrodes that are submerged into the solid raw material charge, and positioned so that the tip of the electrode is close to the bottom of the furnace (the hearth).

Temperatures in excess of 2,000°C are generated by arcs between the electrodes and the furnace hearth, as well as by some resistive heating due to electrical currents passing through the raw materials. Silicon dioxide is reduced to silicon at this temperature by the carbon source, which is in turn oxidized to carbon monoxide. This is a thermochemical reaction driven only by heat; as contrasted with an electrochemical reaction, like the production of aluminum, which requires a large electrical current flow through the raw materials to proceed. Electricity is only needed for silicon smelting to generate the extreme temperatures necessary for silicon dioxide reduction to occur.

The overall reaction that takes place in a silicon-producing furnace is shown below. However, this is only a generalization of the global reaction and does not take into consideration the numerous other reactions that take place simultaneously in different temperature zones to form key intermediate species:

SiO_2 (s,l) + 2 C (s) → Si + 2 CO (g)

The most important of these other reactions (there are at least 8 of them in total) are:

SiO_2 (s,l) + C (s) → SiO (g) + CO (g) (Silicon dioxide to silicon monoxide gas)

SiO (g) + 2 C (s) → SiC (s) + CO (g) (Silicon monoxide gas to silicon carbide)

SiO (g) + SiC (s) → 2 Si (s.l) + CO (g) (Silicon monoxide gas plus silicon carbide to mgSi)

17.1.4 Submerged Arc Furnace

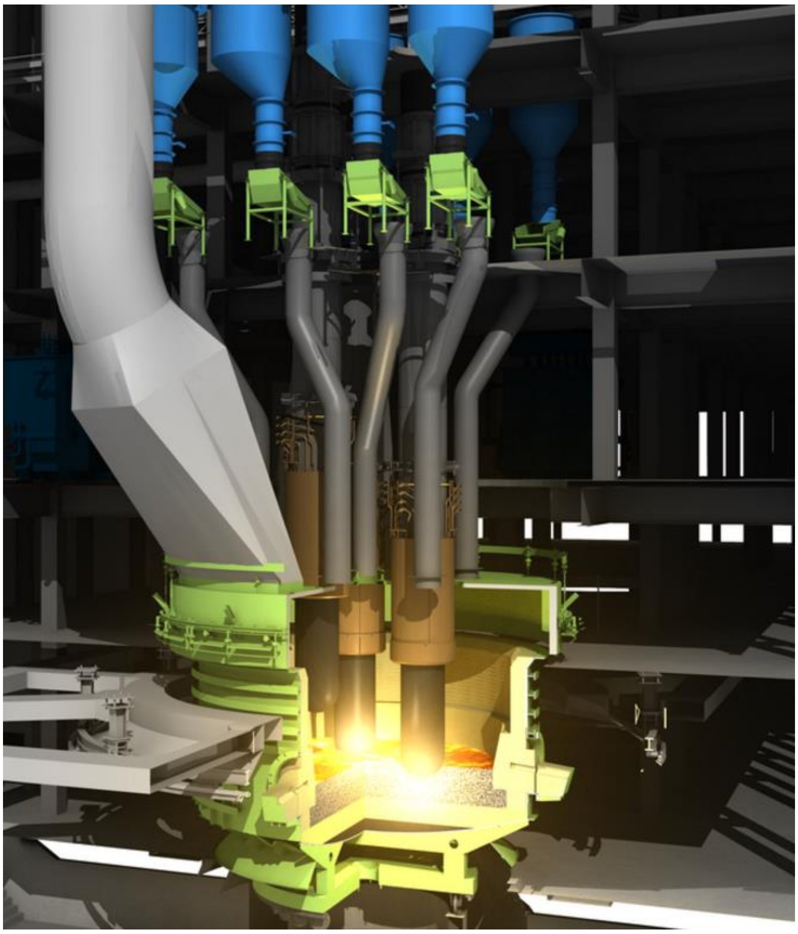
The furnace is principally a high temperature reactor, capable of providing the environment required for the reduction of silica, and the handling and containment of the molten alloy, slag and off-gas.

The SAF mainly consists of[15]:

- A rotating AC furnace with a steel shell, shell rotation device, refractory materials, hearth air cooling system, refractory-lined roof panels, water cooling systems and electrical components, gas off-take systems and other equipment
- Three carbon-based electrodes per furnace with associated slipping devices and hydraulic power packs
- Tap-holes constructed of refractory blocks with pre-drilled holes
- Stinger for opening the tap-holes
- Tap-hole lancing infrastructure
- Refractory-lined holding and pouring ladles
- Casting bay crane, laminated steel plate ladle hooks, and auxiliary hoist for ladle tilting
- Tap-hole fume extraction system with fume hoods, interconnecting ductwork and dampers
- Furnace rotating device
- Electrical power supply system
- Rotating tapping car
- Rotating tapping platform
- Stoking machine

15 Information regarding furnace equipment provided by Tenova Pyromet

Figure 98: SAF stoking deck level



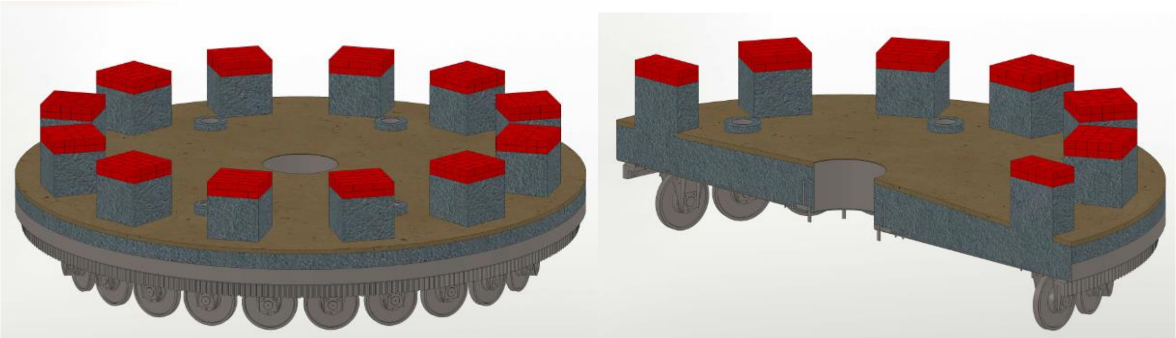
Source: Viridis.iQ GmbH

The charge mixture is fed into the furnace through a number of feed pipes that can be seen in the figure above. Stoking machines are used to distribute the new material evenly over the surface of previous raw material charges. When the charge level becomes too low, the furnace operator will again start the individual tube feeders to replenish the raw materials.

Thermal energy is delivered to the process by arcing to the hearth and molten alloy at the bottom of the furnace, as well as by resistive heating of the charge materials. Process parameters including power input and electrode positioning to maintain a specific resistance set point are continuously, rapidly and accurately regulated for optimum performance.

The furnace shell sits on a rotating device, as shown below. The rotating device allows the shell and hearth to rotate slowly at approximately one revolution every three days. Rotation of the furnace is necessary to minimize build-up of silicon carbide banks and to distribute energy evenly across the hearth.

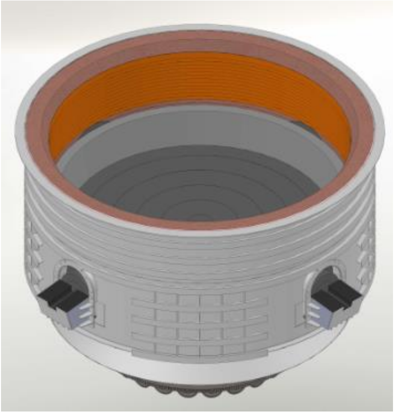
Figure 99: Rotating device



Source: Viridis.iQ GmbH

Four tap-holes for removing molten silicon are spaced evenly around the circumference of the furnace shell as shown below. The tap-holes move with the shell, and the ladle car containing the ladle and tapping platform are also on trolleys to enable them to follow the tap-hole.

Figure 100: Furnace shell with 2 of 4 tap-holes shown



Source: Viridis.iQ GmbH

The tap-holes are positioned at hearth level and tapping is done continuously through only one of them at a time. The tap-hole in use is only closed for changing ladles and during furnace shutdowns. New tap-holes are opened with a device called a stinger when needed. The stinger uses an electric arc to melt solidified material in the tap-hole. Oxygen lancing is used as a back-up when the stinger cannot be used to open a tap-hole. However, this is not a desirable procedure since the steel pipe used to carry the oxygen contaminates the silicon product with iron. The first molten material from the tap-hole, therefore, must be set aside for other uses by tapping it into an overflow box, which is also housed on the travelling tapping car.

A fume hood is installed over the tap-holes to capture and extract gas and dust emissions during tapping and lancing operations, thereby minimizing emissions into the building. The hoods are ducted to a manifold in the furnace building, after which the flow is split to each of the raw material feed chutes. This prevents furnace off-gasses from being drawn into the feed chutes where the high temperature of these gasses could cause fires.

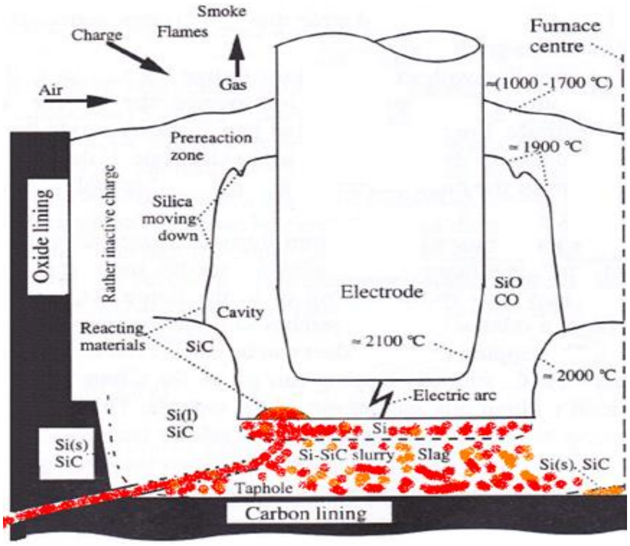
The furnace process consumes the electrodes by abrasion with the feed material, side wall oxidation and volatilization of carbon in the arc at the electrode tip. The electrode positioning device compensates for consumption by gradually moving the electrode tip downward into the furnace charge, thereby maintaining a constant arc length and resistance set point. When the positioning device nears the bottom end of its travel, the electrode column must be slipped to regain position and lengthened with additional electrode pieces (mgSi case) or supplementary electrode paste and casings (FeSi case) above the SAF.

17.1.4.1 Inner Structure of the SAF

The inside of a furnace can be depicted as shown below, simulating a time in the process when stoking of the furnace is needed. The electrode is surrounded by a gas-filled cavity that is created as the furnace slowly rotates. The burden—raw materials charged to the SAF—is comprised of raw materials in various states of reaction and reaction products formed in the different temperature zones of the furnace. These different compositions can be generalized as:

- Slurry: consists mainly of liquid and solid Si + solid SiC
- Slag: consists mainly of more than 50% SiO_2 with some SiC (both species are valuable materials in the process), and Al_2O_3 + CaO
- Condensate: refers to the condensation reaction products of SiO with itself or other species

Figure 101: Inner structure of an operational SAF



Source: Production of High Silicon Alloys. A. Schei; K Tuset; H. Tveit

The very bottom of the cavity, beneath the electrode tip, consists of slurry (Si + SiC), with possibly an upper layer of relatively pure silicon. The lower part of the cavity walls consists of SiC crystals with the space between the crystals partly filled with molten Si. The SiC crystals are sintered together and make the upper part of the deposit firm enough to form a wall. Above the SiC, the cavity wall consists of carbon lumps partly converted to SiC, molten silica (SiO_2) and condensate (SiO_2 + SiC + Si). The materials close to the inner surface of the walls are heated enough to have experienced some reactions, but are generally considered inactive in the process.

The silica in the cavity is molten, but highly viscous; and slowly flows down along the cavity wall. The particles in the roof of the cavity are glued together so firmly that they do not slide down. When the roof has lost its capacity to capture SiO from the gas mixture in the furnace, the furnace operator breaks down the charge top with a stoking machine, fills in loose mixture from the sides, and refills the top of the furnace with additional raw materials from the feed system.

The remains of the older charge consist mainly of SiO_2 and SiC, with some Si from the condensate. These species react together and produce SiO gas that flows up through the new charge and undergoes reactions to produce more Si and SiC. The condensate glues the particles together to form a new thick deposit, which is consumed from below as the silica melts and sinks down with other materials. The size of the cavity then gradually increases again, so stoking and raw material addition must be repeated at regular intervals.

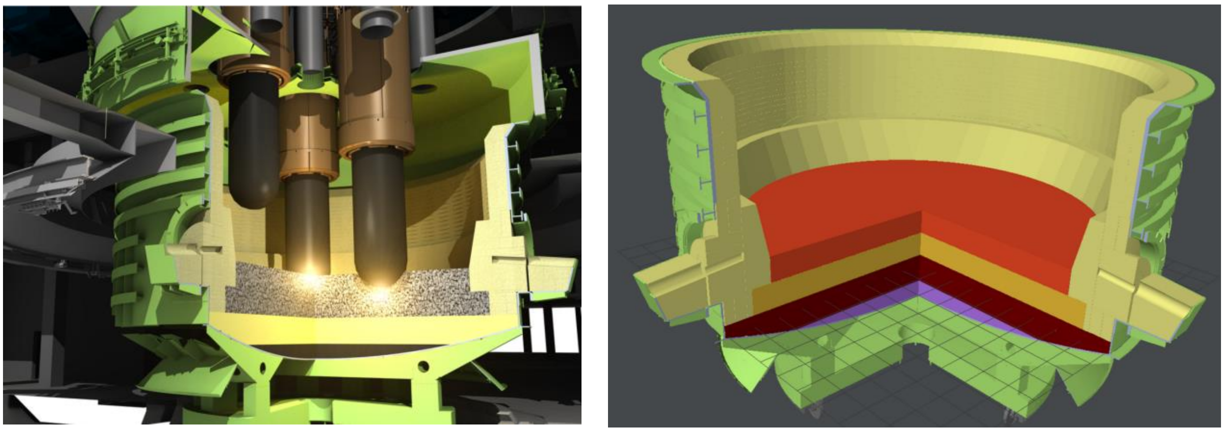
SiC is a key intermediate in the production of silicon and is always present in a furnace in solid form. However, in operations with too much carbon in the raw material charge, the surplus carbon is deposited as additional SiC at the bottom of the furnace. When the carbon balance in the mixture is corrected, the SiC close to the electrode can be consumed, but at a certain distance away from the electrode, the SiC will be left as a wall and will leave a depression around the electrode. When the furnace is rotated, the depressions left by the three electrodes will form a circular trench with walls of SiC. These walls are undesirable and continued operation of the furnace with excess carbon levels will necessitate shutting it down for a few days to physically remove them.

The molten product, be it mgSi or FeSi, is tapped through a tubular channel that reaches into the SiC + Si (or FeSi) slurry under the electrodes from the outside of the furnace.

17.1.4.2 SAF Shell

The furnace shell is manufactured from steel and heavily reinforced with steel plates to allow for operation at the elevated temperatures which are associated with the furnace tapping process. The shell has a dished bottom to provide additional mechanical strength and multiple tap-holes for extraction of molten product.

Figure 102: SAF shell

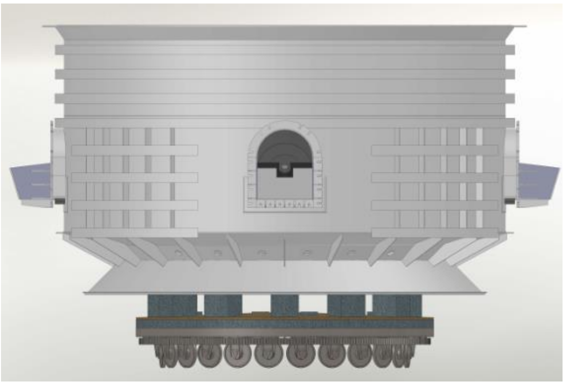


Source: Viridis.iQ GmbH

17.1.4.3 SAF Shell Rotating Mechanism

The furnace shell rests on a circular table, which is rotated at a predetermined rate. The table sits on high-strength wheels with a central pivot point, as shown in the figure below.

Figure 103: Shell and rotating mechanism



Source: Viridis.iQ GmbH

17.1.4.4 SAF Cooling Water System

The furnace cooling water system consists of water pumps, an emergency diesel water pump, heat exchangers and piping.

The cooling water is distributed from a supply header to water-cooled equipment such as the furnace hood, electrode support equipment, feed chute outlets and exhaust gas off-take ducts. The return water from the equipment is collected and returned to the pumps after it has cooled.

Figure 104: SAF cooling water system

Source: Tenova Pyromet

Emergency cooling water is provided by means of a diesel-engine-driven pump. The diesel engine starts automatically in the event of a cooling water loss, caused, for example, by a power failure. The emergency water flow is sufficient for emergency conditions with the furnace switched off, but not for normal operating conditions. A booster pump provides high pressure water for the electrode pressure rings to clamp and slip the electrodes in the unlikely event of an electrode breaking above the contact shoes.

17.1.4.5 SAF Gas Off-takes

The furnace hood has two off-takes for extracting the furnace gas to the bag house. The first section of ducting is water cooled due to the high gas temperatures. The water cooled section of duct is manufactured from seamless pipe. The rest of the duct inside the building is not water cooled, but is refractory lined. The duct from the building to the bag house is not refractory lined.

A stack is provided for venting gasses to the atmosphere in case the bag house must be shut down. In some countries a stack for venting is not required because local environmental regulations do not allow venting to the atmosphere. Other preventive measures, such as a redundant bag houses, may be required in these countries.

17.1.4.6 SAF Exit Gases

Any unreacted SiO gas leaving the furnace immediately reacts with oxygen in the ambient air thusly:

$SiO + ½ O_2 \rightarrow SiO_2$

Carbon monoxide leaving the furnace also reacts rapidly with oxygen in the ambient air since it is hot enough to burn in this environment:

$CO + ½ O_2 \rightarrow CO_2$

17.1.4.7 SAF Gas Hood (Roof)

The furnace gas hood consists of horizontal water cooled steel panels suspended from the floor above. Panels in the central area between and around the electrodes are manufactured from a non-magnetic stainless steel to avoid electrical losses due to electromagnetic heating. The center panels are manufactured from plate sections with channels for the cooling water and have water cooled copper tubes cast into the refractory below the panels to increase the cooling in this high temperature zone. The outer horizontal panels and the fixed side skirts are manufactured from thick-walled seamless pipe. Panels around the electrodes are insulated from each other to prevent stray electrical currents from circulating in the hood.

The hood has lifting doors that can be raised and lowered for stoking the furnace and for maintenance access. The doors are raised and lowered by means of hydraulic cylinders connected to the doors with steel chains.

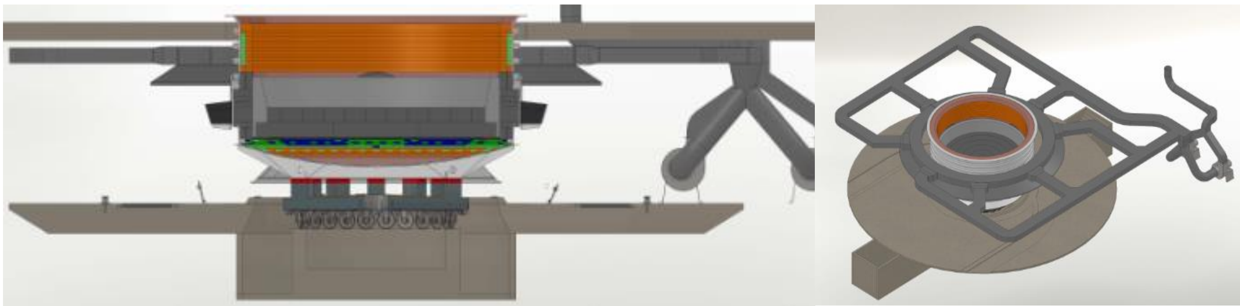
Figure 105: SAF hood

Source: Tenova Pyromet

17.1.4.8 SAF Tapping-Fume Extraction Hood

A tapping-fume extraction hood is located around the full circumference of the furnace, below the operating floor. The inside of the hood is lined with refractory material and it provides protection for operators and equipment directly below the operating floor. The hood also collects any water run-off from the operating floor and diverts it to a safe place to prevent water from entering the ladle. The fumes and air collected by the hood can either be sent to the furnace bag house or into a separate, dedicated bag house. They can also be used for an air curtain hood, blowing down the feed chutes and the electrode seal to protect them from high-temperature furnace gasses.

Figure 106: Tapping fume extraction hood and ducting

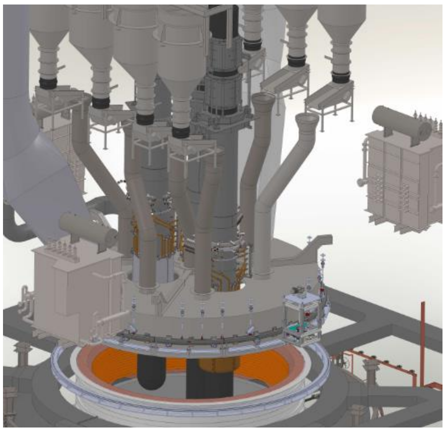


Source: Viridis.iQ GmbH

17.1.5 SAF Feed System

The feed system is comprised of raw material storage bins above the furnace. The bins contain the blended raw materials received from the proportioning system. Each bin has a feed chute through which the raw materials are fed to the furnace. The amount of feed is regulated by a slide gate or vibrating feeder. A hydraulic power pack for operating the slide gates is incorporated with the electrode-positioning power pack. The feed chutes each have a water cooled outlet below the furnace hood from which the raw materials are discharged into the furnace. Raw material storage bins and the feed chutes can be seen in the figure below.

Figure 107: SAF feed system

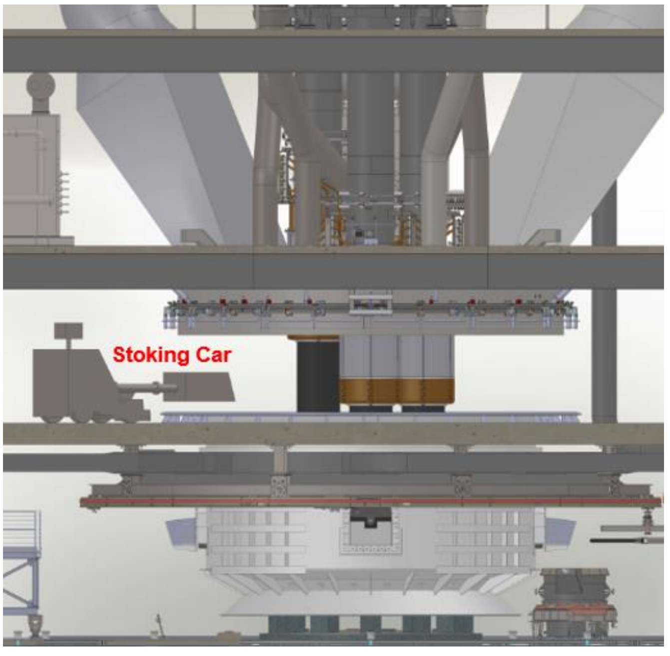


Source: Viridis.iQ GmbH

17.1.6 SAF Stoking

The raw material charge within a furnace is stoked with specially designed stoking cars. Access is provided to allow 360° stoking across to the furnace. A heat-resistant concrete is used in the floor area around the furnace on the operating level. The stoking car is powered by either a diesel engine or electrical motor which powers a hydraulic system for the drive wheels and the boom. The fume hood doors and feed chute gate valves can be remotely operated from the stoking car.

Figure 108: Furnace stoking



Source: Viridis.iQ GmbH

17.1.7 Deposits in the SAF

The formation of deposits in the furnace cause a well-known problem in the production of silicon and understanding why they form is critical for the correct operational performance of the furnace and the process as a whole.

There are three main types of deposits that can occur in the furnace:

- Incompletely converted charge materials at the bottom of the furnace (slagging)
- SiC with Si at the bottom of the furnace
- Sintered charge materials in the upper layers of the SAF (also called crusts)

These deposits obstruct the process and can increase operational costs significantly. It is preferable that the process is operated so that deposits are avoided, but if large deposits do occur, they have to be removed by various process steps (i.e., burning down, etc.).

17.1.8 SAF Electrode Systems

Carbon-based electrodes are a key component of the SAF. They are responsible for delivering electrical energy into the furnace to generate the high temperatures necessary for smelting reactions to occur. Electrode systems typically employed for the production of silicon and ferrosilicon are not identical. The HFP concept takes this into consideration and allows for a rapid transition between the different products on any furnace.

Electrodes used in silicon furnaces are generally of the “pre-baked” style. Amorphous carbon segments up to 1.4 m in diameter and 2.5 – 3.5 m in length are purchased in a ready-to-use state. These segments each have a tapered, threaded pin on one end and a threaded socket that accepts the threaded pin at the other end. Individual segments are screwed together to build a long column extending from high above the furnace into the raw material mix within the furnace, almost touching the hearth at the bottom. New segments are routinely added to the top of the column as it is slowly consumed by reaction and abrasion within the furnace. The advantage of pre-baked electrodes is that they don´t add any considerable contamination to the product (e.g. Fe), which is a critical parameter for mgSi production, and that they are generally easier to use from an operations standpoint. The downside is that they are more costly than Søderberg electrodes.

The self-baking, or Søderberg, electrode system was developed over 100 years ago to reduce costs for ferroalloy production. It is by far the most common choice for electrodes used in ferrosilicon furnaces. The Søderberg system is based on round, sheet-steel casings with the same diameter as the electrode to be formed, again up to 1.4 m, and about 2 m in length. These casing are welded together lengthwise at the top of the electrode column, high above the furnace. New casings are added as the electrode column is consumed. Carbon paste, in the form of briquettes or large blocks, is routinely added to the top of the casings as new ones are welded in place. The carbon paste is baked into a solid electrode high in the column by a combination of heating elements, conductivity from the furnace, and resistive heating from the high current flowing through the electrode. Baking of the electrode is an important and difficult part of the formation process, but it has been studied and refined extensively since the process was developed, and is now quite reliable. The self-baking electrode has the advantage of lower cost than pre-baked electrodes. The disadvantage is that it adds several percent of iron to the alloy produced. The increase in iron content is irrelevant for the production of iron-containing alloys like ferrosilicon, but cannot be tolerated for production of mgSi.

Attempts to adapt self-baking electrodes to mgSi production in recent years have been fairly successful, however, these new systems are highly dependent on operator skill level, and can be just as costly as prebaked electrodes when not operated correctly.

The electrode support and slipping system for both prebaked and self-baking electrodes consists of the main components shown in the figure below. There is, of course, some additional heating equipment and ductwork required for the self-baking electrode column.

Figure 109: Electrode system

Slipping Device	Inclination System	Column Isolation	Pressure Ring	Contact Shoe
				

Source: various suppliers, Viridis.iQ GmbH

17.1.8.1 Slipping Device

The slipping device is the principle system to manipulate the electrode in the furnace and consists of a series of subsystems that slowly lower or “slip” the electrode into the furnace charge. The slipping device must be designed with:

- A fail-to-safe-mode hydraulic system
- Robust and trouble free design
- Low maintenance and operator involvement
- Ease of access for maintenance and adjustment purposes
- Accurate laser cutting ensures tight tolerances
- Small envelope
- Dedicated slipping cylinders (long or short slips)

17.1.8.2 Inclination System

This system maintains the vertical position of the electrode. This is a necessary control due to rotation of the furnace and frictional drag of the burden on the electrodes. While various highly sophisticated systems can be employed, one common method is to use a laser and mirror system to maintain alignment.

17.1.8.3 Column Isolation

Due to the complex electrical conditions that surround the electrode columns, adequate electrical and magnetic isolation is required to prevent damage to the equipment and process. The isolation system, installed in the heat shield, should include the following design elements:

- Segmented but joined, easy to remove or replace
- 304L stainless steel construction
- Insulation on back
- Firmly affixed to mantle
- High cooling water velocity
- A mild steel strip on heat shields to ease maintenance and allow for easy access to pressure rings and contact shoes

17.1.8.4 Pressure Ring

A multi-component device known as a pressure ring surrounds each electrode. Its function is to hold several contact shoes in tight mechanical contact with the electrode, which provides for complete electrical energy transfer to the electrode. This is accomplished by the use of a hydraulically operated, stainless steel bellows assembly for each contact shoe in the pressure ring. The design features of a pressure ring should include:

- Delivers required contact force to the contact shoe
- A reliable system
- Easy to install and maintain
- Keep it simple, cost effective and easy to manufacture
- Eliminate water leaks
- Double-insulated pressure ring hanger
- Good insolation
- Good water cooling on entire pressure ring
- Reduced possibility of stray arcing
- Shoes with high-temperature insulation
- Aid electrode baking when not using prebaked electrodes

17.1.8.5 Contact Shoes

Electrical energy is actually transferred to the electrode through contact shoes. In general, they are made of copper due to that material's excellent electrical conductivity. The design features of the contact shoes should include:

- Forged, high-conductivity copper construction
- Silver-soldered connections to bus tubes, designed for ease of installation on site
- Improved cooling while decreasing unnecessary pressure drops
- Cooling channels which stay below 100°C to prevent steam jacketing
- Temperature profiles checked (worst case)
- Long life expectancy

17.1.9 SAF Bag House

Dust from the furnace is collected in a bag house for processing. New smelters are likely to be required to install a bag house to comply with environmental regulations, but it is also a good design feature since the small particulate matter captured is commercially saleable and such an installation has value. The exhaust gasses from the furnace enter a dust hopper and pass through filter bags made of woven glass material coated with a Teflon membrane. The bags are cleaned periodically with a pulsed air jet or reverse air processes. The silica fume is pneumatically conveyed to storage silos, collected, and processed further or sold as is.

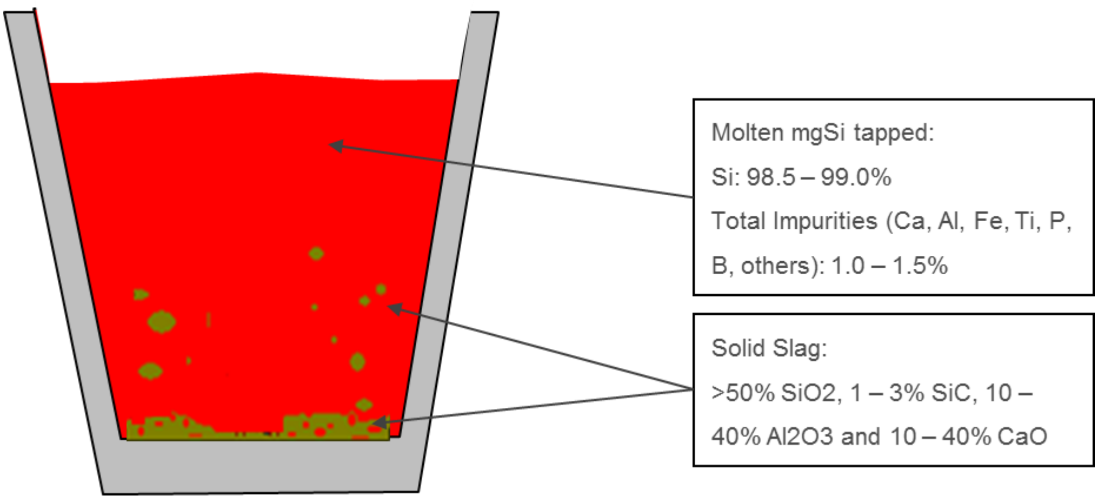
Figure 110: Bag house

Source: Chinese Equipment supplier

17.1.10 The Refining Process

After molten silicon is obtained from the reduction of silica with carbon and it has been tapped into a ladle, there are refining steps that are usually required to remove certain impurities, most often aluminum and calcium, in order to meet product specifications. The molten silicon is commonly called "tapped metal" and is a mixture composed of 98.5 – 99.0% silicon with the remaining 1 – 1.5% made up of major impurities, e.g. calcium, aluminum, iron, titanium, phosphorous, boron, and other trace elements.

Figure 111: Schematic composition of "tapped metal" in a ladle



Source: Viridis.iQ GmbH

The primary objective of refining is to reduce the amount of impurities in the molten alloy without losing saleable silicon units in the process. However, this effort is limited by practical and thermodynamic constraints.

Refining of tapped, molten ferrosilicon may also be required, depending upon the grade being produced and customer specifications.

Refining processes for silicon and ferrosilicon can theoretically involve solid, liquid and gas elements; however, there are no commonly employed uses of liquids to refine silicon products. Two optional methods using gasses and solids have been developed:

- Oxidation and slagging impurities
- Chlorination and removal of impurities as volatile chlorides

The chlorination process is more effective for removing alkali and alkaline-earth metals, like sodium and calcium, and also aluminum, but the process is of minor industrial interest owing to the environmental problems associated with the use of chlorine gas and the formation of corrosive metal chlorides. Thus, the oxidation process is the method used commercially nowadays. It is accomplished via gas injection into the molten silicon, usually combined with the addition of slag-forming compounds to assist gas refining

17.1.10.1 Oxidative Refining

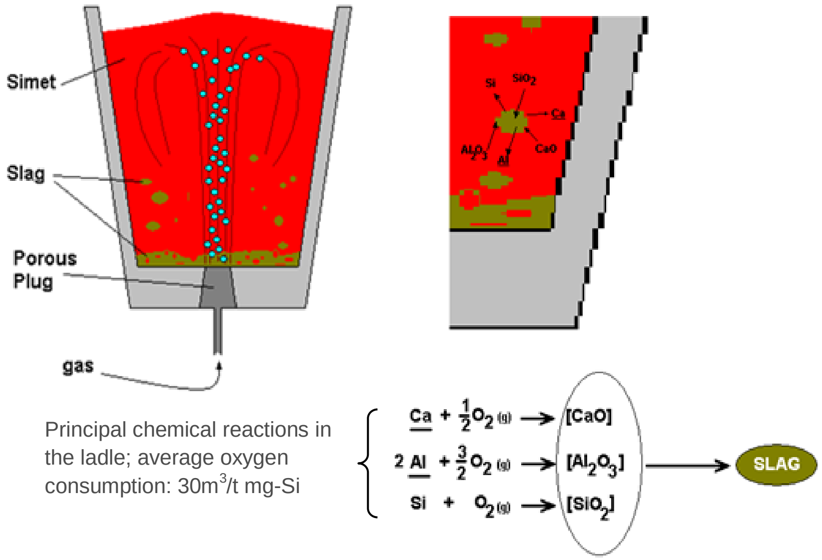
Oxidative refining is conducted by injecting dry, pure oxygen or a dry mixture of oxygen and air into the molten silicon or ferrosilicon once it begins collecting in the ladle. Using an oxygen plus air mixture is more economical and practical since much of the injected oxygen is not consumed by reaction with impurities and is wasted by venting to the atmosphere.

Gas injection is usually carried out by “bottom bubbling” through a specially designed plug incorporated in the bottom of the refining ladle.

17.1.10.2 Gas Injection Using a Bubbling Plug

Bubbling plugs are made of refractory concrete and allow the preferential flow of gases over liquids. Molten silicon or ferrosilicon cannot flow through them and out of the ladle during the refining process, yet the desired gas flow can be introduced into the molten alloy contained within the ladle.

Figure 112: Schematic of bottom bubbling gas injection for oxidative refining



Source: Viridis.iQ GmbH

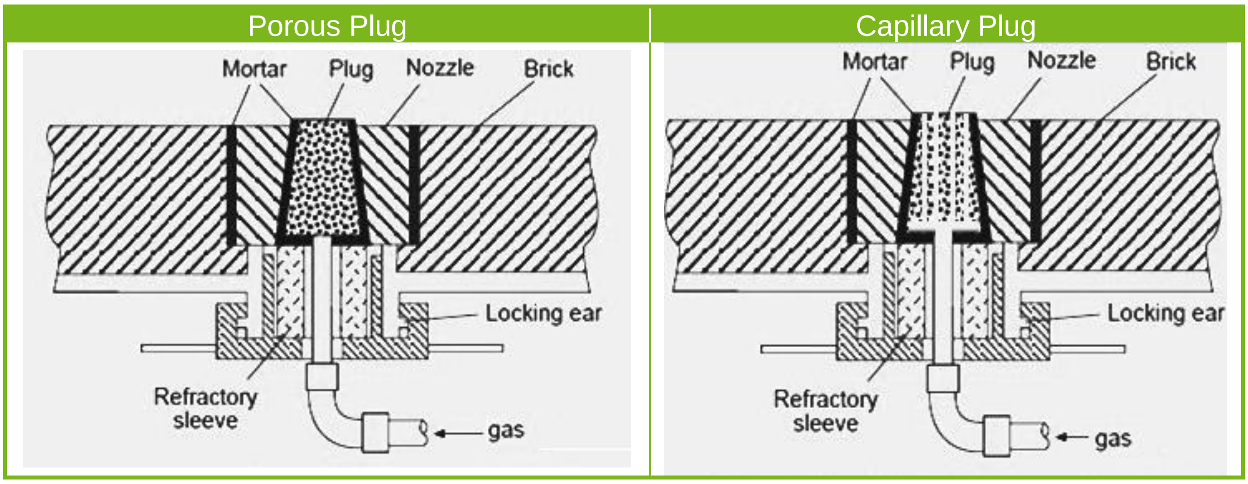
Bubbling plugs are manufactured in two styles:

- Porous concrete plugs containing no metal tubes, which are simply called porous plugs
- Non-porous, concrete plugs containing copper tubes to conduct the gas flow, which are called capillary plugs

Porous plugs are made from low-density, refractory concrete in a manner that incorporates very small, interconnected channels throughout the concrete. The channels allow gas introduced at the bottom to flow through the plug to its top, and then into the molten alloy.

A capillary plug is manufactured from higher-density concrete, with small-diameter, copper tubes inside, through which the refining gas flows into the molten alloy in the ladle.

Figure 113: Schematic cross-sections of porous and capillary bubbling plugs



Source: Viridis.iQ GmbH

The advantage of the capillary design is that it can accommodate higher gas flow rates and generate different bubble sizes. The latter is an important consideration for refining mechanics. The disadvantage of this style plug is the ease of clogging of the capillary tubes, and the need for a small, continuous gas flow to keep them open.

17.1.10.3 Refining with Synthetic Slag

The refining process can also be accomplished through limited modification of the chemical equilibrium in the ladle by the addition of silica sand or other synthetic slag.

In the refining ladle there are three states-of-matter that must be considered—solid, liquid and gas—however, for refining purposes, only two of them are important—solid and liquid. Metallic oxides and SiO_2 comprise the solid slag phase, while the elements to be removed are in the liquid phase. For each desired final aluminum and calcium composition in the molten alloy, there is a specific composition for the slag. If the initial concentrations of CaO, Al_2O_3 and SiO_2 in the slag are known, it is possible to add synthetic slag to move in the direction of the final desired composition for the alloy. Practical limitations to this methodology include the long time required to reach the equilibrium point, where the desired final alloy composition is achieved, and the need for a slag analysis before adding synthetic slag components. Consequently, synthetic slag is normally added to the ladle only in small quantities to assist refining via gas injection into the ladle.

17.1.10.4 Practical Refining Limitations

There is a time limit for refining due to rapid heat loss from the ladle. Once the molten silicon cools to just above its freezing point, product losses increase due to solidification on the walls of the ladle. This is why refining with only synthetic slag is rarely a viable option.

17.1.10.5 Thermodynamic Refining Limitations

At 1,550°C, thermodynamically, the oxidation reaction with highest driving force is for calcium, followed by magnesium, aluminum, titanium and finally silicon.

The meaning and interpretation of this is that by blowing oxygen into molten alloys, only calcium, magnesium, aluminum and titanium will be oxidized before silicon itself. However, the amounts of these elements that will be removed depend on their initial content in the molten alloy. For instance, the typical low concentration of titanium in the molten alloy will not be influenced greatly by oxidative refining. In general, the quantities of magnesium and titanium are low, but the content of calcium and aluminum are high. Therefore, the principal motivation for refining is reducing the content of calcium and aluminum in the alloy.

17.1.11 Casting

The typical casting process employed by silicon and ferrosilicon smelters has not changed much over the last 100 years. It is very basic technologically, yet the least expensive and most reliable option available today. More elegant casting methods have been conceived and tested by equipment suppliers in recent years. However, these new solutions to an old issue suffer from reliability and safety problems at this stage of their development, so they will not be considered herein.

Once refining of the molten alloy is complete, it is cast into molds to solidify. Casting is a process that consists of the sum of the following processes:

- Pouring molten, refined silicon or ferrosilicon into an iron mold
- Solidification of the molten material by cooling in ambient air or with water-cooled molds

The pouring operation is extremely important and requires a skilled crane operator to avoid slag contamination in the product and product losses due to splashing. To avoid ladle skulls—the accumulation of solid silicon and slag compounds on inner ladle surfaces that eventually reduce ladle volume—the pouring temperature must be well above the melting point of the product. Silicon has a high heat of solidification when compared to most metals and a large amount of heat is released during solidification, which results in technical challenges for the casting equipment employed.

Figure 114 and Figure 115 show examples of the basic casting process for silicon and ferrosilicon. A minor amount of contamination with iron originating from the mold is caused by its dissolution in the molten alloy. This can generally be avoided by spreading a layer of crushed silicon in the bottom of the iron mold. Silicon fines accumulated from crushing operations or crushed, “in-grade” silicon product can be used for this purpose. Silicon fines often have higher levels of undesirable contaminants, so preservation of the molds comes at some risk to product purity when they are used. Crushed, “in-grade” silicon does not suffer from this drawback, but is more costly to use. Ferrosilicon casting is more forgiving and silicon or ferrosilicon fines are generally acceptable for use as a protective agent.

Accurate control of pouring temperature is very important to final product quality for silicon. Pouring temperatures higher than 1,480ºC increase the risk of slag contamination due to similar densities of the slag and molten silicon at those temperatures. Ferrosilicon casting does not suffer from this drawback, owing to the higher density of molten ferrosilicon.

There are two main types of pouring and casting processes: static casting and continuous casting.

17.1.12 Static Casting

In the static casting process, the mold is stationary and the ladle is moved by crane from mold to mold. The ladle is tilted and the liquid silicon is poured into a mold. The ladle is returned to a partially upright position after the mold is filled, then moved to the next mold for the next pouring motion. While a common method, this type of casting can impart a higher risk of slag and silicon mixing due to the motion of the ladle and the pouring process, resulting in higher slag content in the final material.

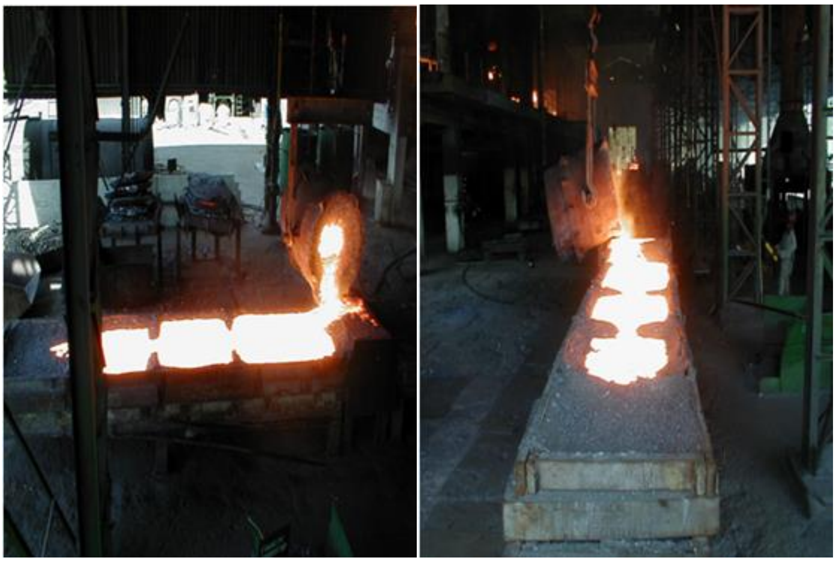
Figure 114: Example of static casting

Source: Viridis.iQ GmbH

17.1.12.1 Continuous Casting

Improvements to static casting have been made in the past decades by following innovations in the steel industry, i.e., by making only one pouring motion and moving the molds or by use of a continuously connected series of molds. In the latter case, the first iron mold is modified at one end with the addition of a graphite block, which is the singular pouring point for the entire series of molds. Each individual mold is connected to the next, and the mold is slightly inclined so that the flow of molten silicon from one mold to the next can proceed unimpeded. This process optimization reduces the possibility of slag carry over due to fewer ladle tilts, and provides a safer, more controlled casting environment. An example of continuous casting is shown in the Figure 115.

Figure 115: Continuous casting operation



Source: Viridis.iQ GmbH

17.1.12.2 Optimizing the Quality of Cast Alloy

The quality and performance of silicon, and ferrosilicon to a small extent, for the end-user can be influenced by the casting process. This is much more important to control for silicon quality than for ferrosilicon. The following variables influence quality during casting:

- Fines recycling procedure
- Iron mold depth

17.1.12.2.1 Fines recycling procedure

Due to the high solubility of iron in molten silicon and ferrosilicon, some form of protection for the iron molds is required. Low-value silicon fines from milling and sizing processes are often used for this purpose. Special attention must be given to recycling procedures to avoid cross contamination of high-grade silicon product with low-quality fines used to line the mold. While the use of fines is a simple and common procedure, the downside is a risk of contamination that, while unavoidable, can be minimized. As mentioned previously, using crushed “in-grade” silicon in place of recycled fines eliminates possibilities for cross contamination, but is a more costly alternative. The requirements for fines used to line ferrosilicon molds are, of course, not so stringent.

17.1.12.2.2 Iron Mold Depth

The discussion in this section applies only to silicon production. The composition of a solidified silicon ingot is not uniform. Different concentrations of impurities and alloying elements can be found in different areas of the ingot. This variation is the result of differing solubilities of impurities in molten and solid silicon, with most impurities being much less soluble in solid silicon. The solidification proceeds from the bottom of the ingot to the top, and the first zone that solidifies is less contaminated than the last to solidify since impurities accumulate in the rapidly diminishing volume of liquid. However, the lower part of the ingot may also be at risk of contamination from fines used to line the mold. In the end, there is a nonlinear variation of contamination from the bottom of the ingot to the top, as well as from side to side. If casting thickness is increased to reduce operating costs, then the cooling rate decreases further and compositional differences are exacerbated. This potential quality problem is mitigated for many customers by crushing the silicon to a fine size, in accordance with their specification, which aids greatly in reducing compositional differences. Generally speaking, however, the optimal casting thickness of an ingot is 10 – 12 cm.

Once the cast ingots are cooled, they are processed in a manual or automated manner such that they are broken into large chunks, measuring about 5 – 100 mm, that can be fed into the crushing and milling unit. They are then temporarily packaged in big bags to await further processing.

17.1.13 Crushing and Milling

Supplying silicon to the polysilicon (photovoltaic, solar cell) industry is an opportunity with great potential. Therefore, providing the capability for secondary milling of silicon to a final size of 45 – 425 µm has been taken into consideration since this is the size distribution typically purchased by that industry.

Ferrosilicon is not usually milled to fine sizes. Its journey through the smelter can end at the 5 – 100 mm size or it may be crushed further to 0 – 35 mm or even 0 – 20 mm, depending on customer requirements. Screening may also be necessary to separate a particular ferrosilicon size fraction for a customer.

Criteria for the design of a crushing and milling system are highly dependent on the characteristics of the material to be processed. Its hardness, initial size distribution, desired final size distribution, as well as the production capacity of the plant must all be factored into the design. While many equipment configurations exist, most are designed as fully automatic package units with a local control panel and an interface for data transfer to the process control system for the smelter.

17.1.13.1 Primary Crushing System

The primary crushing system is the first step in the crushing and milling process. In this step, silicon or ferrosilicon chunks from the ingot casting department are discharged from big bags into the system.

The material is transported to the main collecting silo following the primary crush. An important factor to highlight in the engineering and design of the primary crushing system is the combined performance of the jaw crusher, horizontal roll crusher and vibrating screens. These sub-system elements serve the sole function of ensuring that all the silicon or ferrosilicon processed and stored in the main collection silo has the required size distribution for sale or for use as a feedstock to the secondary milling system. Some essential equipment for the primary crushing system is described below.

17.1.13.1.1 Big Bag Discharge Station

Silicon or ferrosilicon arrives, via fork lift, at the discharge station for the primary crusher packaged in big bags. The size distribution of the material is typically 5 – 100 mm at this stage of the process. The discharge station is constructed from a steel frame and houses a cyclone dust collector and lifting device, and is used to feed the material to be crushed into the hopper of the primary crusher.

17.1.13.1.2 Primary Crusher

The primary crushing machine, usually a jaw crusher, is the first step in the sizing process. The jaw crusher reduces the maximum particle size of the silicon or ferrosilicon from 5 – 100 mm to 0 – 35 mm. The crushed material is then transported to the next step in the process, often a horizontal roll crusher, by a conveyor belt.

17.1.13.1.3 Dust Collector for the Primary Crushing System

A cyclone is used to collect dust generated in the primary crushing system. Ductwork from different points in the system conducts dust-laden air to the cyclone. Contaminated air is cleaned and the dust stored for use in other processes. If not properly abated, fine particulate matter escaping from the crushing system can lead to dust explosions, as well as being a health risk for equipment operators due to the inhalation of fine particles.

17.1.13.1.4 Conveyor Belt

These devices transport material to and from different stages of the crushing and milling process. Multiple conveyors will be used in the crushing and milling area of the smelter.

17.1.13.1.5 Vibrating Screen

Vibrating screens are also used at various points in the crushing and milling process to control the size of the material being processed. The screening unit separates the correct size to feed into the next step in the process and uses a recycling loop to move oversize material back to the previous sizing unit. In this example the next step is the roll crusher and the previous unit is the jaw crusher.

17.1.13.1.6 Horizontal Roll Crusher

A roll crusher reduces the silicon particle size from 0 – 35 mm to 0 – 20 mm, which is the correct size to feed into the secondary milling system.

17.1.13.1.7 Bucket Elevator

Finally, a vertical bucket elevator is used to convey silicon from the roll crusher to the top of the main collection silo.

17.1.13.1.8 Main Collection Silo

The collection silo receives and stores silicon crushed to 0 – 20 mm in the primary crushing system. It is an intermediate holding point before the material is packaged for sale or fed to a ball mill via a controlled valve system.

17.1.13.2 Secondary Milling System

This second subsystem is the last step of the crushing and milling process. It produces silicon with the size distribution required for feedstock sold to the photovoltaic industry (45 – 425 µm), and other specialized customers. As noted previously, ferrosilicon is not usually milled to fine particle sizes and its journey through the smelter is complete after primary crushing. A secondary milling system often includes the equipment described below.

An important factor to highlight in the engineering and design of the secondary milling system is the combined performance of the ball mill and air classifier to ensure that the size distribution of the particles produced has ideal characteristics for use by customers.

17.1.13.2.1 Ball Mill

A ball mill works under an inert, pressurized atmosphere to prevent dust explosions. The size distribution of the silicon fed to it is reduced to 45 – 425 µm, which is in turn fed into an air classifier. Ceramic or metal balls inside the ball mill reduce the size of the material by abrasion and crushing processes.

17.1.13.2.2 Air Classifier

An air classifier is a machine that separates material based on a combination of the material's size, shape and density. It works by injecting the material stream to be sorted, silicon in this case, into a chamber which contains a column of rising air. Inside the separation chamber, air drag on the material to be separated supplies an upward force that counteracts the force of gravity and lifts the material into the column of rising air. Due to the dependence of air drag on an object's size, the silicon particles in the moving air column are sorted vertically and different particle sizes can be withdrawn. The air classifier is used to obtain the final size distribution which is commonly used as the feedstock for the photovoltaic industry. It can also be adjusted to provide specialized particle size distributions required by other customers.

17.1.13.2.3 Dust Collector for the Secondary Milling System

A small bag house is necessary to remove fine particulate matter from process air used in conjunction with the ball mill and air classifier. Additionally, particulate emissions during loading of milled product are controlled by a fabric filter connected to the transport vessel and the collected dust is recovered for shipment or recycling. To ensure dust-free loading into the transport vessel, a flexible loading spout consisting of concentric tubes is used.

17.1.14 FeSi and mgSi Products – Purity Grades

The grades for FeSi are mainly based on the elemental silicon content and the amount of contamination with carbon and aluminum, while the spectrum of grades within the mgSi market is much broader in terms of parameters that define the quality of the material and its usability in the various end-market applications described in Section 19.1.

The typical standard grade of ferrosilicon on which the vast majority of global trade is based is FeSi75 that has the following specifications:

- Si content of 72% minimum
- Al content of 2% maximum
- C content of 0.2% maximum

There are also higher-purity ferrosilicon grades for specialty steel and iron applications, which are not defined by higher silicon content but through maximum impurity levels for aluminum, carbon, titanium or magnesium. The specific impurity levels are typically negotiated with the end-user.

The pure silicon content of mgSi needs to exceed a minimum threshold of 98.5%. Important impurities that determine the overall quality of mgSi are most often iron, aluminum, calcium, phosphorus and titanium. Next to the chemical composition, another determining factor for the assessment of the quality of a silicon supplier is the consistency of the supplied material. This basically means that the standard deviation of impurities should be held within specified limits to improve feedstock and process control for the various consumers of the material. The latter point is of special importance for consumers that produce silicon-based precursors, for example methylchlorosilanes (MCS) for the production of silicones or trichlorosilane (TCS) for the production of polysilicon used in photovoltaic cells. The specific quality and consistency needs of these two industries are an explanation for the average selling price premiums that can be achieved by qualified mgSi suppliers.

There are general chemical specifications for mgSi in the market that are delineated by the composition of Fe, Al and Ca. These grades are mostly known by their acronyms: 553, 441, 3303, 2202, etc. The first number in the sequence refers to the percentage of Fe in the material, i.e., 5 means 0.5% Fe max., the second number refers to the percentage of Al, i.e., 5 means 0.5% Al max., and the third number refers to the content of Ca, i.e., 3 means 0.3% Ca max., and 03 means 0.03% Ca max. Some common examples of the naming scheme are shown in the table below, which can be extended to include any other combination of these 3 elements as needed.

Table 52: Common acronyms for silicon grades

Acronym	Max. Fe%	Max. Al%	Max. Ca%	Typical Use
1101	0.1	0.1	0.01	Low Fe primary aluminum grade
2202	0.2	0.2	0.02	Chemical Grade: chemicals (MCS, TCS) and specialty primary aluminum
3303	0.3	0.3	0.03	Chemical Grade: chemicals (MCS, TCS) and specialty primary aluminum
441	0.4	0.4	0.1	Primary Grade: primary aluminum
553	0.5	0.5	0.3	Standard Grade: secondary aluminum

Source: Viridis.iQ GmbH

Despite attempts to assign typical uses to specific chemical compositions shown in the table, individual consumers may have different chemical requirements, or additional requirements that transcend the acronym scheme. For instance, chemical-grade consumers often set limits for titanium, phosphorous and boron contents in mgSi that are not part of the naming scheme and must be determined in discussions with the end-user.

17.2 Process Resources and Materials Balance

A variety of raw materials are used for the production of mgSi and FeSi.

To summarize the major raw-material requirements for mgSi:

- Carbon-containing reducing agents (coal and/or charcoal)
- Silicon dioxide (a.k.a. silica, quartz or quartzite)
- Wood chips (also a minor carbon source)
- Pre-baked electrodes
- Limestone
- Electricity

And for FeSi:

- Carbon-containing reducing agents (coal, charcoal or petroleum coke)
- Silicon dioxide (a.k.a. silica, quartz or quartzite)
- Iron source (hematite or scrap iron)
- Wood chips (also a minor carbon source)
- Self-baking electrode paste
- Limestone
- Electricity

17.2.1 Raw Materials Specific to mgSi

The raw materials used to manufacture mgSi usually have specifications for higher purity, and lower ash content than for FeSi production since the ash in carbonaceous materials is a source of impurities. The raw materials with specific requirements for mgSi production are described below.

17.2.1.1 Carbon Source / Reducing Agent for mgSi

The quality of carbon-containing reducing agents is very important with respect to achieving a high yield of silicon from the furnace. One of the most important characteristics of the carbon source is its ability to react with SiO gas deep in the furnace. The various carbon sources that can be used do not have equivalent reactivities. The carbon source frequently selected is low-ash, metallurgical coal, but the choice is often an economic consideration. Charcoal is a more desirable option since its reactivity is higher than that of coal, and it may contribute lower quantities of unwanted elements to the alloy. It is often used as a carbon source in regions where charcoal production is plentiful, relative costs are low and losses due to handling can be minimized. Petroleum coke is not generally considered to be a good carbon source for mgSi production since its reactivity is lower than that of coal, much lower than charcoal, and it contributes far more unwanted elements to the final product. Therefore, metallurgical coal is a good compromise and widely used carbon source.

17.2.1.2 Silica (Quartzite) for mgSi

Silica utilized for mgSi smelting must meet certain quality requirements. First, its inherent mechanical strength should be high enough to prevent excessive breakdown into smaller particles during handling. Small particles ("fines") generated during transportation and handling will either be material losses prior to the silica being charged to a furnace or, if included in the furnace charge, may cause problems with furnace operation. Second, the silica's thermal stability must be high enough to prevent breakdown into small particles at the temperatures it will encounter in the furnace, again from a furnace-operation standpoint. Test methods to determine mechanical strength and thermal stability have been developed to qualify silica sources for use in smelting. Finally, the silica must also meet specific chemical requirements to be capable of producing mgSi that meets industry standards.

MINTEK, during their laboratory-scale furnace tests, determined Langis silica has acceptable thermal degradation, explosive disintegration and reduction-to-silicon characteristics for use in ferrosilicon smelting.[16] These results are expected to be applicable to silicon production

16 MINTEK, Investigation on the Production of Ferrosilicon from Canadian Quartzite Using MINTEK's 100KVA DC Arc Facility, p. 27-28

also. GENIVAR evaluated the thermal stability of Langis silica, using the “SKW” test method, at the CTMP laboratory and found it to be entirely suitable.[17] This finding applies to both silicon and ferrosilicon production.

Langis silica may need to be blended with supplemental, higher-purity silica for production of the best premium mgSi grades, due to the inherent chemical analysis of the material, but this must be confirmed in further test work. The blending topic and estimated process outputs are covered in detail in Section 13.2.

17.2.1.3 Pre-baked Electrodes for mgSi

The diameter of electrodes necessary for mgSi smelting is dictated by the load—operating power—of the furnace itself. For the size and power of the furnaces chosen for this project, electrodes with a diameter of 1320 mm are required to prevent breakage due to thermal overload. The length of the electrodes is usually determined by the capabilities of the supplier and can vary between 2.5 and 3.5 m. Electrodes must also meet certain physical and chemical requirements such as flexural strength and ash content.

17.2.2 Raw Material Specific to FeSi

The raw materials with less stringent requirements than for mgSi productions are described below.

17.2.2.1 Carbon Source/ Reducing Agent for FeSi

The requirements for the carbon source to be used in FeSi smelting are not as severe as they are for mgSi production, as a result of lower purity requirements for the product and thermodynamic factors. Petroleum coke can, and often is, used in FeSi furnaces when economic conditions warrant. However, it is still not the optimum choice for a carbon source due to its lower reactivity than coal or charcoal. Using charcoal to produce FeSi would be overkill unless it is plentiful and inexpensive in the vicinity of the smelter. Metallurgical coal, albeit with a higher ash content than that used for mgSi, is again the best compromise.

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17 GENIVAR, Characterization Study of the Langis Silica Deposit, p. 52

17.2.2.2 Silica (Quartzite) for FeSi

The chemical requirements for silica used to produce standard-grade FeSi are also less stringent than those for mgSi smelting. Langis silica is completely suitable for this application because its iron content is not deleterious.

17.2.2.3 Søderberg Paste for FeSi

A variety of chemical and physical characteristics can be specified for paste used to produce electrodes. The tolerable ash content of the paste is higher than for prebaked electrodes, as is the case for other raw materials in the FeSi process. Parameters like softening point are adjusted for specific smelter conditions and must sometimes be fine-tuned by trial-and-error. The paste used must be capable of producing electrodes in the size necessary, and with appropriate physical characteristics to prevent breakage under normal operating conditions. Paste is supplied as briquettes, small bricks or large cylinders. The choice of which material format to use is based on smelter preferences.

17.2.2.4 Iron Ore or Scrap Iron for FeSi

Either iron ore (hematite) or scrap iron are used to control the iron content in FeSi. Using hematite reduces the amount of electrical energy consumed, compared to smelting scrap steel, because the hematite reduction reactions generate heat. The chemical analysis of the FeSi product may be easier to control with the use of hematite, and hematite pellets or lumps are better suited for automatic raw material handling equipment than non-uniform pieces of scrap steel.

17.2.3 Raw Materials Common to Both, mgSi and FeSi

Raw materials common to both products are described below. Additionally, there are several consumables that will be necessary to facilitate furnace tapping operations, as well as steel electrode casings used to contain electrode paste while it bakes for the FeSi self-baking electrode configuration. These consumables are not described individually, but are listed in the summary table of raw materials and consumables in Section 17.2.4.

17.2.3.1 Wood Chips

Wood chips are added to the furnace to increase porosity of the entire raw material mixture during the smelting process. This allows the key SiO intermediate gas species to travel through, and react with, other raw materials and reaction products to complete the reduction of silica to mgSi. Hardwood chips are often specified by smelters, however, any chips can be used as long as they meet requirements for specified physical and chemical parameters. Wood chips are also a minor source of reactive carbon due to the *in situ* formation of charcoal in the high-temperature, oxygen-free furnace environment.

17.2.3.2 Limestone

This material is added to mgSi and FeSi furnaces to adjust the calcium content in the tapped alloy. While it may seem counterintuitive, the content of this essentially unwanted element in the final product may have to be increased in the molten alloy tapped from the furnace to provide the conditions necessary for refining the molten alloy to desired specifications.

The limestone used must meet certain physical and chemical requirements to be acceptable for use.

17.2.3.3 Electricity

The primary consideration for the electricity supply to a smelter is stability. Even short power outages can have unwanted consequences. Loss of power for as little as 1 second can start to cause slag build-up and porosity problems in a furnace, as well as temporarily shutting down raw material delivery, ongoing crushing and milling processes, bag houses and other operating systems.

The deleterious effects of very short power outages are usually mitigated by the installation of capacitor banks and filters in the smelter power station. Power outages longer than 1 second enhance slag build-up and porosity problems in a furnace, and bring thermodynamic issues, increased consumption of electrodes, and reduced operating time into play; in addition to shutting down other operating systems for a longer period. These problems are not mitigated with capacitor banks and filters, so a stable electricity supply is essential to successful smelter operation.

17.2.4 Raw Materials and Consumables Summary

Projected requirements for the major raw materials described herein are given in Figure 26, in consideration of the Phase 1 base-case where all 3 furnaces are producing mgSi. A silica blend ratio of 67% Langis silica and 33% externally sourced silica was assumed in the calculation of quantities. Also included in this table are various other consumables used to aid furnace tapping operations.

Table 53: Raw materials and other consumables necessary for Phase 1 of the smelter

Raw Material or Consumable	Requirement (tons/year)
Langis Silica	97,524
External Silica	48,034
Total Silica	145,558
mgSi Coal	61,852
Limestone	1,022
Wood Chips (estimate based on assumed density)	62,758
Prebaked Electrodes	5,566
Steel Tubes	23
Graphite Electrodes	112
Aluminum Tubes	35
Wooden Sticks	27,552 units
Electrical Power Furnaces Balance of Plant	753,144 MWh 675,860 MWh 77,284 MWh

Source: Viridis.iQ GmbH estimates

17.2.5 Product Output Matrix

Product distribution targets for the various outputs from the smelter are suggested in the table below. Emphasis should be put on producing the best grades of mgSi and FeSi possible to maximize the smelter's potential.

Table 54: Typical product output matrix

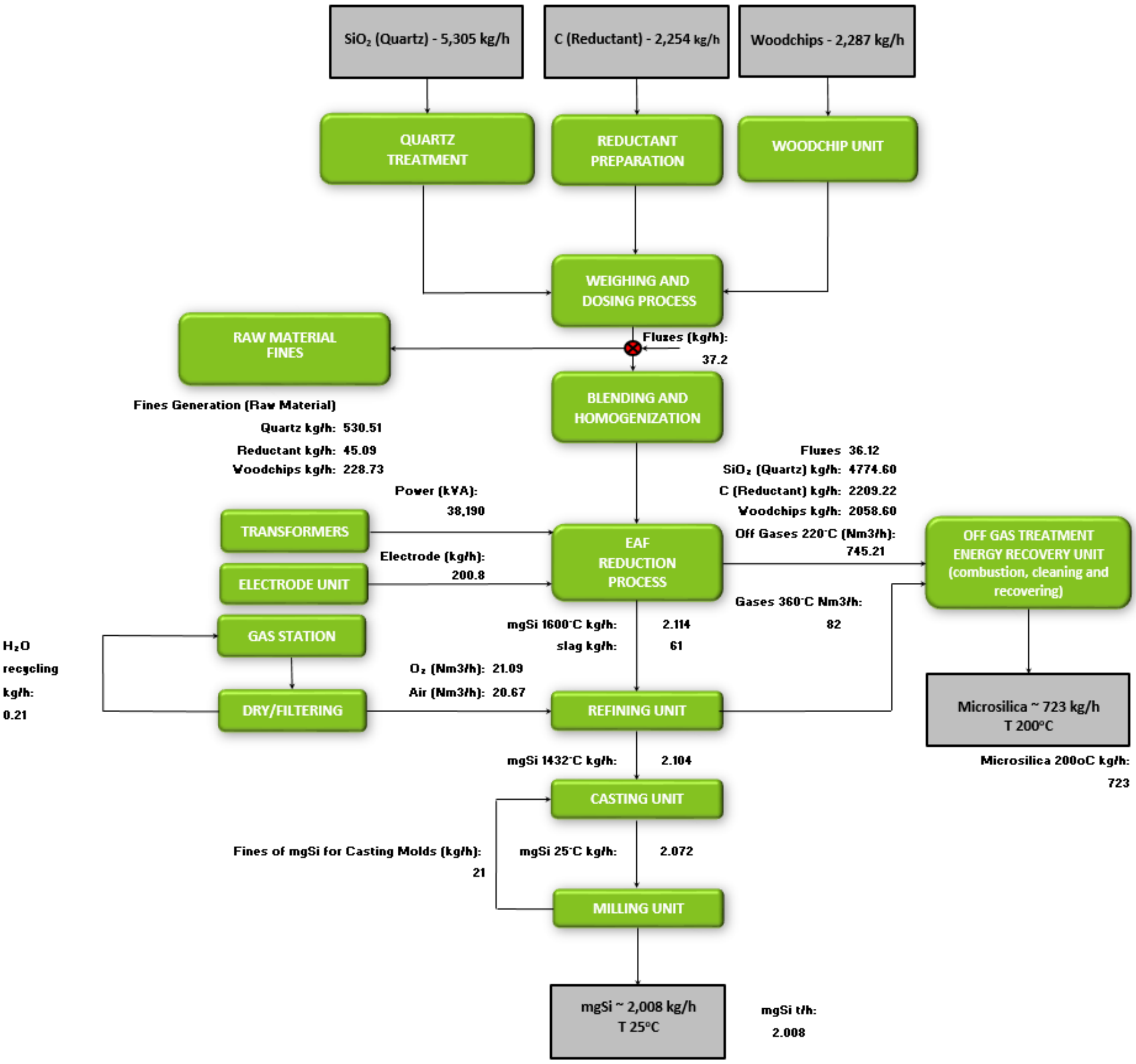
<table>
<tr><th>Product</th><th>% of Targeted Output</th><th>Feasibility</th></tr>
<tr><td>1101 mgSi</td><td>None</td><td>Difficult, would require using 100% high-quality, externally sourced silica.</td></tr>
<tr><td>2202 mgSi</td><td>Some</td><td rowspan="2">Best target zone, but 2202 may require a high ratio of externally sourced silica to Langis silica.</td></tr>
<tr><td>3303 mgSi</td><td>Majority</td></tr>
<tr><td>441 mgSi</td><td rowspan="2">None</td><td rowspan="2">Not target outputs, but likely to be main products during “learning curve” period. Once operators are proficient, 441 and 553 output is generally due to process upsets.</td></tr>
<tr><td>553 mgSi</td></tr>
<tr><td>Std. FeSi</td><td colspan="2" rowspan="2">Specialty FeSi grades such as “low Al” and “high purity” (low carbon) sell for a premium price and should be targeted over standard grade.</td></tr>
<tr><td>Specialty FeSi</td></tr>
<tr><td>Microsilica</td><td colspan="2">Entire smelter output typically sold to Microsilica distributors.</td></tr>
</table>

Source: Viridis.iQ GmbH

17.3 Process Flowcharts

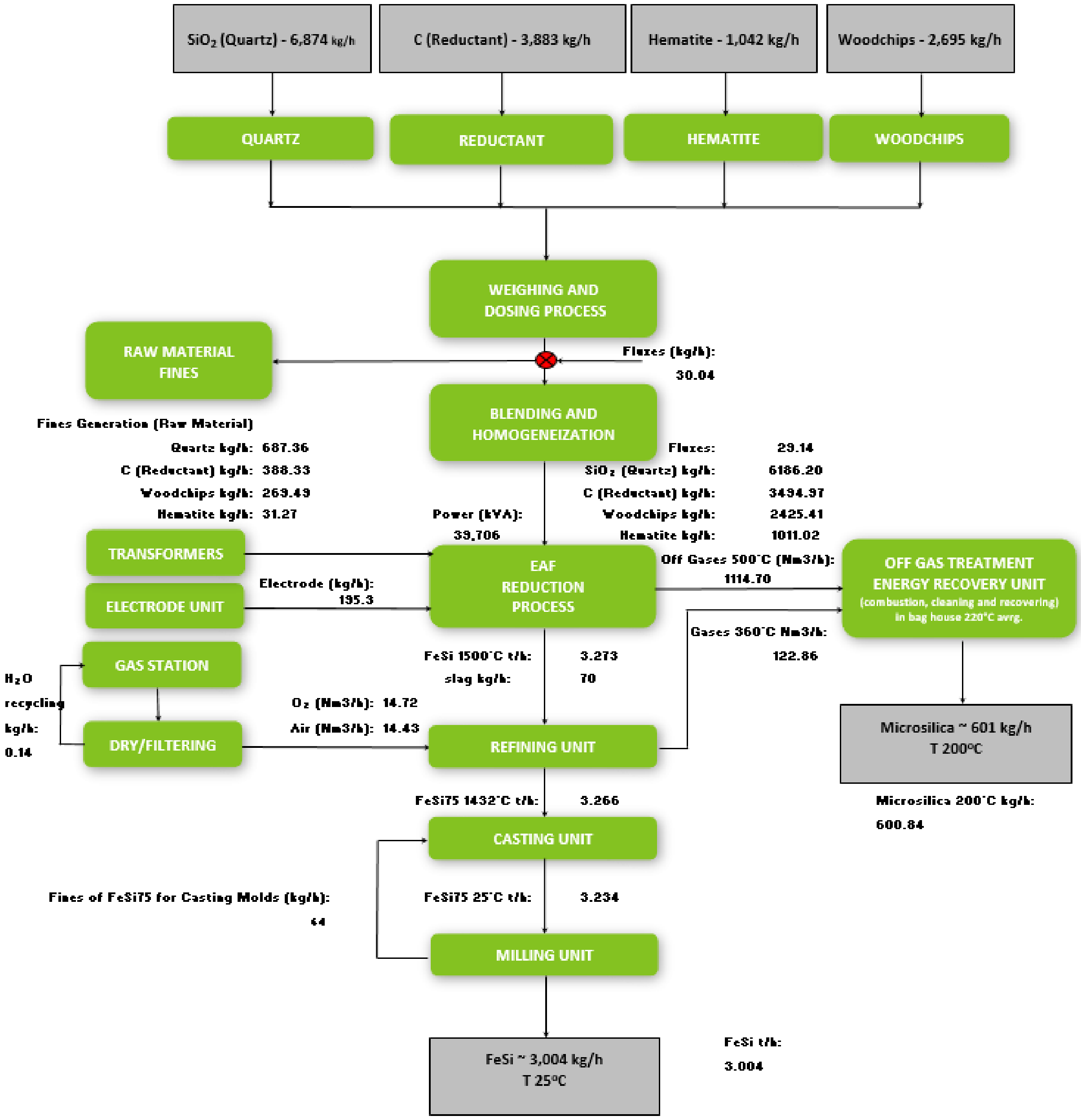
The following process flow charts are given for both mgSI and FeSi production, including the respective mass flows, for each individual furnace:

Figure 116: mg Si process and mass flows on a "per furnace" basis



Source: Viridis.iQ GmbH estimates

Figure 117: FeSi process and mass flows on a "per furnace" basis



Source: Viridis.iQ GmbH estimates

17.4 Logistics

Raw materials and other inbound supplies to the smelter, as well as mgSi, FeSi and microsilica products sold to customers can arrive and depart by a variety of transportation modes.

Highways in the area are plentiful and capable of accommodating heavy truck traffic, which is especially important for delivery of silica from the Langis quarry to the smelter via Highways 195 and 132.

A railroad siding will be integrated into the smelter site plan to facilitate delivery and distribution of high-volume, inbound raw materials and outbound products.

The Port of Matane offers some ocean transport services, but large, ocean-going vessels cannot dock there. Consequently, cities with deep-water ports such as Montreal, Québec City or Halifax will need to be used to accommodate large deliveries arriving from overseas.

The rail ferry at the Port of Matane is a viable option for moving supplies and products across the St. Lawrence River.

Large inbound or outbound shipments can be loose bulk or packed in containers. Containerized shipments can also be loose bulk or the materials can be packaged in big bags when necessary.

The most cost-effective mode of transportation for high-volume, inbound raw materials arriving from overseas is clearly large, bulk shipments. Shipping rates can drop USD 10 – 15 per ton when the shipment size increases from 6,000 to 12,000 tons, for instance. However, the size of shipments that can be accepted by the smelter at one time is determined by storage capacity, both on-site and off, and economic factors.

Table 55 provides a snapshot of the estimated annual inbound and outbound traffic for raw materials, furnace tapping aids, and manufactured products for the 3-furnace, mgSi product base-case.

Table 55: Inbound and outbound raw materials, supplies and products for 3 furnaces producing mgSi

Material	Inbound tons/year	Outbound tons/year
Langis Silica (assuming 10% loss in screening)	97,524	9,752
External Silica (assuming 10% loss in screening)	48,034	4,803
Total Silica (assuming 10% loss in screening)	145,558	14,556
mgSi Coal (assuming 2% loss in screening)	61,852	1,237
Limestone (assuming 3% loss in screening)	1,022	29
Prebaked Electrodes	5,566	
Wood Chips (estimate based on assumed density and 10% loss in screening)	62,758	6,276
Steel Tubes	23	
Graphite Electrodes	112	
Aluminum Tubes	35	
Wooden Sticks	27,552 units	
mgSi		Approx. 50,000
Microsilica		Approx. 24,000

Source: Viridis.iQ GmbH estimates

Materials expected to arrive from overseas include externally sourced silica for mgSi production, coal, hematite, pre-baked electrodes, Søderberg electrode paste and perhaps a few of the tapping aids. Hence, the payback obtained from large bulk shipments should not be underestimated. Shipments of bulk or containerized raw materials are expected to be transported from the port to the smelter by railroad or truck.

It may seem counterintuitive that some of the raw materials listed in the table also appear in the outbound category. The outbound quantities are estimates of the amount of undersize material that will be removed from the raw materials at the smelter prior to charging them to the furnaces.

The undersize fractions are the result of anticipated breakage of the materials during transport, which is a normal occurrence. These undersize fractions can often be sold to local industries to recoup some of the capital invested.

Synchronization of the Langis quarry output with the smelter's silica requirement is a major consideration to address. The assumed capacity of trucks shuttling silica to the smelter is 25 tons. This means about 3,918 truckloads per year or 11 truckloads per day, on average, will need to be delivered. The figure is closer to 16 truckloads per day if weekend and holiday deliveries are excluded. Several dedicated trucks will be necessary for this task, likely 3 - 4 if a 4-hour round trip and 24-hour per day deliveries are assumed.

Wood chip deliveries fall into much the same category as silica with respect to the number of dedicated trucks required. Although the annual requirement for wood chips is lower in weight than that for silica, the low density of wood chips means that the volume capacity of the truck becomes the limiting factor, not the weight capacity.

An even larger number of dedicated trucks may be necessary to transport wood chips, depending on the distance of the local supplier from the smelter and the weight per load. Transportation modes and packaging for outbound product shipments are highly customer dependent and will need to be considered once a customer base is developed.

17.5 Labor Resources

Year-round operation of the quarry was assumed in this technical report for the sake of simplicity. Other operating models, such as seasonal operation and outsourcing to third parties, are possible and should be explored at later project stages, however, these other models will not be considered in this work.

Table 56: Quarry labor plan

Qualification	Total
Quarry Manager	1
Mining Engineer	1
Geologist	1
Mining/Geology Technician	1
Safety Technician	1
Mechanical Technician	1
Electrical Technician	1
Electrical/Mechanical Maintenance	1
Operators	3
Drivers	3
Operation Auxiliars	1
Others	1
Total (Phase 1)	**16**

Source: Viridis.iQ GmbH

The smelter will require approximately 204 employees (Phase 1) of varying disciplines and skill sets. The overall labor plan for the smelter is shown in Table 57:

Table 57: Smelter labor plan

Qualification	Total
Management	3
General & Administration	6
Sales	4
Operator	136
Technician	36
Engineer	12
Administration	7
Total (Phase 1)	**204**

Source: Viridis.iQ GmbH

The smelter will work on a 4-shift model with 8 hours per shift. The main working hours are:

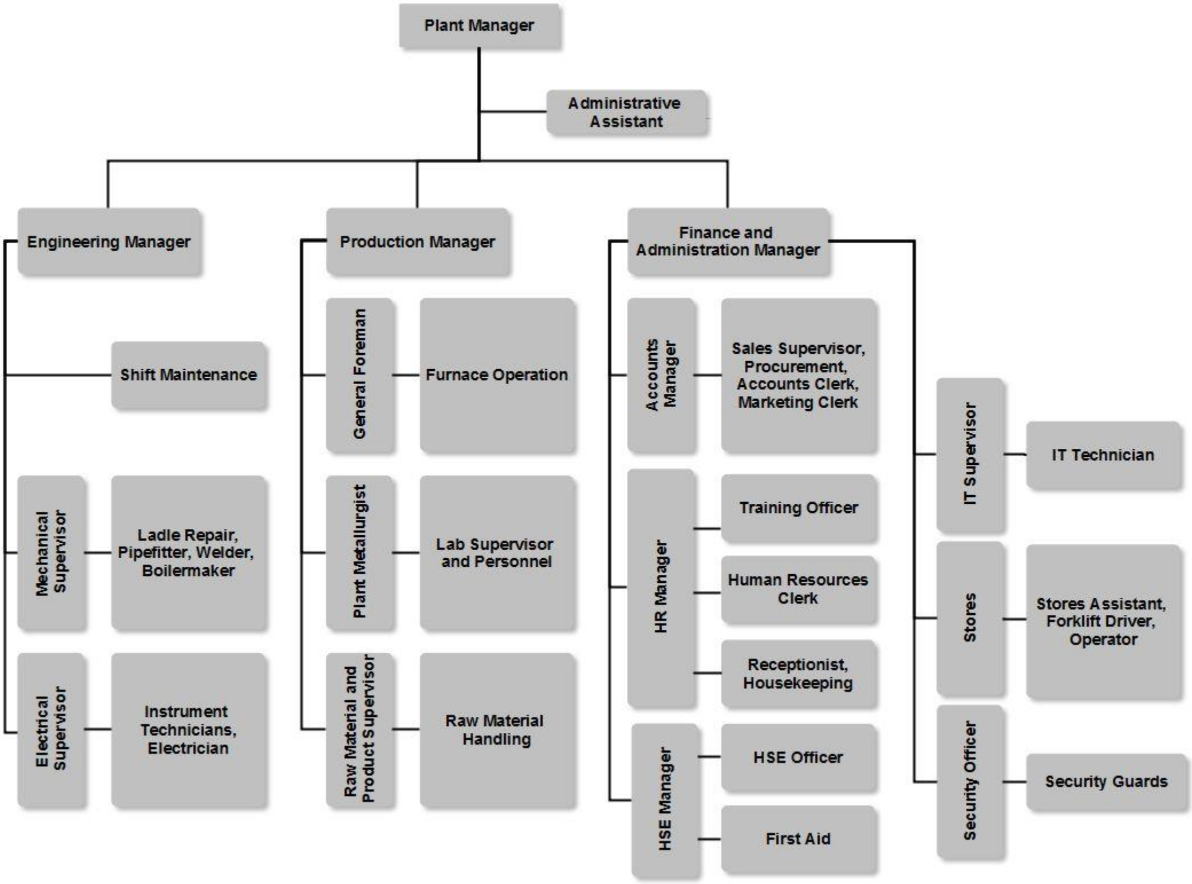
Management/Admin: Monday – Friday, 40 hours per week, 8am – 5pm

Production: Monday – Sunday, 40 hours per week, according to shift roster

No guarantee is given herein as to the number of permanent jobs that will be created either at the Langis quarry or the smelter. All labor and headcount assumptions are indicative only. Local labor regulation should be revisited in further project phases.

17.5.1 Typical Organigram

Figure 118: Exemplary organigram for HFP



Source: Viridis.iQ GmbH

17.5.2 General Description of Labor Requirements

17.5.2.1 Plant Manager

The Plant Manager supervise and coordinates all plant activities. This person works regular hours mainly in an office environment but also has technical and business understanding, interdisciplinary experience, entrepreneurial thinking, and leadership capability. Travel to national or international destinations is required to benchmark with other companies and to cultivate business contacts.

17.5.2.2 Supervisor/Manager

Supervisor/Managers usually work in an office environment. Their hours are mostly regular, although additional time may be required when deadlines approach or critical issues have to be addressed

17.5.2.3 Engineer

Engineers supervise technical processes and communicate with Supervisor/Managers and with the production staff.

Process Engineers work in production areas of the smelter. The working hours are usually regular but could be extended in special circumstances. These engineers oversee manufacturing processes and services to insure they meet all standards and quality requirements. They communicate with Supervisor/Managers, Engineers, Technicians and Operators.

17.5.2.4 Technician

Technicians work under the direction of engineering staff and carry out technical support of production. They work in the production areas, laboratories, maintenance workshops and only to a small degree in an office. Technicians usually work in a team with Engineers as well as Operators. The working hours are regular but might be extended in special cases.

17.5.2.5 Operator

Operators perform repetitive tasks along the production lines. Shift work is obligatory for this staff category due to the uninterrupted production process. Their working hours are regular on a shift model. Conditions may be noisy and/or hot. Operators may have to sit or stand for long periods.

17.6 Preliminary Layout of HFP in Matane

The proposed layout was developed respecting the characteristics and topography of the base-case site in Matane. It accounts for implementation of the project in two phases. The Phase 1 base-case scenario consists of 3 submerged arc furnaces built in a hybrid-flex configuration to allow rapid conversion between metallurgical silicon and ferrosilicon production. Phase 2 accounts for the addition of 3 more furnaces, also in a hybrid-flex configuration.

The complete infrastructure and equipment necessary for both the first and second phases of the project was designed and taken into account in the lay out development, however, only the equipment necessary for Phase 1 of the project was considered and included then.

The lay-outing process was entirely developed based on a 3D model, and all furnace equipment was included with high level of detail. This insures high levels of reliability in the lay out, even at this early stage of the project. The software, hardware, tools and techniques used are the vanguard of the engineering development in plant design, which also increases accuracy for future stages of the project.

The position of all equipment, including furnace and auxiliary equipment, was defined considering best process practices, ViQ expertise of more than 150 years of experience in the silicon and ferrosilicon industries, and site access routes and topography.

The main entrance for the site was installed at the Avenue du Phare Ouest to insure easy access for incoming raw materials and outgoing products, via trucks and rail cars.

The layout was developed respecting the dimensions of Block 1, and the topography was studied in detail to achieve the best design solution, thereby minimizing costs for earthworks and civil works. All the facilities were distributed in three main plateaus.

The cross-sectional view of the site given in Figure 119 below shows the varying elevation of the plant, based on the topographic studies provide during the lay-outing process and the conceptual engineering design. The earthworks calculated in the project where considered in the CAPEX.

The layout was designed respecting the best-value streaming mapping for industrial process flow. The material storage area was placed at the back of the site, on the second plateau, divided into two main lines, one for the first phase of the project and one for the second phase. As can be seen in the layout items PB02 and PB03, the space for an additional storage structure was placed at the back of the plot.

Considering the high elevation of the back of the plot and the possibility of raw material supply using rail cars, the raw material discharge shed (LS05) was installed on the first plateau, at the front of the plot and at the same elevation as the rail lines. It’s not possible to discharge the railcars on the back of the site due to the elevation difference between the first and the second plateaus and the minimum rails necessary for railways that cannot exceed the property limits. The transport of raw material from this shed to the raw material storage will be made through a conveyor belt installed on the left side of the plot.

The railways and limits of the property boundaries are respected, with the exception of a small railway that crosses the adjacent property. Rights of use of this small portion of the rail access should be addressed with the property owner in the following stages of the project.

All the other raw materials are stored in the same area, decreasing the transport distance, and consequently decreasing the fuel and man-hour requirement.

The wood chip production unit, item PB04, is also installed on the second plateau, near the log and wood chip storage area, which is installed near the day-bin feed hoppers PB 6.6, PB7.10 and PB7.11.

The raw materials are transported from the storage point to the furnace day bins using a feed hopper, lay out item P08.6, installed next to the storage areas, and fed using front-end loaders. The installation of these feed hopers will decrease fuel consumption, the equipment utilization and the man hours used in these activities. This design also decreases the possibility of furnace stops due to equipment failures.

Raw materials are transported to the day-bin system, scales and batch preparation through a conveyor belt, lay out item PB06.5, PB7.10 and PB7.11. These day bins were designed and positioned in order to take advantage of the elevation difference between the plateaus one and two.

From the batching preparation, the mixed raw material charge will be transported to the furnace using bucket conveyor belts. This type of solution decreases the space necessary compared with regular conveyor solutions. The mixed charge segregation is also decreased when comparing with other systems. The reliability of this system is higher than other solutions increasing the MTBF (mean time between failures).

The layout design accounts for the possibility of installing a second batch preparation system and a second bucket conveyor belt, which should be considered and decided upon in the next project phase; along with the duplication of the raw material handling system capacity for Phase 2. This solution increases the initial investment, but is highly suggested due to an increase in the reliability of the furnace feeding system and avoiding furnaces stops due to batch preparation failures.

The furnace dust collector system and microsilica storage bins (PB06 and PB07) have been placed on the second plateau. This solution takes advantage of using the existing topography to create a design with more integration, reducing the total area needed for the smelter.

The first plateau, at the same elevation as Avenue Phare Ouest, accommodates the main furnace building PB01.1 to 1.6, prepared for three furnaces at the first project phase. The space necessary for installation of three additional furnaces in the second project phase was considered in the lay out development.

The electrode storage shed (PB01.8), and refractory processing and storage shed (PB01.9) are installed close to the furnace building using the available space, with a more integrated design that reduces transport distances.

All the facilities where developed considering modern furnace-project techniques and best practices available in the market. These details will supply valuable information for subsequent project phases and generate a strong data base to be used during project development.

The casting station, refining station, and product process shed are located next to the furnace building, improving process integration.

All the furnace auxiliary equipment, including the gas storage area (LS03, LS14, and LS16) and water treatment plant (LS13), are installed close to the furnace area on the first plateau, reducing installation costs.

The crushing system (PB05), and final product storage and handling area are located close to the furnace building, reducing transportation costs and increasing production integration, based on lean-manufacturing concepts, for process waste reduction/avoidance.

The workshop (SB01.2) and warehouse (SB01.3) are installed in a strategic position, close to the furnace building, the crushing system and the raw material discharging system on the first plateau. The distribution of the equipment on the plateau will reduce the energy requirements during the operations of the plant.

A container area (LS06), which can be used for final product storage in containers for further transport by rail lines, is situated on the first plateau. The ability to load and unload containers on-site brings lower costs to the project's operating cost structure.

In the first plateau, next to the Avenue Phare Ouest, we can also find the main entrance including the weighing bridge, the main building, SB0.1, which includes the administrative building, laboratory and engineering department, and also the parking lot that can be used by employees and visitors.

Behind these buildings we can find the rail lines inside the plant, truck parking (LS10) and the fuel station (LS04).

The main substation is located close to the main entrance on the clean side of the plant, in the best position to be connected to the transmission lines.

The in-plant street lay out was designed in order to allow easy access to all buildings, shorten travel distances for the supply of materials and equipment, and to facilitate production flow.

A forestation and gardening project was developed using typical plants of the area, which helps integrate the smelter with the local environment. This project includes a green belt around the smelter that will mitigate negative visual impact from the industrial installation. This will also increase the "environmentally friendly" identity of the project.

The third plateau, at the back of the site may be used for future expansions, other than furnaces, that can be studied by Canadian Metals. This area does not need much earthwork at this stage of the project, to avoid increasing the initial CAPEX.

This proposed integrated and compact design of the site will assist the operations from an energy consumption standpoint and reduce overall equipment costs due to the short raw material transit distances on-site.

Figure 119: Elevation view layout of HFP in Matane

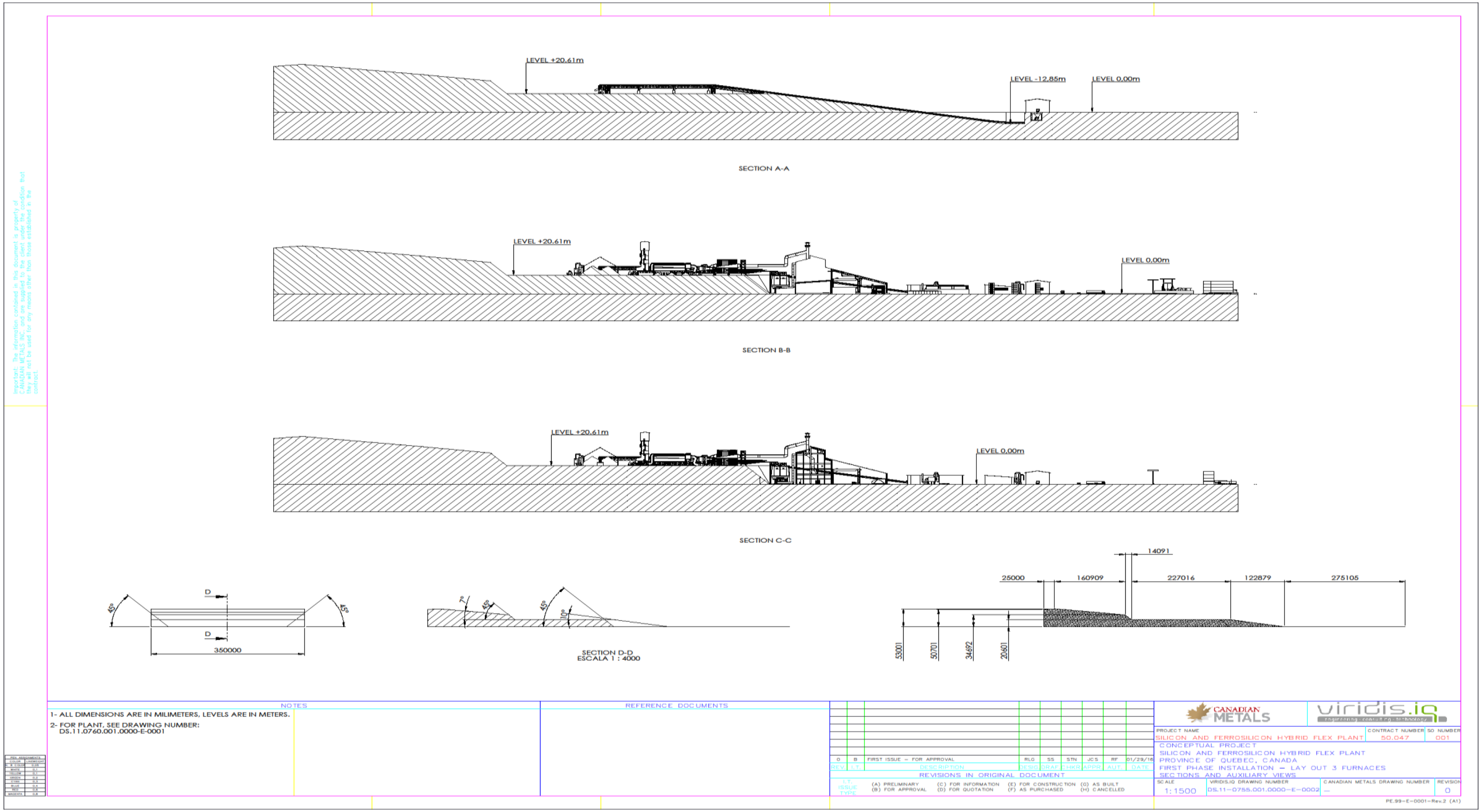
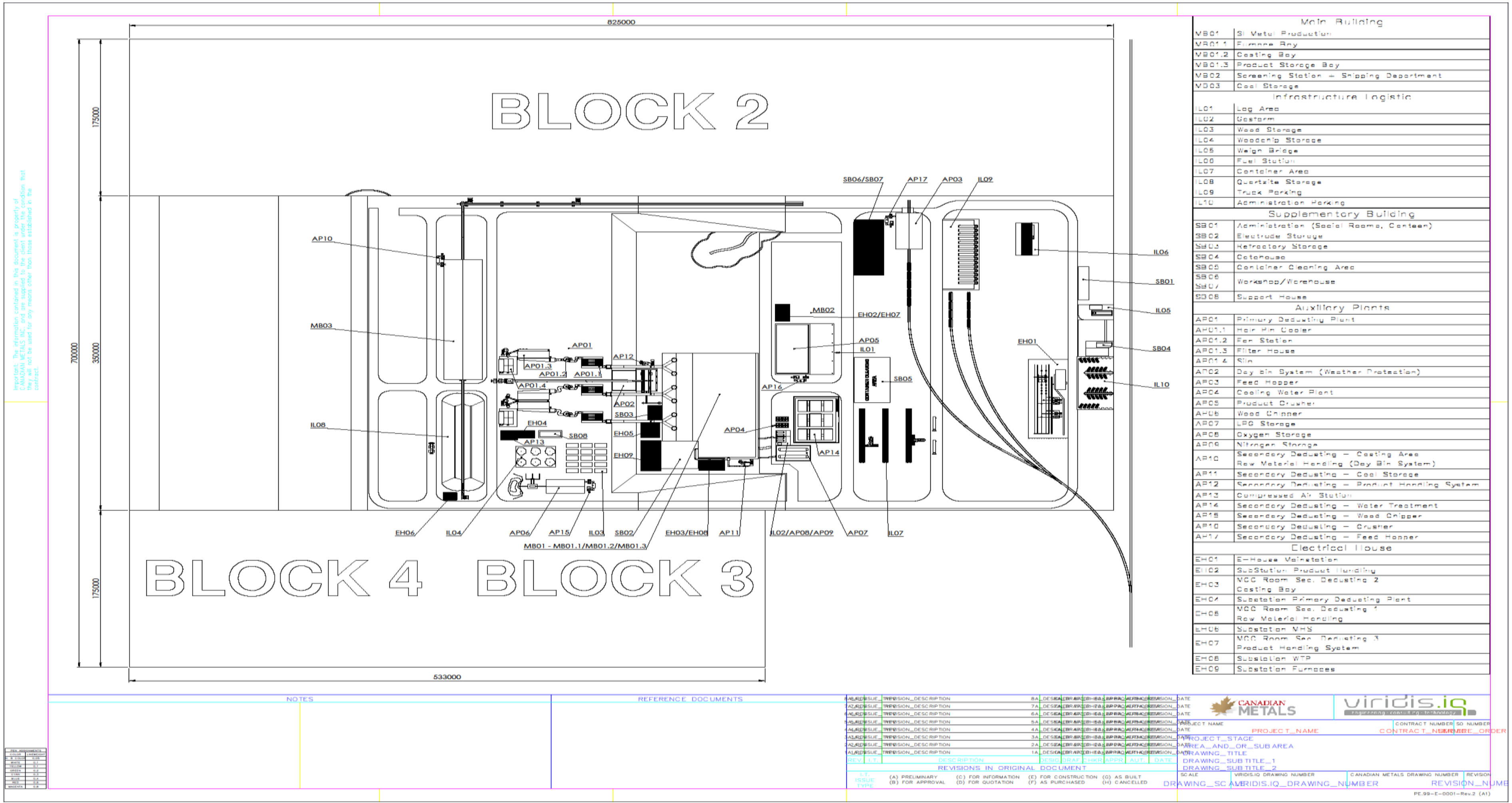


Figure 120: Top view layout of HFP in Matane



17.7 3D Model of HFP in Matane

The HFP layout in Matane was developed in 3D using advanced engineering software, mainly SolidWorks and 3D Studio. This layout has a very high level of detail for a conceptual engineering work.

The main objective of the 3D model´s development was to create integrated production facilities that insure high flexibility (including raw material supply and final product delivery), rationalization of building areas, and placing all the process buildings in line with the production process flow. This design enables a reduction of necessary building areas, which reduces CAPEX and operational costs. The lean-thinking method was used in accordance with operational-excellence practices to the maximum extent of ViQ’s expertise in silicon and ferrosilicon operations, maintenance, project design and engineering development.

The design considered the installation of three furnaces in the first phase, but the layout is also accounts for the second phase, when three additional furnaces will be installed, as described in Section 17.6 of this Technical Report.

The process flow was designed starting on the backside of the plant, placing in this area the less aesthetically pleasing elements, such as the raw material storage area, away from the main highway, main entrance and office buildings.

All the pre-determined and informed assumptions and characteristics of the base-case industrial site in Matane, Quebec were included during 3D model development. The authors also considered the equipment, people and materials flow inside the smelter as key factors, creating a very flexible and compact design, which decreases operational costs.

After definition of all types of final products to be expected, as well as the annual expected production, the raw material consumption, raw material storage capacity and many other parameters, all the project calculations where developed. All furnace equipment, including dimensions of all furnace parts and all related auxiliary equipment were calculated.

After the calculation and specification process, all the equipment was individually modeled in 3D using SolidWorks. With all these models completed, it was possible to design the necessary buildings for the plant.

At this point the Earthworks study was developed and all plateaus where defined. In the proposed solution, the amount of earthwork was reduced as much as possible, considering the topography of the plot site. The elevation differences between the plateaus were used as a process advantage. The installation of the raw material bins using this height difference between the plateaus is one of these advantages.

After completing the development of all buildings, and finishing the earthworks study, the 3D lay out was developed and finalized. The main design solutions considered in this lay out were listed in the previous section, which includes details about the reasons considered for the chosen position for each building.

This 3D model of the proposed Phase 1 (3 SAF) of the HFP project in Matane is shown in the figures that follow. The level of detail in this 3D model can be demonstrated by the pictures that show the zoom-in for the process and crushing systems.

The 2D layout was also developed using SolidWorks software, and was developed after the finishing the 3D Models. These 3D models were also used to supply information for other parts of this document, such as the CAPEX elaboration process, for example.

Figure 121: Aerial (back) view of the HFP smelter – Phase 1 (3 SAF)

Figure 122: Aerial (front) view of the HFP smelter – Phase 1 (3 SAF)

Figure 123: Zoom to the production process main building – SAF overview (Phase 1)

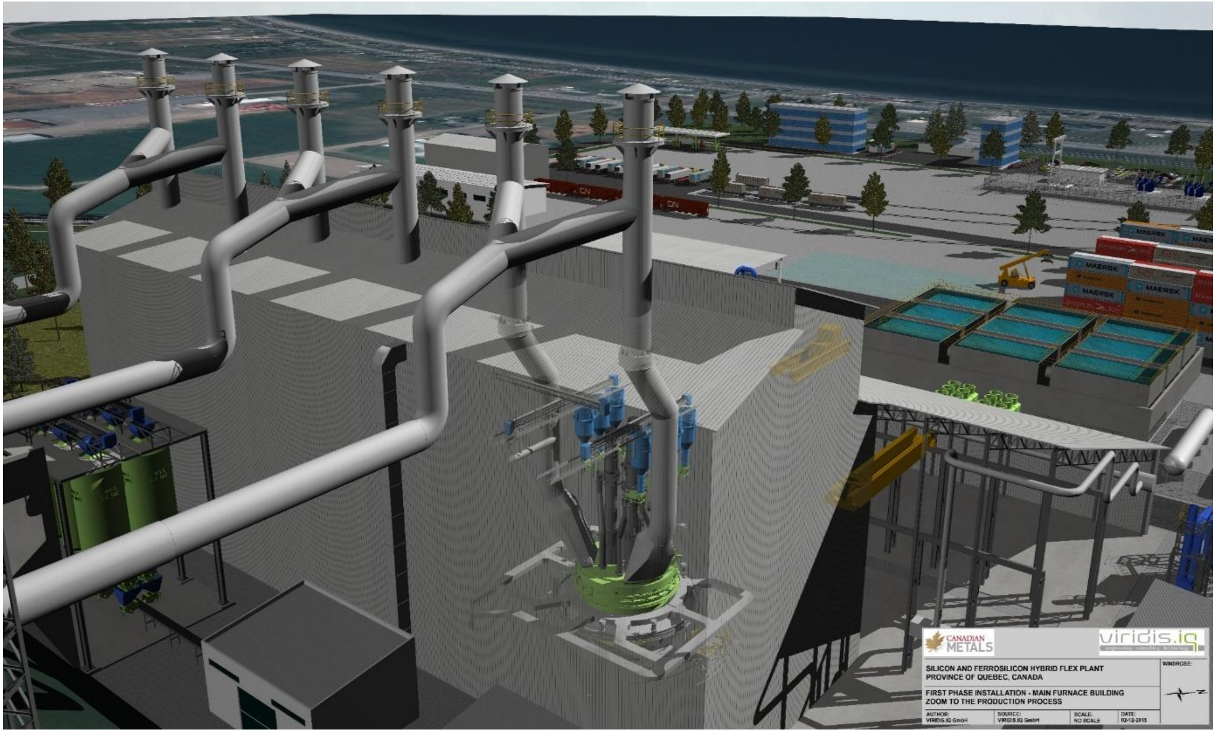
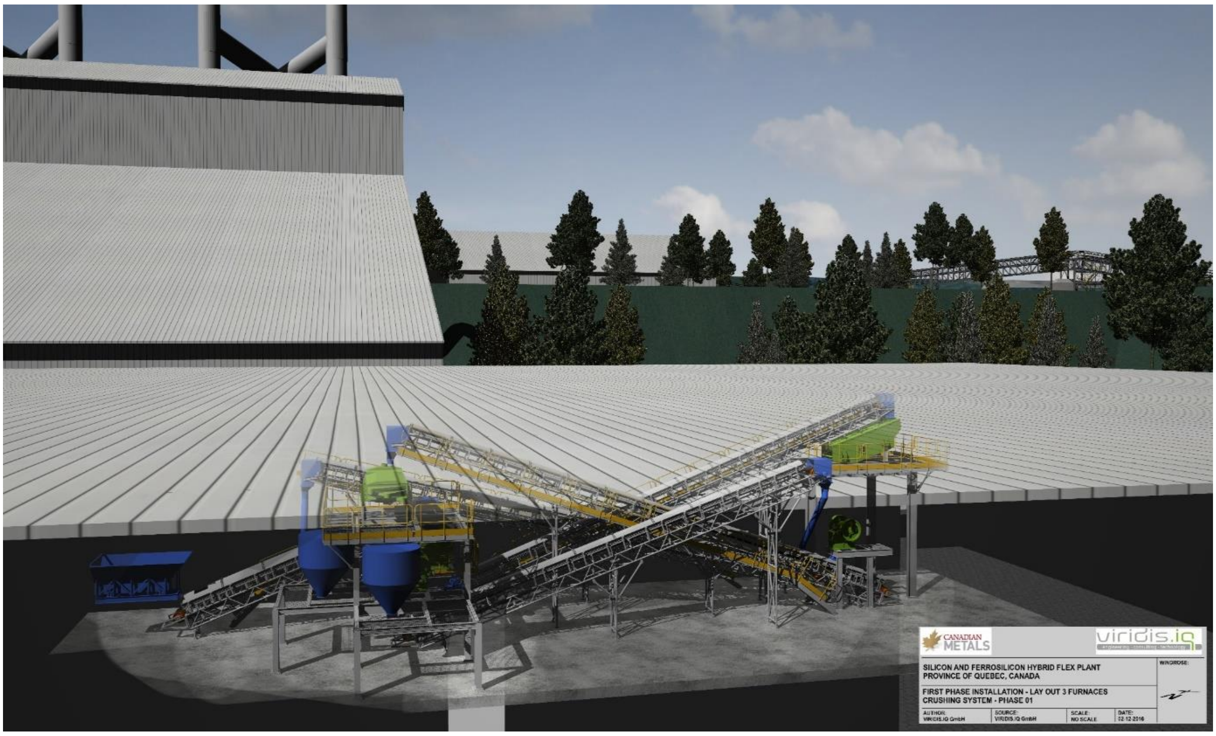


Figure 124: Zoom to the production process crushing system



18 Project Infrastructure

18.1 Introduction

The Langis quarry infrastructure has been described in Section 16.3 (Mining Studies) and 16.4 (Water Management) above. Reference is made to those sections for further details.

The Matane industrial site has been described in Section 4.2 above and will not be repeated here, however, main infrastructure details for the site are addressed in the sections that follow. A detailed site evaluation for the eventual selected site should be performed in future project stages as the current assessment is preliminary only.

18.2 Operation at HFP in Matane

The site requirements for the proposed factory are quite diverse and yet are fairly straightforward. The main site criteria are shown below:

Table 58: Infrastructure Requirements HFP, Matane

Site Area	Sufficient area for the site development must be allocated, including additional margins for reasonable expansion potential. The smelter layout should be rational and integrated, insuring easy access to all plant facilities for the large quantities of materials that moves in and out of the site. The risk of over estimation of the area requirements is low at this stage due to the stage of development of the layout. The site should be free of the risk of flooding, and, preferably, in an area with a low risk of earthquakes.
Electrical Power	Access to a stable and solid grid connection that insures the supply of the required amount of energy in a stable high-voltage connection, without interference, is paramount for the proposed smelter since sensitivity to grid interruptions is extremely high and can severely impact the economic viability of the smelter. This aspect is of high priority and should not be underestimated.
Geology and	Geology requirements are important to the site mainly due to the

Topography	heavy loads for equipment and machinery needed. Adequate subsoil and geological evaluations must be undertaken for initial site selection due to the heavy loads and possible requirements for piling. Since the base-case site presents large elevation variations, special mitigation techniques where adopted during the layout development that take advantage of the elevation changes, leading to an operational cost reduction. Areas subject to high wind loads should be avoided.
Utilities and Infrastructure	As noted herein, large quantities of industrial gases and materials are needed for the project. As such, adequate infrastructure for delivering these consumables to the site should be pre-existing to keep CAPEX costs and project schedule under control. Power generation, high-power transmission lines, telecommunications, water utilities, gas transportation and road/rail access are important toipics that must be considered during project development.
EPC and Construction	It is envisaged that all site construction works will be managed by one Managing Construction Contractor who will take overall responsibility for site activities and employment of Sub-Contractors. Such an EPC company would be familiar with local zoning and construction rules and should have experience in similar factory projects. The following sub-contractors are anticipated: ▪ Earthworks and civil; ▪ Structural steel supply and erection; ▪ Mechanical fabrication and welding, equipment manufacturing; ▪ Welded structures contractor; ▪ Mechanical and piping installation; ▪ Refractory supply and installation; ▪ Electrical automation, instrumentation equipment, and materials supply; ▪ Electrical automation, instrumentation equipment and materials installation; ▪ Commissioning

Access and Transportation	Large numbers of people and materials must be lead into and out of the facility each day. Adequate road access should be prioritized and suitable ingress and egress points made available. Access to port facilities and airports should be available, the later for emergency shipments of key equipment and ease of access to customers and suppliers.
Land Use, Zoning and Public Policy	Site should be appropriately zoned for heavy industry in accordance with existing local and national laws and public policy in order to obtain operational permits. Rights-of-use for rail access should be addressed.
Air Quality	In general terms, there are very low level emissions from the proposed furnaces, therefore no direct impact on air quality is expected. However, emergency procedures for accidental discharges and for emmissions from emergency generators must be in accordance with local laws. Emissions during the construction phase may however, be high due to the large amount of truck and vehicle traffic, which would subside once manufacturing commences.
Noise	Project construction and start-up activities would result in temporary increases in ambient noise levels that have the potential to affect adjacent industrial properties. During operations, the manufacturing facility would generate ambient noise consistent with industrial uses, aligned with local regulations.
Water	Large amounts of water are required for various aspects of production, as well as large amounts of emergency water should the need arise. Easy availability of water resources near the site should be required. The water consumption license should be obtained during the next project phases.
Natural Resources	The site should not be located near important natural resources that may be later exploited due to the generation of dust that such exploitation may generate, which can negatively impact the project site. Additionally, floodplains and other valuable estuaries or water based resources should be carefully evaluated for

	potential risks in case of an accident or emergency releases.
Cultural Resources	The location of the site should be selected with attention paid to cultural resources such as indigenous tribes or historic sites so as not to negatively impact these assets.
Justice and Legal	Legal jurisdiction should be clearly defined for the sites with little or no risk of disputes or political unrest.
Health and Safety	The project involves materials and temperatures that can be dangerous to human and animal health, and, therefore, should be adequately protected with detailed and clear health and safety rules.
Cumulative Effects	Attention must be paid to the cumulative effects of other industries in the vicinity so environmental rules and regulations are abided.
Railways and Ports	Access to railways and ports are of high importance as the heavy industrial portions of the project require the importation of large amounts of materials. The site must be accessible by containerized cargo and bulk cargo deliveries. Local infrastructure should be suitable for offloading ships and moving the raw materials to the site with minimal costs and time or adequate infrastructure for this aspect must be built into the site planning.
Warehousing and Storage	On-site storage is required for several large-volume raw materials to be used in the process, which has been taken into account in the layout developed; however, some offsite storage can also be used.

source: Viridis.iQ GmbH

Based on the above criteria and the selection of sites available, the selected site for the base-case assumptions is in the municipality of Matane, Québec.

18.3 Access to Site

The project site is surrounded by Highway 132 to the west, occupied farmland to the south and east and Rue Yves Bérubé to the north. One access road to the site is used and will be the main ingress to the site for the project purposes.

This ingress enters the property from Highway 32 with an existing railroad crossing currently in place. No other ingress/egress is envisioned for the site at this stage and this entry point will serve for all traffic entering and leaving the site.

Within the boundaries of the site, there will be internal paved roads, detailed on the project layout, for movement of materials and product within the site perimeter, and to grant access to all facilities.

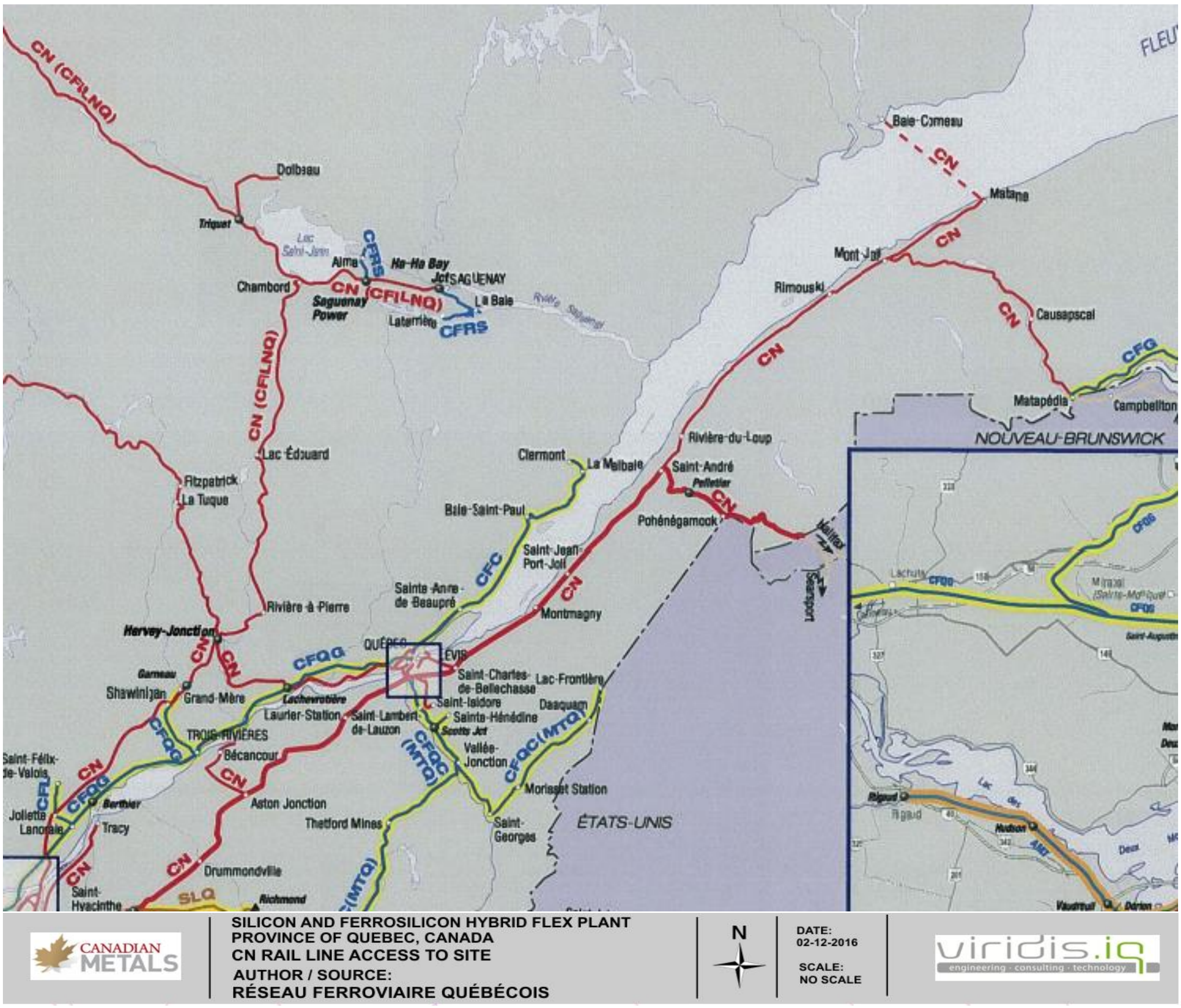
No other ingress/egress is envisioned for the site at this stage and this entry point will serve for all traffic entering and leaving the site. Within the boundaries of the site, there will be internal gravel and/or paved roads for movement of materials and product within the site perimeter.

Rail access to the site will be used to transport raw materials and final products. The Canadian Railroad line travels adjacent to the site and will be used as the primary rail access for the project.

This rail access can provide raw materials such as coal from the main ports of Québec or Montreal to the site and also provide for shipments of rail cars of finished product to off-take markets in the region.

The train ferry, located at the port of Matane, also provides incoming and outgoing access to the other side of the St. Lawrence River to the industrial complex of Baie-Comeau and can be used to source raw materials and other consumables from this region.

Figure 125: CN rail line access to site



Source: Viridis.iQ GmbH

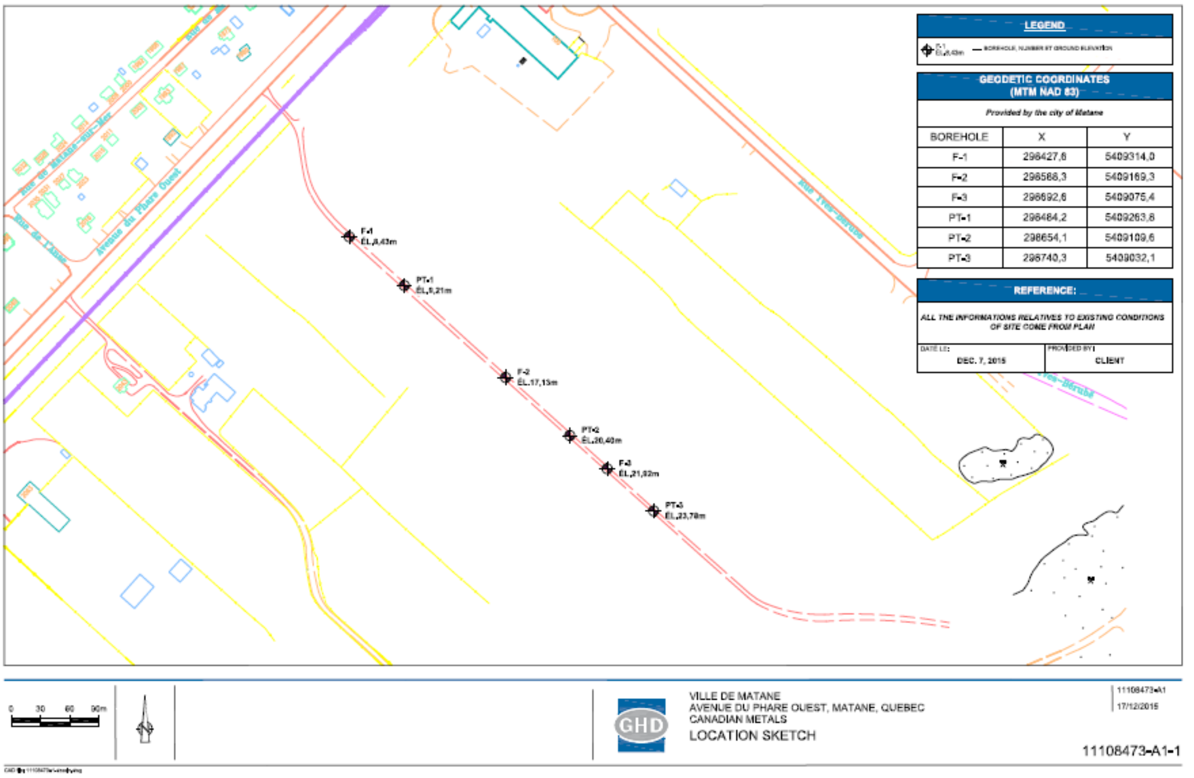
A side spur will enter the site from which rail cars will be directed into the site and processed, unloaded, and prepared for reconnection on the main line.

18.4 Geotechnical Aspects of the Site

On January 14, 2016, during the finalization of this PEA, a preliminary geotechnical study was initiated on the proposed Matane industrial site by the City of Matane in which 6 boreholes were made in a vertical mid-line of the site. Only 2 of the 6 boreholes are in the vicinity of the current site layout and provide minimal data on the distribution of the subsoil conditions of the site. Future project steps require an extensive geotechnical review of the subsurface features of the site for a determination of effects on construction of the proposed smelter.

The information received from the preliminary geotechnical study will be used during the development of basic civil and earthworks projects and will guide further geotechnical evaluations that should be executed in the next project phases.

Figure 126: Matane site borehole locations



Source: GHD

18.5 Plant Utilities (Metallurgy – Smelter)

The main plant utilities needed for the base-case scenario are provided below:

Table 59: Overview on plant utility requirements – Phase 1

Power	Active Power Total	101.5 MW (< 107 MW max)
	Apparent Power Total	103.2 MVA
	Annual Demand	846,410 MWh
	Frequency	60 Hz
	Incoming Line	230 kV
Water	Potable (0.3 m^3/person/day) Evaporation Losses Bleeding Losses (blowdown) Total Make Up Water	61 m^3/day 1100 m^3/day 305 m^3/day 1435 m^3/day
O_2	Refining	1,013,103 m^3/yr

Source: Viridis.iQ GmbH estimates

18.5.1 SAF Power Supply

The technical specification hereafter describes the following equipment related to SAF Process Power supply:

- Furnace switchgears
- Furnace transformers
- Uninterruptible Power Supply (UPS)

The following description is provided for conceptual purposes only. The figures, technical data and information indicated below are preliminary design data which may be subject to later adjustments during engineering design work and component manufacturing.

18.5.1.1 Furnace Switchgear

The furnace switch circuit breaker and the star/delta (Y/Δ) switches are integrated into the 35 kV distribution switchgear center. The installation of a vacuum type circuit breakers for the furnaces is recommended. The star/delta (Y/Δ) switches increase the secondary voltage range, increasing operational flexibility.

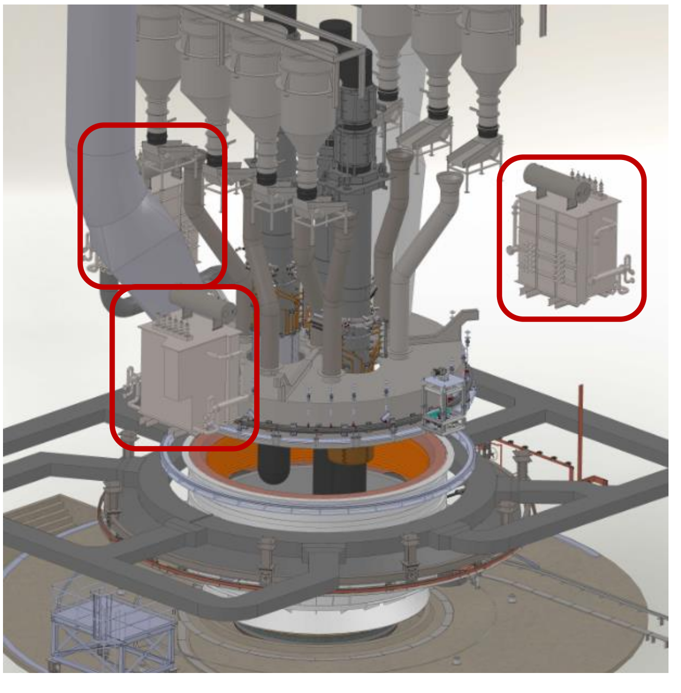
The star connection is necessary to ensure the required electrical conditions for the start up of furnaces, or during any abnormal operational conditions. The installation of an automatic star delta switch is recommended, but a manual version can be used as well.

18.5.1.2 Furnace Transformers

The submerged arc furnaces are powered by single phase transformers located in the furnace building. Three single-phase transformers will be installed per furnace.

Each single-phase transformer should be installed in a separate room, according to the applicable protection standards and electrical regulations. The transformers should be of the indoor, oil-immersion type. The cooling system and on-load tap changer will be detailed below. International standards should be considered during further project phases in the technical design and definition of the best equipment for the plant. The transformers should support any effects from external short circuits without damage, respecting the short-circuit limits to be defined in the next project phases. The primary and secondary current levels should be monitored by current transformers connected to the furnace measurement and protection system.

Figure 127: Location of furnace transformers



Source: Viridis.iQ GmbH

18.5.1.3 Transformer Connection

Cables will be installed from the furnace switchgear to connect with the high voltage side of the the transformers, these cables should be correctly dimensioned during the next project phases. On the secondary side of the transformer, a set of cooled copper buss bars will be installed for each transformer, these buss bars will be connected to the electrode column buss bars through copper flexibles. Each single-phase transformer will be connected through the buss bars to two electrodes. A special design for the buss bars is necessary to reduce electrical losses, including special cooling system connections. Surge arrestors (phase to phase and phase to ground) with counters should be mounted at the primary bushings.

18.5.1.4 On-Load Tap Changer

Voltage changes on the primary side of the transformer are necessary during normal operation due to furnace operational conditions. These changes are made through on-load tap changers. The tap changers should be controlled automatically by the furnace control system that will monitor the furnace conditions to determinate the necessity of tap changes. A remote control should also be supplied for these tap changers. During every furnace shut-down process, the control system will reset the tap changer to the first position for the furnace transformers, ensuring a secure reconnection of the system during the next start-up operation. For maintenance procedures, a tap changer counter should also be supplied for each tap changer to determine the correct time to perform preventive maintenance.

18.5.1.5 Transformer Cooling System

Transformers are subject to electrical losses that generate heat during normal operation. To avoid a temperature increase that may damage the transformer, it should be equipped with a carefully designed cooling system. The system should be an oil/water cooling system, where the pressure of the oil should always be higher than the pressure of the water. The equipment should be provided with pressure and temperature monitoring equipment for water and oil, and an alarm must be raised in the event of failures in the cooling system. If the transformer temperature reaches the predetermined set point, then the furnace should be turned off. Filters should be installed in the water circuit to avoid obstructions in the cooling system.

18.5.1.6 Protection Facilities

The transformers must be provided with all necessary protection facilities, wired to the terminal strip inside a box attached to the transformer. Each transformer should have at least the following information available for protection:

- Oil temperature
- Water flow
- Water inlet temperature
- Water outlet Temperature
- Gas detection relay (Buchholz) signal
- Oil level indicator
- Temperature in the cooling coils
- Tap changer pressure relief relay device
- Tap changer pressure relay alarm
- Tap position

18.5.1.7 Power Requirements

The main power requirements (Phase 1) for the project are estimated below:

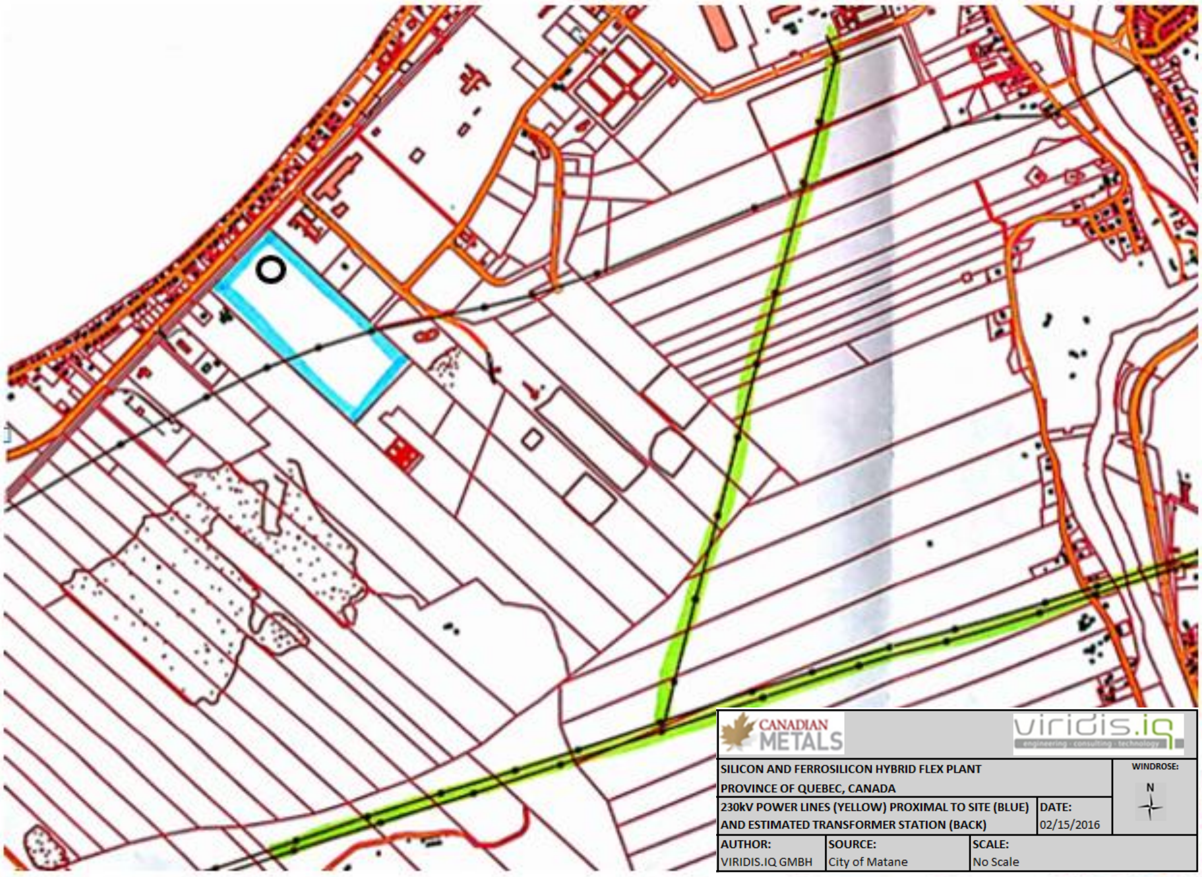
Table 60: Estimates of power requirement – Phase 1

Process	Transformer	Total Apparent Power (MVA)
Furnace 1	3 x 13.5 MVA	40.5
Furnace 2	3 x 13.5 MVA	40.5
Furnace 3	3 x 13.5 MVA	40.5
Auxiliary Equipment		3.0
Main Dust Collectors		8.5
Secondary Dust Collectors		1.0
Tapping and Casting Dust Collectors		1.5
Crushing and Handling		1.5
Cooling System		1.5
Raw Material System		2.0
Auxiliary Equipment		1.5
Offices, Lab and Other Buildings		0.75
Other System Loads		0.75
Total Plant Load	143.5 MVA expected **before** capacitors and filters; 103.2 MVA expected **after** capacitors and filters; 101.5 MW (<107 MW max.) with expected 0.98 power factor	

Source: Viridis.iQ GmbH estimates

Figure 128 provides an overview on high-voltage power lines in close proximity to the industrial base-case site in Matane, Québec:

Figure 128: 230 kV power lines (green) proximal to site (blue rectangle) and estimated transformer station (black circle)



18.5.2 Supplementary Equipment and Auxiliary Plants

The main supplementary equipment and auxiliary plants are listed below:

- Utility Systems and Main Distribution
- Material and Product Handling
- Primary and Secondary Dust Collectors
- Power Supply and Distribution
- Workshops and Laboratories
- Logistic Systems
- Cable and erection materials for process equipment
- Casting Bay Equipment
- Process Information System

For this HFP, the main utility systems and media main distribution would be:

- Fluid Generation
- Cooling Water Plant
- Compressed Air Station
- LPG Storage
- Oxygen Storage
- Nitrogen Storage
- Media Main Distribution
- General Description of Required Fluids
- Cooling Water Distribution
- Compressed Air Distribution
- LPG Distribution
- Oxygen Distribution
- Nitrogen Distribution
- Definition of Piping and Valves
- Piping Hydraulic
- Piping Cooling Water Systems
- Piping Media Systems
- Valves Filters, Gauges (Instruments)

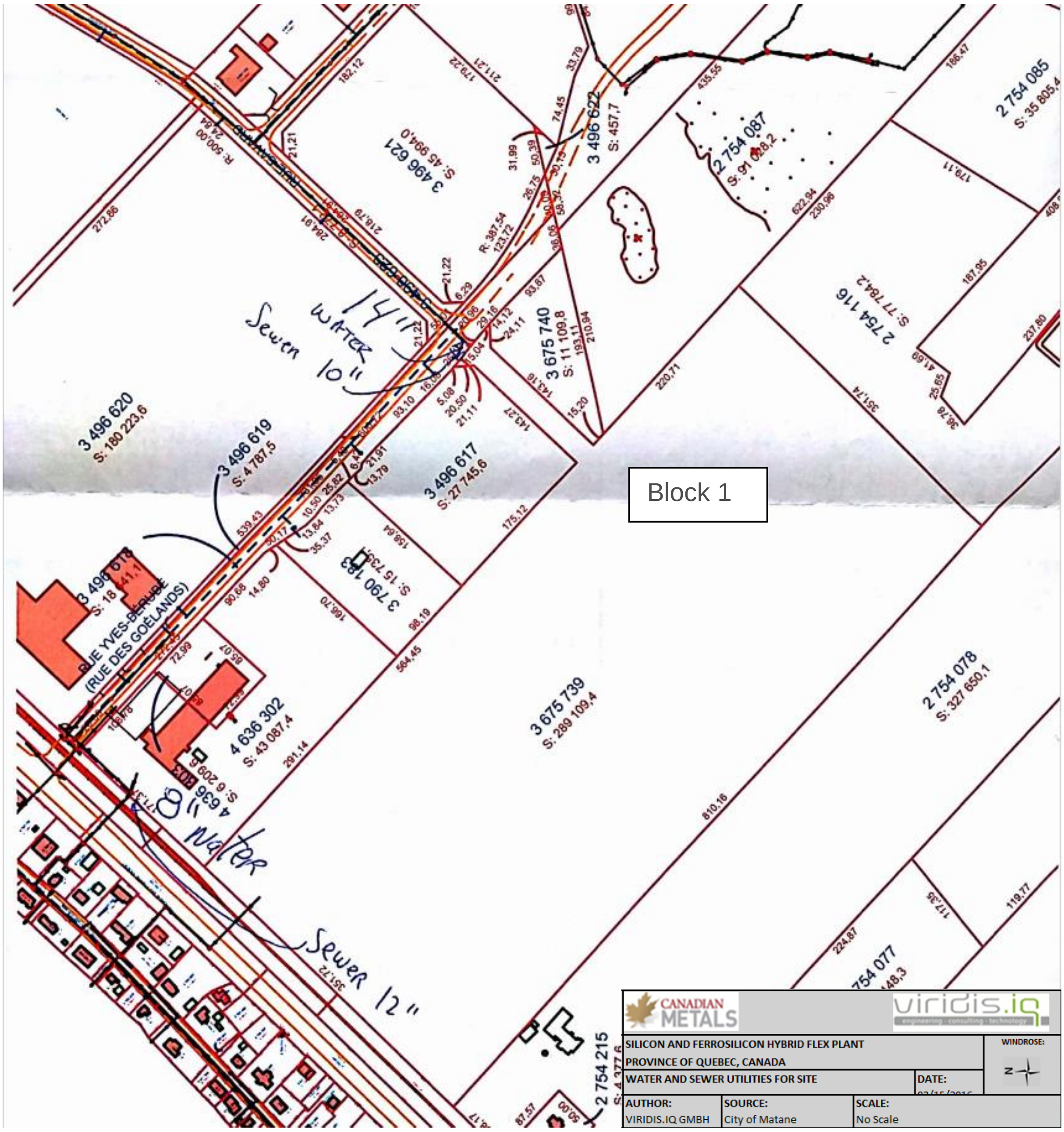
18.5.3 Water

Potable water is required for domestic use by the plant workforce, for support services, fire protection and for certain furnace component cooling circuits. City water can be used for indirect cooling of the closed cooling-water circuits and systems. Proximal water access to the site has been identified as shown in 2 locations:

- Between Blocks 3 and 4 with a 10” sewer line and a 14” water line
- Near the corner of Block 1, near Highway 132, with a 12” sewer line and an 8” water line.

Due to the contours of the site and the required earthworks needed, the preference would be to use the primary water service from the corner of Block 1 nearest Highway 132 (see Figure 129).

Figure 129: Water and sewer utilities for site



18.5.3.1 General Description & Make-up Water Requirement

The total make-up water consumption expected is 1,435 m^3/day. The water treatment system must be designed in order ensure potable water for human consumption and treatment of the water used in the furnace circuits.

A comprehensive chemical analysis of local water quality has not been undertaken by the authors, but is recommended in future project stages, if this site is chosen, in order to increase the accuracy during the conceptual and basic engineering phases. This analysis will be used in future stages of the project to define the specification of the water treatment system. The make-up water in prescribed quality will be supplied to the cooling water circuits.

For future project phases, the correct design and engineering of the water treatment process and equipment will be required. Special attention to total hardness, pH, temperature, chemical analysis (ions) and conductivity is very important to limit corrosion and other problems in the cooling system. The authors recommend a closed loop water system that wills precludethe formation of deposits in the furnace cooling piping, but this issue should be evaluated at further project stages.

18.5.3.2 System 1 – SAF1, SAF2 and SAF3 Furnace Cooling

Heated water from these processes will be connected together and cooled in one closed loop water circuit that can use closed-system cooling towers connected to chillers or air-cooled heat exchangers to decrease the temperature of the water. The energy accumulated in the water can also be used to heat buildings on the site. Special filters must be installed to avoid the formation of deposits. Flow and temperature measurement devices should also be available.

Circulation pumps–2 in operation, 1 as stand-by per SAF–will supply water to other equipment as needed. During emergency operation a diesel driven pump will start automatically and insures the cooling water supplyis uninterrupted. The recirculating water will be kept clean by a side stream filter. Dosing stations for addition of corrosion inhibitors and biocide are recommended. Make-up water of softened water quality will be injected into the circuit depending on the water level inside the surge tank.

18.5.3.3 System 2 – SAF1, SAF2 and SAF3 Transformer Cooling

Hot water from the transformers will be cooled in a closed-loop water circuit via cooling towers connected to chillers or air-cooled heat exchangers. Circulation pumps–1 in operation, 1 as a stand-by–will supply water to the equipment. The recirculating water will be kept clean by a side stream filter. Dosing stations for addition of corrosion inhibitors and biocide are recommended. Make-up water of softened water quality will be injected into the circuit depending on the water level inside the surge tank.

18.5.4 Industrial Gases

18.5.4.1 Compressed Air Station

The compressed air station will fulfil the safety, quality, operational and environmental requirements for legal and international regulations. This station should consist of 4 compressors (3 in operation, 1 as stand-by) that will supply the required compressed air via an adsorption air dryer into the distribution system that will contain the air filters to avoid any oil or another type of contamination. There will be provisions to install a fifth and sixth compressor to accomodate the additional compressed air requirements for SAF4, SAF 5 and SAF6 (Phase 2 expansion). For each line, an air receiver tank should be installed to compensate for short-duration peak flow rates (4 receiver tanks in total for Phase 1).

18.5.4.2 LPG Station

The LPG station will consist of storage tanks and other equipment in accordance with local and international standard regulations. Evaporator units are needed to supply gaseous LPG for the distribution system. The storage tanks are provided to store liquid propane for the duration up to 2 months. Additional space for identical LPG stations should be possible for the Phase 2 of the project.

18.5.4.3 Oxygen Station

An oxygen station will be necessary to supply oxygen to the plant. The main components of this station would be one (or multiple, depending on demand calculations) storage tanks, evaporators units to supply the gaseous oxygen to the lines and one (or more) distribution systems to supply operational processes and other plant needs. The entire storage system will be installed and operated by the oxygen supplier, who will be responsible for tank filling and maintenance to insure trouble-free operation.

18.6 Plant Services and Facilities

18.6.1 General

The factory will be a stand-alone facility producing metallurgical silicon with the possibility to partially or completely switch to ferrosilicon production at a later-stage. The total labor requirement for the downstream is estimated at 204 people. The main site facilities are described below.

18.6.2 Buildings/Offices

A variety of buildings will be located on-site, from office/admin structures to factory workshops to laboratories. The main buildings are described here.

18.6.2.1 Foundation

The foundation is 900 m^2, made of 0.2 m thick reinforced concrete with a double layer of reinforcement. The floor will be made of concrete C35/45. The visible surface of the floor will have a floated surface of U2 classification. The slab has to be able to withstand heavy loads from trucks, loaders and the material piles. Therefore the concrete chosen will have high resistance against abrasion and traffic loads.

18.6.2.2 Security and Weigh Station

Adjacent to the administration building will be a security building which will be a brick and mortar structure that is heated and cooled. This building will house the security teams for the site who will control ingress and egress. The security building will consist of a main control room, bathrooms, file room, meeting room, tool storage, and kitchen facilities for staff. The building will be a single story structure.

The security team will manage incoming and outgoing traffic to the site (visitors, staff, raw materials, final product, and external services) via a computer control system. Outside of the security room will be an in-ground weighing station that will serve as the official weigh-in and –out location for the smelter. The weigh station will have an entrance gate that is closed unless entry or exit is needed and permitted. Data recording from the security control room will be connected with the main data center for the site for record keeping and tracking of incoming materials.

18.6.2.3 Administrative Building

The main administration building will be a single or multi-story brick, mortar and glass structure at the main entrance to the site which will house offices and general administrative and production management staff. The building will be equipped with high speed internet access, phones and fax lines and will consist of office space, kitchen facilities, bathrooms, file rooms, a first aid station and meeting rooms. The building will be air conditioned and heated for climate control. It will house the main visitor reception area and a safety room from which visitors can view safety videos before entering the site, and collect hardhats and other personal safety equipment.

Adjacent to the administrative building will be a parking lot for staff and visitors to the site. Handicapped and standard parking spaces will be made available and may contain prioritized parking spaces for senior management.

18.6.2.4 Furnace Building

The main factory building will be a steel framed structure with sheet metal covering that will house the main furnace equipment, furnace off-gas ventilation, production and maintenance workshops, and storage facilities. The building is multi-functional and will contain overhead cranes, steel stairways, and walkways to allow production staff to reach all functional areas. Production offices and storage rooms will also be part of the structure.

18.6.2.5 Crushing / Sizing and Product Packaging

Each project phase will have one building for product crushing, sizing and packaging. The building will be a steel-frame structure with sheet metal covering, and will house the crushing unit and packaging systems, as well as offices for production staff, and storage and tool areas. A small workshop also might be used for equipment maintenance as well as internal covered storage for finished goods. The building will be the last quality check for the product and will have a computer system to control and record product information as well as delivery orders, Bills of Lading, etc.

18.6.2.6 Vehicle repair and maintenance

There will be various vehicles used on the site, which will require a separate maintenance area. This area will consist of a small brick and mortar building and a covered garage area to provide space for vehicle maintenance. The building will be equipped with sufficient ventilation systems to protect against fumes and gases.

18.6.2.7 Laboratory

The laboratory will be a single story building of brick and mortar construction with forced ventilation. The building will have a series of rooms that house equipment and test apparatus for quality control.

18.6.3 Facilities Area

18.6.3.1 Liquid Oxygen

A storage area will be provided where oxygen supplies can be positioned, ready for use by the smelter staff. The size and capacity of this area will be subject to supplier designs as this industrial gas will likely be provided on a per use basis. The location of the area will be proximal to road access for refilling of the tanks as needed. A security fence will be installed to protect the area.

18.6.3.2 Fuel Storage

A storage area for fuel to be used by onsite vehicles will be provided. This area will contain an underground tank or other storage media and will be accessible to roads for refilling and maintenance.

18.6.3.3 Generators

A backup generator will be housed in a small brick and mortar building specifically for this purpose and will be ventilated for safety.

18.6.3.4 Electrical Substation

A substation area will contain transformers and power correction equipment for the site. The area will contain brick and mortar air conditioned buildings containing transformers and electrical equipment, and will be fenced off for safety with appropriate signage.

18.6.3.5 Control Rooms

The site will contain automation and equipment control rooms in the furnace area that will be the main control area for the furnace-building processes. This will be an internal building inside the main furnace structure and will be air conditioned for comfort as well as for proper functioning of the automation controls.

18.6.3.6 Storm-Water Storage

Multiple storm-water storage areas will be planned on-site to collect rain water run-off resulting from storm events. This storm water will be treated and discharged as waste water or re-used within the plant for vehicle wash down, dust suppression, irrigation, etc.

18.6.3.7 Fire Water and Potable Water

A fire water and potable water station will be installed with storage tanks for both purposes.

19 Market Study and Contracts

The present section is based on an in-depth review of the “Silicon and Ferrosilicon” market report from Roskill Information Services, as referenced in Sections 1.1 and 27 of this PEA. Whenever appropriate other credible and renowned market sources are referred to substantiate conclusions and certain aspects. These are disclosed in the respective footnote as well as in the reference section of this report (Section 27).

This section starts with a brief description of the respective end-markets for both, metallurgical grade silicon and ferrosilicon (Section 19.1), after which a detailed analysis of the supply- and demand- side for both market segments follows in Section 19.2 and Section 19.3, respectively.

A synthesis of the potential supply and demand is provided in Section 19.4, followed by an overview on pricing trends and typical contractual arrangements (Section 19.5). The subsequent section elaborates on the institutional trade environment with a specific focus on North America, CME’s likely target region (Section 19.6), while Section 19.7 gives a brief review of the findings in context of the proposed Hybrid Flex Plant (HFP) in Matane City, Québec, Canada.

19.1 Global Market Drivers

Metallurgical silicon is principally used in the chemical-, aluminum-and the photovoltaic- / semiconductor sectors. Other side industries also make up the market such as steel producers, concrete manufacturers, refractory producers, etc., but these are overall insignificant and depend on by-products or off-grade production capabilities.

The by-products such as micro silica bring relevant importance for the plant market positioning and also would generated revenue from the commercial operations of this material (normally selled for concrete and refractory industries).

A distinctive and relevant factor of the mgSi market is its broader end-market exposure when compared to ferrosilicon which provides both diversification and leverage to higher growth applications such as photovoltaics.

The ferrosilicon market in contrast is commonly segmented by its end-usage as alloying-, additive- and inoculation compound for steel-, iron- and magnesium production. These three FeSi application segments account for 99% of the global demand for FeSi of which the steel industry consumes the vast majority, comprising 64% of the total global FeSi consumption in 2013.[18] The relative ferrosilicon consumption share for cast iron products stood at 25% in 2013, while 10% was consumed for the production of magnesium (Mg).[19]

19.1.1 mgSi end-usage markets

Since its early-stage evolvements beginning in the mid-20th century, the industry has become a staple raw material for everything from consumer goods to photovoltaic devices. The use of mgSi has increased in the past decades at a pace that exceeds GDP growth. This can be explained by the diverse nature of the use of the material in everything from consumer goods to construction materials to electronics to aluminum. An additional explanation can be attributed to the fact that as consumer goods and quality of life increases for the middle class, many of the goods consumed or used by this rapidly growing demographic happen to be high in silicon containing products. The addition of the move toward renewables and the respective impact these energy sources have on silicon, one can easily see that the future for mgSi is encouraging.

The diverse end-market exposure of mgSi leads to divergent demand drivers for the consumption of this alloying element and raw material:

- Aluminum: The automotive sector is the largest driver for mgSi via its consumption of aluminum alloy castings. The percentage of aluminum (and thus silicon) in automobiles continues to grow and the transition toward a higher reliance on secondary aluminum feedstock will further add demand for mgSi.[20] The price of mgSi

18 Roskill Information Services Ltd. (2014), pp 140-141

19 Roskill Information Services Ltd. (2014), p. 198

20 The continued need to improve fuel efficiency levels in the automotive industry leads to the substitution of heavy- with light-weight components, such as alloyed Al.

compared to the final aluminum casting is low, e.g. silicon is not a significant cost-driver.

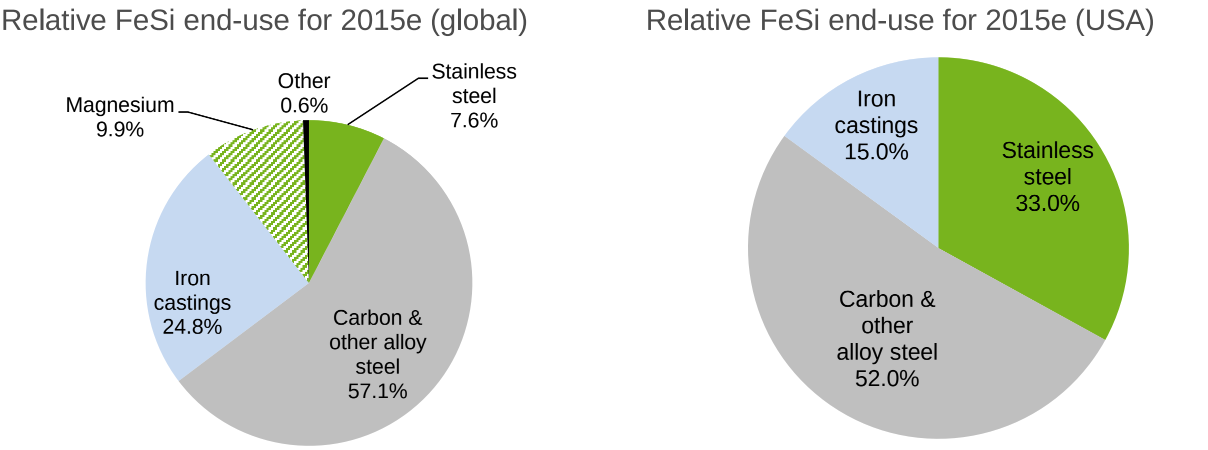
- Chemicals: Directly a function of construction and consumer goods demand. The price of mgSi compared to the cost of the final chemical product is very low.
- Polysilicon: Primarily related to PV and is expected to continue on strong growth curves as PV enters non-subsidized markets, meaning that levelized cost of electricity (LCOE) is financially more attractive than other sources of electricity generation. With continued cost reduction efforts the impact of mgSi on poly-Si unit costs is constantly increasing.

19.1.2 FeSi End-usage Markets

FeSi is being consumed in steel-, cast iron- and manganese production processes. The steel industry is by far the biggest end-market for FeSi producers, absorbing roughly 65% of global FeSi demand in 2013 to 2015. The overall compounded ferrosilicon consumption growth of almost 6% over the past 15 years is mainly a result of the infrastructure investment boom in China and other emerging markets, which led to a corresponding increase in the demand for steel products.

Figure 130 gives an overview for the relative distribution of FeSi consumption for its different end-uses. Two breakdowns are provided, one for the global and one for the USA specific consumption, as the latter would be a prospective major end-market in case that the HFP would switch all or partial capacity to the production of FeSi. Both pie charts use 2015 as the base reference year. The comparison reveals that roughly 85% of the ferrosilicon is being consumed for the production of stainless and carbon steels in the USA, while on a global basis this combined share stands at circa 65%. The discrepancy in the shares is a result of the relative unimportance of iron casting and a consequence of the fact that no magnesium is being produced based on FeSi in the USA. Almost all of FeSi used in Mg production is consumed in China.

Figure 130: Distribution of FeSi end-use markets



Source: Roskill Information Services Ltd. (2014), MetalBulletin Research (Nov. 2015), Viridis.iQ GmbH

19.2 Global Production Capacity Distribution

This section provides an overview on the capacity distribution by region, individual smelter sites and companies for the mgSi (Section 19.2.1) and FeSi (Section 19.2.2) markets, respectively. This section concludes with a brief comparative assessment and discussion of CME's prospective capacities under the hybrid-flex plant concept for both market segments (Section 19.2.3).

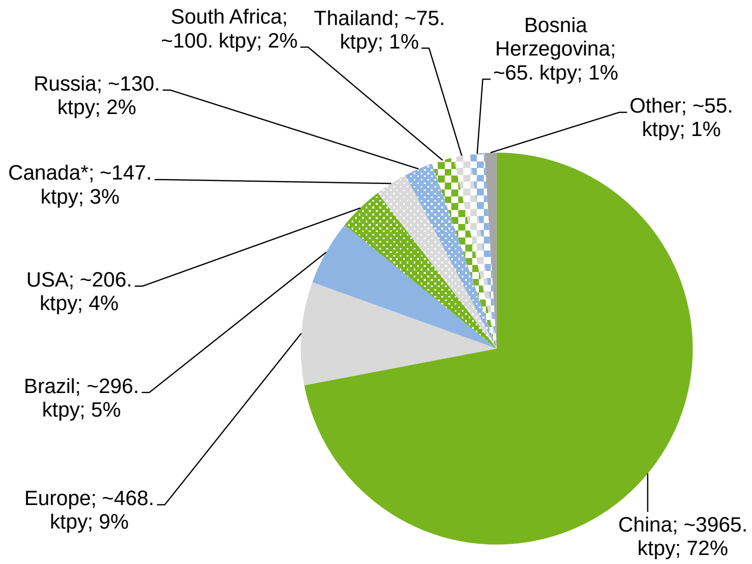
The global geographic distribution of production plants for metallurgical grade silicon and ferrosilicon is typically a function of three factors: First, the availability of low (and clean) electric energy, second, accessibility to low-cost ore and third, access to local and regional off-takers within the respective processing industries introduced in Sections 19.1.1 and 19.2.2. While the second factor is typically a function of the natural abundancy and therefore the scarcity price of the specific mineral, which in the case of silicon-based alloys is not the major determining factor,[21] the latter is typically a result of both, the region's attractiveness to energy intensive industries and the global institutional trading environment for silicon alloys.

21 De Linde, Jorn P. (2001), p. 60

19.2.1 mgSi Production Capacity Distribution

The number of global metallurgical silicon smelter sites is comparatively large, however, not to the same extent as it is the case for ferrosilicon (compare Section 19.2.2). The Roskill Study provides a detailed profile on 77 mgSi smelter sites and estimates that an additional 165 smelters are located in China with a sub-optimal average scale for each production location of below 14ktpy. Hence, the total number of mgSi smelter sites worldwide exceeds 240, of which over 80% or almost 200 sites are based in China. On a capacity basis the report estimates that almost 3,965ktpy out of a total projected global production capacity of 5,581ktpy is located in China or approximately 71% of the total mgSi production capacity worldwide. Figure 131 provides a breakdown for the top ten regions with the respective absolute and relative capacity shares[22]:

Figure 131: mgSi production capacity distribution by region (2013)

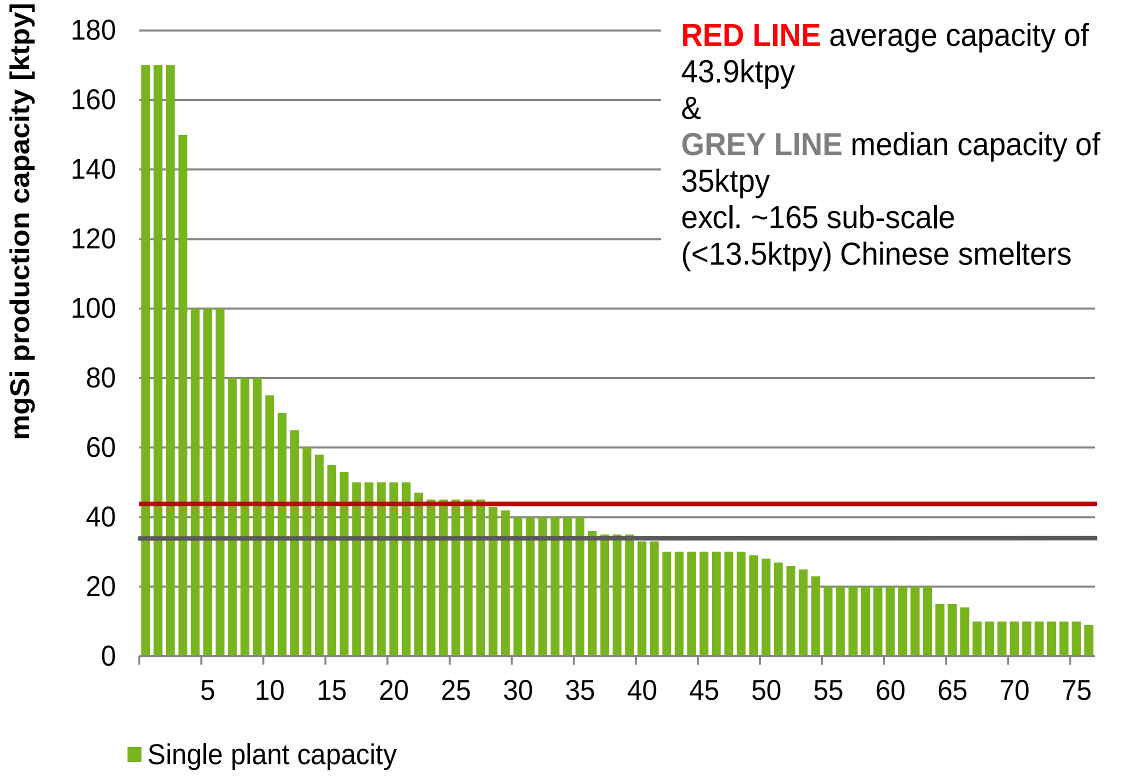


Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

22 The capacity figures of Figure 131 also include projects under development, e.g. in Iceland or the announced 100ktpy mgSi plant of Ferroatlantica SA in Québec, Canada. The latter mgSi smelter development project in Port Cartier has been cancelled on the 16th of Dec., 2015; compare: http://www.newswire.ca/fr/news-releases/la-nouvelle-dynamique-du-marche-force-ferroatlantica-a-renoncer-a-son-projet-de-port-cartier-562681031.html

While on a regional basis the capacity is highly concentrated in China, on an individual smelter site micro level the absolute number of market participants is high. Again, this could lead to the false perception that the mgSi supply-side resembles a state of nearly perfect competition which in reality is not the case as the distribution of production capacity over different smelter sites reveals:

Figure 132: Global mgSi production site ranking by single plant capacity



Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

The global site specific mgSi capacity distribution graph (Figure 132) shows that only 28 smelters exceed the average mgSi capacity of ~44ktpy and 37 single locations exhibit a production capacity above the median of 35ktpy. The computations of the simple statistical metrics are based on a universe that excludes the large number of 165 low-scale Chinese players.

Hence, even though the mgSi market is characterized by a large number of participants, the market is also concentrated around a relatively small number of larger production sites, indicating that a certain level of concentration exits and that scale does matter.

While the dispersion between higher scale and median scale mgSi sites is not as pronounced as it is in the ferrosilicon segment, there is nevertheless a skewed distribution towards higher scale producers.

Strikingly, out of the top-five production sites only one is not based in China and this site is not even operational as it is currently still under development. The list below provides an overview on the top-five production sites as shown in Figure 132:

- Hubei Sanxin – Hubei, China, with an estimated production capacity of 170ktpy
- Gansu Sanxin – Gansu, China, with an approximate nameplate capacity of 170ktpy
- Xinjiang Hesheng – Xinjiang, China, with a nameplate production capacity of 170ktpy
- Guizhou Shibing Hengsheng – Guizhou, China with a projected production capacity of approximately 150ktpy
- Ferroatlantica SA – Québec, Canada, with a prospective nameplate capacity of 100ktpy if development proceeds as announced. This project has been cancelled on the 16th of Dec. 2015, during the compilation of the PEA. As a consequence, the top-five capacity ranking of individual smelter sites remains to be dominated by Chinese players, with Zhejiang Kaihua Yuantong Silicon and Maoxian Panda Silicon, sharing number 5 position with production capacities of approx. 100ktpy, each.

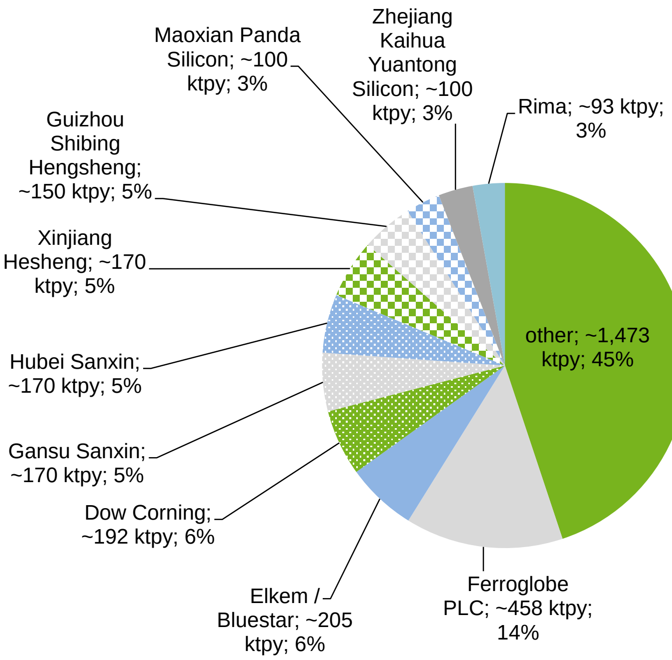
As some producers own and operate multiple sites a capacity based comparative assessment on individual producers yield valuable insights as regards to company specific economies of scale. Figure 133 shows the global distribution of producer specific manufacturing capacities.

The breakdown excludes 165 sub-scale Chinese manufacturers. While the top-five capacity ranking for single production sites is dominated by Chinese players, the top-five ranking on the producer level yields a slightly different picture.

The three leading mgSi manufacturers are either Western companies or have a Western origin. These companies are Ferroglobe PLC, Elkem / Bluestar and Dow Corning Inc. In total the top-ten control slightly above 50% of the global manufacturing capacity (excl. capacity from sub-scale Chinese smelters) while the remaining 47 mgSi producers control less than 50% of the global production capacity.

On Dec. 23rd of 2015, Grupo FerroAtlántica and Globe Specialty Metals Inc. announced, that the two companies finalized the merger which was announced in February of 2015, after both companies received all necessary regulatory clearances and approvals. The new entity is called Ferroglobe PLC with headquarters in London, UK and a public listing on the NASDAQ.[23]

Figure 133: Capacity breakdown for top-ten mgSi producers



Source: Roskill Information Services Ltd. (2014), data compiled and modified by Viridis.iQ GmbH

While there is certainly a tendency towards concentration in the metallurgical silicon market, the top-ten producer ranking in this segment is more evenly distributed as compared to the FeSi market. The dispersion from low to high capacity within the top-ten mgSi producer list is

23 Compare press release from 23rd Dec., 2015: http://investor.glbsm.com/releasedetail.cfm?ReleaseID=948109

not as pronounced as it is the case for the top-ten ferrosilicon producers. The scale of the leading mgSi company,

Ferroglobe PLC with a capacity of nearly 458ktpy is only 4.9 times higher than the capacity of the tenth largest mgSi producer, with a scale of 93ktpy. In comparison, in case of the ferrosilicon producer ranking the same multiple stands at roughly 11.25.

While there are –at least to some extent– similarities between the ferrosilicon- and metallurgical-silicon supply structure, e.g. large number of production sites and players, regional concentration levels, significant number of sites with sub-optimal scale and questionable economics as well as regards to the relative importance of the top-ten producers, there are also some important nuances: First, while the number of contestants is high in both segments, the number of ferrosilicon smelter sites (>1,120) exceeds the number of metallurgical silicon facilities (>240) by a factor greater than 4.5. Second, the composition of the leading group of top-ten producers is more homogeneous in the metallurgical silicon segment, e.g. not a single player is dominating the sub-group.

As the producer capacity distribution shows (compare Figure 133 & Figure 136), the top-ten metallurgical silicon producers have more evenly distributed capacity shares which points to a more oligopolistic market structure.

Further, the threshold level that allows a new entrant to become a member of this distinct quasi-oligopoly with meaningful market share stands at 93ktpy, which is below the respective threshold in the ferrosilicon market arena.

19.2.2 FeSi Production Capacity Distribution

The global ferrosilicon production base is in comparison significantly larger with over 1,110 smelter sites recognized by ferroalloy market research firms such as Roskill or CRU. The overwhelming majority of these smelter sites are located in China (>1,020) of which almost

1,000 have a sub-optimal plant capacity of below 10ktpy.[24] The second biggest country in terms of number of FeSi smelter sites is India which has “at least 30” production sites, “the vast majority with an annual production capacity of below 10ktpy.”[25]

Consequently, the focus of the Roskill ferrosilicon market report is placed on capacities in excess of the aforementioned 10ktpy threshold, an approach that is deemed rational and followed in the present PEA.

The regional concentration of production capacity in China is a direct consequence of the country’s infrastructure investment boom over the past one to two decades. These infrastructures related investments led to a rise in steel demand and a corresponding need for alloying materials.

Chinese manufacturers responded with an unforeseen capacity expansion spree that brought China’s global capacity share to approximately three-quarter in 2013. This regional distribution is expected to have not changed significantly as the underlying data already reflects OMH Holding’s capacity from its Malaysian mega FeSi Greenfield facility, which has gradually been ramping-up over the past 12 months.[26]

Figure 134 provides a top-ten capacity breakdown by region. For each market the cumulated capacity is given in absolute and relative terms. As can be seen, the second and third biggest regions (Russia and Europe) provide a capacity share of approximately 5% each, with a cumulated production capacity of roughly 755ktpy and 740ktpy, respectively.

The capacity based domination of the FeSi world market by Chinese producers led to the aforementioned implementation of trade barriers in various regions.

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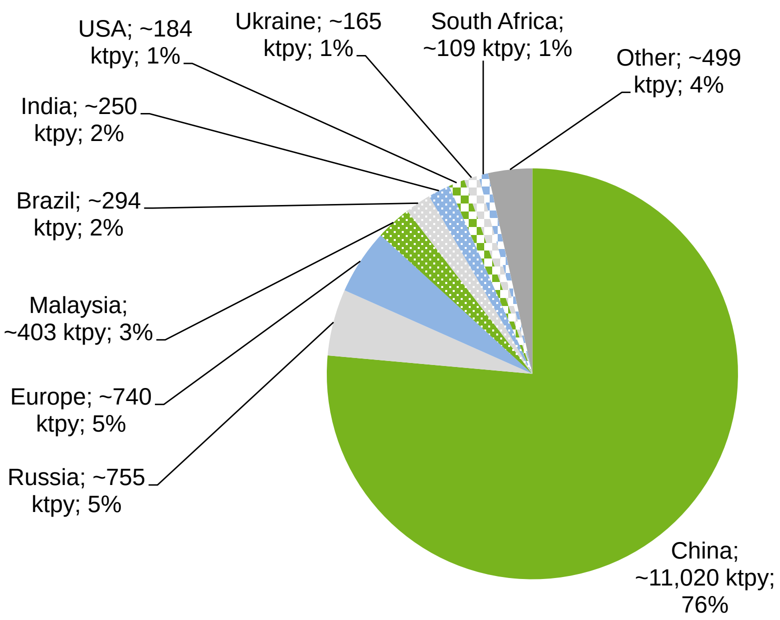
24 Roskill Information Services Ltd. (2014), p. 81; Table 23 of the report lists major ferrosilicon producers in China and states that roughly 1,000 additional producers command a cumulative capacity of an estimated 8,300ktpy which equates to an avg. smelter capacity of 8.3ktpy

25 Roskill Information Services Ltd. (2014), p. 92

26 Compare “September 2014 Quarterly Production and Market Update” in which OM Holdings Ltd. discloses initial FeSi production volumes; http://www.omholdingsltd.com/news_announce14/24.pdf

Figure 134: FeSi production capacity distribution by region (2013)



Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

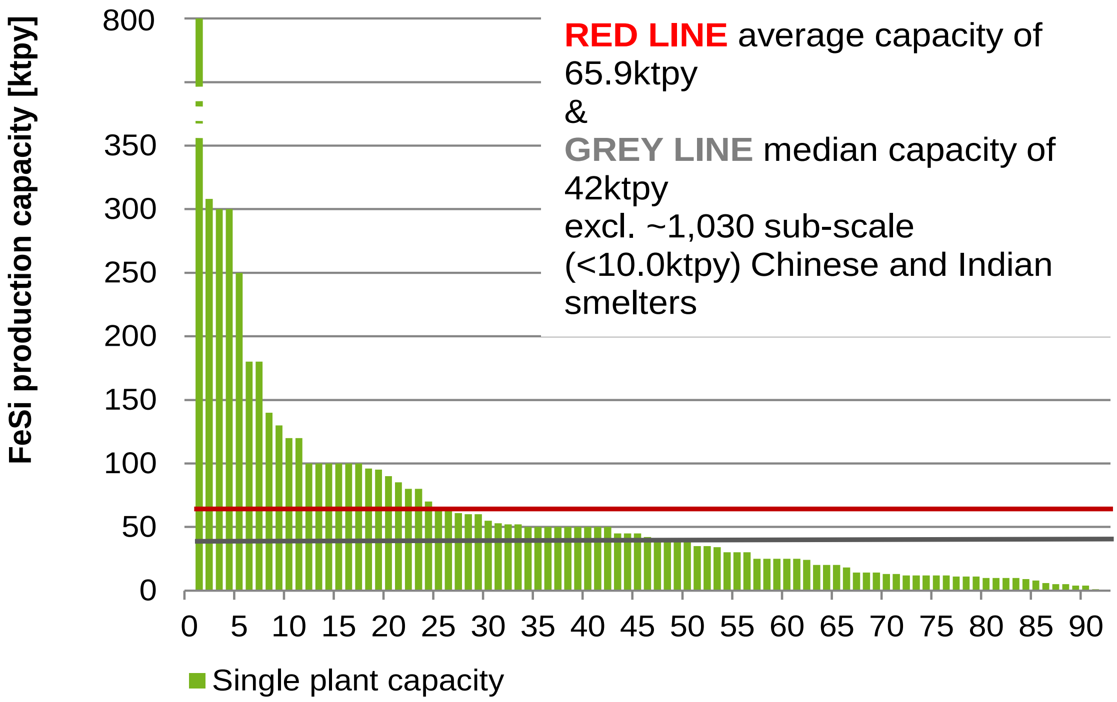
Figure 135 gives an overview of the global capacity distribution for single production sites, excluding the majority of the aforementioned sub-scale, below 10ktpy capacities in China and India. As shown in the graph, the majority of the FeSi smelter sites have a production capacity of below 50ktpy with a median capacity of 42ktpy. The global average capacity of single smelter sites based on the same universe with 91 constituents stands at 65ktpy, significantly skewed upward by the following 5 mega-sites with annual capacity in excess of 200ktpy:

- Erdos Metallurgy Group – Inner Mongolia, China, with an estimated production capacity of 800ktpy
- OM Holdings Ltd. – OM Sarawak, Malaysia, with nameplate capacity of 308ktpy. The authors of this PEA categorize this smelter as operational. The plant is in the ramp-up phase according to a trading statement from July 2015[27]

27 According to a trading statement with the ASX Group (Australian Securities Exchange) from 30th of July 2015, the site produced a total of 16,294 tons of ferrosilicon during the 2nd quarter 2015; http://www.omholdingsltd.com/news_announce15/11.pdf

- Russian Ferro Alloys (RFA) – Novokuznetsk, Russia, with a production capacity of 300ktpy
- Erdos Metallurgy Group – Quinghai/ Baitong, China, with an estimated production capacity of 300ktpy
- Erdos Metallurgy Group – Quinghai/ Wutong, China, with an estimated production capacity of 250ktpy

Figure 135: Global FeSi production site ranking by single plant capacity

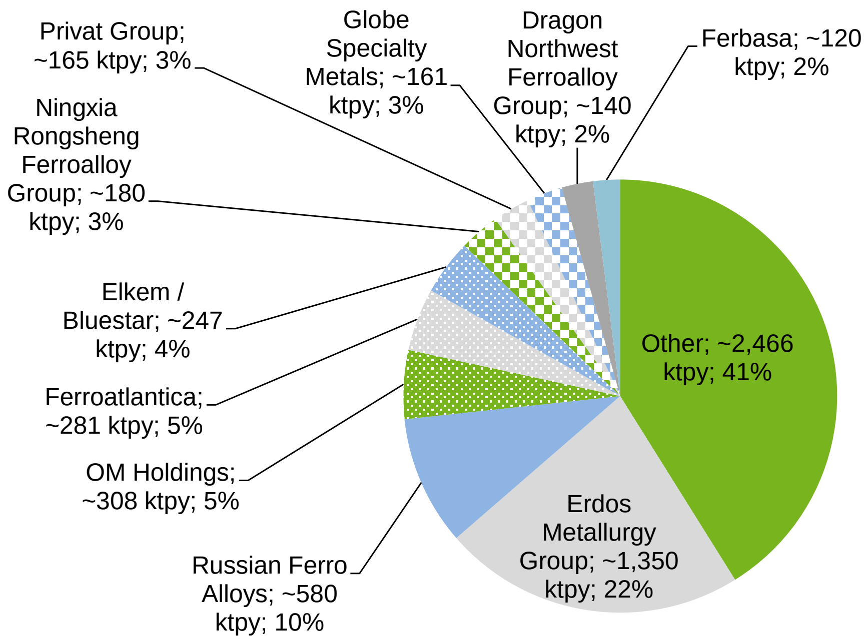


Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

A company specific capacity breakdown for the universe with 91 constituents that excludes sub-scale Chinese and Indian FeSi producers reveals that the top-ten producers roughly comprise 60% of the manufacturing capacity. The capacity range within the top-ten group is very large, reaching from 120ktpy at the low- to 1,350ktpy at the high-end. The remaining 81 producers have a cumulative capacity share of roughly 40%. The company specific distribution of manufacturing capacities mirrors to some extent the observation for the single production site ranking introduced above.

The pie chart in Figure 136 provides a capacity breakdown for the top-ten FeSi producers. Next to the company name, the estimated consolidated company specific production capacity is disclosed in absolute and relative terms.

Figure 136: Capacity breakdown for top-ten FeSi producers (2013)



Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

In conclusion, the global FeSi market is characterized by a very large number of production sites and producers. However, this situation does not constitute a state of perfect competition as concentration tendency is clearly observable, both, on a geographic and producer specific level.

19.2.3 Synthesis: Benchmarking CME's HFP Concept

The base case operating assumption for the Hybrid Flex Plant (HFP) for Phase 1 is that all three furnaces are dedicated to metallurgical silicon production only. In practice operation can be switched in one furnace increments to the production of ferrosilicon up to the other extreme case that all three furnaces of the HFP produce ferrosilicon only. For a more detailed discussion of possible configuration options see Section 17.1.2.

The analysis of the capacity ranges provided below is based on the presumption that the respective produce is manufactured either in single- or three-furnace operation mode. Hence, two furnace outputs are not explicitly modelled but can either be gauged by averaging the lower and upper bound capacity limit for each product (Phase 1) or by simply referring to the lower bound capacity exemplification for Phase 2.

As highlighted in Section 26.1.7, the developed Phase 1 layout for the Greenfield Industrial Park site in Matane is designed such that a prospective later-stage doubling of capacity to a 6-funace smelter site can be accommodated.

The implications on potential production capacities for mgSi and FeSi in dual- and single-product operation mode for both phases are outlined in more detail as follows:

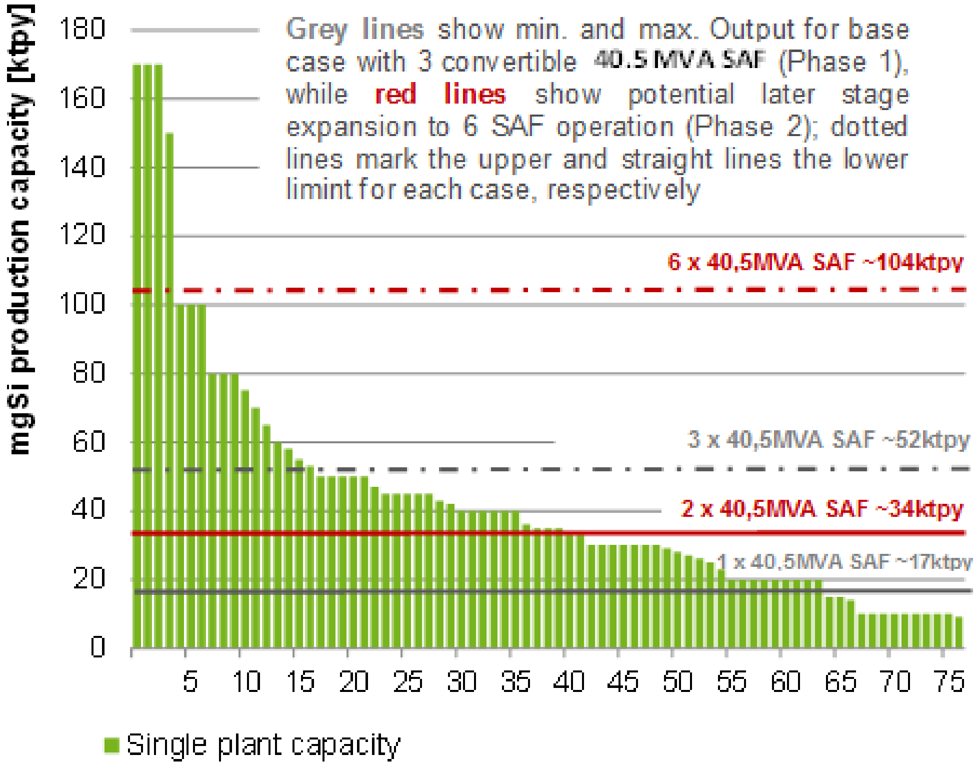
Figure 137 shows how the potential mgSi production capacities would compare to the international competition under different operation and phasing scenarios. Even though, a single furnace or two furnace operations is currently not foreseen, lower boundaries for possible mgSi production capacities are established by referring to the hybrid operation case.

As indicated by the respective hypothetical capacity lines the potential mgSi output varies between ~17 and ~52ktpy, depending whether one- or three-furnaces produce metallurgical grade silicon in Phase 1 (grey lines).

This constitutes a capacity rank within the 4th to 1st quartile of a global peer-group of mgSi smelter sites. For Phase 2 the potential mgSi output would vary between ~34 and ~104ktpy, if two- (hybrid-operation) or six-furnaces (single product operation) are dedicated to metallurgical silicon production (red lines).

Again, the vast majority of the previously mentioned sub-scale Chinese smelters (<14ktpy) have been omitted from this analysis, making the comparative ranking more conservative and meaningful.

Figure 137: Comparative capacity benchmark CME vs. competition – mgSi



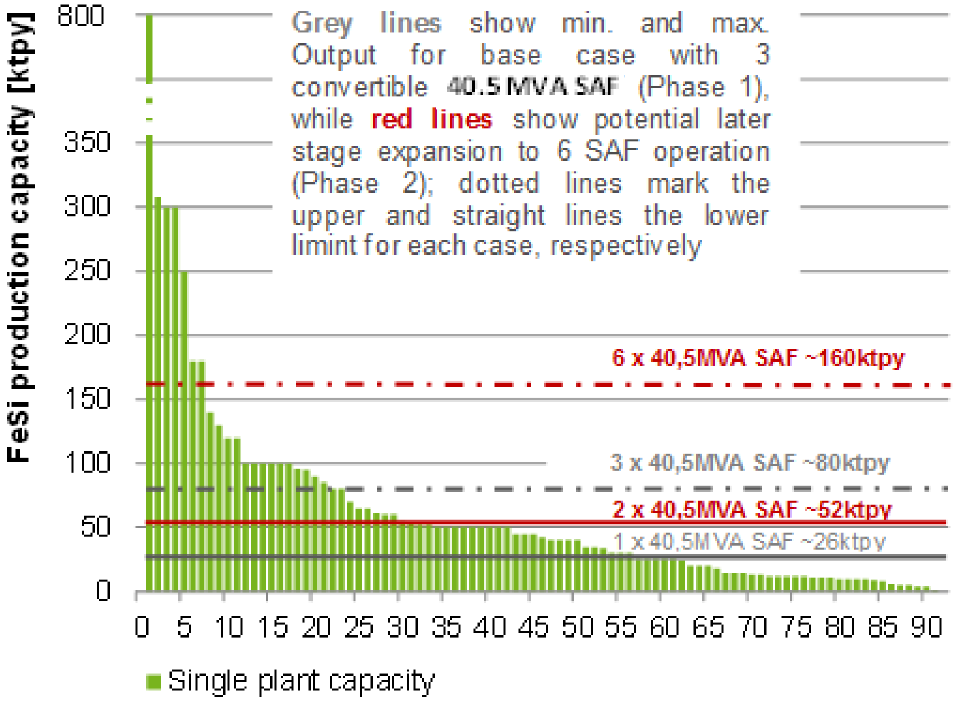
Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

Figure 138 shows how CME's HFP ferrosilicon capacity would compare to the international competition under different operation and phasing scenarios. As depicted in the graph, the potential capacity or output at 100% utilization varies between ~26 and ~80ktpy, depending whether one- or three-furnaces produce ferrosilicon (grey lines).

This constitutes a capacity rank within the 3rd to 1st quartile of a global peer-group of ferrosilicon smelter sites. The potential ferrosilicon capacities for Phase 2 based on a dedicated two- and six-furnace ferrosilicon operation are depicted by the red lines.

Again, previously mentioned sub-scale Chinese and Indian smelters (<10ktpy) have been omitted from this analysis.

Figure 138: Comparative capacity benchmark CME vs. competition – FeSi



Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

The results of the comparative capacity benchmarking are listed in Table 61. The rankings for the base-case reveal that CME's HFP would be a 3rd quartile FeSi and 2nd quartile mgSi producer, while most likely being capable to reach purchasing power advantages that can match 1st quartile smelter sites as indicated by capacities. Procurement advantages from scaling are a direct consequence of material sourcing synergies, as both products utilise to a great extent the same resources.

Table 61: mgSi and FeSi capacities for various operation and phasing models

	Phase 1		Phase 2	
	1 Furnace	3 Furnaces	2 Furnaces	6 Furnaces
		potential capacity		
FeSi	~26ktpy	~80ktpy	~52ktpy	~160ktpy
mgSi	~17ktpy	~52ktpy	~34ktpy	~104ktpy
		peer-group ranking		
FeSi	3rd quartile	1st quartile	2nd quartile	top 10
mgSi	4th quartile	1st quartile	3rd quartile	top 10

Source: Viridis.iQ GmbH

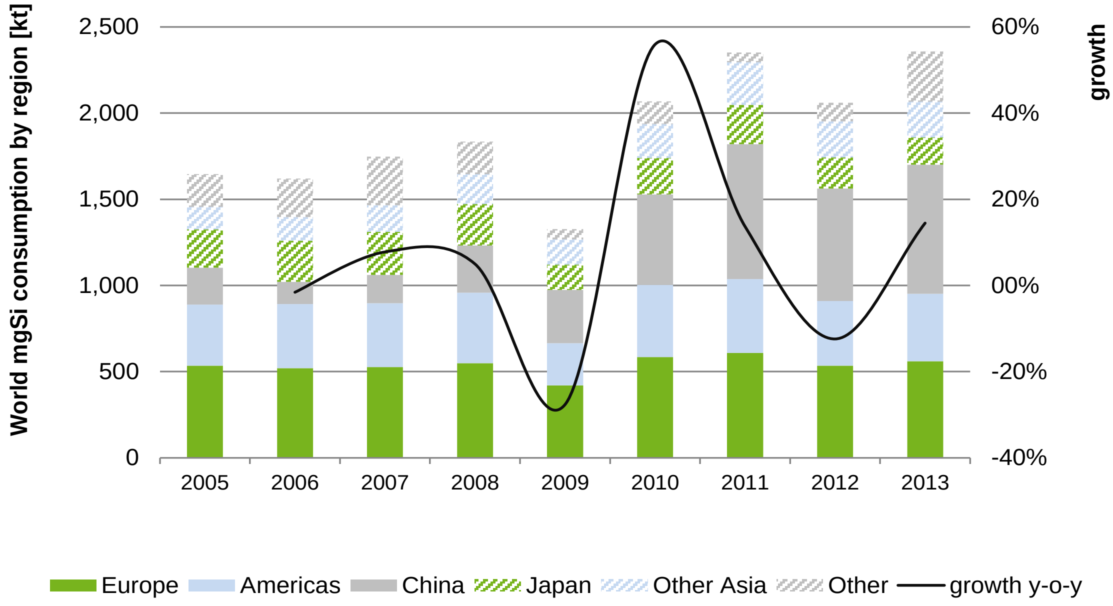
19.3 Global Demand by Region and Application

This section gives a detailed overview of the historical demand composition by region and application for mgSi and FeSi in Sections 19.3.1 and 19.3.2, respectively. Section 19.3.3 provides a more detailed discussion on the market dynamics in Canada and the USA, two of the main potential off-take markets for the CME's prospective HFP output.

19.3.1 Global Demand Profile mgSi

The regional distribution of the annual mgSi consumption is depicted in Figure 139 for the period from 2005 to 2013. While there has been also an increase in the relative consumption of mgSi in China and other emerging markets in Asia, the shift from Western to Asian off-takers has not been as pronounced as it has been the case in the ferrosilicon market. The mgSi quantity consumed in China increased by an annualized rate of 17.0%, while the consumption in the prospective target markets of CME, namely the Americas and Europe, increased by a more moderate CAGR of about 0.8%. The latter regions consumed roughly 40-50% of the global mgSi output, while Chinese consumption share fluctuated between 25-35% over the same period from 2010-2013.

Figure 139: Historical apparent mgSi consumption by region



Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

The major drivers for mgSi demand are the aluminum-, silicone- and photovoltaic industries as elaborated in previous sections. The consumption of mgSi in these end-applications is cyclical as they are influenced by a multitude of socio-economic and technological factors. Nevertheless, the market researchers from Roskill estimate the following compounded annual growth rates (CAGR) for the period from 2000-2013 and make a projection for the period from 2013-2019:[28]

- Aluminum: Historical CAGR 2000-‘13 ~3.1% & projected CAGR 2013-‘19 ~3.7%
- Silicones: Historical CAGR 2000-‘13 ~4.8% & projected CAGR 2013-‘19 ~3.9%
- PV/ Semiconductors: Historical CAGR 2000-‘13 ~17.0%* & projected CAGR 2013-‘19 ~8.3%
- Total mgSi market: Historical CAGR 2000-‘13 ~5.0%* & projected CAGR 2013-‘19 ~4.2%

28 CAGR rates marked with the asterisk sign are not explicitly mentioned in the Roskill report. These have been deduced from reported volumes, growth rates and market share estimates as provided in the text. See also Roskill Information Services Ltd. (2014), p. 2-3

The mgSi market projections by end applications do often vary as a consequence of differing market scenarios for the higher value-add silicone and PV industries. The estimates in Figure 140 are based on a composite of CRU estimates as presented at the CRU Silicon Forum in November 2015[29] and ViQ projections for the c-Si PV market segment.

As can be seen the compound annual growth rates for the individual mgSi end-usage applications and forecast period up to 2020 vary such that the Aluminum based mgSi consumption is expected to increase moderately, while the silicone and PV related demand is expected to increase more dynamically in direct comparison to the Roskill projections introduced above. In specific, the underlying projected CAGR's for the mgSi consumption in the respective end-markets are as follows:

- Aluminum: Projected CAGR for 2014-'20 of approximately 2.9%
- Silicones: Projected CAGR for 2014-'20 of ca 4.5%
- PV/ Semiconductors: Projected CAGR for 2014-'20 of ca 9.4%
- Total mgSi market: Projected CAGR for 2014-'20 of approximately 5.0%

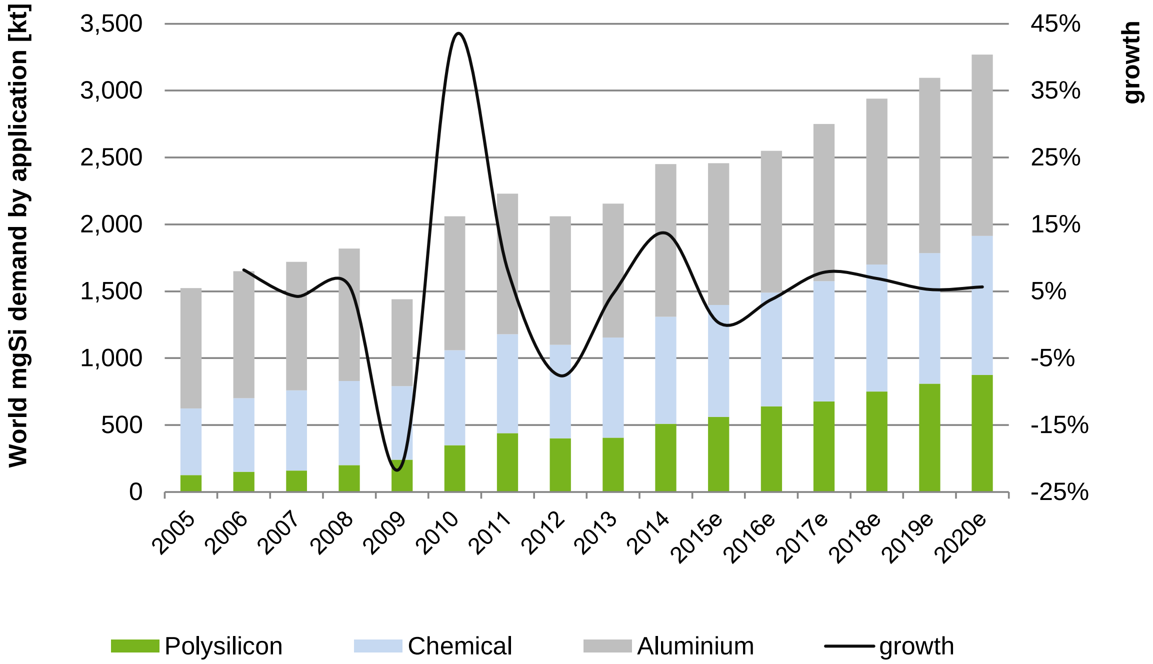
As already highlighted, the slightly higher CAGR expectation for mgSi demand growth leading up to the year 2020 is a direct result of the renewable energy investment boom and in particular a consequence of promising PV market installation growth expectations. While still the smallest mgSi end market, the relative consumption of mgSi within the polysilicon industry is expected to increase from approximately 20% in 2015 to an estimated 27% share in 2020.

Therefore, the increasing attractiveness and sustainable economics of PV power plants within the global power generation mix lead to a corresponding material need for top-quality polysilicon and hence, higher grade mgSi.

This transformation of the energy supply infrastructure is a secular trend which is expected to last well into the future and keep on supporting mid-single digit growth rates within the metallurgical silicon industry.

29 De Linde, Jorn P. (2015) p.18

Figure 140: mgSi consumption by end-market consumpion - absolute



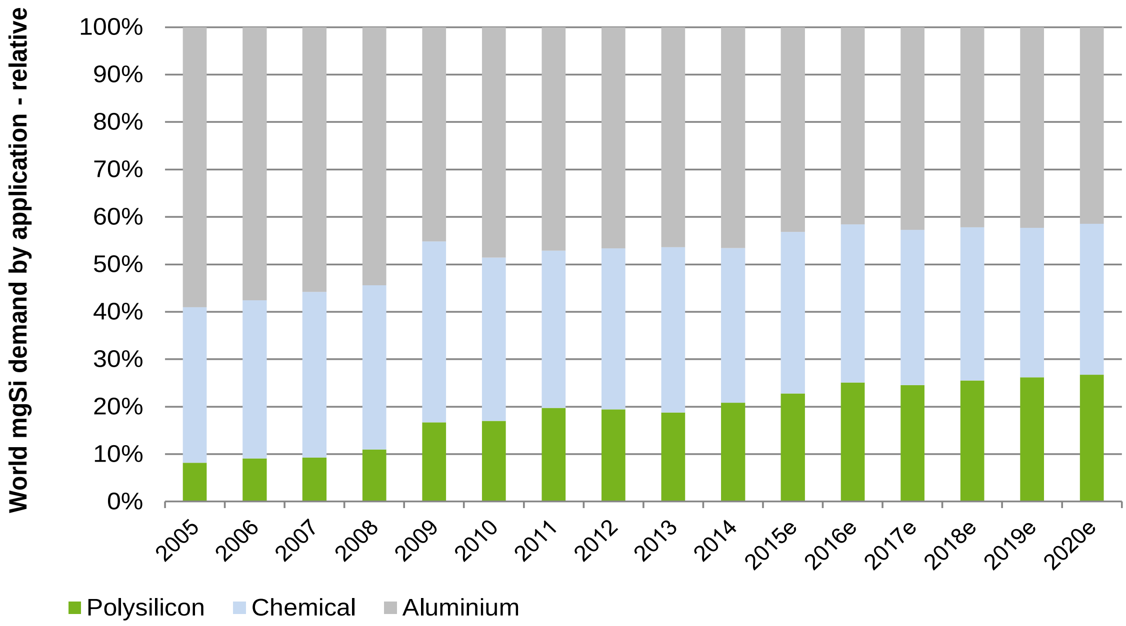
Source: CRU (Nov 2015), Viridis.iQ GmbH estimates

The development of the relative end-usage shares (or sales channels) for the mgSi market over the time period from 2005 to 2020 are depicted in Figure 141.

The relative annual shares of material processed in the silicone industry remained or are expected to remain relatively constant throughout the survey and projection periods, fluctuating within a bandwidth of 30-35%. The relative increase in the material consumption within the polysilicon industry largely led to a suppression in the importance of the Aluminum industry, in relative terms. While in 2005 roughly 60% of the total mgSi demand was processed in the Al industry, this share has been declining ever since, reaching approximately 49% in 2010 and is expected to decrease further to the lower 40%-age range in the period from 2015-2020. While the Al industry will still be the single biggest off-taker for mgSi producers at this point time, the potential higher value-add end-usages of mgSi in the silicone and PV industries will reach a combined share of almost 60%.

This end-market development has important implications for the operation and marketing strategy of the HFP concept.

Figure 141: mgSi consumption by end-market consumpion - relative



Source: CRU (Nov 2015), Viridis.iQ GmbH estimates

19.3.2 Global Demand Profile FeSi

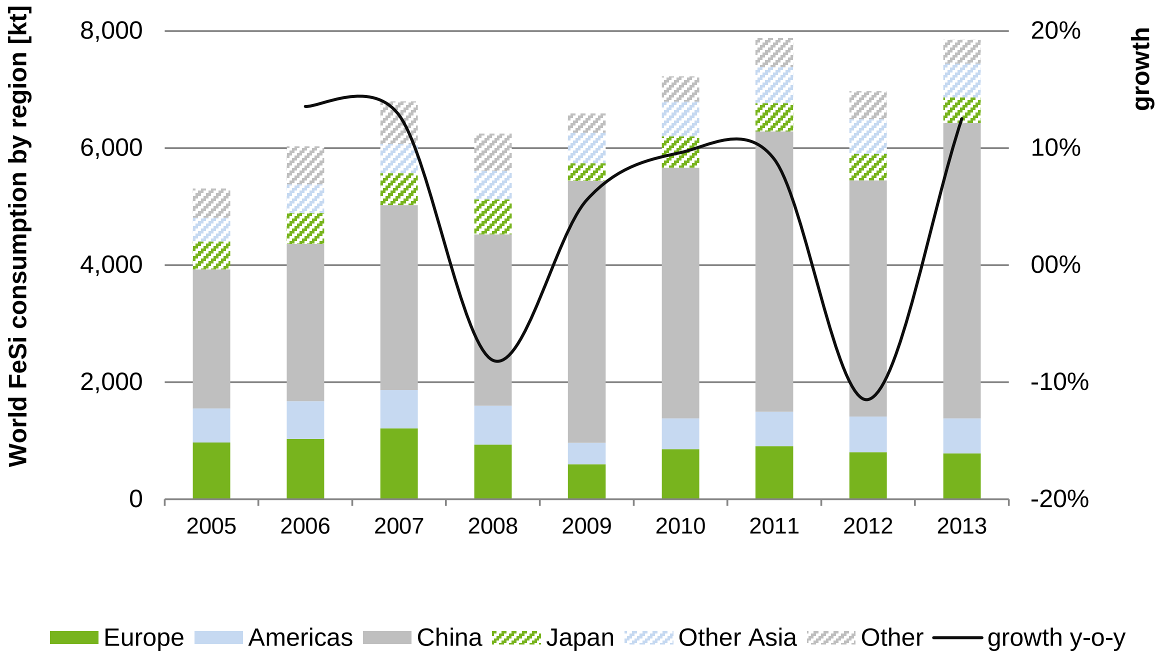
The regional distribution of the apparent consumption of ferrosilicon has shifted from Western markets to Chinese and other Asian markets over the past decade. As the vast majority of FeSi75 is consumed in steel production (>60%) this shift in regional consumption patterns for ferrosilicon can be traced to the secular West-East-Shift of the steel industry.[30]

Figure 142 provides a geographic breakdown of FeSi apparent consumption for the period from 2005-2013. Total global apparent consumption of FeSi75 increased by a CAGR of 5.0% from ca 5,300ktpy in 2003 to >7,800ktpy in 2013. As can be seen, the consumption in China increased more than two-fold, while the second biggest consumers are other Asian countries

30 Apparent consumption is deduced from export and import trading statistics and therefore does not reflect changes in the inventory stock for the respective region. The Roskill report provides a global consolidated “reported consumption” figure which incorporates annual changes in inventory. The reported consumption figure is provided on worldwide basis without a breakdown by geographies.

excluding China. In the other regions, demand either stagnated or declined over the same assessment period. While the average linear annual trend growth of FeSi consumption was approximately 5.0%, annual changes in apparent consumption fluctuated between -12.0 and 14.0%.

Figure 142: Historical apparent FeSi consumption by region

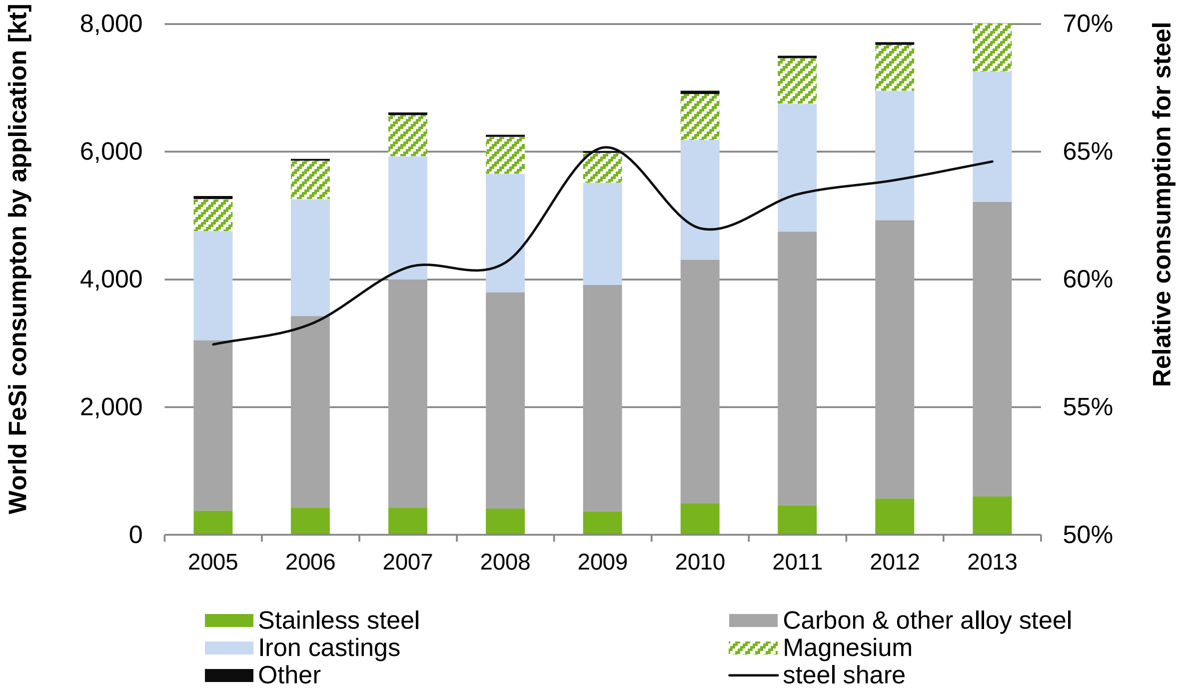


Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

The reported FeSi consumption breakdown by end-usage is depicted in Figure 143 for the period from 2005 to 2013. The discrepancy between the total apparent consumption as used for the geographic breakdown in Figure 142 and the reported FeSi consumption by end-usage is a consequence of global inventory fluctuations. In cases where apparent consumption is greater (smaller) than reported consumption, the aggregated world FeSi inventory decreased (increased) in the respective year.

The strong and increasing dependency of steel market related FeSi consumption is shown in Figure 143. The steel market related FeSi consumption share for the individual years is depicted on the secondary y-axis. The share of FeSi usage for different steel products increased from ca 57.0% in 2005 to almost 65.0% in 2013. Going-forward the steel market related end-usage share of FeSi is expected to stabilize and fluctuate around the 65.0% threshold, established in 2009.[31]

Figure 143: Historical reported FeSi consumption by end-usage



Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

The major drivers for FeSi demand are the steel-, iron casting- and magnesium industries in declining order of importance. These three end-markets together consume approximately 99.0% of the global FeSi output. The changes in annual demand for FeSi have been cyclical to some degree in the period from 2000 to 2013, but by no means exhibit the same volatility as it has been the case for the mgSi demand.

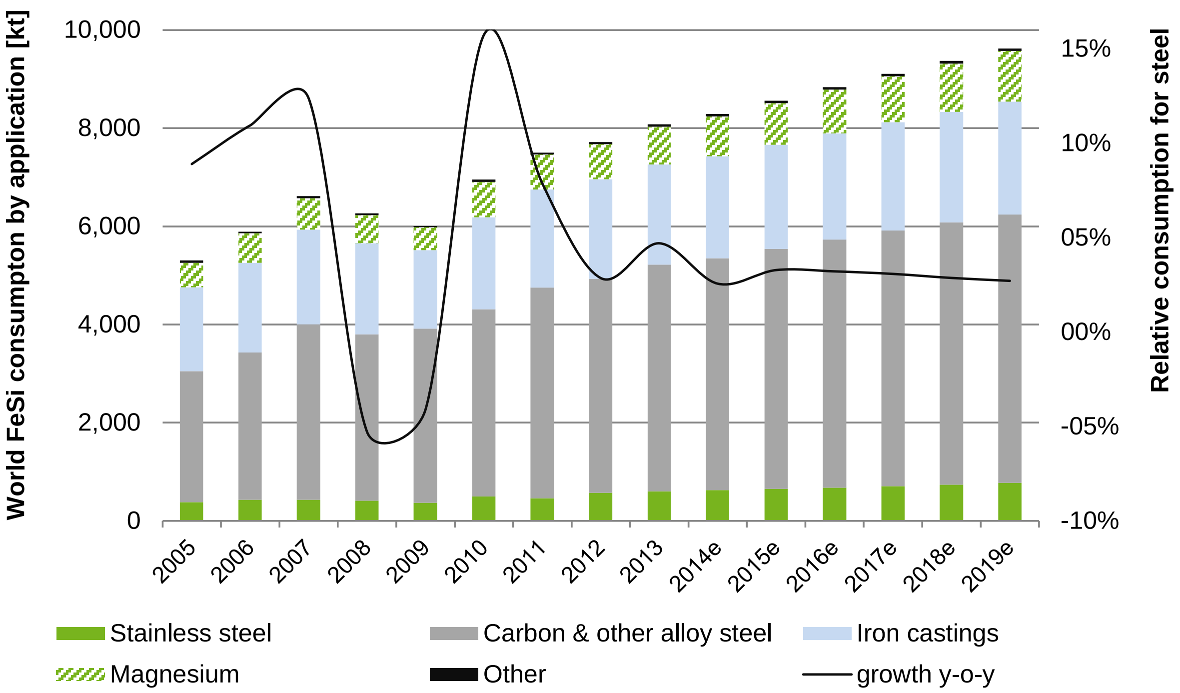
The market researchers from Roskill estimate the following compounded annual growth rates (CAGR) for the period from 2000-2013 and make a projection for the period from 2013-2019:[32]

31 Roskill Information Services Ltd. (2014), p. 274

- Stainless steel: Historical CAGR 2000-'13 ~5.6% & projected CAGR 2013-'19 ~4.2%
- Carbon and other alloy steels: Historical CAGR 2000-'13 ~7.1% & projected CAGR 2013-'19 ~2.9%
- Iron castings: Historical CAGR 2000-'13 ~3.3% & projected CAGR 2013-'19 ~2.0%
- Magnesium: Historical CAGR 2000-'13 ~13.2% & projected CAGR 2013-'19 ~5.0%
- Other: Historical CAGR 2000-'13 ~0.0% & projected CAGR 2013-'19 ~0.0%
- Total FeSi market: Historical CAGR 2000-'13 ~6.1% & projected CAGR 2013-'19 ~3.0%

Hence, total average FeSi demand is expected to increase more modestly at a compounded growth rate of approximately 3.0%, reflecting a saturation of the investment spending related steel boom in China and other emerging markets. Figure 144 shows the underlying annual FeSi demand forecast by end-use.

Figure 144: FeSi consumption by end-market consumpion - absolute



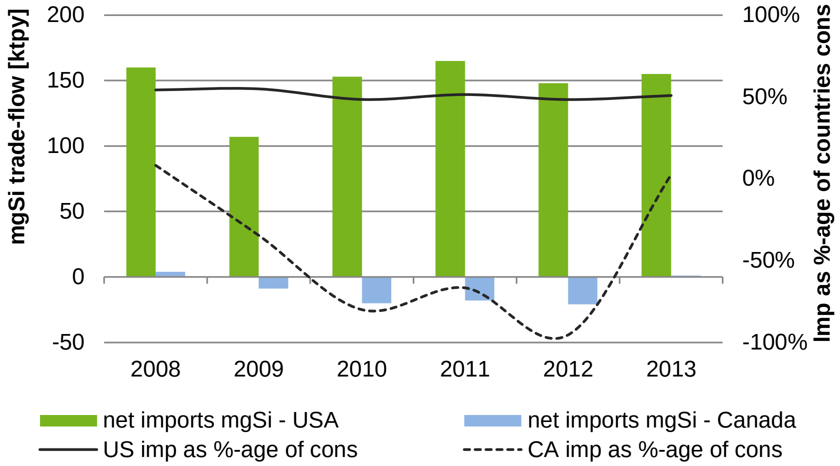
Source: Roskill Information Services Ltd. (2014), data compiled by Viridis.iQ GmbH

32 Ibid

19.3.3 Overview on Potential Off-takers in North-America

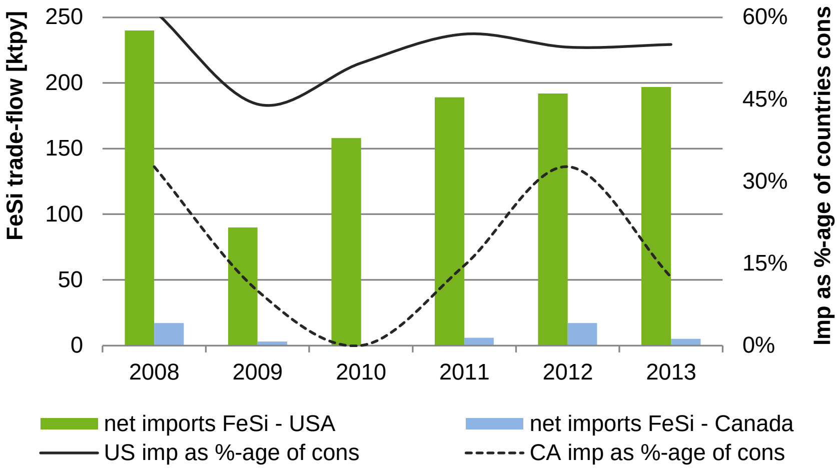
The obvious initial target markets for CME's prospective mgSi and hypothetical FeSi output are Canada and the USA. While the latter market has been a net importer of both products, the available trade flow statistics for the domestic market show a trade surplus (positive net exports) for mgSi and only a relative insignificant volume of net imports for FeSi. As depicted in Figure 145 and Figure 146, the net trade flows for both materials have been significant for both materials in the USA and constitute around 50% of the respective metallurgical grade and ferrosilicon consumption in the USA throughout the reference period.

Figure 145: Historical trade flows in USA & Canada mgSi



Source: Roskill Information Services Ltd. (2014), Global Trade Atlas, Viridis.iQ GmbH estimates

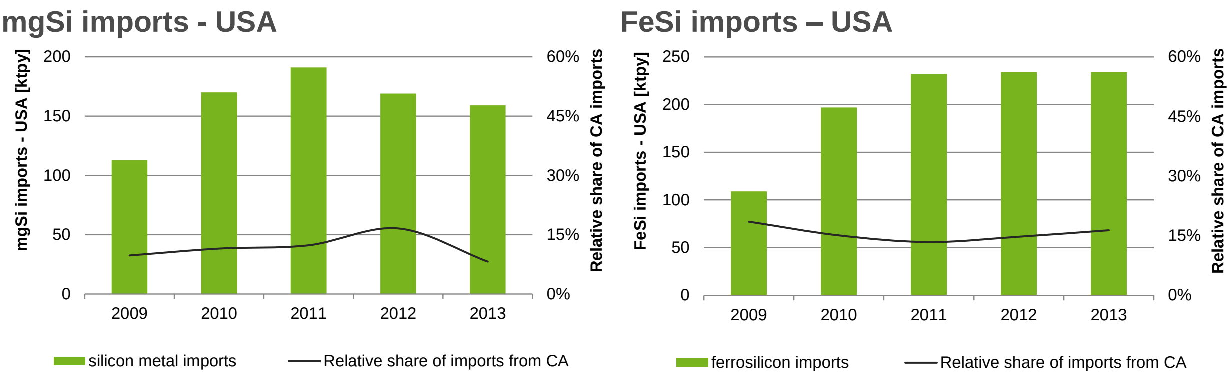
Figure 146: Historical trade flows in USA & Canada FeSi



Source: Roskill Information Services Ltd. (2014), Global Trade Atlas, Viridis.iQ GmbH estimates

Hence, the USA relies on significant volumes of foreign supply for both materials. This supply-gap could constitute a possible competitive advantage for CME's output due to both, logistic cost- and preferential trade status advantages. The last point seems to be substantiated by the fact that only a relatively small amount of imports into the USA originated in Canada over the respective reference period. As highlighted in Figure 147 the absolute annual volumes of mgSi imports into the USA fluctuated between 100-200ktpy, while FeSi imports stabilized at around 230ktpy in the recent past. In neither market segments Canadian exporters are dominant market players as evidenced by the import share which fluctuated between 8-12% and 15-20% for mgSi and FeSi, respectively. In other words, shipments from third countries excluding Canada comprise the vast majority of imports into the USA, substantiating the notion that Canadian producers have sufficient leeway for further market share gains in the USA.

Figure 147: Imports into the USA with Canadian share



Source: Roskill Information Services Ltd. (2014), Global Trade Atlas, Viridis.iQ GmbH estimates

19.4 Supply, Demand and Utilization

The mgSi and FeSi markets are mature markets in which participants closely monitor the respective dynamics and maintain a tight balance between supply and demand. Imbalances between production and demand do occur at time but are quickly stabilized by cuts in production, furnace downtime, or in more extreme cases, conversion of the furnaces to other ferroalloys. As a consequence, excessive inventory build-ups do not occur as production is closely managed according to price signals, with the highest marginal cost producers –at least in theory- providing balance capacity.

Indeed, empirical data shows that production closely tracks demand in both end-markets meaning that a large proportion of global production capacity remains underutilized to a great extent.

Sections 19.4.1 and 19.4.2 provide an overview on historical mgSi and FeSi production by region while Sections 19.4.3 and 19.4.4 investigate Chinese and Non-Chinese utilization levels for both, the mgSi and FeSi markets. Here, simple macro-utilization levels are derived by dividing the production output for a specified time period and region by the potential nameplate production capacity for the respective region and time.

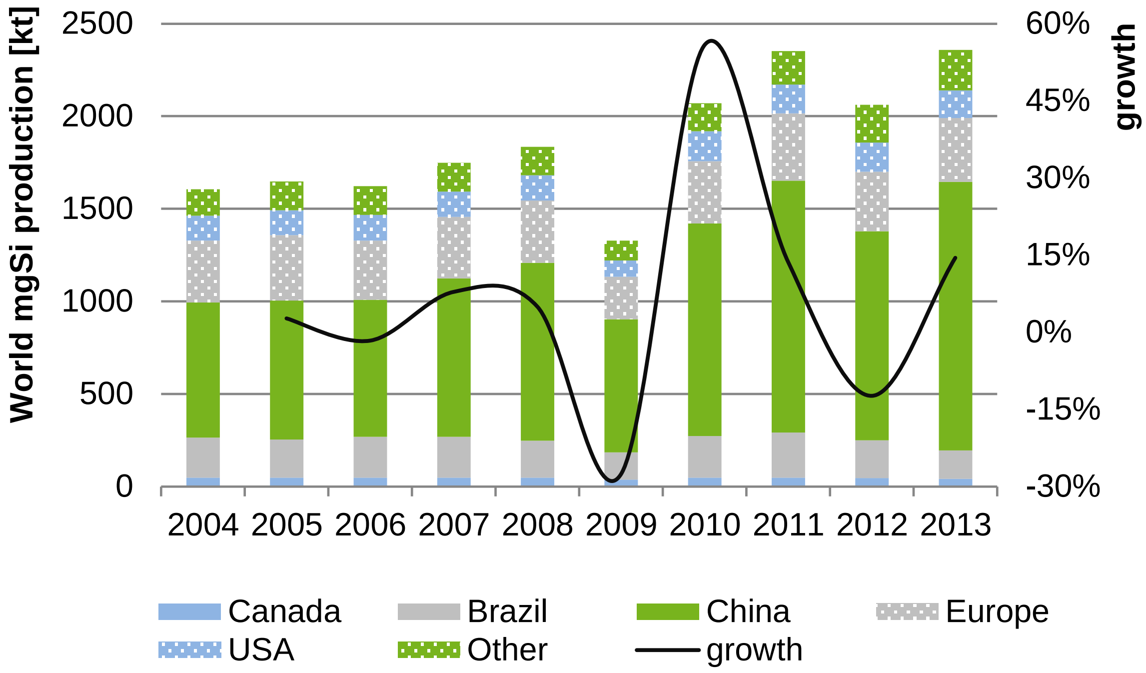
19.4.1 mgSi Production

The regional production profile mirrors, at least to some extent, the regional distribution of production capacities, with China being the world's biggest producer of metallurgical grade silicon. As shown in Figure 148, in the period from 2004-2008 the production of mgSi has been slightly fluctuating around the trend growth line of 3.4%.

Production was curtailed dramatically by almost 30% in 2009 at the height of the financial crisis. From this moment onwards both, the output volatility and the trend growth line increased, with the latter reaching almost 5.2%. A major reason behind higher growth rates and bigger fluctuations is the uptake of the crystalline silicon photovoltaic market which increased almost six-fold during the same time span. The added volatility in the mgSi market is a direct consequence of the PV market fluctuations.

PV market installations have not declined in any single year. Therefore, it can be assumed that the demand pull from the polysilicon industry has compensated cyclical weaknesses within the other major mgSi end-markets.

Figure 148: mgSi production by region - absolute



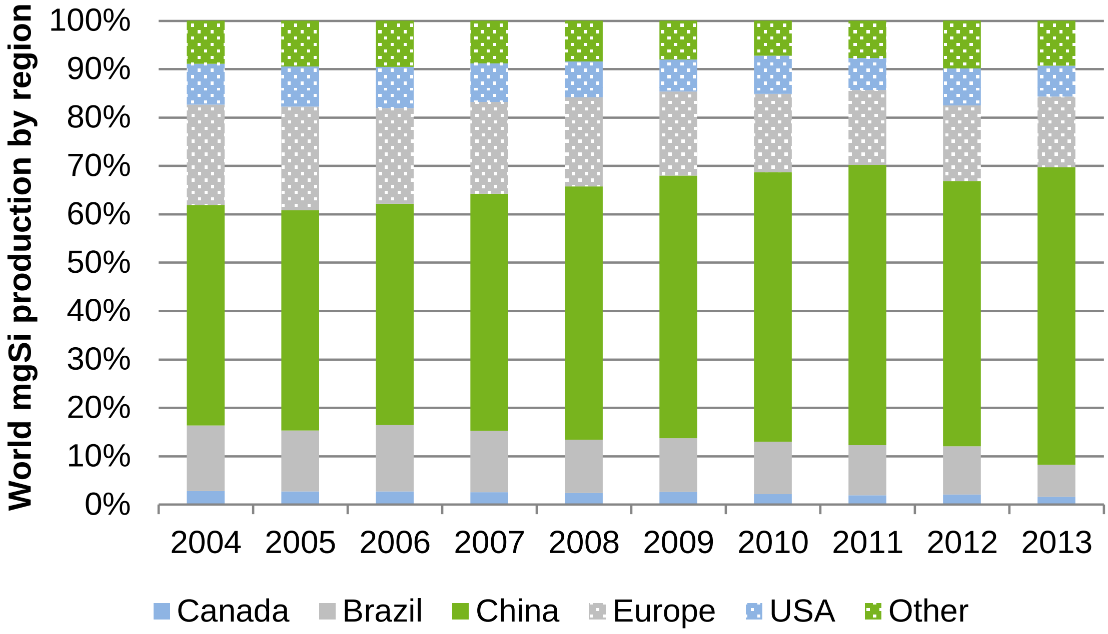
Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

The supply of mgSi originating in China has almost doubled in the period from 2004 to 2013. The increase in the supply that was not absorbed by a corresponding rise in local demand led to the replacement of supply originating in other regions. The region that suffered most is Brazil, where the annual supply has declined by almost 30% in the same period or in absolute terms by more than 60ktpy.

The other region where supply has been curtailed is Canada, here the production declined by approximately 13% over the same time-period. However, the absolute curtailment in Canada was rather small, with a decline in annual supply by just slightly more than 5ktpy. This decline is more related to company specific issues and likely not a consequence of a Chinese replacement. In this aspect trade tariffs play a role, which are discussed more thoroughly in Section 19.6.

Figure 149 provides an overview on the evolution of the relative supply composition by region of origination for the time period from 2004-2013:

Figure 149: mgSi production by region - relative



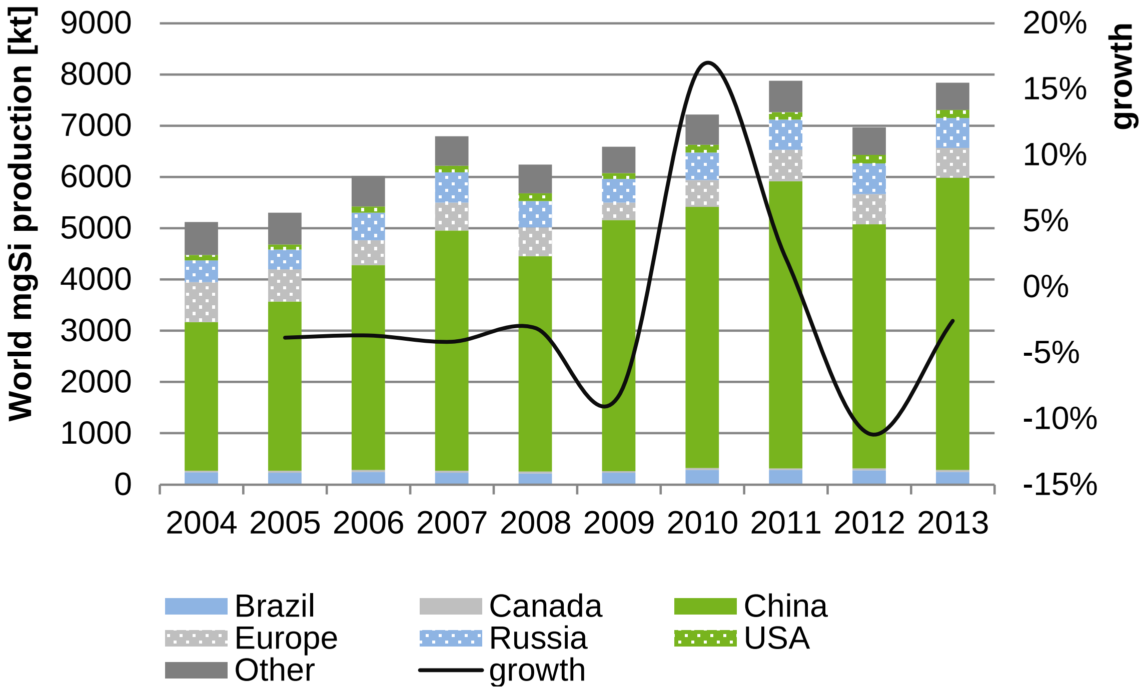
Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

The USA, Canada and Europe are potential target off-take markets for CME's prospective metallurgical silicon output.

19.4.2 FeSi Production

The total global production of ferrosilicon increased by 53.0% in the period from 2004-'13 or in absolute terms from ~5,100ktpy to ~7,800ktpy in 2013, which represents a CAGR of approximately 4.8%. A large proportion of this expansion is attributable to the infrastructure related investment boom in China, which is expected to moderate in the near future as the country transitions from an investment driven to a consumer/ service driven economic growth model. The regional production distribution and the y-o-y growth rate are exhibited in Figure 150. While the global production of ferrosilicon fluctuated moderately around its trend growth rate of 5.1% from 2004-'08, volatility in growth rates jumped drastically with the financial crisis. In the subsequent period from 2009-'13 the trend growth line declined moderately by approximately 40bps to 4.7%. In general, global growth rates in ferrosilicon production are expected to moderate in conjunction with slowing infrastructure related investments in emerging markets.

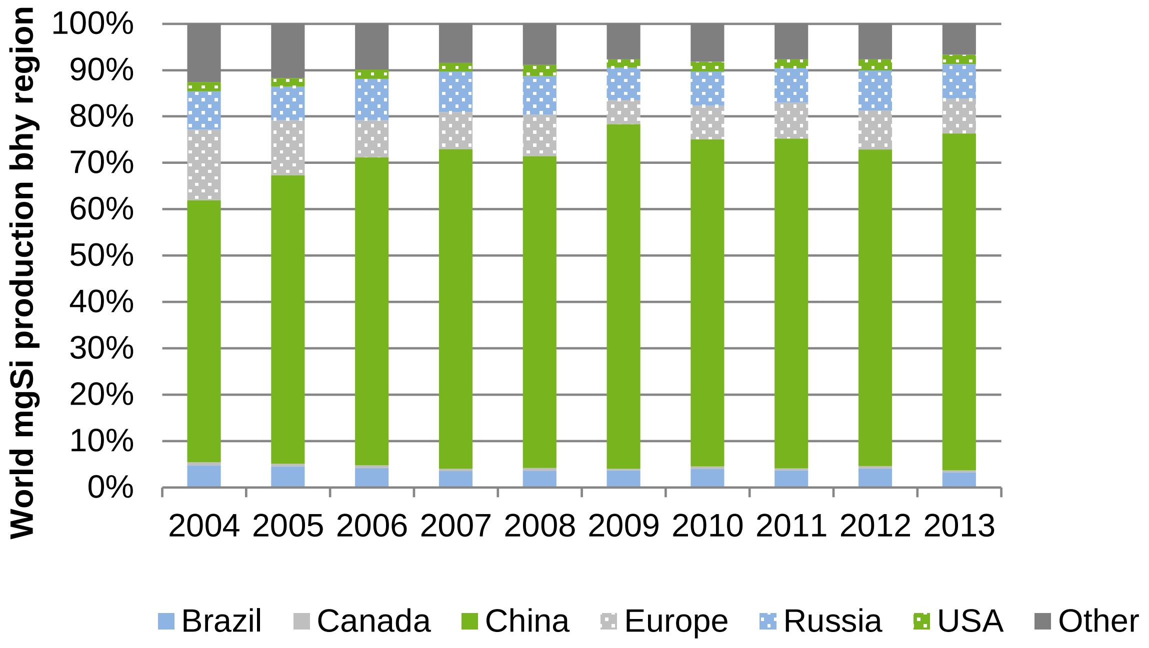
Figure 150: FeSi production by region - absolute



Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

The dominance of Chinese production is not a surprise given that more than ¾ of the global production capacity is located in this country (compare Figure 134). The share has increased from circa 57% in 2004 and peaked in 2009 with a share of almost 75%. In the subsequent years the Chinese FeSi production share declined back to the 70%-age range, a level where it has remained and fluctuated around. The doubling of the annual FeSi output in China went along with a significant decline of the production in Europe, where output declined by 25% over the same period. A broad number of other countries also curtailed production while FeSi production in the USA and Russia increased strongly, by more than 50% and almost 40%, respectively. Figure 151 provides an overview on the relative production breakdown by region for the period from 2004-2013.

Figure 151: FeSi production by region - relative



Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

The USA, Canada and Europe would be potential target off-take markets for CME's prospective ferrosilicon output if the project moves forward and the smelter's foreseen operation shifts to include FeSi at a later stage.

19.4.3 Industry Utilization

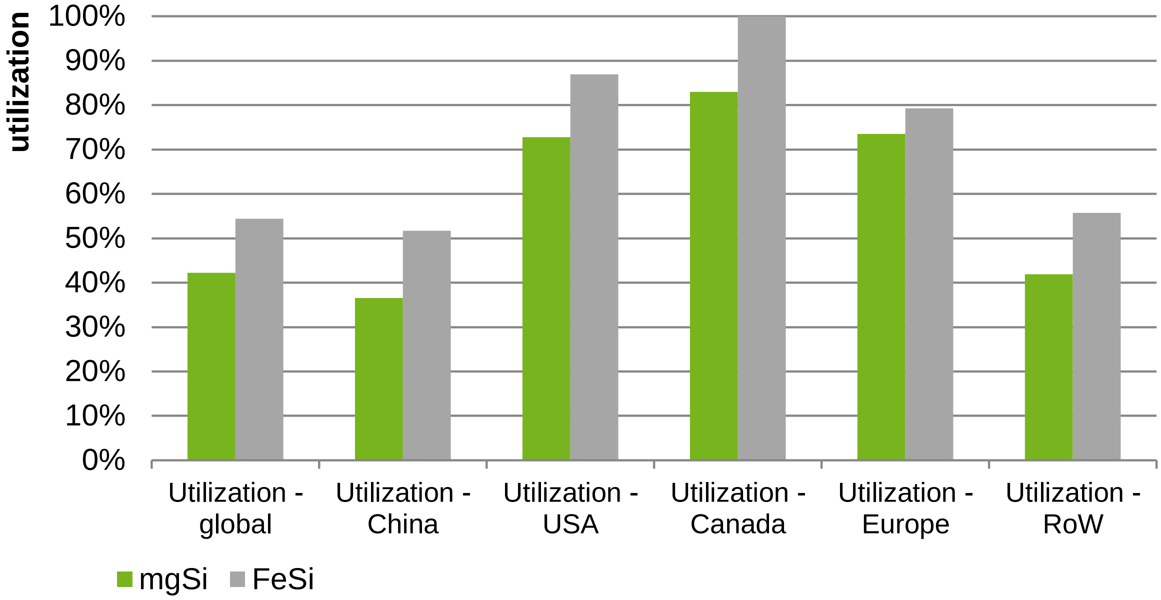
In the context of this PEA, industrial utilization levels are computed by dividing the aggregated production volume of a given year for pre-defined regions by the relevant nameplate capacities. In order to improve understanding of the dynamics within CME's relevant target markets, the following utilization levels are of interest and have been compiled for both end-markets based on data disclosed in the previously referenced Roskill market report:

- Global industry utilization
- Chinese industry utilization
- USA industry utilization
- Canadian industry utilization

- European industry utilization
- Rest of World (ROW) industry utilization

The different industry utilization levels vary to a great extent depending on the underlying geography. Figure 152 gives an overview on the estimated industry utilization levels for the different regions based on capacity and production data estimates for 2013:

Figure 152: Industry utilization estimates by geography



Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH estimates

The average global capacity utilization levels of ~42% for mgSi and ~55% for FeSi are obviously being dragged down by the aforementioned vast over-capacity and corresponding low-utilization levels in China. The prospective target markets for CME, namely the USA, Canada and potentially Europe, exhibit higher and healthier industrial utilization levels in the range of >70 up to 100% for both products in the respective base-year.

The higher industrial utilization levels in markets that are protected by trade-tariffs underscores that there is room for new entrants with competitive cost structures that can supply regional material needs at reasonable price points. Trade legislation based market-entry barriers are reviewed in Section 19.6 while a comparative assessment of the industry merit order (e.g. industrial cost-stack curves) is provided in Section 21.4.

19.4.4 New Western Greenfield Silicon Projects

Based on previously discussed global utilization levels, the question might arise as to the need for new western Greenfield sites for the production of metallurgical silicon. The answer to this question lies in the fact that the nameplate capacity of the Chinese industrial players are overstated vis-à-vis their real capacity. While capacity statistics from China are commonly considered dubious, there have been efforts in recent years to assess the real silicon capacity in China versus the announced capacity. The real Chinese capacity is mainly moderated by access to cost effective electricity as much of the Chinese capacity is in areas that are geographically subject to seasonal interruptions of water flows that feed the hydroelectric grid. This leads to some provinces in China having less than 25% of real capacity utilization year to year.

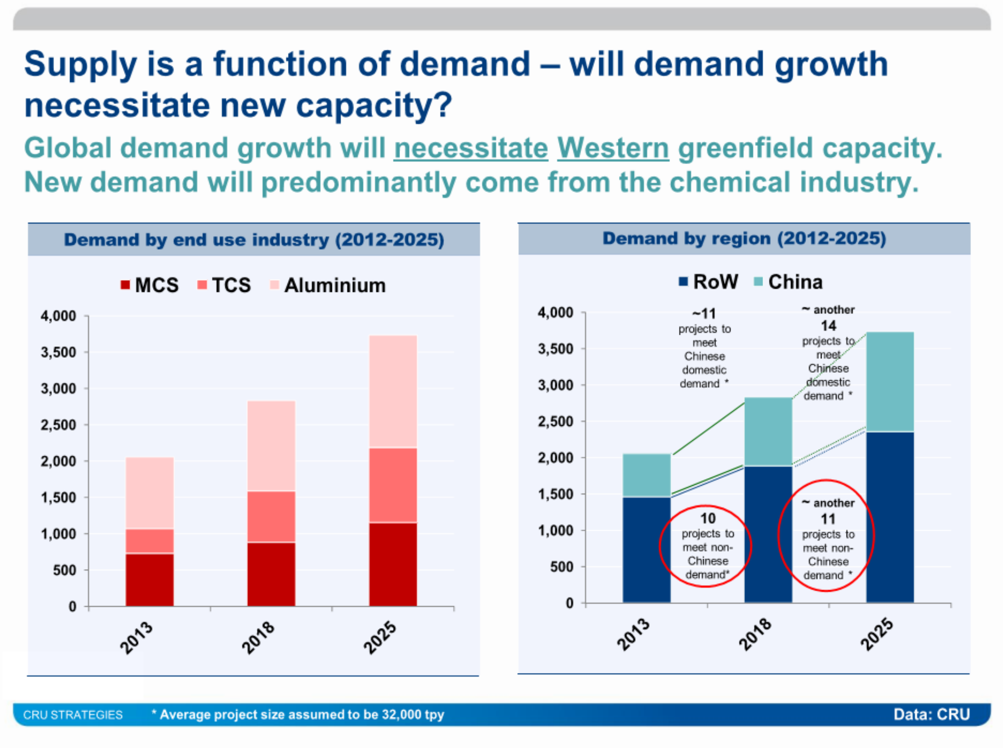
The real Chinese capacity is thought to be much lower than that announced. 2013 Chinese capacity was listed by market analysts as nearly 3.8 million tons. This has been disputed by extensive work on this subject by Mr. Daniel Bajolet,[33] an independent consultant and ex-production manager at Elkem Bluestar in China who estimates of the 3.8 million tons of announced capacity in China in 2013, only 2.4 million tons was actually real, effective capacity and only 1.48 million tons of that was really utilized. This results in a utilization rate for Chinese silicon manufacturing in 2013 of 38% of the announced capacity.

CRU[34] reported that there is a severe need for additional Greenfield production capacity to meet annual growth rate predictions on silicon.

33 BAJOLET, 2014

34 CRU, November 2013

Figure 153: Greenfield silicon expansion



Source: CRU Nov. 2013

The rationale behind this expansion need has been in large part due to cost effectiveness of new installations, the persistent increase in Chinese electricity prices and the increasing movement in China to shutter high polluting small industrial facilities. The net effect of these events has been a rebirth of Greenfield silicon factories outside of China. Currently, there are the following Greenfield silicon projects either planned or under various stages of construction and execution:

Table 62: Greenfield expansion (outside China)

Project	Location
Elpion	Malaysia
PCC Bakki	Iceland
United Silicon	Iceland
Mississippi Silicon	USA
Saudi Silicon	KSA
SIMA	UAE

Source: Viridis.iQ GmbH

19.5 Contracts, Grades and Prices

This section gives an overview on typical market exchange practices or seller-buyer relations within the silicon and ferroalloy industries (Section 19.5.1) before it briefly touches on quality and material grading related aspects that constitute a source of differentiation that potentially can increase average selling price (ASP) premiums for producers with sufficient operational excellence. The section continues with a review of past, present and forecasted pricing trends by geography for both, the metallurgical grade silicon (Section 19.5.3) and ferrosilicon (Section 19.5.4) markets. The section concludes with a brief review of current spot-market price trends for both materials in the USA, which are used as price reference points for the financial project assessment.

19.5.1 Contract Structures and Supplier-Buyer Relations

The market exchange mechanism for both materials, silicon and ferrosilicon, is facilitated based on private contractual agreements. The commodities are not traded on metal exchanges such as the London Metal Exchange (LME) or Chicago Mercantile Exchange (CME). As a consequence the markets are less transparent when compared to other commodities, such as steel or aluminum for which market transaction prices are instantaneously available. Hence, aggregated price information as reference for benchmark purposes needs to be obtained from specialized market research firms that track prices and provide various time series for different geographies in regular time-intervals. In many instances contracts are indexed to various price publications such as Ryans Notes, Platts and others.

Typical contract durations for metallurgical silicon and ferrosilicon are observed to be short- to medium term, where the former refers to a period of less than 12 months and the latter to a period of 2-3 years. The contract duration is a function of the material specification, meaning that higher- and consistent quality producers usually can obtain longer-term off-take agreements. In order to gain acceptance as a higher- or specialty grade material supplier with additional value-creation potential, the mgSi and/ or FeSi producer needs to pass a customer specific qualification process, that is more or sometimes less extensive depending on the end use application. Once a long-term relationship is established the inter-value-chain linkage between supplier- and customer increases with corresponding benefits for both parties. Volume and price settlement follows in accordance with contractual specifications and might contain a variable price index for energy price inflation. In general, established partners tend to roll-over contracts at expiration date due to high-transaction costs associated with expensive qualification procedures.

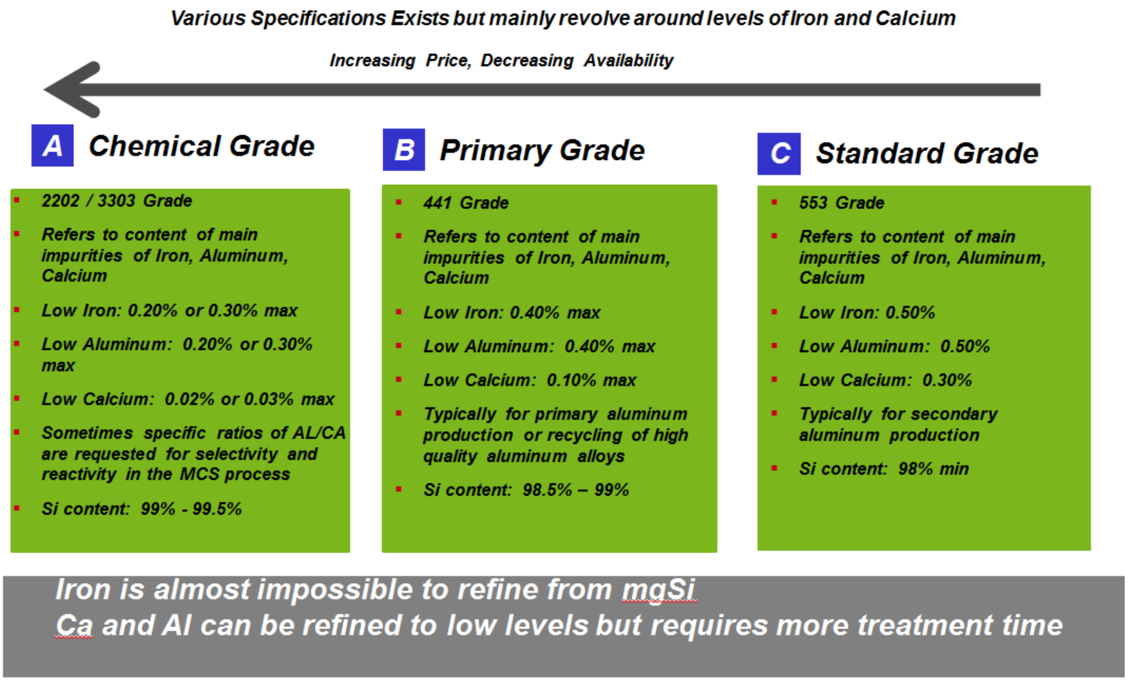
19.5.2 mgSi and FeSi Grades

The pure silicon content of mgSi needs to exceed a minimum threshold of 98.5%. Important impurities that determine the overall quality of mgSi are Iron (Fe), Aluminum (Al), Calcium (Ca), Phosphorus (P) and Titanium (Ti). Next to the chemical composition, another determining factor for the assessment of the quality of a silicon supplier is the consistency of the supplied material. This basically means that the standard deviation of impurities should be held within pre-specified limits in order to improve feedstock and process control for the various off-takers of the material. The latter point is of special importance for off-takers that produce silicon based precursors, for example methylchlorosilanes (MCS) for the production of silicones or trichlorosilane (TCS) for the production of polysilicon. The specific quality and consistency needs of these two industries are an explanation for the average selling price premiums that can be achieved by qualified mgSi suppliers.

There are general chemical specifications for mg-Si in the market that are delineated by the composition of Fe, Al and Ca. These grades are mostly known by their acronyms: 553, 441, 3303, 2202, etc.:

- The 1st refers to the percentage of Fe in the material, i.e. 5 means 0.5% max; in this aspect, feedstock control is of utmost importance as Fe is almost impossible to refine
- The 2nd refers to the percentage of Al, i.e. 5 means 0.5% max
- The 3rd number refers to the content of Ca, i.e. 3 means 0.3% max, 03 means 0.03% max.

Figure 154: mgSi grades



Source: Viridis.iQ GmbH

Generally speaking, the consuming industries are concerned about the following:

- Chemical industry: Sizing, ratio of Ca/Al, Fe content
- Aluminum industry: Ca and Fe content, aluminum is not a problem
- Polysilicon: Sizing, consistency in chemistry, Calcium and Aluminum content

The grades for FeSi are mainly based on the elemental silicon content and the respective contamination with Carbon (C) and Aluminum (Al).

The typical standard grade of ferrosilicon on which the vast majority of global trade is facilitated in, is FeSi75 that has the following specifications:

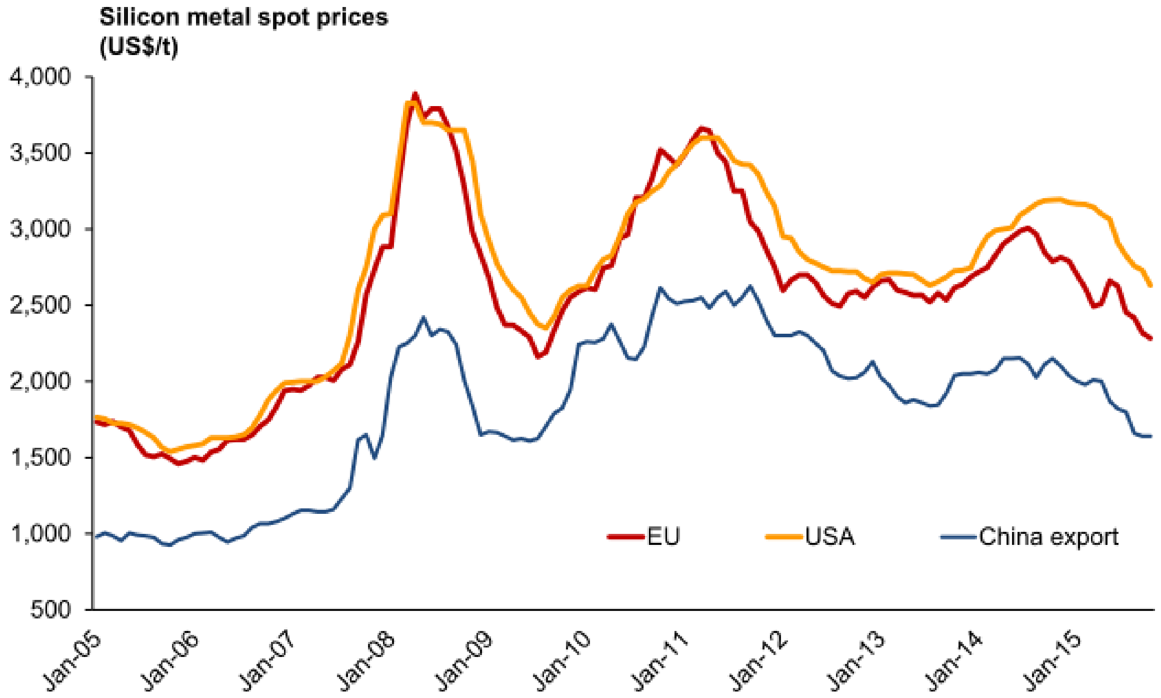
- Min. Si content of 72%
- Max. Al content of 2%
- Max. C content of 0.2%

There are also higher ferrosilicon grades for specialty steel and iron applications, which are not defined by higher silicon content but through maximum impurity levels for Al, C, Titanium (TI) or Magnesium (Mg). The specific impurity levels are typically negotiated with the end-user.

19.5.3 Historical and Forecasted mgSi Pricing

The historical metallurgical silicon spot-market prices for standard 553 material have been volatile over the past decade, while the extent of the volatility has been slightly more pronounced in the Western target markets of CME, namely the USA and the EU. Prices for standard grade material in Western end-markets almost doubled from mid-2007 to early-2008 and ever since fluctuated around the US$3,000/t threshold. After reaching temporary local peaks at the turn of last year prices declined in both regions, the USA and the EU, and have reached previous trough levels by the end-of this year. Figure 155 gives an overview on regional spot-pricing for standard grade material and different regions:

Figure 155: Average mgSi spot-market price history by region / AlloyConsult



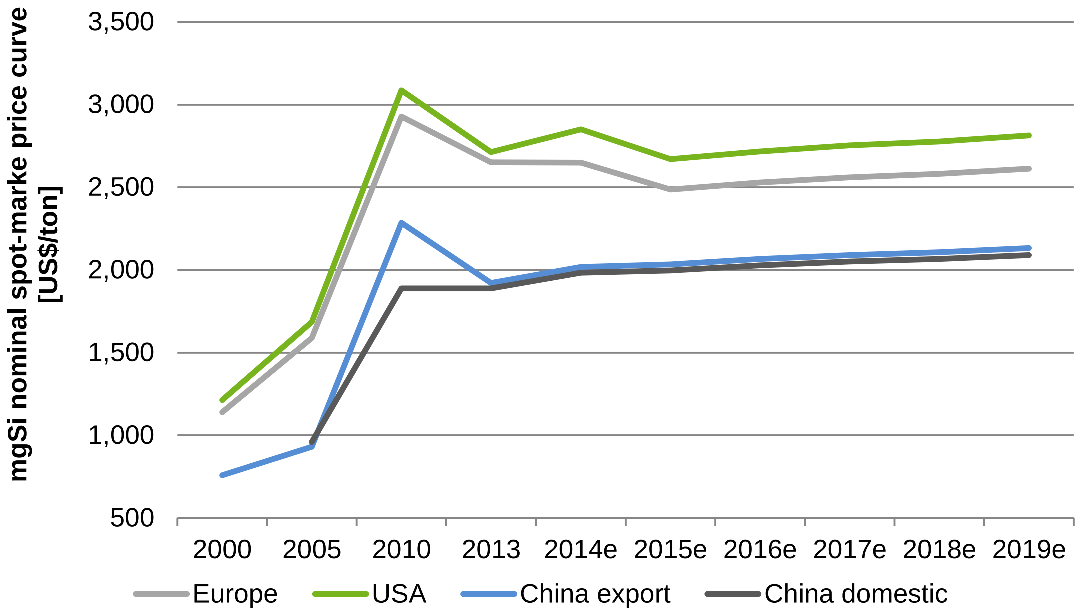
Source: AlloyConsult (Nov. 2015)

The mgSi price curves are influenced by the following major determinants:

- Prevailing commercial raw material sourcing conditions (cost determinant)
- Region of origin and consumption of end-product (institutional determinant)
- Absolute level of demand and marginal cost producer (marginal producer determinant)

Usually, mgSi spot price curves are based on standard quality grade material (e.g. 553 grades). As more consistent and higher purity material suppliers typically can generate average selling price premiums in the respective end-markets, an additional price determinant needs to be considered in the case of mg-Si, the “differentiator determinant”. Figure 156 gives an overview on the historical mgSi spot price curve for various regions and provides the mgSi price forecast as published in the 2014 Roskill report. While not explicitly specified in the Roskill report the underlying material quality of the price data is obviously a composite of lower mgSi grade material. This follows from the fact that historical spot prices as disclosed by Roskill are below the price points communicated for standard grade material, according to AlloyConsult or CRU (see Figure 155 and Figure 157).

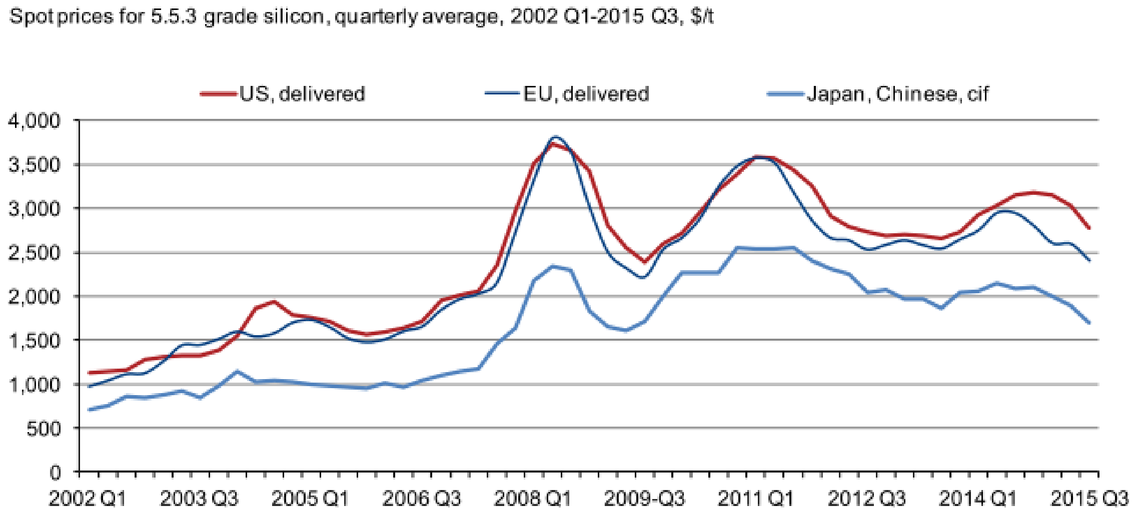
Figure 156: mgSi nominal spot-market price forecast



Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

The average compounded nominal price growth rates for the regional markets depicted in Figure 156 vary between 1.1-1.3%. Again, while the absolute level for the Western mgSi price curves and the relative growth projections for the different geographies might be disputed, the authors concur in the selected approach by Roskill, which utilizes linear forward price curves. While the achievable price level can partially be influenced through discretionary measures taken by individual producers, e.g. composition of regional and application based target markets and dedicated product differentiation strategies, the volatility and frequency of relative price changes as well as the longer time price cycles are determined by external macro-factors and cannot be influenced or predicted with any meaningful degree of accuracy. As a consequence, the PEA will introduce different linear forward price curve scenarios in order to compile price scenario-based project values in Section 22.5.

Figure 157: Average mgSi spot-market price history by region / CRU



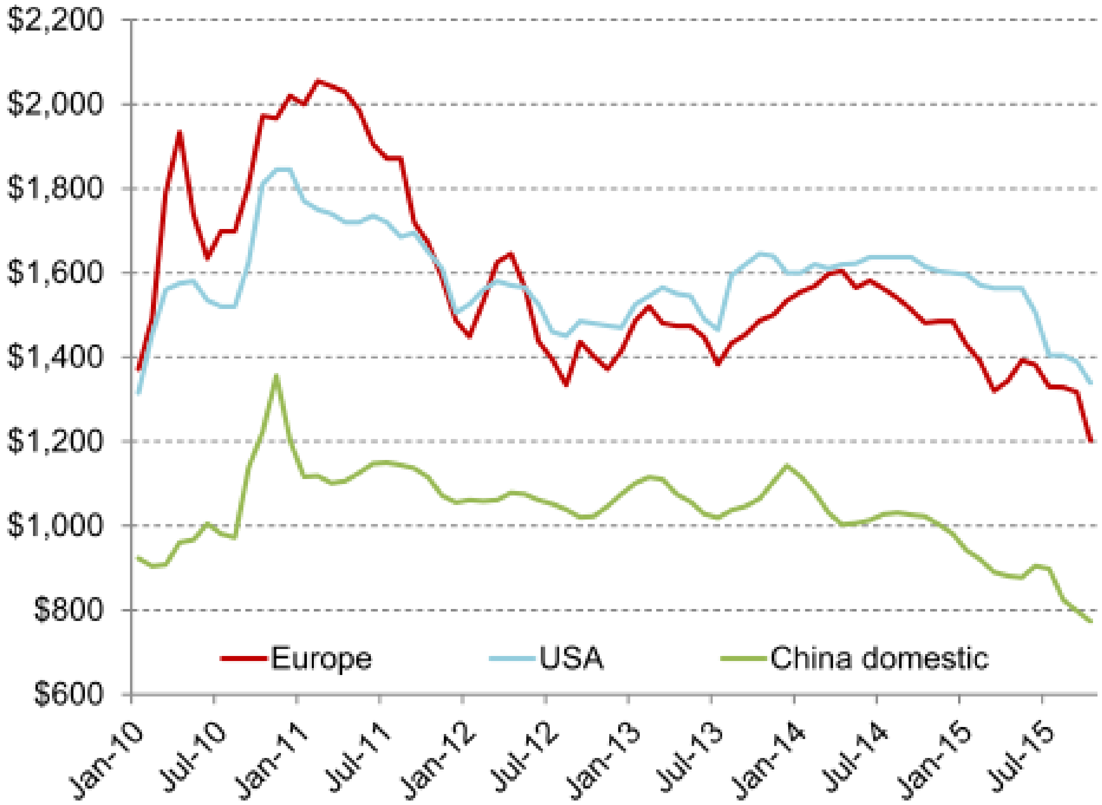
Source: CRU (Oct. 2015)

The mgSi standard grade price curves introduced in the present section, exhibit similar patterns as the FeSi price curves further elaborate in Section 19.5.4. In mid-2007 both, Western and Chinese mgSi prices increased dramatically and reached new plateaus around which prices fluctuated ever since. The reference mgSi price level in Western markets is approx. US$3,000/t, while the reference Chinese CIF price stands at about US$2,000/t. Prices retreated from local peaks in the latter half of 2014 and reached previous through levels in Q3 2015 (Figure 157). Going forward, the estimated average compounded annual price inflator of 1.1-1.3% for the period leading up to 2019 as projected by Roskill is regarded to be a conservative estimate that does not reflect potential benefits resulting from market share increases of higher-margin PV and silicone end-usages (see Section 19.1.1). While the authors do not necessarily concur with the explicit price progression paths as modelled in Figure 156, the methodology of providing linear price forecasts is deemed practical and will be followed in Section 22, where additional scenario based linear price forecasts are provided.

19.5.4 Historical and Forecasted FeSi Pricing

Average grade ferrosilicon spot-market prices have been hovering between the US$1,500-1,600/t range over the past five years in the EU and the USA, while Chinese FeSi prices fluctuated around the US$1,100/t mark. In conjunction with the throttling of the investment spending based GDP growth in China and other emerging markets the global demand for steel declined which led to a corresponding decrease in the demand for FeSi. As a consequence, prices started to retreat from their respective levels in all major geographies since 2014 and recently reached temporary local troughs at around US$1,300/t in Western markets and <US$800/t in China. Another factor that has influenced temporary supply dynamics and prices is the ramping of the OM Holdings Ltd. FeSi mega smelter site in Sarawak, Malaysia. Figure 158 gives an overview on regional spot-prices for standard grade material and different regions:

Figure 158: Average FeSi spot-market price history by region

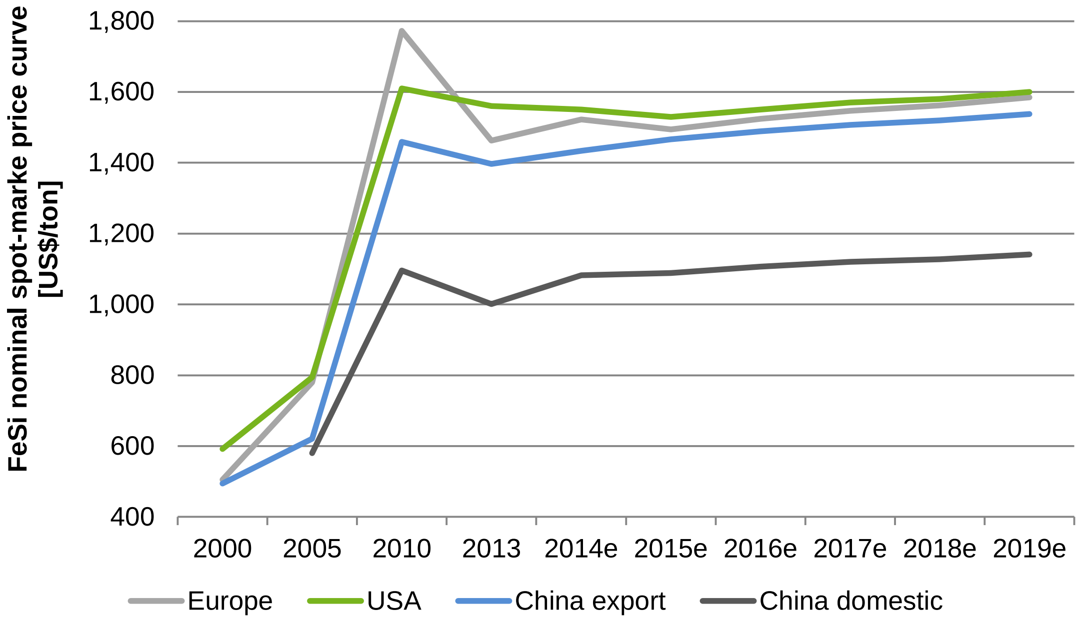


Source: AlloyConsult (Nov. 2015)

The major determinants of FeSi prices are prevailing sourcing conditions for production resources (cost determinant), region of origin and consumption of end-product (institutional determinant) and the absolute level of demand that determines the marginal cost producer within the merit order (marginal producer determinant). These determinants explain discrepancies in the price level by geography (e.g. export and import tariffs, anti-dumping and countervailing duties, etc.) and short- to medium-term fluctuations due to the economic cycle and implicit FeSi market tightness (e.g. # of producers with cash-costs below current price level). Obviously, each of these influencing factors is a function of multiple and correlated sub-parameters, explaining the interdependency of the aforementioned major FeSi price determinants.

Detailed price forecasts for commodities or quasi-commodities are by nature error prone due to the inherent complexities associated with the projection of dynamic and randomly interrelated parameters. Figure 159 shows the linear forecast for regional FeSi spot-prices (nominal) as introduced in the Roskill market report from 2014. As can be seen, a slight decline in Western spot-prices for the period of 2014 to 2015 had been anticipated at the time when the report was published. From 2015 onwards, nominal prices were expected to increase at a moderate compounded average rate of 1.2-1.5%.[35]

Figure 159: FeSi nominal spot-market price forecast



Source: Roskill Information Services Ltd. (2014), Viridis.iQ GmbH

35 Roskill Information Services Ltd. (2014), p. 5; the headings of the price tables for FeSi and mgSi in the Roskill report are incorrect and need to be exchanged with the respective other product (ibidem p. 5 and p. 11)

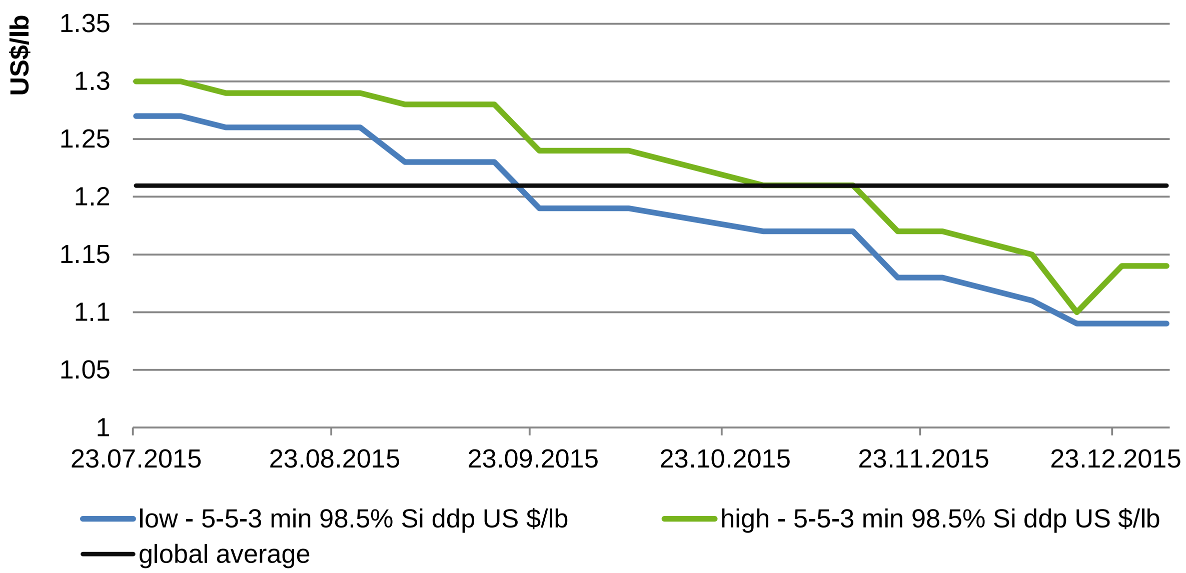
In conclusion, FeSi75 prices cannot be expected to increase to a large extent over the medium-term due to an overcapacity issue which is currently being magnified as a consequence of declining steel production volumes. The different scenario driven FeSi forward price curves introduced in later economic sections incorporate the implications of this secular market imbalance to different degrees.

19.5.5 Recent US Spot Prices

This section provides a brief review of current spot-market trends for the USA, which would likely be the main off-take market for CME's smelter output. While the price curves introduced in the previous sections give a good indication on longer-term pricing histories, trends and cycles for major geographies, the presented data is not sufficient to establish solid reference price points for project evaluation purposes. In order to overcome this short-coming, recent spot market price curves are introduced for 553-grade silicon material and FeSi75, respectively.

Figure 160 shows a price bandwidth for lower 553 purity grade material for a 5-month time period from from 23rd of July to 31st of December 2015, on a weekly basis. The depicted 553 grade silicon prices experienced a decline in the region of 12% to 14%. The global average price was US$1.21 per lb as indicated by the solid black line. This price reference will be used as the t=0 reference price for the determination of the project value (Section 22).

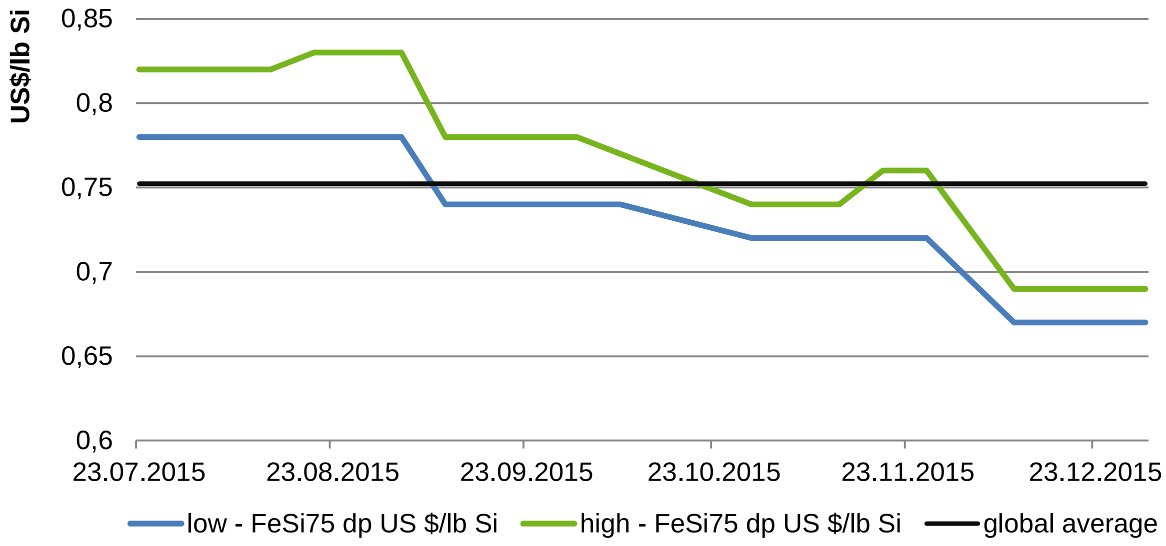
Figure 160: 5-5-3 min 98.5% Si ddp US low- and high-price for 5-month period



Source: Argus Ferro-Alloys, Viridis.iQ GmbH

Figure 161 shows the bandwidth for low- and high-FeSi75 prices for the same time-period. The price quote is provided in US$ per pound silicon content. Over the past five months prices retreated by approximately 14% to 16%. The global average price for the time period under investigation is US$0.752 per lb Si.

Figure 161: FeSi75 dp US low- and high-price for 5-month period



Source: Argus Ferro-Alloys, Viridis.iQ GmbH

19.6 Trade Restrictions in CME's Target Markets

This section provides a high-level overview on current trade barriers being in place in CME's likely off-take markets, e.g. USA, Canada and potentially Europe. Next to product quality determinants, trade barriers in the form of anti-dumping (AD) and anti-subsidy (AS) or countervailing duties have a distinct impact on geographic price structures as shown in Sections 19.5.3 and 19.5.3. It is therefore essential to understand present trade practices in relevant markets and get an understanding of uncertainties associated with recurring review processes by national trade bodies as well as super-ordinated WTO rules. The latter point is of particular importance as a number of international trade clauses that apply non-market economy status to China are set to expire in 2016.

Table 63 provides an overview on regular and special trade duties in place in the prospective target regions for CME. In principle trade flows within and between the listed regions are frictionless according to bilateral agreements between NAFTA members and the EU, meaning that no special duties, other than regular duties, apply to trade flows between these regions. There are no duties on mgSi and FeSi trade flows between Canada and the USA.

Table 63: Overview on duties in prospective target markets

		metallurgical silicon	
	USA	**Canada**	**EU**
AD & AS rates	China: 139.49% Russia: 61.41-79.42%	China: up to 235%	China: 16.3-19%
Regular Duty on CIF price	5.3-5.5%	0%	5.5%
		ferrosilicon	
	USA	**Canada**	**EU**
AD & AS rates	Venezuela: 27%		China: 15.6-31.2% Russia: 17.8-22.7%
Regular Duty on CIF price	1.9-5.8%	0%	5.7%

Source: Viridis.iQ GmbH

All of the listed AD and AS rates have been enacted or reconfirmed in the period between 2013 and 2014. Hence, formal review processes will in most instances be initiated after a period of 5 years in the time-frame of 2018 to 2019.

The regular duty is payable upon import of the goods and customs clearance and are applied on the respective CIF price. In cases where AD and AS duties need to be applied, the applicable rate will be charged on top of the regular duty. A local import agent normally pays the duty, based on an agreement between the shipper and consignee and the goods are recorded into the countries import register.

China has implemented an export tax of 25% on ferrosilicon in 2007, which led to a decrease in the export share of FeSi from a bandwidth of 30-40% to 10-15% starting in 2008. This export tax has been prolonged in 2013 for a period of one year. The current status of the duty review process on Chinese ferrosilicon exports is unknown.[36]

36 Roskill Information Services Ltd. (2014), p. 10

The upcoming expiration of certain non-market economy status clauses for China is likely to increase complexity in future anti-dumping and anti-subsidy proceedings in general and in particular affect the determination process of the respective dumping margins. While the reference price for the determination of the normal value can be based on third country export prices in cases where proceedings target companies that are situated in non-market economies, the investigating body must take into consideration the domestic price structure in cases where subject companies are based in market-economies. While the expiration of WTO clauses will not automatically render China a market-based economy, the anticipated diplomatic struggle on the interpretation of the actual status is likely to increase complexity of future trade proceedings.

19.7 Conclusion

The metallurgical silicon and ferrosilicon markets are highly disparate with little to no overlap in their end market applications. Both markets are subject to their own distinct drivers and share only one key similarity, namely the existence of large, under-utilized production capacities in China. As a counter effect to this build-up of capacities in China, non-Chinese producers have evolved to combat this reality by improving cost and technology efficiencies, economies of scale and the installation of trade barriers to keep Chinese production exports in check. Regulatory, environmental and labour costs in China constantly push the production costs higher in that country.

The metallurgical silicon market is a trade protected market that can benefit CME's factory in Canada by making premium ASP markets available with lower transportation cost. Regional demand for silicon is strong in North America and is increasing due to increasing demand for consumer goods, which are silicon based. Another supporting factor is the ongoing decentralization and decarbonisation of the energy-supply infrastructure that has led to continuous strong-growth in the demand for silicon based PV applications. It should be noted that market forces in the North American market are subject to regulatory influence as trade barriers keep ASPs higher than in other markets.

The ferrosilicon market in North America is tied to the volatilities of the steel industry, which is currently in a correction phase. The prospects might therefore be regarded as less attractive than those for metallurgical silicon. Further market related investigations should be commenced at later project stages. In that respect the flexibility of the project to serve diverse end market segments seems to be an advantage.

The proposed HFP concept allows CME the potential to reach meaningful scales that are higher than the average silicon production profile and thus increases the likelihood of maintaining its competitiveness over smaller factories. The potential expansion phase would only increase the scaling benefits over the competition and aid project viability.

20 Environmental Studies, Permit and Social or Community

20.1 Project components and main characteristics

The project under study is based on two distinct but complementary components: an open quarry and an industrial complex with the process plant.

The quarry consists mainly in the development and operation of a silica deposit. The deposit is easily accessible by actual roads; no new access infrastructures will be required. A processing plant with a capacity of approximately 100,000 tons per year of coarse silica will require approximately 133,333 tons per year to be extracted and processed at the Langis quarry to provide the smelter with the anticipated 97,524 ton annual silica requirement. The life of the project is expected to be 25 years. The quarry project includes the following activities: standard drilling/blasting, excavation, dump trucks, stockpiling, crushing, wet screening, dewatering and stockpiling product. Process water will come from a nearby river.

The deposit operations will supply the industrial complex aimed at producing both relatively pure silicon (99.0 - 99.5% metallurgical grade – mgSi) and/or ferrosilicon (FeSi). The complex will consist mainly in an electric arc smelting plant where silica is mixed with reducers such as iron, coke and wood chips for the production of mgSi and FeSi. This process is highly energy intensive, on the order of 7 to 9 MWh per ton of FeSi and 12 to 14 MWh per ton of for mgSi. Electricity will come from hydropower and be provided through Hydro-Québec grid. Process water will come from the city system.

Phase 1 of the project will consist of three smelting furnaces. The base-case configuration assumes an annual production of about:

- 50,000 tons of mgSi
- 24,000 tons of Silica fume, a by-product of the smelting process

Phase 2 of the project will consist of adding three more smelting furnaces and associated equipment. Phase 2 would be put in place at about the 5th year of the project.

Raw materials required for the smelting process consist of silica (SiO_2), carbon reductant (charcoal, coal), limestone and wood. Hematite is also required for manufacturing FeSi. Raw materials will be brought in to the site through trucking and railway, silica and wood coming from local sources. Large volumes of materials and overseas products could also go through the St-Lawrence River and ports in Québec and the Maritimes region. Final products may go through the same transportation modes but will be highly dependent on the customer base.

20.2 Study Area

The two main project components have different locations, both in eastern Québec (figure 1). The quarry is located in the municipality of Saint-Vianney while the plant is located in Matane. Still, the two components are close to each other, separated by about 40 km. Consequently, environmental studies for each of the two components display a specific study area.

The study area for the quarry encompasses an area of about 240 ha, so that human features are taken into consideration. Within this study area, a smaller area of about 25 ha has been surveyed for its biophysical characteristics. Within a radius of 25 km, special features such as parks or preserves as well as habitats have also been identified. The quarry is located in a forested area with a low human and activity density. It is worth noting that the quarry had been under operation in the 1980’s and is now decommissioned. To our knowledge, there is no detailed information about soil contamination.

The study area of the smelting process plant encompasses an area of about 30 ha. It is located in an industrial park within the municipality of Matane, about 2 km west of the city centre. The site is undeveloped, mainly forested and surrounded by industrial and commercial features.

20.3 Regulatory Context

Both project components (quarry and process plant) fall under the same regime, the Québec Environmental Quality Act. However, for the industrial plant, the procedure for the environmental impact assessment shows some distinct features. Permits under the Québec jurisdiction as well as municipal by-laws will also apply to the project.

20.3.1 Quarry

The quarry environmental assessment procedure is under the responsibility of the Québec Ministère du Développement Durable, de l'Environnement et de la Lutte contre les Changements Climatiques (MDDELCC) (Ministry of sustainable development, environment and fight against climate change).

The project is subject to the Québec Environmental Quality Act (EQA), section 22 which states that no one can erect or modify a construction, undertake the exploitation of an industry, exercise an activity or use an industrial process nor increase the production resulting in the emission, deposit, release of contaminants or the modification of environmental quality, without first obtaining the authorization from the ministry.

The Québec Regulation on quarry and sand pit also states that no one can undertake the exploitation of a quarry or a sand pit unless the authorization from the ministry has been obtained under section 22 of the EQA. Permits under the Québec jurisdiction as well as municipal by-laws will also apply to the project.

The requirements are mainly related to the knowledge of the surrounding environment and the project main characteristics and the application and respect of guidelines related to the location of the quarry and its distance from key neighborhood features such as houses, wells, roads, and watercourses.

While there is no specific timeline for the section 22 EQA procedure, it usually requires only a few months to go through. The federal procedure on environmental impact assessment does not apply to the quarry component.

20.3.2 Industrial Process Plant

The process plant environmental assessment procedure is also under the responsibility of the Québec Ministère du Développement Durable, de l'Environnement et de la Lutte contre les Changements Climatiques (MDDELCC) (Ministry of Sustainable Development, Environment and Fight against climate change).

In addition to section 22 of the Québec Environmental Quality Act (EQA), the process plant component is also subject to section 31.1 of the EQA which states that the procedure for the evaluation and examination of impacts to the environment must be applied to such type of project. Permits under the Québec jurisdiction as well as municipal by-laws will also apply to the project.

This means that a complete Environmental Impact Assessment (EIA) must be performed for the process plant. The requirements and steps include:

- Project notice, a document describing the project, its surroundings and potential impacts, filed to MDDELCC, from which guidelines will be issued by the government and will serve as a road map for the EIA;
- Consultation activities with the community and stakeholders, at the right beginning and throughout the project;
- Project technical analysis and optimization;
- Baseline fieldwork, studies and analysis;
- EIA evaluation and reporting;
- Filing of the EIA report and Q&A with government experts to obtain the receivability of the EIA report;
- EIA final report is posted for public comments and request for public hearings.
- Requests for public hearings are received and analysed by the “Environment” ministry. If a request is granted by the ministry, public hearings are held by the Bureau d’Audiences Publiques sur l’Environnement (BAPE).
- Final analysis is performed by the MDDELCC and a report is issued to the ministry.
- Final decision is taken and a decree is issued, authorizing the project. Once the decree is obtained from the provincial Government, the detailed engineering of the project will be finalized. It shall consider all applicable environmental standards included in other relevant provincial laws and regulations
- Requests are filed by the proponent for sectoral certificates of authorization as well as municipal permits.
- Construction can go ahead.

The timeline to go through an EIA usually requires about 18 to 24 months. The federal procedure on environmental impact assessment does not apply to the process plant component.

20.4 Baseline Studies

Baseline studies serve a key purpose: to gather information and understanding of the surroundings that will receive the project. These data are mandatory for the filing of the form required for the governmental procedure as well as the environmental impact assessment (for the industrial process plant).

20.4.1 Quarry

Baseline studies for the quarry have consisted in a desktop review of existing information and data, mainly from governmental sources, and a field survey performed in July 2015.

The quarry study area is located in the Eastern Matapedia region of Québec, within a hilly terrain with low elevation generally less than 300 m. The study area is included in the Appalachian geological region and covered by glacial deposit with highly siliceous sandstone.

The region is mainly forested and human infrastructures are generally scattered.

There are no major watercourses or lakes within the quarry study area, the closest river being 2 km from the site. Only two small and intermittent brooks have been identified at the limits of the exploitation site.

The area is dominated by terrestrial vegetation (80.4%) with aspen, fir, spruce and birch being the most common trees. The second largest unit is represented by the abandoned quarry (16.2%). Finally, wetlands represent only a small portion of the area (3.4%).

A few, small and isolated wetlands have been identified within the future exploitation site. However, these wetlands have a non-natural origin (from the last quarry operation) and are of very low quality. Two other wetlands, also small in size, are located at the limits of the future exploitation site. Wildlife typical of these regions has also been observed.

No species of vegetation or wildlife designated as threatened or vulnerable have been observed throughout the survey.

20.4.2 Process Plant

Baseline studies for the process plant have consisted in a desktop review of existing information and data, mainly from governmental sources, and a field survey performed in October 2015.

The process plant study area is located in the Eastern region of Québec in the municipality of Matane, 2 km west of the city centre and about 200 m from the St-Lawrence River. The process plant site is surrounded by the following:

- South: sand pit;
- West and East: industrial/commercial;
- North: commercial and scattered residential.

The site itself is mainly forested, the south-east portion being occupied by a sand pit. A small dirt road, going from north-west to south-east, crosses the entire lot, no other infrastructure has been observed on the site. However, ditches are observed at the limits on both sides of the lot.

About 58% of the site is forested while a good portion (31%) is composed of wetlands. The rest, about 11%, includes disturbed and human activities areas. Wetlands are drained by ditches located at the periphery of the study area.

Four small watercourses have been identified, three of them being intermittent and one permanent. None of these four watercourses are linked to the local hydrologic water network.

Very few wildlife has been observed on site since the habitats are generally limited and of low quality.

No species of vegetation or wildlife designated as threatened or vulnerable have been observed throughout the survey.

20.5 Social and community engagement

Under the environmental assessment procedure for the quarry, public hearings are not mandatory. However, as a good neighbor and because permitting will involves the municipality, continuous engagement and information will be sustained with the municipality of Saint-Vianney to make sure any question arising from the local community can be answered promptly and properly.

For the process plant, the procedure for social engagement is different. Throughout an EIA procedure, consultation with the community and the stakeholders is EIA state of the art as well as mandatory and requested by the authorities.

Consultation serves many objectives: to provide information to the community and stakeholders about the project and its impacts, to give the opportunity to the community to express concerns and questions and to obtain information from the community in order to adjust the project and apply mitigation measures if needed.

Since the EIA has not started, no activities pertaining to community and stakeholder engagement have been initiated yet. However, activities are planned and will include the following:

- A first consultation early at the beginning of the EIA to present the project and to inform the population about the upcoming steps and studies;
- A second consultation near the end of the EIA to present the population with the results of the EIA impact analysis;
- A public hearing with the government representatives and Bape at the end of the environmental assessment procedure.
- All along the course of the project, communications will also be ongoing with the community to make sure information is always available and engagement is sustained.

20.6 Issues and Potential Impact

The construction of the quarry and process plant components and infrastructure and its operation could be the source of physical, biological and human issues affecting the flora and fauna of the project area. These issues include:

- The loss of vegetation cover caused by the logging required for the site preparation at the construction stage;

- The loss of terrestrial fauna habitat through vegetation cutting, excavation and backfilling as well as through the presence of the quarry, plant and storage areas;
- The potential perturbation of local fauna activities through the increase in noise levels, vibration generation and dust production through dust fallout generated by blasting activities, handling and process plant operations.

20.6.1 Quarry

With the environmental studies almost completed for the quarry, the potential issues and impacts are well understood. In fact, based on our analysis, there are no major issues or impacts that may affect the project implementation or its outcome.

The remote location of the quarry contributes to the low level of impacts. Access roads are already in place. There are no residential or intensive human activities in the area that could interfere with the quarry location or operations.

Only a few environmental features (wetlands) at the limits of the future quarry are of concerns but will be dealt with through proper measures to ensure that a safe distance between the working zone and these features is implemented and respected. Measures will also be identified to control potential sources of disturbance and contamination.

20.6.2 Process Plant

Since the environmental impact assessment is yet to be initiated, the analysis of issues and impacts is still to come. However, the knowledge of the study area from the baseline studies as well as the experience from similar projects allow for a first understanding of the issues and impacts of the project.

For such projects, environmental and social issues are mainly related to:

- Site location: siting of the project will trigger interactions with the environmental and social features, an analysis for project location will be performed;
- Project footprint: since the site is mainly covered with forest/wetland, project infrastructures may interfere with natural habitats;

- Atmospheric emissions of contaminants and notably particulates: material handling, truck routing and plant process will be sources of emissions that will have to be modeled and managed in order to respect regulations;
- Greenhouse gases emissions: in Québec as well as worldwide, GHG emissions are an issue for which the project will be a contributor through plant process and project global life cycle;
- Water source location and consumption: an important and constant flow of water will be required for furnace cooling;
- Regional economic spinoffs: the project will be a source of employment and spinoffs for the municipality and the region and a potential for economic diversification, the Bas-St-Laurent administrative region has unemployment rates systematically over the Québec average between 2004 and 2014.

Considering these issues and the actual understanding of the project and study area features, impacts may include potential change and loss of natural vegetation and wildlife habitats, potential change in local hydrology and water quality, potential local contamination of soils, potential local change in air quality, and potential change in noise for local neighbouring. The small footprint of the project, its location outside the city centre and away from residential neighbourhoods will contribute to lower the impacts.

Mitigation measures will be identified to ensure that impacts are dealt with in order to minimize as much as possible their intensity, spread and duration. For key impacts that cannot be mitigated properly, compensation measures will be identified.

Finally, monitoring and follow-up programs will be set up to ensure that environmental and social impacts are managed throughout the life of the project and in respect with authority’s requirements and permitting conditions.

21 Capital and Operational Costs

This Section provides a breakdown for estimates on major capital cost items for the development of both entities of the planned integrated HFP operation, the upstream Langis quarry and the downstream refining part in Matane, respectively (Section 21.1). The economic interlinkage between both operations is a result of Langis silica being provided at cost to the smelter where it will be blended with higher purity spec silica procured from other domestic sources. Hence, unit-production costs for mgSi and FeSi contain the SiO_2 source at partial cost in accordance with the underlying blending ratios for internal and external silica needs. Section 21.3 provides unit-cost estimates in absolute and relative terms as all-in- and cash-cost breakdowns for the different intermediate and end-products of the integrated HFP concept. A comparative cost analysis in which projected cash-costs are benchmarked with cost estimates for existing smelters is provided in Section 21.4. A review of the main findings of the present section is provided in Section 21.5.

Capital budget and production cost estimates have been based on USD with non-USD quotes, e.g. quotes received in CAD, converted at the exchange rate of 1.35USD/CAD according to the closing rate from 1st of March, 2016.[37]

The following capital cost estimate for CME's integrated HFP project has an accuracy of +/- 30%. This bandwidth provides a sufficient basis to derive at a sensible continuation or discontinuation decision for further pre-ground-breaking early-stage engineering and evaluation works, but not for project appropriation, financing, or forming the cost basis for controlling the engineering procurement and construction management (EPCM) stage of the project. In order to commence with the latter stages it is recommended to initiate feasibility- (FS) or definitive feasibility study (DFS) as next pre-ground-breaking planning stage (Section 26).

37 For a detailed overview on the preliminary and indicative supply-chain analysis refer to Appendix X

21.1 Capital Costs

This section provides a cost estimate breakdown for the expected capital budgets in connection with the development of the Langis exploration activity and the HFP smelter operation in Matane. The capital cost breakdown is provided on a stand-alone basis for each site of the integrated quarrying and refining project. Potential minor sourcing advantages from dual site development, e.g. for mechanical and electrical components as well as civil work structures, have been disregarded at PEA stage and should be integrated as a value engineering exercise during FS, DFS and/ or BE stages.

Individual components of the capital budget are classified either as direct field costs (DFC), indirect field costs (IFC) or other costs (OC). The classifications are defined as follows:

- Direct field costs include estimates for mechanical, electrical and production equipment, labour and materials for erection of plant elements including specialist subcontract work that are required to deliver the fixed assets
- Indirect field costs include all project specific cost items that are incurred in order to support direct field cost items, e.g. engineering design, project management, site management and supervision during construction, commission and ramp-up stages as well as temporary support facilities on-site
- Other costs include an allowance for contingencies or project cost overruns, fees for insurances, bonds and guarantees as well as fees for external advisory services, such as technical, financial, tax and legal advisors, while project supervision costs incurred by project sponsor are not included in the baseline estimate

The capital budget estimate is based on multiple sources, incl. internal bottom-up assessments for individual line-items, a quotation from a furnace technology package provider, certain balance-of-plant (BOP) components expressed as a percentage of processing equipment and benchmarks for capital budgets from similar projects as cross-references for sense-checking. The baseline project budget estimate for the up- and downstream stands at approximately US$278.8m including a contingency of 15.0% on the DFC budget.

The contingency buffer accounts for project uncertainties related to events that might lead to revisions or cost overruns for individual capital components during the various project execution stages, including early-stage planning, detailed design and engineering, procurement, construction, commissioning, ramp-up and process stabilization phases.

The overall estimation bandwidth is within the aforementioned range of +/-30% in accordance to the current early-planning stage of the project and is deemed sufficient to evaluate project economics to derive at a sensible go- or no-go decision for the integrated project.

The development of the Langis silica quarry as outlined in Section 16 leads to the following fixed asset and capital equipment requirements with associated capital budget estimates as disclosed in Table 64:

Table 64: Base-case capital budget estimate for Langis quarry operation

#	line-item description quarry operation	base-case
1	Quarry Equipment	848,478 USD
2	Quarry Infrastructure + Administrative Buildings	672,100 USD
3	Beneficiation Plant	2,607,000 USD
	Total Estimated Investment for Fixed Assets - Upstream	**4,127,578 USD**

Source: Caban Geoservices, Viridis.iQ GmbH

The capital expenditure estimate for the silica deposit operation located in close proximity to the village St. Vianney, Québec, Canada is based on a data bank of similar open pit mining operations. The indexation for individual plant-, beneficiation- and other capital equipment items has been cross-referenced with a data-bank in accordance to the quarrying plan specific fixed and mobile asset needs as described in Section 16.

The individual line-items as outlined in Table 64 include a planning contingency reserve of 10%. Viridis.iQ GmbH has assessed and reviewed the data and is of the opinion that capital expenditure estimates for the upstream quarry operation is within a reasonable range as customary for early PEA planning stages.

The base-case estimates for major fixed capital investment items and project development expenses for the proposed initial 3 furnace HFP base-case operation at the Industrial Park of Matane are disclosed in Table 65:

Table 65: Base-case budgetary estimate for the HFP concept in Matane

#	type	line-item description smelter	base-case
1	DFC	Earthworks	20,848,668 USD
2	DFC	Civil Construction (incl. Buildings and Building Steel Structures)	27,482,608 USD
3	DFC	Furnace Technology Package	51,029,371 USD
4	DFC	Furnace Primary De-dusting System Package	25,790,342 USD
5	DFC	Raw Material Receiving and Handling System	8,148,145 USD
6	DFC	Product Handling System (incl. Tapping Area, Casting Area and Crushing System)	5,758,029 USD
7	DFC	Cooling System, Water Treatment and Piping	1,644,194 USD
8	DFC	Other Mechanical Equipment and Steel Structures	5,186,494 USD
9	DFC	Electrical, Automation & Instrumentation (excl. Main Substation)	17,626,588 USD
10	DFC	Main Substation	5,685,000 USD
11	DFC	Roads and Urbanization	1,939,758 USD
12	DFC	Erection and Assembly Rented Equipment	3,457,901 USD
13	DFC	Mechanical, Electrical and Automation Assembly Costs	11,178,636 USD
14	IFC	Engineering Projects, incl. Detailed Engineering	6,156,304 USD
15	IFC	Plant Commissioning, Vendor Assistance during Installation & Construction	10,935,000 USD
16	IFC	Spare Parts	9,124,653 USD
17	IFC	EPCM Cost	23,221,967 USD
18	OC	Estimate Contingency @ 15.0% of DFC budget	27,866,360 USD
19	OC	Insurance @ 3.0% of DFC budget	5,573,272 USD
20	OC	Other Advisory Services (Technical, Financial, Tax & Legal) @ 2.5% of DFC budget	4,644,393 USD
21	OC	Bonds, Guarantees, etc. @ 0.75% of DFC budget	1,393,318 USD
		Direct Field Costs - Subtotal	**185,775,734 USD**
		Indirect Field Costs - Subtotal	**49,437,924 USD**
		Other Costs - Subtotal	**39,477,343 USD**
		Total Estimated Investment for Fixed Assets - Downstream	**274,691,001 USD**

Source: Viridis.iQ GmbH estimates

The budget estimate for the downstream operation is based on a thorough bottom-up assessment of the pre-conceptual engineering design of the HFP in Matane as outlined in Sections 17.6 and 17.7. The capital budgeting process is based on widespread engineering techniques, usually applied in industrial projects of this scale once a technical feasible layout has been identified. The layout design is a fundamental step for budgeting purposes, as it builds the basis for underlying construction parameters such as earthworks, area requirements for light- and heavy industrial structures, warehouses, office and administrative spaces, associated concrete- and steel-consumption, as well as total man-hour needs and others. In addition, the process modeling, mass and energy balances are important input factors as these determine equipment needs, which impact building dimensions and handling system requirements for raw materials, intermediate, by- and final products.

The recommended and project specific HFP layout has been developed based on SolidWorks 3D modeling software, considering most adequate engineering solutions for all envisioned plant sub-systems. After the conclusion of the layout process and various 2D drawings, all systems, sub-systems, components and sub-components of the plant have been listed in order to determine the quantities, volume and area requirements for the aforementioned construction parameters from the sequentially derived 3D model. A similar conceptual engineering process is also applied to all mechanical equipment, steel structures, civil works and earthworks. The expected earth excavation volume for the plant was derived from the actual topography of the plot in Matane. The investment budget for electrical equipment is calculated from the conceptual design and also based on references from other projects. The bottom-up capital budget estimate provides a high level of accuracy already at an early project stage.

The estimates for the underlying unitary price reference points for the local construction budgeting part are disclosed in Appendix II. The presented data points are preliminary references and are subject to wide variations depending on finalized construction specifications and requirements. The unitary price points are also expected to be influenced by the general economic environment and in specific, by the utilization of the local construction industry at the time when negotiation start with the selected prime contractor.

All equipment and material costs outside of Canada were included as FOB (free on board) and exclusive of taxes and duties. A freight and packaging mark-up for the “Furnace Technology Package” and “Spare Parts” has been included in the respective line-items in Table 65. Equipment related transportations costs needs further evaluation as part of a more detailed procurement and supply-chain analysis (Section 26.1.2).

The working assumption for the PEA is that fixed capital equipment imports fall under the “Economic Action Plan 2015”[38] initiative that intends to eliminate all tariffs on machinery and equipment imports. Hence, the import duties for foreign machinery imports have been set to zero in accordance with the “Duty-free Manufacturing Tariff Regime” initiative.[39] This working assumption might change once the intended due-diligence for project specific tax and duty

38 Compare: http://www.actionplan.gc.ca/en/initiative/tariff-relief-manufacturing-inputs-and-machinery
39 Compare: http://www.fin.gc.ca/ftz-zf/index-eng.asp

implications has been finalized by an accredited Canadian tax advisory firm. CME intends to commence this work-stream in the next project development stages.

Initial stocks of spare parts have been included in the capital budget estimate. As outlined in Section 21.3 continuous spare part needs are included as regular and recurring maintenance expenses over the project evaluation period and therefore are reflected in the unit production cash-cost estimates. A mark-up for project insurance costs have been included in the IFC line-item "Others".

Table 66 provides an overview on major capital- and project development cost items including a preliminary working capital estimate for the downstream part. As can be seen the capital needs for fixed assets for the quarry operation comprise only about 1.5% of the total budgeted capital requirements for the integrated exploration and processing operation:

Table 66: Consolidated capital budget

Total capital budget estimate for CME's quarry and smelting operation	
Item	**Amount**
Quarry Equipment - upstream	848,478 USD
Smelter Equipment - downstream	74,340,959 USD
Total Equipment related Invest	**75,189,437 USD**
Quarry Infrastructure + Administrative Buildings - upstream	672,100 USD
Beneficiation Plant - upstream	2,607,000 USD
Building, Plant, Facility, Infrastructure & Auxiliaries - downstream	111,434,775 USD
Contingency	27,866,360 USD
IFC eligible as fixed investment	29,662,754 USD
Consolidated Balance-of-Plant excl. Furnace Technology Package	**172,242,990 USD**
Project management, non-capitalized development costs & insurances	31,386,153 USD
Total - Fixed Capital plus development expenses	**278,818,579 USD**
Working Capital Assumption (60 day cash conversion cycle)	23,758,003 USD
Total	**302,576,582 USD**

Source: Viridis.iQ GmbH

Under the assumption that planning contingencies will be fully utilized the aggregated capital budget estimate for the integrated quarrying and smelter operation excluding working capital requirements amounts to approximately USD278.8m. The authors are of the opinion that the presented capital costs constitute an accurate early-stage assessment for CME's integrated HFP project that is within the above specified PEA estimate range. It is expected that the accuracy level of the budget estimate will be further enhanced by later stage initiation of a value based engineering work stream.

21.2 Baseline Cost Assumptions

The presumed operation mode is of relevance as it influences the allocation of indirect production costs to the various potential end-products. While production cost estimates are introduced for both end-products of the HFP concept (metallurgical silicon and ferrosilicon unit cost estimates), the reader should be reminded that the base-case economic project evaluation as introduced in Section 22 is solely based on the hypothesis that market dynamics will remain in favour of metallurgical silicon and that the HFP will therefore operate in single product mode and only produce higher margin metallurgical silicon over the entire project evaluation period of 20 years.

For key cost drivers and major input factors (e.g. resources, consumables, utilities) indicative quotes have been obtained as disclosed in Table 67.[40]

The table below only refers to those quotes that have been short-listed for production cost computation and estimation purposes. A more comprehensive list of contacted suppliers with the respective indicative unit supply price is given in Appendix X.

Table 67: Indicative quotes for major input factors

#	resource	price	unit	delivery type	delivery port/ destination	total price @ FG [USD/t]
1	High-purity quartzite - Blackburn Quartz	45.0	CAD/t	CFR	Montreal	59.3 USD/t
2	Quartzite - Langis	18.3	USD/t	FOB	St. Vianney	21.0 USD/t
3	Carbon reductant FeSi - Carbon Partners	140.0	USD/t	CIF	Matane	140.0 USD/t
4	Carbon reductant mgSi - Carbon Partners	185.0	USD/t	CIF	Matane	185.0 USD/t
5	Carbon Electrode - SGL	2,850.0	USD/t	CIP	Matane	2,850.0 USD/t
6	Söderberg paste - Elkem Carbon	850.0	USD/t	CIP	Montreal	890.0 USD/t
7	Woodchips - Group GDS "North Shore"	95.0	CAD/t	FOB		76.7 USD/t
8	limestone	25.0	CAD/t	FOB	Quebec City	44.4 USD/t

Source: supplier as indicated, Viridis.iQ GmbH

40 The term ‘indicative“ means that VIQ received written pricing indications from potential suppliers but not official binding- or non-binding offers. A more comprehensive supply-chain analysis needs to be conducted in which short-listed suppliers need to be evaluated in regards to capability to provide demanded volumes in-time and within pre-defined specification ranges.

In cases where the individual quote is based on non-insured delivery and/ or a destination outside of Matane, an insurance- and inter-province delivery mark-up has been included in order to derive at a factory gate delivery cost estimate in USD.

The assumed insurance mark-up is fixed at 1.5% of product value and the underlying bulk delivery rate per kilometre-tonnage is estimated to stand at approximately 0.086CAD/t/km. The exchange rate for conversion of CAD quotes has been fixed to 1.35USD/CAD according to the closing rate from 1st of March, 2016.

From a commercial perspective the integrative aspect of CME's project is reflected in line-item 2 of Table 67, which discloses the internal transfer price of Langis silica source at US$21.00/t, including the expected delivery costs to Matane.

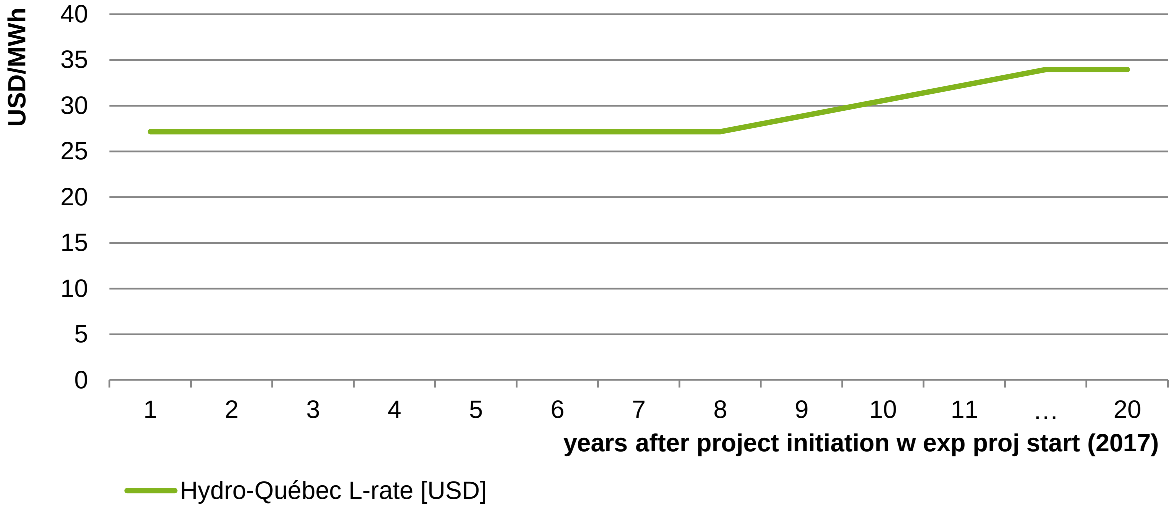
In accordance with the intended project set-up, silica from Langis will be provided on a cost-basis, which further reduces unit-production costs for both end-products, mgSi and FeSi. A detailed overview on the deduction of the relevant silica transfer price is provided in Section 21.3.1.

Apart from processed resources in the SAF the biggest cost driver is the applicable electricity rate, as both production processes are highly energy intensive. Here, the project clearly exhibits a competitive advantage when compared to other locations of incumbent smelter sites.

A preliminary power rate estimate conducted by the provincial utility Hydro-Québec based on the smelters anticipated average power utilisation, projected annual consumption and expected peak load yielded an expected L-rate of 45.84CAD/MWh (Appendix III). In addition, CME's integrated smelter project is expected to be eligible for a rate reduction under Québec's economic development rate for large power consumers (L-rate discount).

The L-rate discount is expected to be available until the end of 2025 upon which it will decline in 5%-age increments over a fade out period of three years. Correspondingly, the underlying L-rate discount is assumed to be accessible for a ten year period starting with a presumed ramp-up in 2018. The assumed electricity rate structure over the 20-year project evaluation period is depicted in the graph in the figure 162.

Figure 162: Assumed Hydro-Québec L-Rate structure with economic development rebate



Source: Hydro-Québec, Viridis.iQ GmbH

The labour requirements and qualification levels have been outlined in Section 17.5.2. In accordance with the specified qualification levels all-in or gross labour costs have been obtained by officials from the City of Matane. All-in or gross labour costs reflect all applicable ancillary costs incurred by an employer in this region, including all relevant fringe benefits such as social security contributions, vacation and statutory holiday payments, and overtime or shift premiums. As the provided ranges have been fairly large and actual salary payments will turn-out to be a function of the regional labour market dynamics as of the time when staffing commences, the financial model benchmark has been set to the upper-end of the provided ranges.

Table 68: Regional labour cost ranges & financial model reference

Labour Category	low (CAD/a)	high (CAD/a)	relative difference	model benchmark (USD/a) @ forex of 1.35CAD/USD
Management	90,000	144,000	60.0%	106,667
Sales Manager	60,000	78,000	30.0%	57,778
General & Administration	42,000	54,000	28.6%	40,000
Engineer	54,000	102,000	88.9%	75,556
Technician	45,600	72,000	57.9%	53,333
Operator	38,400	72,000	87.5%	53,333
Support staff - plant floor	36,000	48,000	33.3%	35,556

Source: City of Matane, Viridis.iQ GmbH

It has further been assumed that the labour costs in the region of St-Vianney will be similar to the underlying labour costs in Matane. This presumption is seen as unproblematic as the quarry is within the catchment area of Matane and labour mobility is typically high for the applicable distance of approximately 50km. Hence, the annual USD labour costs as disclosed in the right column of Table 68 also apply to the different qualification and skill-set levels utilized in the upstream operation of the quarry. The quarry operation needs approximately 16 full-time employees while the downstream silica processing plant deploys almost 204 full-time employees.

Other cost items are comprised of various minor material usages and process chemical deployments in the smelting, tapping and refining processes. The recurring maintenance expense is expected to be at 2.0% of the initial total investment budget or approximately US$5.5m per annum. Minor cost items have been priced based on reference prices from other projects and need to be further investigated in a more detailed supply-chain analysis.

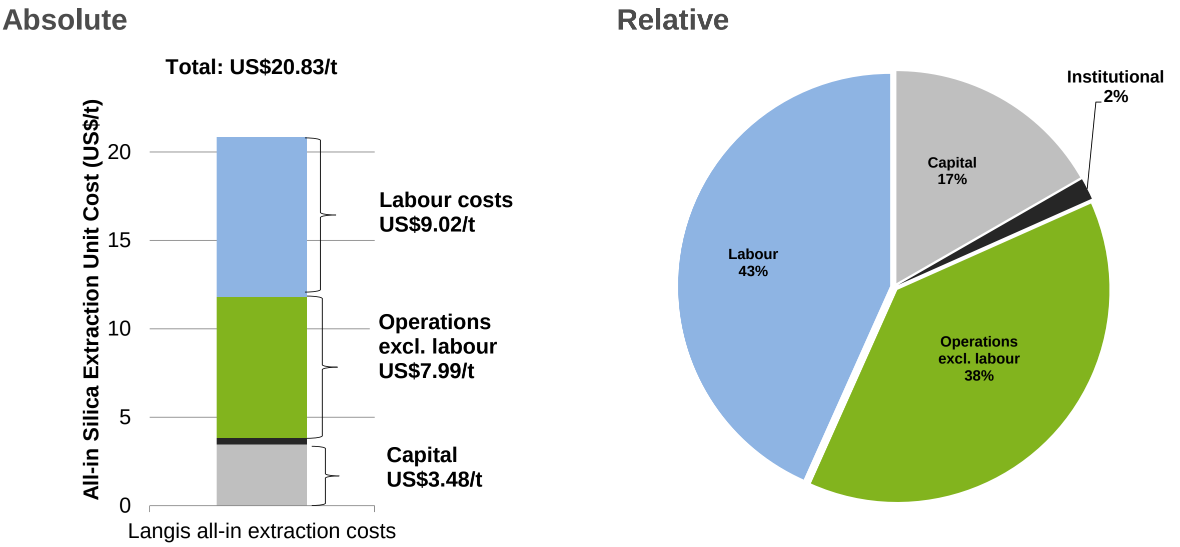
21.3 Extraction and Production Costs

There are various levels of cost estimates and cost breakdowns provided for the expected Langis silica unit extraction costs as well as for the different smelter end-products of CME's integrated project. These are introduced in the respective sub-sections of the present section. The NSR, as introduced in Section 4.1.5, is neither included in the cost estimates for mgSi nor in the hypothetical FeSi case, as this royalty constitutes a general operational expenditure and is therefore, not classified as a production related expense.

21.3.1 Silica Extraction Cost and Transfer Price

As outlined in Section 16, the extraction of silica from the Langis deposit is a labour-intensive operation with the second biggest unit cost driver being "consumables, spare and wear parts" generally associated with blasting, primary- and secondary crushing, screening, washing and material handling activities (operations excl. labour). These two cost-drivers alone comprise approximately 81% of all-in unit extraction costs. The capital cost component which is comprised by depreciation charges, an annualized maintenance and re-investment allowance, as well as by an annuity charge for quarry closure and recreation costs contributes approximately 17% to the all-in unit extraction costs.

Figure 163: All-in unit extraction cost-breakdown - Langis silica



Source: Viridis.iQ GmbH estimates

The absolute and relative cost break-downs as depicted in Figure 163 provide an overview on the expected major cost categories for the proposed operation of the Langis silica deposit. The estimated labour force is comprised of 16 full-time employees, incl. a site manager, a mining engineer, one geologist, one mining and geology technician, one safety manager, one mechanical technician, one electrical technician, one technical and mechanical maintenance worker, six operators and drivers, as well as one operator for auxiliary systems and one clerk for quarry administration.

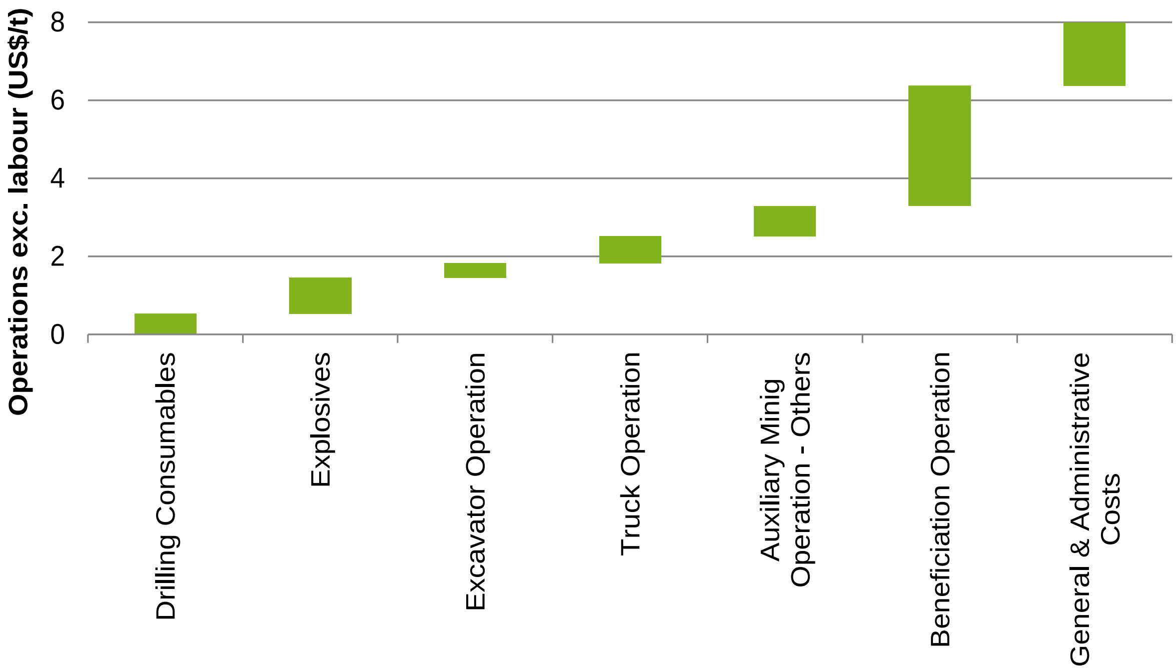
The 2% institutional charge is associated with a fee for extraction rights levied by the Government of Québec on exploration activities as envisioned for the Langis quarry. The applicable public fee is called “lease to mine surface mineral substances” and is comprised of an annual charge of CAD 6,000 per year and a volume related royalty of CAD 0.40 per extracted ton.[41] Neither, the internal project team of CME nor the authors of this PEA are aware of any other levies that would apply to the planned quarry operation. CME intends to

41 Compare: http://www.mern.gouv.qc.ca/english/mines/rights/rights-extraction-fees.jsp

contract an accredited Canadian tax advisory firm to conduct a more thorough due-diligence on applicable federal and state taxes, public fees and possible subsidies in a subsequent project stage, upon which the underlying public quarry extraction fee, as described above, might be revised.

Operation costs excl. labour sum-up to US$7.99/t and are mainly comprised by consumables, spare and wear parts. A detailed cost break-down for this cost-category is provided in the following graph:

Figure 164: Unit-breakdown for “Operations excl. labor” expensed - Langis quarry



Source: Viridis.iQ GmbH estimates

The total annual extraction cost for the quarry operation is estimated to amount to USD2,031,615 per annum for an approximate extracted quartzite volume of 97.5ktpy.

This volume will internally be processed in the smelter in Matane, as a blended 67% silica source for the production of metallurgical grade silicon.

21.3.2 Metallurgical Silicon Production Cost

In the quasi steady-state base-case for the downstream operation the main variables that impact metallurgical silicon unit-production costs over the 20-year project evaluation horizon are labour-underutilization during ramp-up (years 1 to 3), the electricity L-rate discount explained in Section 21.2 (years 1 to 11), and the fade-out of equipment related depreciation charges (years 2 to 12). Hence, the dynamic base-case inflation assumptions introduced in Section 22.5 are not taken into consideration in the following discussion of the various unit-cost breakdowns.

Correspondingly, four phases can be identified in the steady-state base-case in which all-in unit production cost change due to reasons unrelated to specific inflation scenarios effects:

- Phase 1 (years 1 to 3): All-in unit cost decline due to ramp-up
- Phase 2 (years 4 to 8): All-in unit cost stabilizes with full-utilization and L-rate discount
- Phase 3 (years 9 to 12): All-in unit cost increase due to fade-out of L-rate discount
- Phase 4 (years 13 to 20): All-in unit cost stabilize at lowest level with equipment related assets being fully depreciated

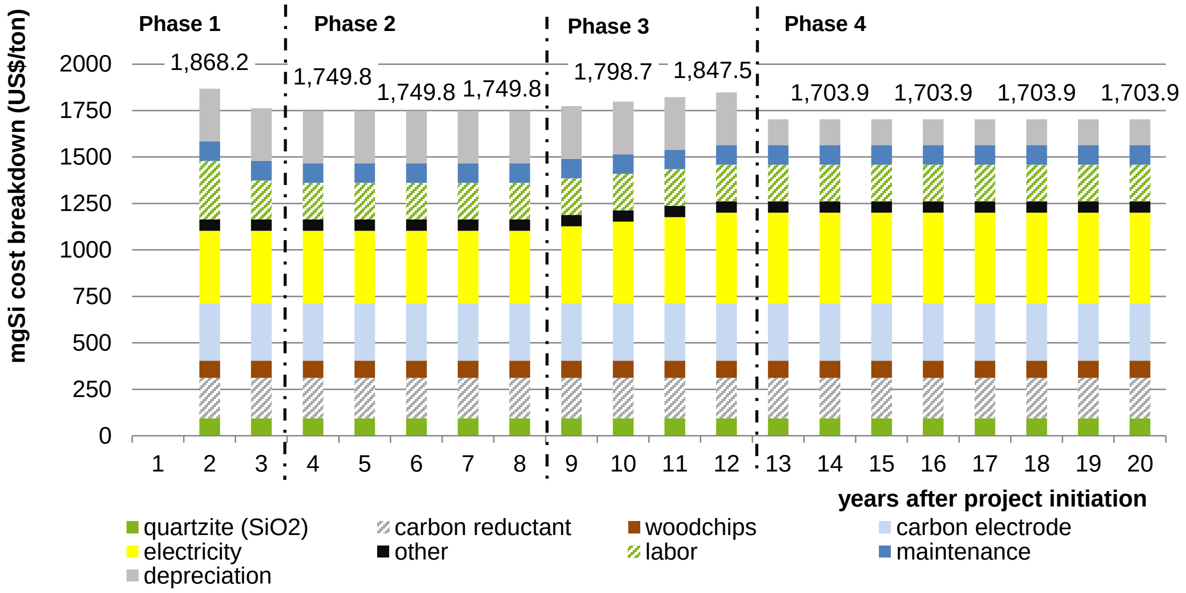
Figure 165 gives an overview on the phase-specific progression of all-in unit production costs for the HFP's metallurgical silicon output over the project assessment period of 20 years.

The all-in silicon production costs are expected to fluctuate between 1,704-1,868US$/ton depending on the project stage.

Important to mention that, the fluctuations are simply a consequence of the underlying labour-ramp-, electricity rate- and depreciation schedules and are not the result of the incorporation of dynamic inflation assumptions for the different cost- and revenue drivers.

The dynamic base-case of the silicon smelter is introduced in Section 22.5 as part of the project scenario analysis shown in the figure 165.

Figure 165: Evolution of all-in mgSi cost over project evaluation period



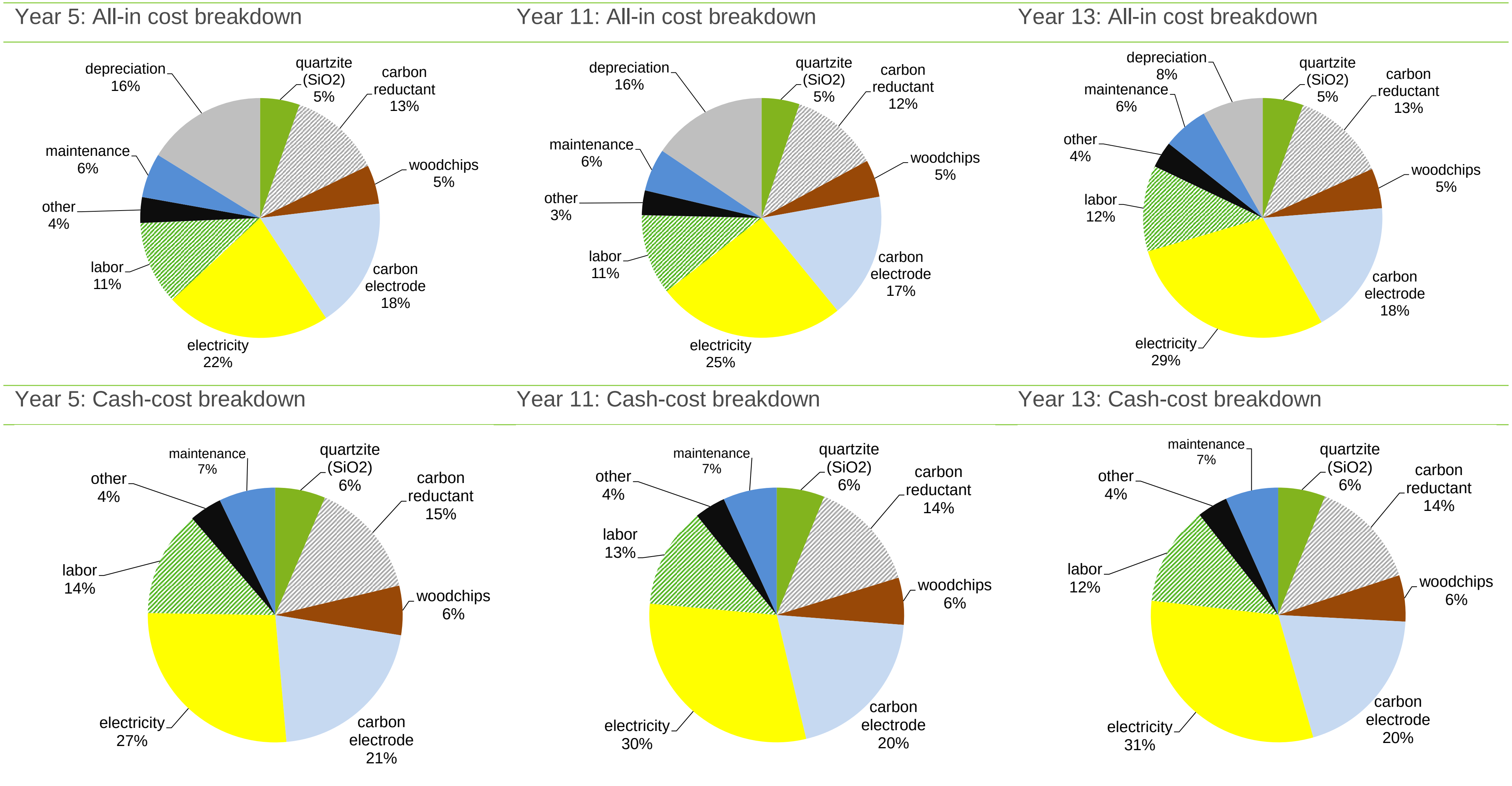
Source: Viridis.iQ GmbH estimates

While CME is expected to procure electricity at comparatively low rates (see Section 21.2), the energy intensity of the production process still causes unit-production costs to be heavily influenced by the overall energy needs.

According to the relative cost breakdowns provided in Figure 166, energy remains the biggest cost driver contributing between 22%-29% to the overall all-in unit costs and approximately 27%-31% to unit-cash-costs. Next to electricity as the primary cost-driver, unit production costs are heavily impacted by expenses for the carbon electrode (2^{nd} biggest cost factor) followed by depreciation charges as the third biggest cost driver for all-in unit costs, which is a direct consequence of the high capital intensity of silicon smelters.

The next biggest influencing factors of unit production costs are the carbon reductant (low ash coal) followed by labour expenses. As a consequence of silica being provided on an extraction cost basis from the Langis quarry, the relative share of the SiO_2 feedstock is comparatively small, varying between 5% on an all-in cost- to 6% on a cash-cost basis.

Figure 166: Relative cost breakdown mgSi all-in and cash-costs for different project phases



Source: Viridis.iQ GmbH estimates

A more detailed cost-breakdown in tabular format is provided below, with estimated annual quantities, underlying unit prices as well as annual total-costs for different cost drivers affecting unitary production costs for the 100% metallurgical silicon base-case and under the presumption that capacities are fully-utilized.

Table 69: Tabular cost break-down mgSi

CME mgSi production cost - breakdown						
resource/ cost factor	**annual volume**	**unit**	**unit price**	**unit**	**total cost (USD/a)**	**unit production cost (USD/t)**
quartzite - Langis	97,526	tons	21.0	USD/t	2,048,046	39.12
quartzite - external	48,035	tons	59.3	USD/t	2,848,487	54.41
carbon reductant	61,850	tons	185.0	USD/t	11,442,326	218.57
woodchips	62,760	tons	76.7	USD/t	4,813,665	91.95
carbon amorphous electrode	5,566	tons	2,850.0	USD/t	15,862,118	303.00
graphite electrode 4'' (Tapping Gun)	112	tons	2,400.0	USD/t	269,797	5.15
steel drawing tube (1mm wall width)	23	tons	850.0	USD/t	19,673	0.38
Al drawing tube	35	tons	500	USD/t	17,358	0.33
wooden sticks	27,553	units	2.5	per stick	68,882	1.32
limestone	1,022	tons	44.4	USD/t	45,362	0.87
oxygen	983,633	m³	0.1	USD/m³	98,363	1.88
other miscellaneous prod costs					2,949,000	56.33
electricity - furnace	675,869	MWh/ye	34.0	USD/MWh	22,949,506	438.38
electricity - balance of plant	77,285	MWh/ye	34.0	USD/MWh	2,624,271	50.13
maintenance					5,493,820	104.94
Operator mgSi	136	people	53,333	USD/a	7,253,333	138.55
Technician mgSi	36	people	53,333	USD/a	1,920,000	36.68
Engineer mgSi	12	people	75,556	USD/a	906,667	17.32
Administration - mgSi	7	people	35,556	USD/a	248,889	4.75
depreciation - equipment					7,518,944	143.63
depreciation - plant					7,320,327	139.83
cash production-costs						**1,564.1**
total production-costs						**1,847.5**
cash-cost incl. L-rate electricity discount @ 20%						**1,466.4**

Source: Viridis.iQ GmbH estimates

21.3.3 Ferrosilicon Production Cost

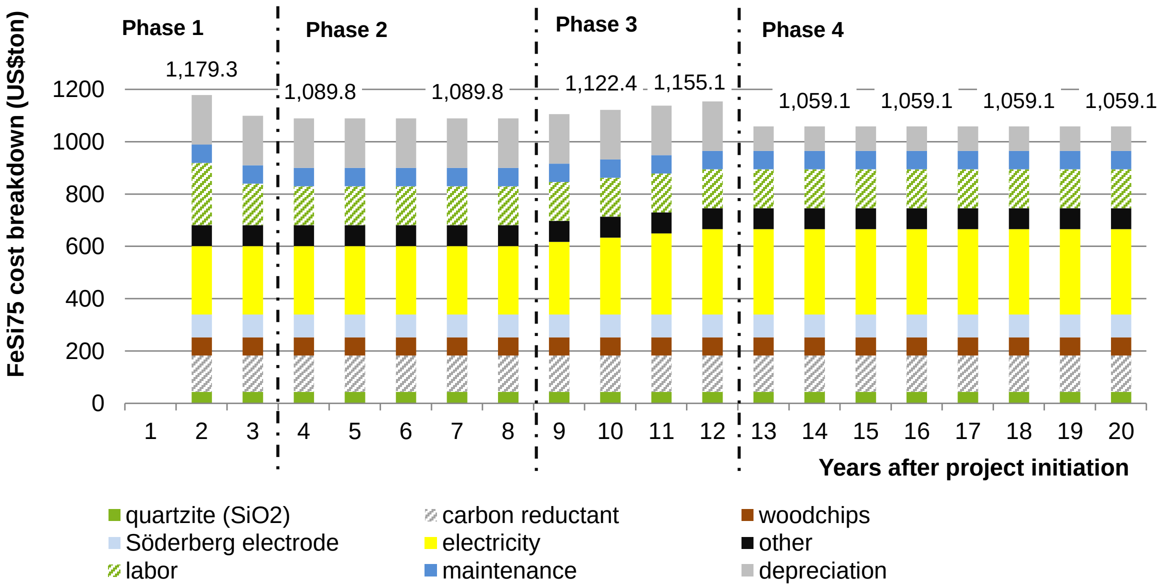
The following disclosures of prospective ferrosilicon unit-production costs are based on the operating assumption that one- out of a total of three furnaces is dedicated to the production of FeSi75. This operating assumption is used to allocate indirect production costs such as depreciation, maintenance and non-product specific plant labour to the different material outputs of the HFP under dual product operation mode.

The quasi steady-state production cost estimates for ferrosilicon exhibit similar phase specific fluctuations over the 20-year projection horizon, as already elaborated for the 100% metallurgical silicon base-case production cost disclosure in the previous section.

A total of four phases can be identified in which all-in production costs would fluctuate due to the very same reasons, as elaborated in the preceding section:

- Phase 1 (years 1 to 3): All-in unit cost decline due to gradual ramp-up
- Phase 2 (years 4 to 8): All-in unit cost reach local trough with full-utilization and L-rate discount
- Phase 3 (years 9 to 12): All-in unit cost increase due to fade-out of L-rate discount
- Phase 4 (years 13 to 20): All-in unit cost decline as equipment related fixed assets are fully depreciated

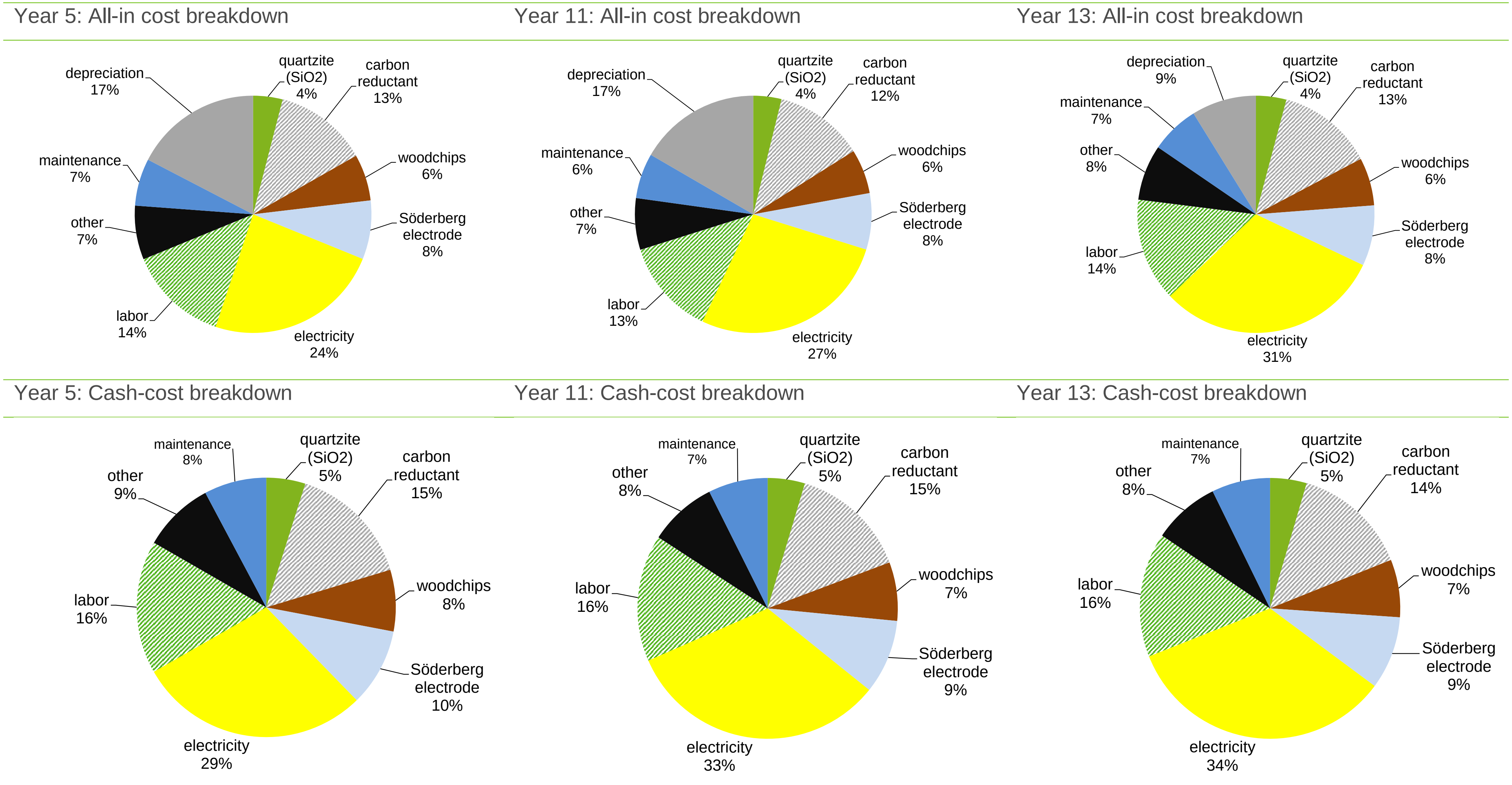
Figure 167: Evolution of all-in FeSi cost over project evaluation period



Source: Viridis.iQ GmbH estimates

The relative cost ranking by the various cost factors shows again that electricity would be the biggest unit-cost driver for ferrosilicon output, despite of the underlying favourable electricity procurement costs. Next to energy as the primary cost-driver, ferrosilicon all-in unit production costs would be heavily impacted by pro rata capital depreciation charges (2nd biggest cost factor), followed by labour, the carbon reductant and unit-expenses for the electrode consumption. Again, as silica will be provided on an extraction cost basis from the Langis quarry regardless of the specific factory output distribution, the relative share of the SiO_2 feedstock would be again comparatively small, varying between 4% on an all-in cost to 5% on a cash-cost basis. Relative all-in and cash-cost breakdowns for a hypothetical one-furnace ferrosilicon production mode are provided in Figure 168.

Figure 168: Relative cost breakdown FeSi all-in and cash-costs



Source: Viridis.iQ GmbH estimates

A tabular unit cost breakdown estimate for cash- and all-in ferrosilicon production cost under a full-utilization assumption for the specified case is provided in Table 70. The unitary cost benefit of the presumed early-stage L-rate discount would be expected to be in the region of USD65/ton.

Table 70: Tabular cost break-down FeSi

CME FeSi production cost - breakdown						
resource/ cost factor	**annual volume**	**unit**	**unit price**	**unit**	**total cost (USD/a)**	**unit production cost (USD/t)**
quartzite - Langis	54,289	tons	21.0	USD/t	1,140,061	43.68
carbon reductant	25,922	tons	140.0	USD/t	3,629,041	139.04
woodchips	23,506	tons	76.7	USD/t	1,802,917	69.08
hematite (Fe2O3)	8,792	tons	120.0	USD/t	1,055,002	40.42
limestone	275	tons	44.4	USD/t	12,198	0.47
electrode paste	1,804	tons	890.0	USD/t	1,605,265	61.50
steel shirt (incl. Flips)	235	tons	1,400.0	USD/t	328,325	12.58
steel rebar 3/4"	252	tons	1,400.0	USD/t	353,096	13.53
steel tube 3/4"	3	tons	850.0	USD/t	2,452	0.09
oxygen	392,329	tons	0.10	US$/m³	39,233	1.50
other miscellaneous prod costs					983,000	37.66
electrical energy - SAF	225,287	MWh	34.0	USD/MWh	7,649,738	293.09
electrical energy - BOP	25,826	MWh	34.0	USD/MWh	876,921	33.60
maintenance					1,831,273	70.16
Operator mgSi	53	people	53,333.3	USD/a	2,826,667	108.30
Technician mgSi	13	people	53,333.3	USD/a	693,333	26.56
Engineer mgSi	4	people	75,555.6	USD/a	302,222	11.58
Administration - mgSi	2	people	35,555.6	USD/a	71,111	2.72
depreciation - equipment					2,506,315	96.03
depreciation - plant					2,440,109	93.49
cash production-costs						**965.6**
total production-costs						**1,155.1**
cash-cost incl. L-rate electricity discount @ 20%						**900.24**

Source: Viridis.iQ GmbH estimates

21.4 Peer-Group Benchmarking

This section will conduct a comparative assessment for both, the capital budget estimate for the HFP concept and the production cost estimates for metallurgical silicon and ferrosilicon, respectively. The capital budget will be compared to other silicon Greenfield projects, while the unit production costs are benchmarked with production cost estimates for existing metallurgical and ferrosilicon producers as provided by third-party market research firms.

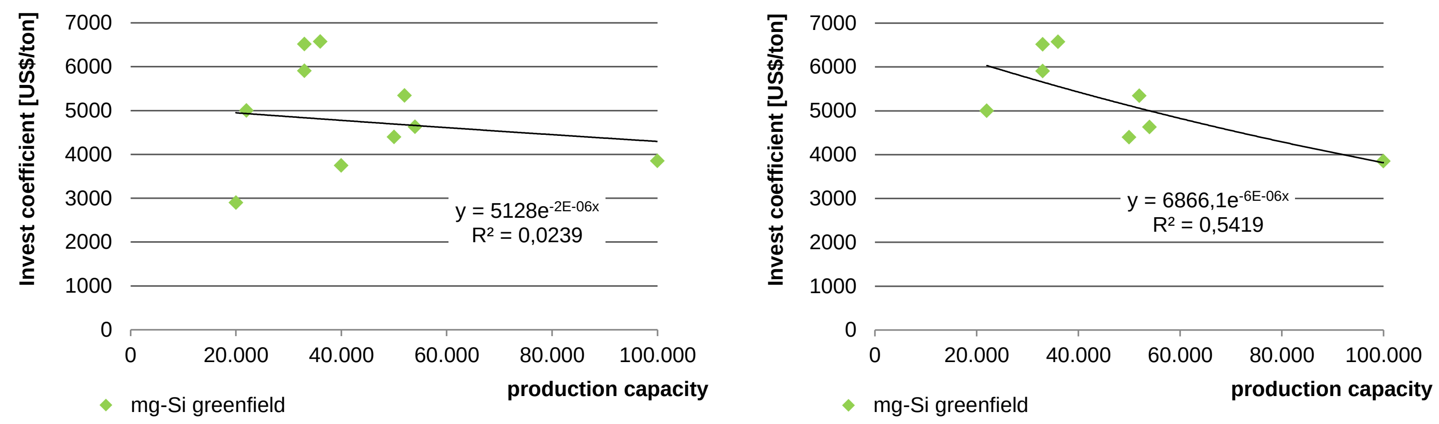
21.4.1 Comparative Assessment: Capital Budget

There have been a couple of Greenfield project announcements outside of China in the recent past, of which some have moved forward into development phase. While initial capital budgets are subject to change in conjunction with project progression and also depend to a great extent on the geography and site location, there are nevertheless some insights to be gained from an international capital budget comparison.

Figure 169 shows two graphs that plot the reference projects' annual production capacities against the deduced project specific investment spending per ton. The left graph is based on 10 reference projects while the right graph is based on the same list of reference projects with the exclusion of two outliers. One of the excluded reference points is associated with the expansion of an incumbent and the other excluded data point belongs to a project that was build based on Chinese equipment[42]. While any mathematical inference would bear no statistical significance in light of the limited population size, the trendline in the right graph seems to indicate that there is a loose negative correlation between the capacity and the investment ratio:

Figure 169: Greenfield projects investment coefficient scatterplots

Based on 10 reference projects **Based on 8 reference project**



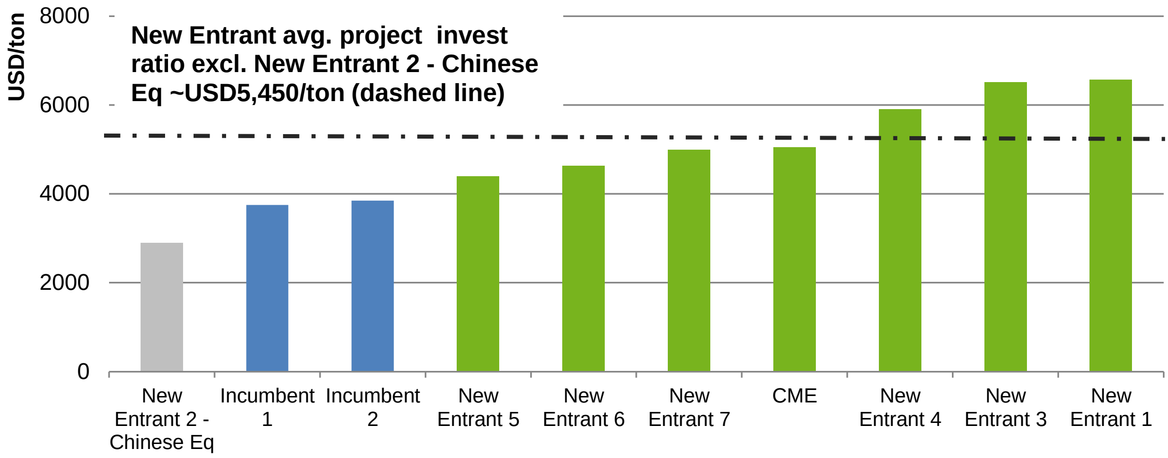
Source: public announcements, Viridis.iQ GmbH

The peer-group of Greenfield benchmark projects can be further categorized, in order to derive at a better understanding of the relative competitiveness of CME's estimated capital budget for the downstream smelter operation:

- New entrant with Chinese equipment
- New entrant with Western equipment
- Western incumbent

42 The Chinese equipment reference used on this part of the report is entirely under the responsibility of Viridis.iQ GmbH. The QP sigining for this part of the report had no access to the reference data base used on these estimates.

Figure 170: Greenfield project investment comparison by high-level project characteristics



Source: public announcements, Viridis.iQ GmbH[43]

Figure 170 provides a ranking for the categorized Greenfield peer-group projects. As can be seen, the capital expenditure coefficient related to CME's HFP is expected to fall within a middle position of the ranked sub-group of new entrant projects that are based on Western equipment. Interestingly, when compared to the other new entrant projects the location in Canada seems to exhibit some benefits when it comes to the overall investment needs. While it is no surprise that incumbents are more efficient in the development of new sites, the question might arise whether or not CME could reduce the capital budget through the deployment of Chinese equipment (compare data point "New Entrant 2 – Chinese Eq."). As this aspect affects project execution and operational risks during construction, ramp-up and early-operation phases a detailed capital equipment procurement review should be initiated in the next project stage that explicitly analyses the risks and benefits associated with a capital component sourcing strategy that takes equipment of Chinese origination into consideration.

21.4.2 Comparative Assessment: Unit Production Costs

A comparative cost analysis can only provide a rough indication on how a project's estimated production costs would compare within the competitive environment of the subject industry.

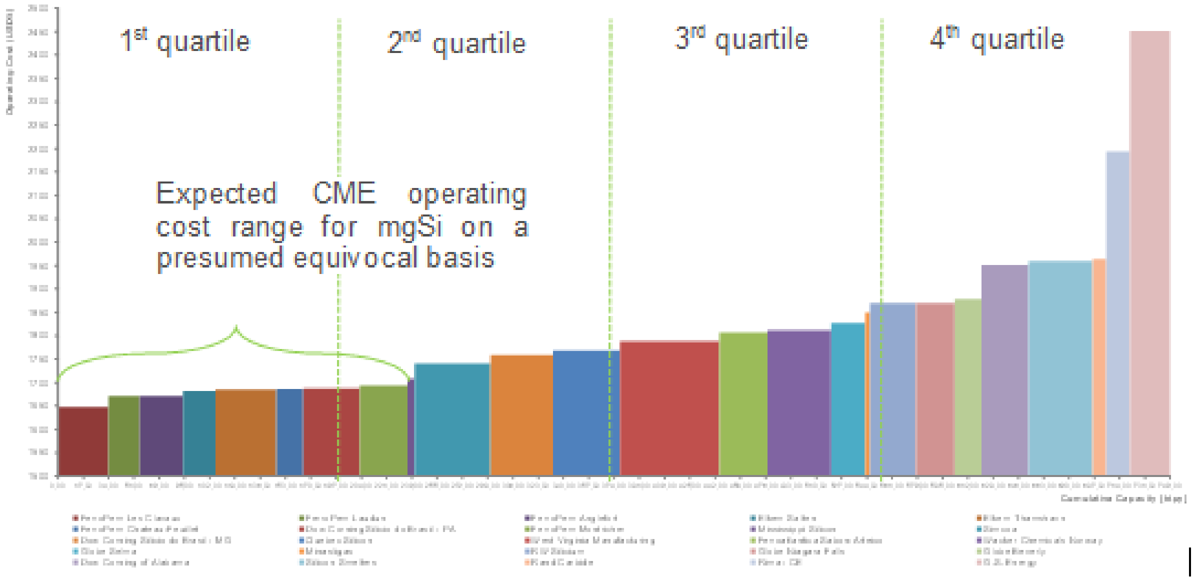
43 The data point "New Entrant 2 – Chinese Equipment" is an estimate done by Viridis.iQ GmbH. The QP signing for this part of the report has no access to the reference data base used for this value and assumes Viridis.iQ GmbH as responsible for this data point.

There are mainly three factors contributing to this blurriness: First, the project cost estimates are early-stage and therefore uncertain in nature and could be subject to material changes due to project specific and/ or market related events that could impact the project's assessment at later development stages. Second, the comparative basis provided by market researchers is ambiguous and do not provide a clear cost definition that could be used in the context of how estimated production costs have been presented in Section 21.3. Third, cost-stack curves are based on estimates and are -in almost most instances- not deduced from publicly available sources and are therefore subject to estimation uncertainties as well.

As a consequence, all-conclusions drawn from such an analysis are highly uncertain and should be interpreted with reasonable care and diligence as customary for early stage industrial project assessments. The definition for cash- and all-in production costs as has been followed in this report refers to all cost-items that are deployed in the production process and are reflected in the cost-of-goods sold line of the P&L. The only difference between the aforementioned cost metrics are the depreciation charges which are not included in cash-costs but are reflected in all-in production costs.

While CRU's definition of "Net operating costs" excludes depreciation charges, there are other expenses included, such as interest on working capital, taxes, royalties and also SG&A overhead charges, which have been classified as operating expenditures or financing costs in this report and therefore have been excluded from the previously presented production cost breakdowns. For the placement of CME's expected mgSi production costs within the net-operating cost stack curve from CRU the following limits have been applied: The lower limit is based on the cash-cost excl. L-rate discount of ~US$1,564/ton while the upper limit is set to US$1,694/ton and includes a SG&A surcharge of ~US$100/ton and a working capital finance surcharge of US$30/ton. Based on this methodology CME's projected production cost would fall into the 1st to top 2nd quartile position within a peer-group of Western producers as depicted in Figure 171:

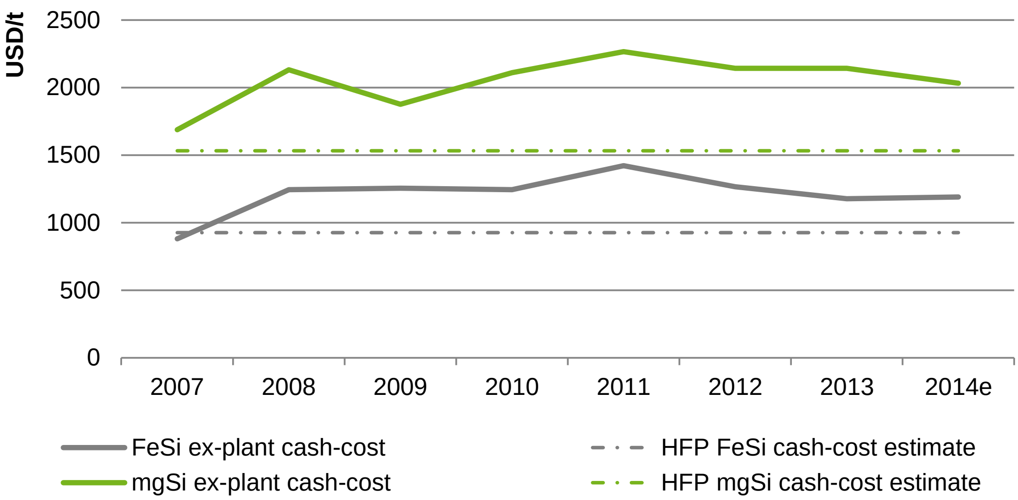
Figure 171: mgSi cost-stack curve – "Operating Costs"



Source: CRU (May 2015), Viridis.iQ GmbH estimates

The "Silicon and Ferrosilicon" market study from Roskill which has been used as the main market data reference point for this PEA provides ex-plant global average silicon metal and ferrosilicon ex-plant cash production costs estimates for the period from 2007 to 2014. While the definition seems to be more in-line with the cash-production cost definition as applied for the purpose of this PEA, the authors cannot attest that the comparative basis is exactly the same. Regardless of this limitation a comparison of projected mgSi and FeSi cash-production costs of the envisioned HFP Matane reveals that production cost for each product can and could be expected to be well below the respective global average cost, as shown in Figure 172 below:

Figure 172: mgSi and FeSi cash-cost comparison



Source: Roskill 2014, Viridis.iQ GmbH estimates

21.5 Preliminary assessment:

The preliminary assessment of the consolidated capital requirements for CME's integrated Hybrid Flex Plant project, which encompasses the development of the Langis silica deposit as well as the proposed first phase of the downstream smelter operation in Matane, is expected to amount to approximately US$278.8m within a range of +/-30%. Included in this budget is an estimated provision of US$31.4m for project management and non-capitalized development costs. The working capital needs are not part of this budget estimate and are expected to be in an order of magnitude of US$23.8m. Hence, the overall capital requirements sum-up to a total project related capital need of approximately US$302.6m. The capital requirements need to be provided in stages to fund project development expenses with the lion's share expected to become due over a three year period once construction has been commenced at the two sites.

The upstream capital requirements for the development of the Langis quarry are expected to amount to approximately US$4.2m and thereby comprise only a minor part or about 1.5% of the total fixed capital budget excl. working capital needs. The vast majority of the capital will be invested in the proposed first-phase, 3-furnace HFP operation in Matane. Therefore, project chances and risks are clearly geared towards the base-case 100% metallurgical silicon production part of the integrated project.

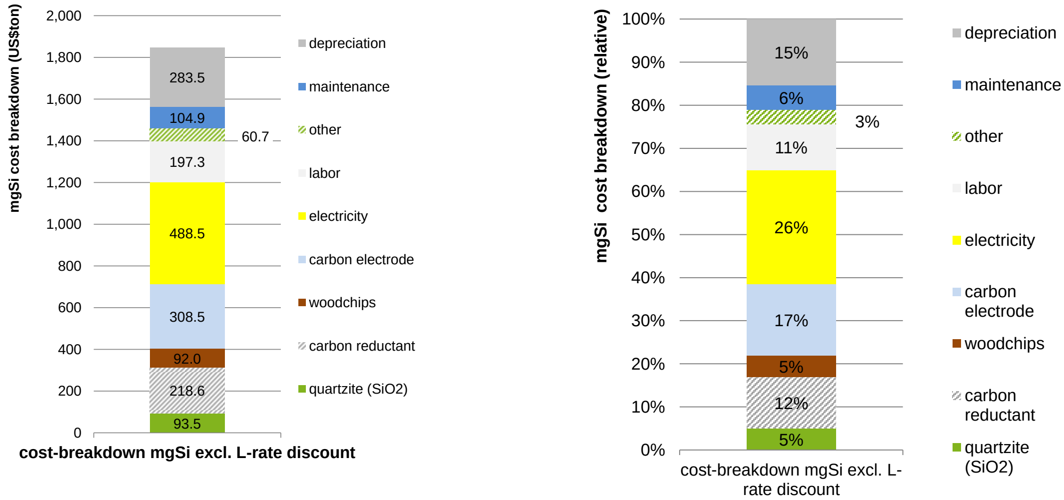
A relative comparison of the underlying investment coefficient for the development of the Greenfield HFP smelter in Matane with other new entrant Greenfield project announcements reveals that the potential site seems to exhibit some budgetary benefits. The investment coefficient is computed by a simple division of the projected investment budget by the plant's annualized production capacity. The investment coefficient for the proposed CME smelter is estimated to come in at approximately US$5,050/ton, approximately 7% below the average investment coefficient from a peer-group of recently announced new entrant Greenfield silicon smelter projects of US$5,450/ton.

The initial extraction cost estimate for Langis quartzite is projected to be approximately US$20.8/ton. This cost basis helps to improve downstream processing costs at the planned smelter site in Matane, as quartzite is planned to be provided on a cost-basis. The benefit of this integrative aspect of the project set-up becomes clear, when the expected transfer price of US$21/ton is compared to the quote for externally sourced quartzite which stands at US$59.3/ton at the factory gate in Matane.

The expected mgSi all-in production costs are US$1,847.5/ton once the smelter reaches full utilization and the L-rate discount has expired. An absolute and relative cost-breakdown for this case is provided below:

Figure 173: Absolute and relative cost-breakdown mgSi

Absolute cost-breakdown **Relative cost-breakdown**

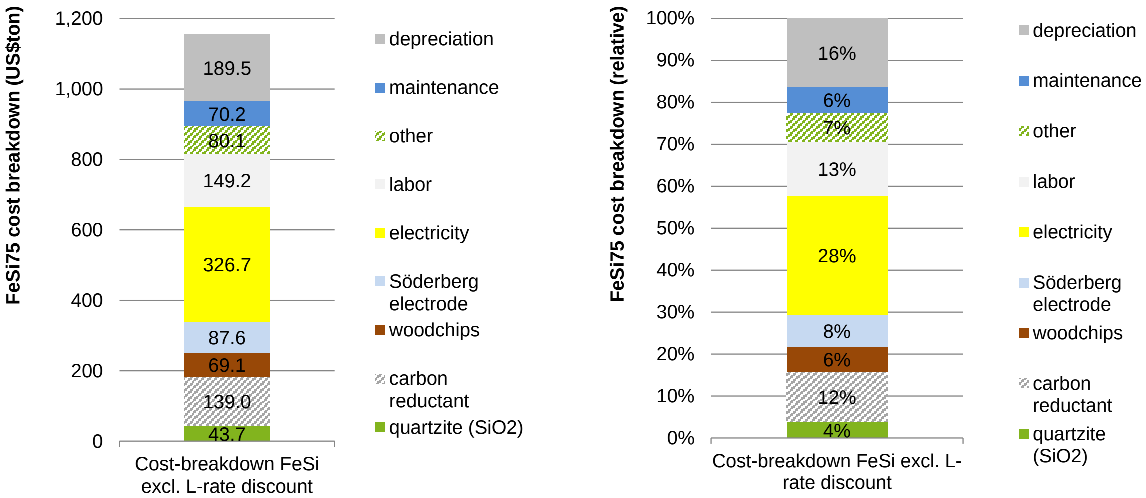


Source: Viridis.iQ GmbH estimates

For the case that HFP switches to dual-material production and dedicates on furnace to ferrosilicon, the all-in production costs are expected to be US$1,155.1/ton once the smelter reaches full utilization and the L-rate discount has expired. An absolute and relative cost-breakdown for this hybrid case is provided below:

Figure 174: Absolute and relative cost-breakdown FeSi

Absolute cost-breakdown **Relative cost-breakdown**



Source: Viridis.iQ GmbH estimates

The comparative cost benchmarking showed that it is not a trivial and unambiguous exercise to find an equivalent basis for cash-production cost comparisons, as market research providers for industrial cost-stack curves use ambiguous cost definitions. A comparison of the estimated mgSi cash-production cost of US$1,564.10/t with a global peer-group of Western producers seems to indicate that the mgSi output of the HFP of CME would fall within the 1st to top 2nd quartile of this ranking. A preliminary indication for both, mgSi and FeSi, with the latter having an estimated cash-production cost of US$965.60/t, indicates that estimated unit-production costs for both end-products would have been well below the average ex-plant cash production costs for the respective product in the periods from 2007-2014.

22 Economic Analysis

This section begins with a short description of the underlying project evaluation methodology and the disclosure of major financial model assumptions (Section 22.1). Section 22.2 outlines the presumed project tax and tax incentive environment for the up- and downstream operation. Afterwards, the project cash flows for the integrated 100% mgSi base-case are introduced in steady-state and dynamic mode (Section 22.3). The steady-state refers to a constant dollar case while the dynamic case takes inflation assumptions into consideration. The associated project evaluation ranges for key value metrics are provided for two cases, one that takes a going-concern value into consideration and the other that disregards the associated terminal value (Section 22.4). The section continues with a scenarios analysis in which ASP forward price-curve driven project scenarios are discussed in more detail (Section 22.5). Section 25.6 introduces sensitivities for key project value drivers of the dynamic base-case. In Section 22.7 follows a brief discussion of the results of the economic project review.

22.1 Methodology and Principal Assumptions

The following project evaluation is based on a free cash flow to the firm (FCFF) or company approach meaning that the project value is determined based on cash-flows available to all capital providers, e.g. debt, equity or holders of mezzanine obligations. Estimated project cash flows are discounted by the weighted average cost of capital (wacc).

The FCFF and wacc are derived based on following formulas:

Formula 22-1:

$$FCFF = EBIT * (1 - normalized\ tax\ rate) - (capex - depreciation) - change\ in\ noncash\ working\ capital$$

Formula 22-2:

$$wacc = equity\ ratio * equity\ hurdle\ rate + debt\ ratio * avg.interest * (1 - tax\ rate)$$

The underlying evaluation time period extends over 20-years after project initiation. The deployed fixed assets usually have an actual life that exceeds the useful-life assumption made for accounting purposes and are therefore not expected to be rendered commercially obsolete due to radical innovations in metallurgical processing. There are examples of furnaces that have been in operation for more than 40 years which substantiates the actual-life working assumption. Hence, two sets of project value metrics will be presented, one that assumes going-concern and correspondingly incorporates a terminal value (TV), and another that is based on a dismantling scenario at cost equal to the remaining book-value of fixed assets in year 20.

The TV is calculated based on a conservative no-growth scenario, e.g. the last sustainable cash-flow is steady-state in perpetuity. Formula 22-3 shows the exemplary computation of the net present value (NPV) under the dismantling scenario (NPV1) and Formula 22-4 shows the project value under the continuation scenario (NPV2). The same methodology is applied to other project value gauges such as the internal rate of return (IRR).

Formula 22-3:

$$NPV1 = \sum_{t=0}^{T} \frac{FCFF_t}{(1+wacc)^t}$$

Formula 22-4:

$$NPV2 = \sum_{t=0}^{T} \frac{FCFF_t}{(1+wacc)^t} + \frac{[FCFF_T /(wacc)]}{(1+wacc)^T}$$

The FCFF compilation is based on a normalized tax rate, meaning that not the modelled P&L income tax payments are utilized for the computation of the project cash flows for valuation purposes. The “actual” P&L income tax payments are based on the operating profit after tax and interest or, in other words, derived from earnings before tax (EBT), meaning that interest payments have already been deducted. However, since the interest tax shield is reflected in the cost-of-capital computation (wacc), the utilization of P&L taxes for valuation purposes would constitute a double-counting of the interest related tax benefit within the valuation framework. This remark is made in order to prevent confusion about the fact that P&L tax charges do not correspond to the tax line-item in the cash flow statement.

The payback period is defined as the time needed for cumulative project cash-flows (FCFF) to reach the breakeven point. The project investment outlays are modelled to occur during the construction and ramp-up period for 36 months after project initiation, with initial positive contributions to cash-flows from operation starting with the gradual ramp-up in month 18. Consequently, the payback period can be divided into an investment period of approximately 36 months and a case-specific recuperation period. The investment period and recuperation period exhibit a time overlap from months 18-36. The distinct sub-periods are separately disclosed for the individual cases presented in this section.

The underlying financing assumptions as outlined in the next pargraphs are based on hypothetical working assumptions. No finanacing has been secured by CME for the integrated quarry and industrial project as of the filing date of this PEA. The financing assumptions for the computation of the discount rate in accordance to Formula 22-2 are disclosed in the following table:

Table 71: wacc components

weighted average cost of capital	
Debt	70%
Equity	30%
Normalized avg corp tax	25.8%
Avg. interest on debt	6.8%
Equity hurdle rate (bef. tax)	16.9%
wacc	7.3%

Source: input provided by project owner

As shown in Table 71 the base-case scenario presumes that the project could be funded with a gearing ratio of ~2.3. Under good circumstances, the project could start generating initial revenues toward the end of the second year after project initiation and turn operating cash-flow positive in year 3, provided that 75% of the capacity will be available and produced material sold to an established customer base at this point in time. Based on these operating assumptions the external funding requirement ratio, defined as the total external funding requirements in relation to the capital needs of US$302.6m (Table 66), could be reduced to 92%.

Table 72: Base-case funding structure

Funding structure (USDk)	
Capital requirement	302,577
Total ext. Funds	278,370
Debt	194,859
Equity	83,511
Funding from OCF	24,206

Source: Viridis.iQ GmbH estimate

The capital contributions are modelled to be provided over a 3-year period after project inception in conjunction with project progress and capital requirements to fund the ramp-up stage (years 1-3) in accordance to with the funding schedule shown in the table below:

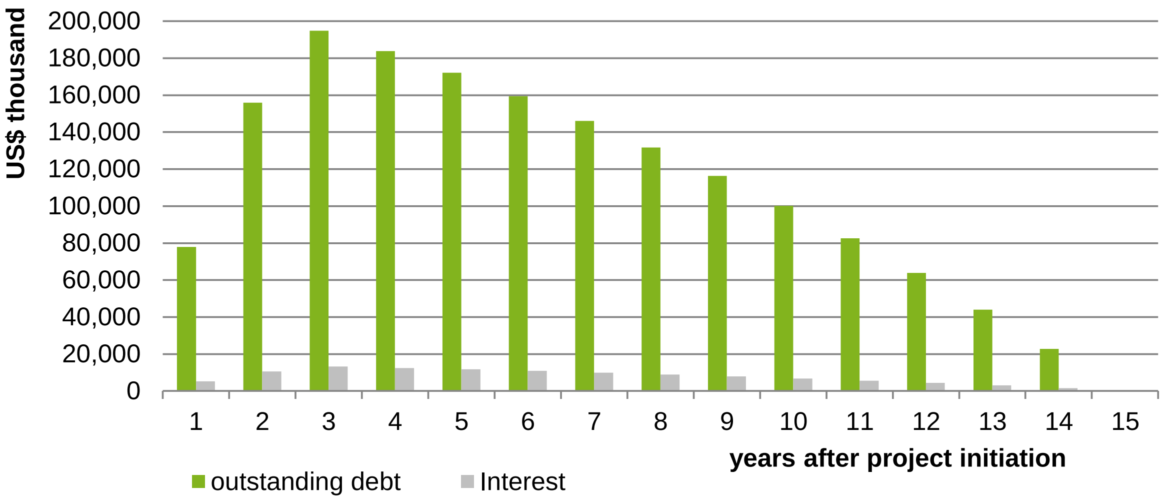
Table 73: Base-case funding schedule

Funding Schedule	years after project initiation		
USDk	1	2	3
debt tranches	77,944	77,944	38,972
equity capital contribution	41,756	25,053	16,702

Source: Viridis.iQ GmbH estimate

The average total project debt is presumed to have an underlying maturity of 15 years with immediate annual interest payments commencing with the first year of the initial debt capital contribution. Debt down payments are modelled to be deferred until the end of year 3, upon which the outstanding debt balance will be repaid as an annuity over a 12 year period. Figure 175 gives an overview on outstanding debt and interest over the first 15 years after project initiation:

Figure 175: Overview outstanding debt and interest



Source: Viridis.iQ GmbH estimate

As shown in Table 66 working capital requirements are expected to be approximately US$23.8m, corresponding with a 60 day conversion cycle in the integrated steady-state base-case model. The term “integrated” refers to the project set-up in which the quarry and the smelter are treated as a single entity, with feedstock being provided at a cost based transfer price, as already elaborated in other parts of this PEA. The implicit assumption under the "dismantling" evaluation scenario (Formula 22-3) is that working capital will be deployed for possible deconstruction or renaturation expenses at the end-of the project evaluation period in year 20.

The underlying steady-state weighted ASP assumptions for the different end- and by-products are disclosed in Table 74:

Table 74: Steady-state base-case ASP assumptions

Product	factory gate	unit
mgSi 553	2,670	US$/t
silica fume - high quality	250	US$/t

Source: Viridis.iQ GmbH estimate

The ASP assumptions for the main metallurgical silicon product is based on recent pricing information from the market research firm Argus Ferro-Alloys, Global market prices, as discussed in Section 19.5.5.

Table 75: Argus pricing reference

	price (USD)	unit	lb/ton	price/ton
553 mgSi dp US	1.21	lb	2,204.6	2,669.8

Source: Argus Ferro-Alloys (2015)

As indicated, the weighted average pricing assumption for mgSi is based on standard 553 grade material. Possible positive impacts on ASPs from premium grade material output have not been taken into consideration as actual grade distributions will ultimately depend on final raw material specifications as well as on the final quartzite blending ratio. A detailed market analysis of regional price structures within prospective target markets for different product grades should be initiated in the next project stage. The by-product prices for the silica fumes are based on experience values and need to be further verified for regional markets in NA in the next project stage.

22.2 Taxes, Tax Benefits and Royalties

This section provides an indicative and high-level overview on identified drains and sources of cash as a consequence of the project specific judicial and institutional settings. The underlying rules and regulatory interpretations were provided by Canadian Metals Inc in consultation with Canadian auditors and passed on to VIQ. A detailed due-diligence on applicable taxes, duties, tax benefits, royalties and other possible cash-flow impacts induced by the institutional setting of the project is planned to be initiated and awarded to an accredited Canadian auditor in the next planning stages, e.g. during the feasibility study stage. As a consequence, the outlined cash-flow impacts from the project's institutional framework are of preliminary nature and could change materially in the next planning stages.

Table 76 provides a commented overview on the findings of the preliminary institutional review of possible applicable taxation schemes, tax benefits and other institutionally induced impacts on project cash flows:

Table 76: Taxation, subsidies & royalties

#	item	value-add step	financial impact	comment - model assumption
1	lease to mine surface mineral substance	quarrying	C$6,000 p.a. plus C$0.4/t extraction fee	increase of @cost transfer price of Langis quartzite to HFP in Matane
2	net smelter royalty (NSR)	refining	3% on HFP EBIT excl NSR p.a.	payment to 9285-3696 QC
3	investment tax credit	refining	16% on process equipment invest of up to C$75m	applicable against income tax in 1st year of operation with subsequent cash-reimbursement in year 4, after conclusion of capital-investment period and finalization of ramp-up
4	labor training compensation	refining	working assumption C$3.5m	assumption: value received by CME in 3 equal instalments during construction & ramp-up phases for first 3 years
5	Hydro-Québec L-Rate	refining	Initial 20% discount on nominal rate with later-stage escalation	20% discount on nominal rate of C$45.84/MWh for 7 years (starting with production ramp-up) subsequent reduction in 5%-age increments over 3-years
6	corporate income tax	quarrying - refining	15% state-tax & 11.5% provincial tax	Quarrying operation will not incur a tax-liability (quartzite supply @ cost); incorporated anticipated Québec state tax reduction to 11.5% starting in 2020
7	tax-loss carry-forward	refining	applied against Federal & State/ Provincial Tax	effective income tax rate of 0% up to year 2; 4.2% in year 3 and 26.5% for remaining project life
8	declining balance depreciation	refining	likely to be available	not incorporated as categorization of eligible capital cost components needs to be determined by tax advisor in next project phase

Source: CME, Viridis.iQ GmbH assumptions

The net smelter royalty (NSR) is a 3% surcharge on smelter EBIT, according to Canadian Metals Inc, in proportion to the Langis silica supply relative to the overall quartzite consumption. In the financial model this charge is treated as a cash operating expense. This contractual obligation by CME is payable to 9285-3696 Québec Inc.

Non-capital related losses are carried-forward and utilized within the first 4 years of operation in accordance to the presumed tax model disclosed in Appendix IX.

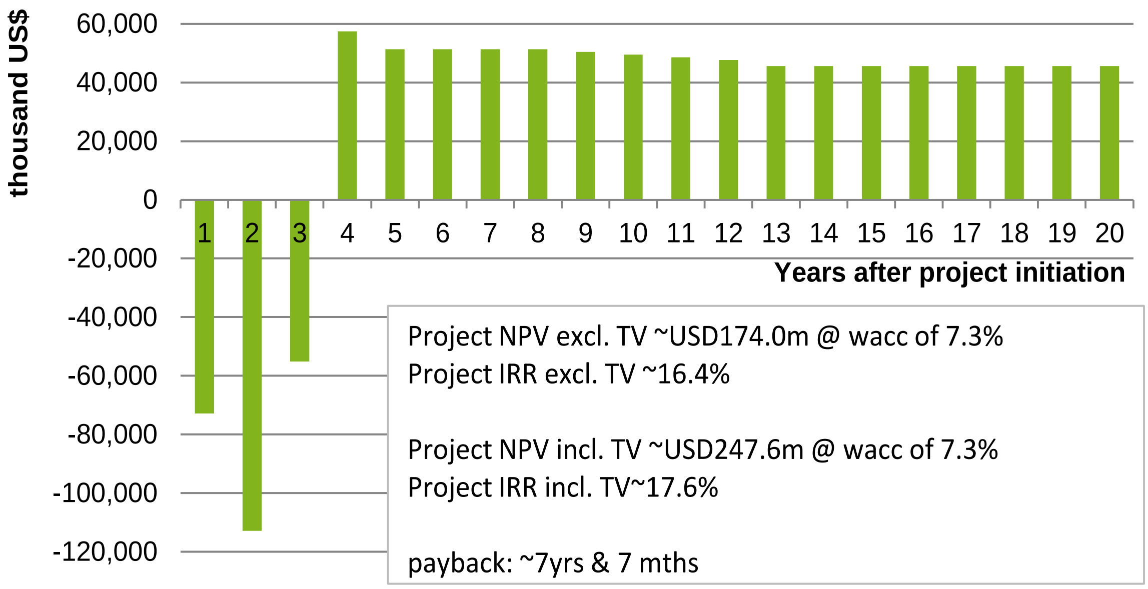
22.3 Project Cash Flows

The present section provides a detailed overview on expected project cash-flows for two steady-state- and one dynamic base-case scenario. The steady-state case distinction is conducted in order to provide transparency on the effects of the project's institutional tax setting as discussed in the previous section. The presented steady-state project cash-flows are derived from the integrated base-case business model as disclosed in Appendices IV-VIII.

22.3.1 Steady-state or Constant Dollar Base-Case incl. Tax

The value determining project cash-flows for CME's integrated quarry and HFP 100% mgSi operation under consideration of the outlined tax regime are depicted in the following graph:

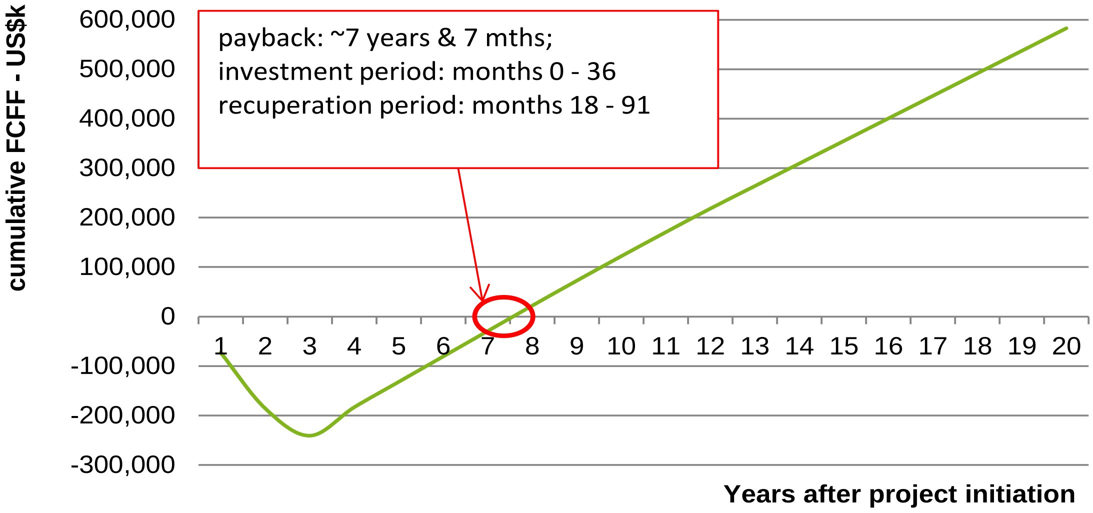
Figure 176: 100% mgSi project cash-flows, steady-state incl. tax



Source: Viridis.iQ GmbH etimates

The resulting cumulative project cash flow profile is depicted in the following chart:

Figure 177: 100% mgSi cumulative project cash-flows, steady-state incl. tax

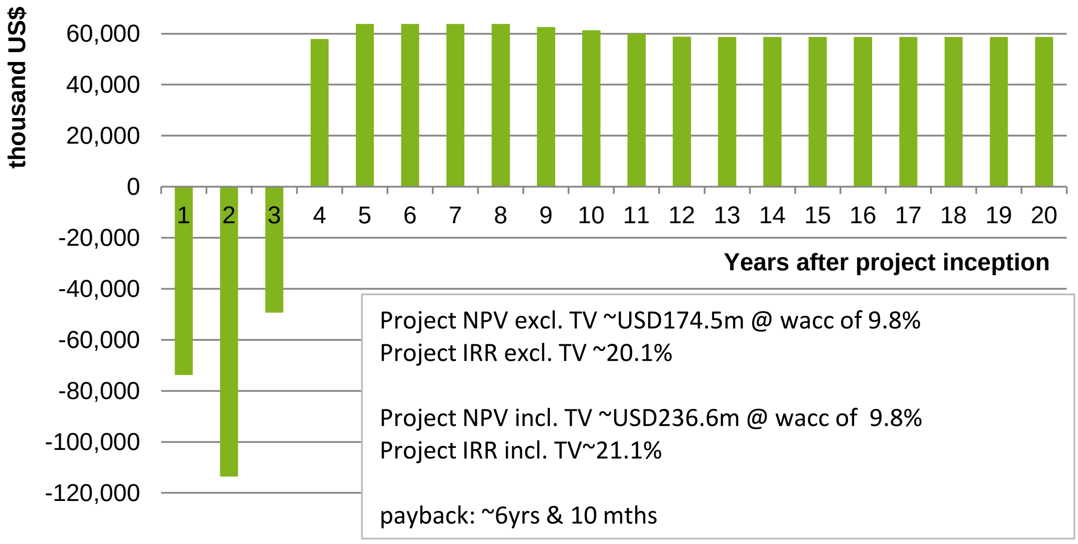


Source: Viridis.iQ GmbH etimates

22.3.2 Steady-state or Constant-Dollar Base-Case excl. Tax

The value determining project cash-flows for CME's integrated quarry and HFP 100% mgSi operation under exclusion of the outlined tax regime are depicted in the following graph:

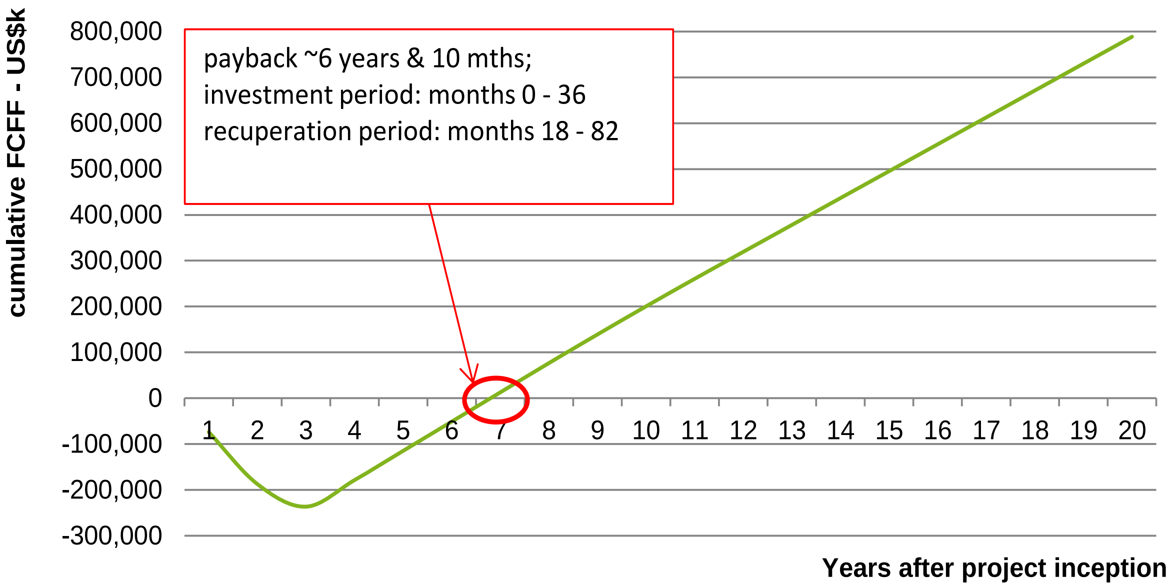
Figure 178: 100% mgSi project cash-flows, steady-state excl. tax



Source: Viridis.iQ GmbH etimates

The resulting cumulative project cash flow profile is depicted in the following chart:

Figure 179: 100% mgSi cumulative project cash-flows, steady-state excl. tax



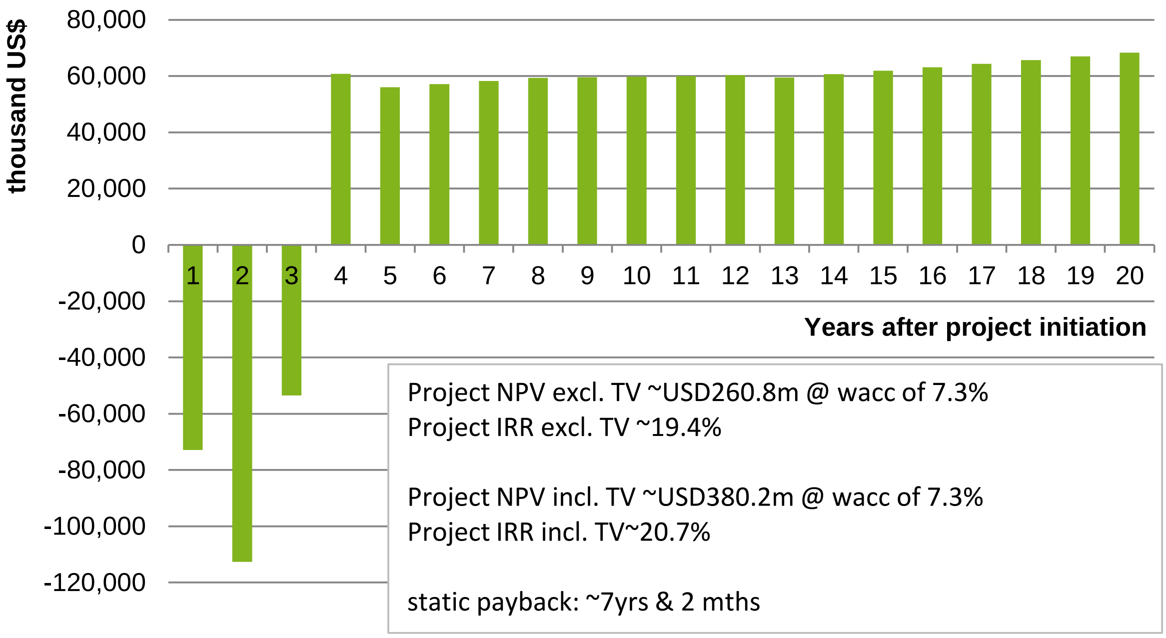
Source: Viridis.iQ GmbH etimates

A direct comparison of the two steady-state cases with and without taxes reveals that the presumed institutional environment as outlined in Section 22.2 reduces the project's internal rate of return by approximately 350bps and increases the payback period by circa 9 months.

22.3.3 Dynamic or Inflated Dollar Base-Case incl. Tax

The value determining project cash flows for CME's integrated quarry and HFP 100% mgSi operation under consideration of dynamic inflation assumptions for key value drivers of the financial model and under consideration of the tax regime as outlined in Section 22.2 are depicted in Figure 180. The derivation and baseline assumptions for the dynamic base-case project cash-flows are further discussed in more detail in Section 22.5.

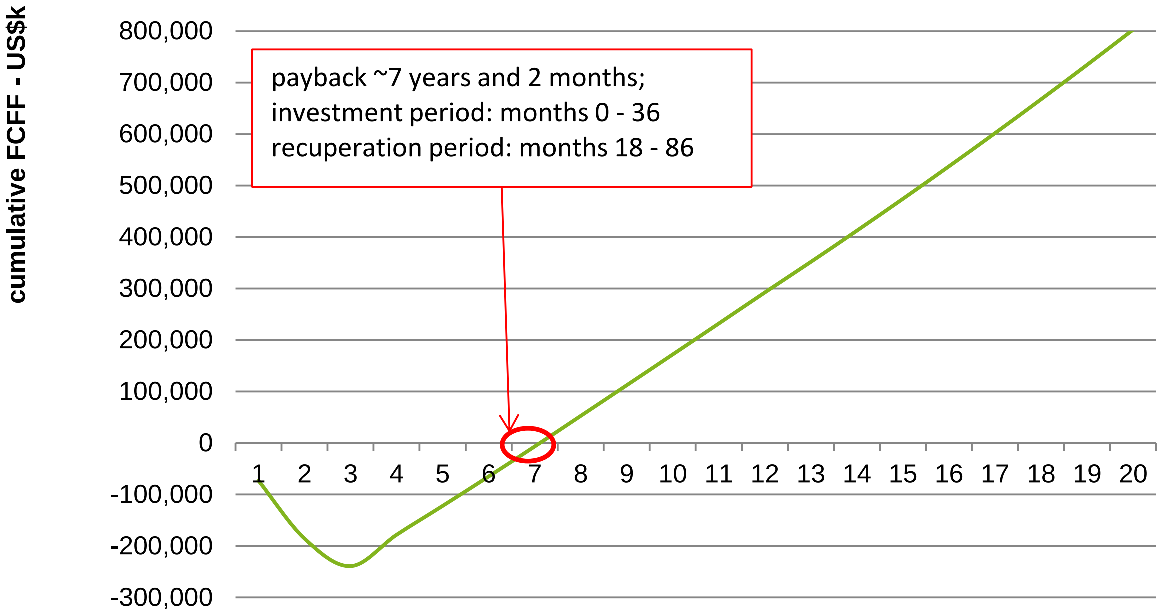
Figure 180: 100% mgSi project cash flows, dynamic base-case incl. tax



Source: Viridis.iQ GmbH estimates

The resulting cumulative project cash flow profile for the dynamic base-case is shown in Figure 181:

Figure 181:100% mgSi cumulative project cash flows, dynamic base-case



Source: Viridis.iQ GmbH estimates

22.4 Project Evaluation

The project value metrics for the cases presented in the previous section are summarized in Table 77. As shown, CME's expected IRR for the integrated quarry and HFP smelter project in the current technical set-up and based on the disclosed financial modelling assumptions is estimated to be in the upper-teen to lower twenty percentage ranges. The dynamic base-case, which will be further outlined in the next section, exhibits a project IRR of 19.4-20.7% depending on the utilized evaluation methodology, e.g. excluding and including a terminal value assumption.

Table 77: Case-specific value metrics (after-tax)

	steady-state, incl. tax	steady-state, excl. tax	dynamic base-case incl. tax
NPV excl. TV (USDk)	173,978.2	174,456.0	260,846.8
IRR excl. TV	16.4%	20.1%	19.4%
NPV incl. TV (USDk)	247,633.6	236,569.3	380,226.1
IRR incl. TV	17.6%	21.1%	20.7%
payback	~ 7 yrs & 7 months	~ 6 yrs & 10 mths	~ 7 yrs & 2 mths
- thereof investment period	months 0 - 36	months 0 - 36	months 0 - 36
- thereof recuperation period	months 18 - 91	months 18 - 82	months 18 - 86

Source: Viridis.iQ GmbH estimates

22.5 Scenario Model

This section introduces dynamic parameter settings or annual inflation assumptions for the different output and input factors of the proposed 100% mgSi downstream operation in Matane. The annual inflation assumptions for major cost drivers are as follows and will not be modified in the subsequently introduced ASP driven scenarios:

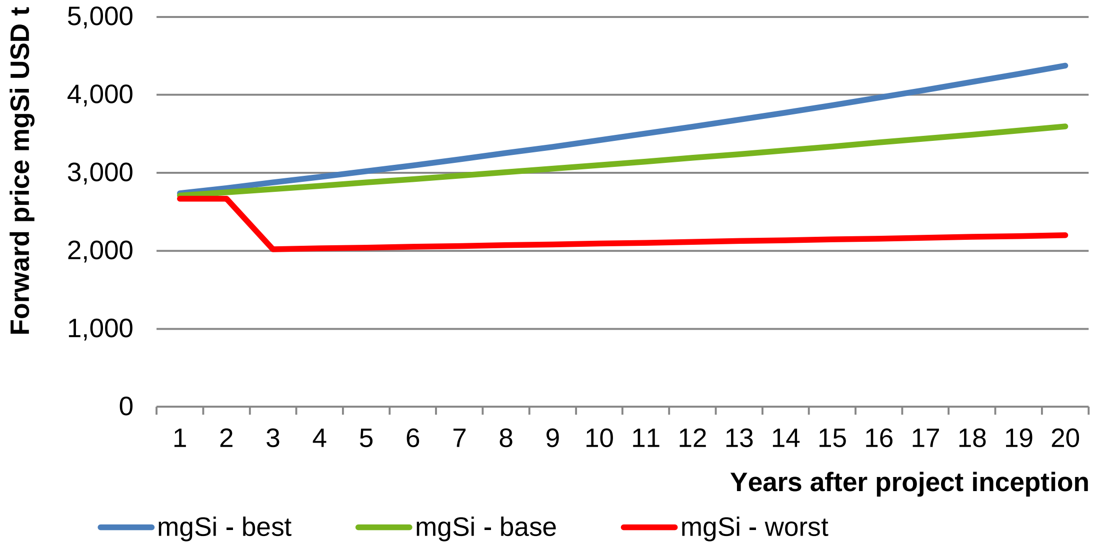
- Constant annual inflation for quartzite: 0.5%
- Constant annual inflation for carbon reductant: 1.0%
- Constant annual inflation for woodchips: 0.5%
- Constant annual inflation for carbon electrode: 2.0%
- Electricity according to rate-schedule: 0.0%
- Constant annual inflation "Other incl. maintenance spare & wear": 1.0%
- Constant annual inflation labour expenses: 1.5%

The scenarios are based on different forward price curve assumptions for both end-products which are defined as follows:

- Best-case: Trade-barriers remain in place in NA markets over the project evaluation period and a balanced supply- and demand lead to an average price increase of 2.5%
- Base-case: Trade-barriers remain in place in NA but the supply-demand balance changes such that the average annual increase is only 1.5%
- Worst-case: Trade-barriers will be abolished in the next review and NA prices drop to European levels 3 years after project inception and only increase by an annual rate of 0.5% from this time onwards. The European price level is established by referring to spot-market quotes from Argus Ferro-Alloys.[44] The average reference mgSi 553 quote is €1,850/t. The reference exchange rate on 31/12/2015 is EUR/US$ 1.09254. Therefore, the worst-case USD reference price mgSi 553 is USD2,021/t.

The underlying price curves for the scenarios are shown in the chart below:

Figure 182: Forward price curves mgSi 553



Source: Viridis.iQ GmbH estimates

The scenario driven project evaluation metrics for the different scenarios are shown in the results overview in Table 78.

44 Argus Ferro-Alloys (Argus 31/12/2015)

Table 78: Overview on scenario results (after-tax)

	dynamic best-case	dynamic base-case	dynamic worst-case
NPV (USDk) excl. TV	364,488	260,847	-53,011
NPV (USDk) incl. TV	542,961	380,226	-39,349
wacc	7.3%	7.3%	7.3%
IRR excl. TV	22.3%	19.4%	4.5%
IRR incl. TV	23.6%	**20.7%**	5.9%
payback (yrs, mths)	6 yrs, 9 mths	7 yrs, 2 mths	13 yrs, 5 mths
- thereof investment period	months 0 - 36	months 0 - 36	months 0 - 36
- thereof recuperation period	months 18 - 81	months 18 - 86	months 18 - 161

Source: Viridis.iQ GmbH estimates

The results of the scenarios analysis suggest that the project economics look attractive even under moderate price appreciation scenarios for the NA metallurgical silicon market. However, the downside clearly rests with the resilience of established trade-barriers. In the event that trade barriers would be removed the project is almost certainly likely to incur extraordinary impairment charges with a drastic drop of the expected internal rate of return from a twenty- to a mid-single-digit percentage range.

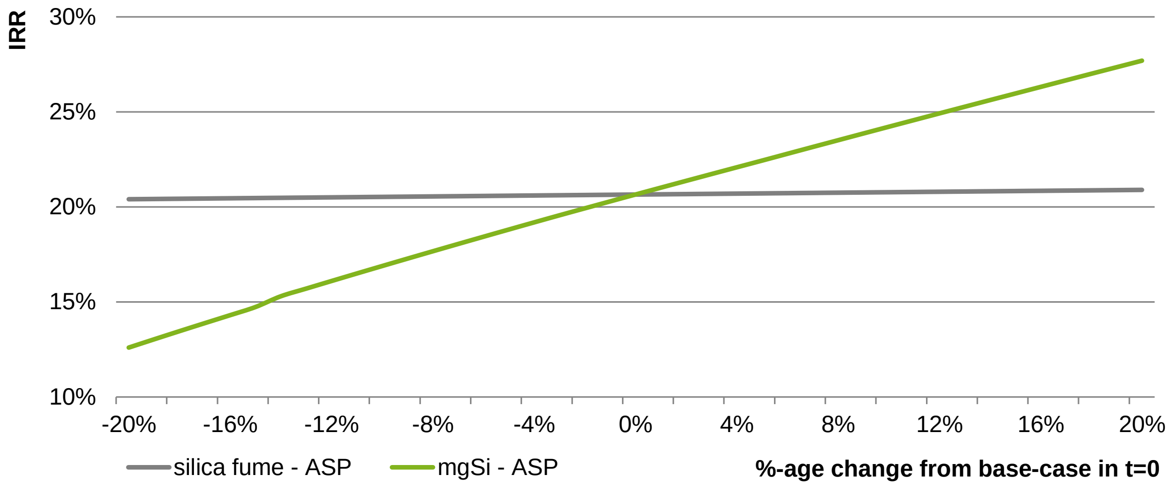
22.6 Sensitivities

The following sensitivity analysis is based on the dynamic going-concern base-case as introduces in the preceding section. The analysis is conducted on an all-else remains equal presumption, meaning that only one parameter changes at a time. The relative impacts on project IRR are assessed by changing the following parameters:

- ASP at project initiation in t=0 for metallurgical silicon and the silica fume by-product
- Procurement costs for main cost drivers: External quartzite, carbon reductant, carbon electrode, woodchips
- Average utilization
- Sensitivity of NPV to capital costs

The following figure shows the sensitivities of the project IRR to t=0 ASP price estimate changes within a bandwidth of -20% to +20% for all top-line contributors namely, metallurgical silicon and silica fume. Unsurprisingly, the sensitivity of the project IRR to changes in the ASP for mgSi is higher when compared to the impact of silica fume ASP changes on project IRR.

Figure 183: Project IRR sensitivity to ASP changes

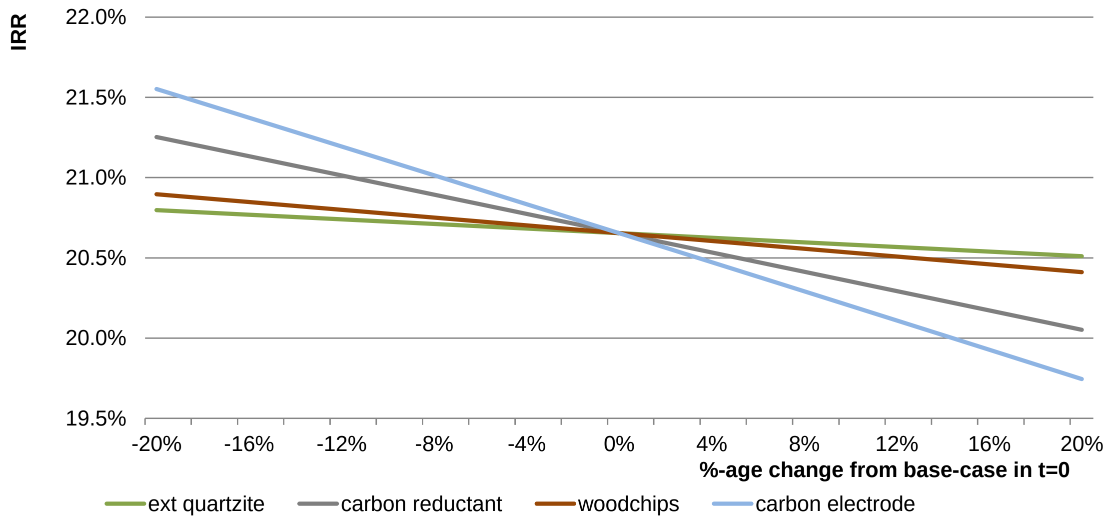


Source: Viridis.iQ GmbH estimates

The sensitivity of the project IRR to changes in the t=0 procurement cost assumptions for major cost drivers are depicted in Figure 184. The sensitivities are again calculated for a relative change from -20% to +20% around the dynamic-state base-case input. A sensitivity analysis for the electricity procurement price has been omitted, as the rate schedule is likely to be fixated by Hydro-Québec in accordance to the rate schedule disclosed in

Figure 162. The project IRR is most sensitive to changes in the procurement costs for the carbon amorphous electrode and the carbon reductant for mgSi.

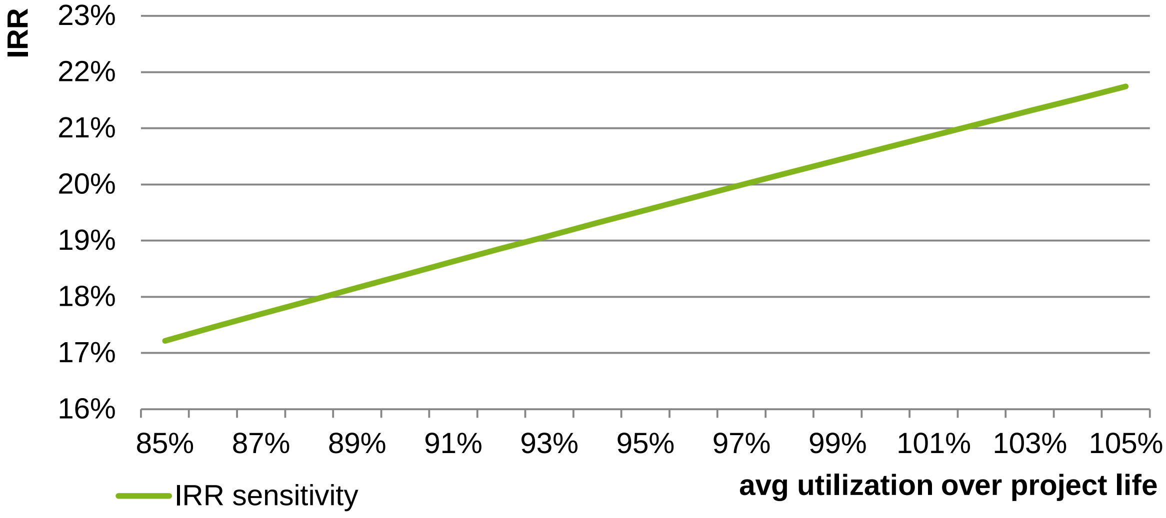
Figure 184: Project IRR sensitivities to key cost drivers



Source: Viridis.iQ GmbH estimates

The influence of the average utilization levels on project IRR are shown in the graph below:

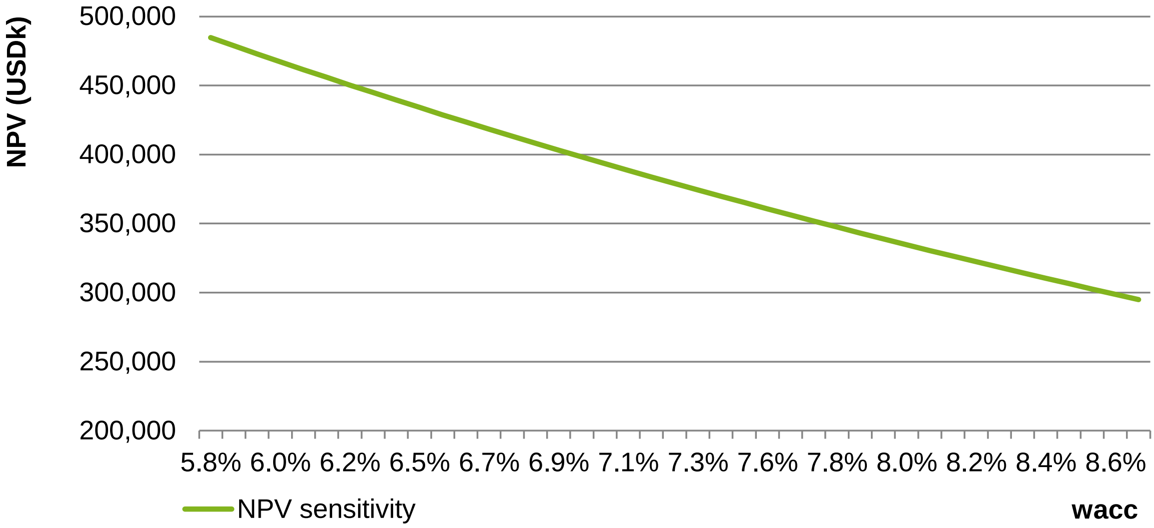
Figure 185: Project IRR sensitivities to utilization levels



Source: Viridis.iQ GmbH estimates

Finally, the sensitivity of the dynamic base-case project NPV to changes in the weighted average cost of capital is disclosed in the chart below:

Figure 186: NPV as a function of wacc



Source: Viridis.iQ GmbH estimates

Overall, the end-product related sensitivities reveal a higher dependence of the project attractiveness towards changes in parameters that are related to the mgSi part of CME's HFP concept.

22.7 Conclusions and recommendations about Economics

The dynamic base-case project IRR lies within a bandwidth of 19.4% to 20.7% (NPV US$260.8m – US$380.2m; wacc 7.3%) depending on the utilized evaluation methodology (termination or going concern assumption). The IRR range can be classified as favourable for an industrial project in a mature and established industry. The project would benefit from existing trade barriers and a balanced North American mgSi market. In the event that trade barriers should not be extended at the next review the project would likely incur impairment charges if European prices remain at current levels. In the case that trade barriers remain in place the project exhibits attractive upside potential even under moderate price escalation schemes.

The established t=0 base-case prices for mgSi have been aligned to most recent price levels in the USA (Section 19.5.5). The input prices are based on average spot-market prices for lower purity 553 grade silicon derived from weekly price reports from the market research firm Argus Ferro-Alloys. No premium prices for possible higher material grade output has been incorporated, as the plant's potential to achieve higher grade and higher price bracket material qualities will ultimately be determined by raw material specifications and final blending ratios for quartzite, which are to be optimized in later project stages. A detailed market analysis of regional price structures within prospective target markets for different product grades should be initiated in the next project stage.

The different sensitivities presented in this section clearly show that the project's internal rate of return is particularly sensitive to the initial t=0 ASP assumption and to the average utilization level of the HFP over the project life. The management of CME should only consider switching to FeSi production in the event that relative end-market attractiveness changes favourable towards ferrosilicon at a later stage. As this is currently not foreseen, not dual product production case has been introduced in this PEA.

The presented investment case is highly dependent on three major assumptions: First, that the current price levels for mgSi constitute a good prediction for market prices in the USA once the smelter starts production. Second, that trade barriers will remain in place once the next round of regular duty reviews will be initiated by national trade authorities in target-markets. Third, that industry utilization levels in North America will remain high and therefore give a lower cost producer the chance to rapidly gain market shares.

23 Adjacent Properties

23.1 Langis Quarry

There are no properties adjacent to the Langis property. Viridis.iQ strongly recommend the acquisition of the Blocks 1, 2 and 3 to avoid future problems with adjacent properties and to warranty buffer for the project phase 2.

23.2 Matane Smelter

Adjacent properties to the Matane smelter site are occupied by existing light industrial businesses and private properties.

24 Other Relevant Data and Information

All the relevant technical data and information available has been provided in the preceding items.

25 Interpretation and Conclusion

The following interpretations and conclusions are made based on the present work.

25.1 Geology

Detailed drilling by Canadian Metals Inc. in 2013 and 2015 enabled the construction of a previously incomplete geological model for the Langis deposit.

The model indicates that the Val-Brillant sandstones are composed of different units, one of which is the Lower White Sandstones, which is 15 to 35 meters thick. This unit was found to be fairly uniform in term of chemistry and to meet the specifications indicated to the authors for ferrosilicon plant feed.

The deposit is dissected by numerous faults, the most important being NNE-SSW or NE-SW oriented thrust faults with a steep dip to the north and uprising of the north block relative to the south block. Horizontal movement is also present along these faults.

In order to eliminate the influence of the vertical displacement caused by the structures, a safe distance was left at the base of the Lower White Sandstone above which it is possible to define an area within the 50-meters drilling pattern where resource blocks can be considered to be in the measured category. Assays confirmed that the estimated resources are quite uniform in terms of silica and impurity content and that any part of the deposit could produce acceptable material for the ferrosilicon plant. The measured resource stands at 3,495,000 tons grading 98.57% SiO_2, with 2,673,000 tons sitting directly under some two meters of overburden. The remaining 822,000 tons are covered by impure sandstone that varies in thickness from 0 to 12 meters.

An indicated resource is also calculated as a direct extension of the measured resource. It is estimated at 1,501,000 tons grading 98.52% SiO_2 with less than 12 meters of waste coverage (the indicated-1 resource) and an additional 2,035,000 tons grading 98.92% SiO_2 with more than 12 meters of overlying waste (the indicated-2 resource). The limits of the indicated resource are essentially related to the drilling coverage as the deposit is open in all directions.

25.2 Metallurgical Process via HFP

The metallurgical processes envisioned for the Matane processing plant are based on standard well known ferroalloy principles and would not represent unforeseen technology risks, either from an equipment or process perspective. As the ferrosilicon and metallurgical silicon processes are similar in many ways, the use of a Hybrid Flex Plant concept brings advantages to the project such that the factory can be designed from the engineering phase with the built in capability for either product. Additionally, as only additional raw materials are needed for ferrosilicon versus metallurgical silicon, there are no large scale differences in technology (excluding electrodes) that can affect the production of one product versus the other.

The ability to switch from one product to the other based on market fundamentals can give CME a competitive advantage. While the authors do not encourage frequent changes in the product mix of the factory, the ability to quickly respond to market dynamics and by having a market position in both end use sectors can put CME into a category of well-known existing Tier 1 producers who have already the capability of producing both products.

25.3 Metallurgical Testing

MINTEK's Phase 1 evaluation of Langis quartzite demonstrated that:

- Thermal degradation of the quartzite in a laboratory smelting furnace was at acceptable levels and no explosive disintegration was observed during visual inspections
- FeSi alloy was formed during the test work, as evidenced from chemical, XRF and Scanning Electron Microscopy (SEM) analyses
- Langis quartzite can be reduced to silicon and normal furnace operation is possible

25.4 Mining

Based on the demands of the Phase 1 smelter in Matane, the Langis quarry is suitable for supplying quartzite for the production of ferrosilicon, and based on preliminary assessments, the material is possibly a source to be blended with external quartzite to produce metallurgical silicon. The quartzite supply is suitable based on the assumptions herein to supply the Matane smelter for more than 20 years.

25.5 Environmental and Social Considerations

Under the environmental assessment procedure for the quarry, public hearings are not mandatory. However, as a good neighbour and because permitting will involves the municipality, continuous engagement and information will be sustained with the municipality of Saint-Vianney to make sure any question arising from the local community can be answered promptly and properly.

For the process plant, the procedure for social engagement is different. Throughout an EIA procedure, consultation with the community and the stakeholders is EIA state of the art as well as mandatory and requested by the authorities.

25.6 Market Studies and Contracts

The metallurgical silicon and ferrosilicon markets are highly disparate with little to no overlap in their end market applications. Both markets are subject their own distinct drivers and share only one key similarity, namely the existence of large, under-utilized production capacities in China. As a counter effect to this build-up of capacities in China, non-Chinese producers have evolved to combat this reality by improving cost and technology efficiencies, economies of scale and the installation of trade barriers to keep Chinese production exports in check. Regulatory, environmental and labour costs in China constantly push the production costs higher in that country.

The metallurgical silicon market is a trade protected market that can benefit CME’s factory in Canada by making premium ASP markets available with lower transportation cost. Regional demand for silicon is strong in North America and is increasing due to increasing demand for consumer goods, which are silicon based.

Another supporting factor is the ongoing decentralization and decarbonisation of the energy-supply infrastructure that has led to continuous strong-growth in the demand for silicon based PV applications. It should be noted that market forces in the North American market are subject to regulatory influence as trade barriers keep ASPs higher than in other markets.

The ferrosilicon market in North American is tied to the volatilities of the steel industry, which is currently in a correction phase. The prospects might therefore be regarded as less attractive than those for silicon. Further market related investigations should be commenced at later project stages. In that respect the flexibility of the project to serve diverse end market segments seems to be an advantage.

The proposed HFP concept allows CME the potential to reach meaningful scales that are higher than the average silicon production profile and thus increases the likelihood of maintaining its competitiveness over smaller factories. The potential expansion phase would only increase the scaling benefits over the competition and aid project viability.

25.7 Tax and Tax Benefit Due-Diligence

The underlying rules and regulatory interpretations as to relevant local tax and tax benefit schemes were provided by CME in consultation with Canadian auditors and passed on to VIQ. A detailed due-diligence on applicable taxes, duties, possible subsidies, royalties and other possible cash-flow impacts induced by the institutional setting of the project is planned to be initiated and awarded to an accredited Canadian auditor in the next planning stages, e.g. during the feasibility study stage.

25.8 Project Economics

The project IRR for the dynamic 100% mgSi base-case is 20.7% (NPV US$380.2m; wacc 7.3%), including a presumed terminal- or going-concern value. The expected project IRR can be classified as favourable for an industrial project in a mature and established industry.

The project would benefit from existing trade barriers and a balanced North American mgSi market. In the event that trade barriers should not be extended at the next review the project would likely incur impairment charges if European prices remain at current levels.

The dynamic base-case scenario presumes that North-American trade barriers will remain in-place for the foreseeable future.

The downstream part of the project benefits from low cost sourcing advantages achieved through the integration with the Langis quartzite deposit. An additional benefit comes from the low electricity rates and the L-rate discount.

The results of the three-case dynamic scenario analysis, which is further explained in Section 22, are presented in Table 79.

Table 79: Results scenario analysis (after-tax)

	dynamic best-case	dynamic base-case	dynamic worst-case
NPV (USDk) excl. TV	364,488	260,847	-53,011
NPV (USDk) incl. TV	542,961	380,226	-39,349
wacc	7.3%	7.3%	7.3%
IRR excl. TV	22.3%	19.4%	4.5%
IRR incl. TV	23.6%	**20.7%**	5.9%
payback (yrs, mths)	6 yrs, 9 mths	7 yrs, 2 mths	13 yrs, 5 mths
- thereof investment period	months 0 - 36	months 0 - 36	months 0 - 36
- thereof recuperation period	months 18 - 81	months 18 - 86	months 18 - 161

Source: Viridis.iQ GmbH estimates

26 Recommendations

The following represents key recommendations of the authors regarding the present work, but by no means represents a complete list of further steps needed to mitigate risks or to see the project to the execution stage.

26.1 Feasibility Study

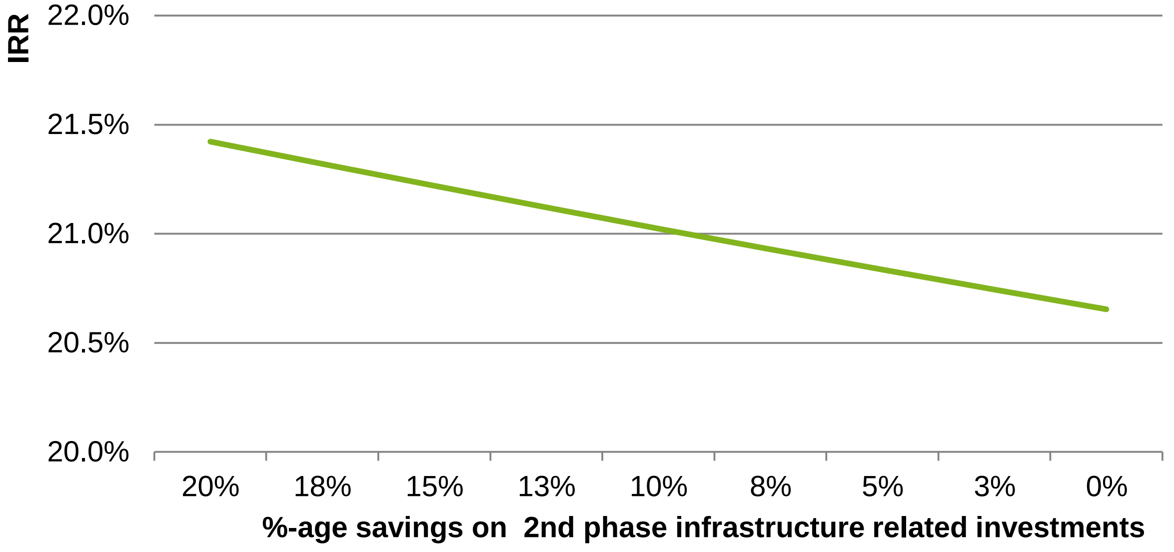
A detailed feasibility study should be initiated to further develop the project concept and to investigate with further granularity main assumptions and conditions of the project and including the following considerations.

26.1.1 Project Economics

A detailed market analysis on price structures for various material grades should be initiated in the next project stage. The by-product prices for the silica fumes need to be determined and verified within North America by directly approaching a number of potential off-takers.

The dynamic base-case project economics (IRR range of 19.4-20.7%) could be further improved in case that capacity is scaled-up by a factor of 2 at a later project stage. A high-level technical description of this scaling option is provided in Section 26.1.7. The potential impact on combined project economics is shown in Figure 187. The expected IRR improvements are solely a result of possible savings on capital investment for shared infrastructure and facilities. Hence, no procurement cost advantages from likely improvements in purchasing power have been taken into account in this high-level analysis. The depicted IRR line estimates the impact on the combined project economics (Phases 1 plus 2) for possible infrastructure related investment savings of up to 20%. As shown, combined project economics could be improved by up to 80bps if infrastructure related investment savings reach 20%. No explicit capital budgeting has been conducted for this analysis.

Figure 187: Possible IRR improvements from Phase 2



Source: Viridis.iQ GmbH estimates

A detailed technical and commercial assessment of this phasing option should be initiated in the next planning stages.

26.1.2 Procurement and Supply-Chain Analysis

Indicative quotations have been received for key cost-drivers from different potential suppliers (Appendix X). In cases where quotations were based on FOB prices, marks-up have been included for insurance and freight costs for the respective target harbour in Québec. In addition, provincial delivery cost estimates have been included in cases where resources have to be transported from a delivery point outside of Matane to the planned factory gate.

While the supply-chain analysis up to this point is deemed to be sufficient for the PEA stage, a more thorough review of supply-chain options is recommended to be commenced as a separate work-stream during next project development stages. Here, the list of potential suppliers should be increased and short-listed suppliers evaluated based on capacity to deliver resources in time in the desired quality, quantity and frequency. Further, the delivery frequency and associated delivery costs should be optimized and balanced with opportunity costs for working capital requirements and by consideration of potential risks from supply-interruption due to harsh weather conditions. The target of this work-stream should be to qualify two to three suppliers for each resource and transform indicative quotes into formal binding or non-binding offers.

More specifically, a dedicated analysis of the use of various external quartzite sources should be undertaken for the purposes of blending with Langis quartzite for the production of mgSi. Such an evaluation should include sampling of various sources and a systematic metallurgical smelting test simulating different blend ratios and subsequent analytical testing for verification purposes and comparison to known customer specifications. These tests should be overseen by CME and silicon metallurgical experts familiar with the process and the Langis quartzite.

In addition the procurement analysis for foreign capital equipment and machinery imports needs to be further improved. For PEA purposes no detailed freight cost analysis for capital equipment imports has been conducted. All equipment and material costs outside of Canada were included exclusive of taxes and duties. As outlined in Section 21.1 a provision for transportation of internationally sourced capital on equipment FOB prices has been included in the relevant line-items of the capital budget estimate. This value is an experience value and needs to be further fine-tuned and verified in a capital equipment logistics analysis.

26.1.3 Process Technology Optimization

Process technology optimization efforts should be in focus in the early project years to overcome the steep learning curve and to set a foundational structure for continuous cost optimization. A technology optimization program should minimally include:

- Specific electricity consumption (SEC) during the first operation years will be higher than the static case demonstrates. Systematic efforts should be made to reduce SEC in early project years via extensive operator training
- Electrode consumption reduction for the mgSi SAFs (prebaked) and for the FeSi75 SAF (Sødeberg paste)
- Optimization of the Søderberg electrode casings (fins and construction)
- Feeding / Batching processes optimization
- Implementation of the ideal blending plant recipes based on the different campaigns in the plant (integrated S&OP plan for both processes)
- Reduction of losses generation in the final product handling
- Improvement of the refining process to achieve higher quality products
- Transition from prebaked to aluminum Søderberg electrodes (mgSi)
- Installation of heat recovery systems for the primary dedusting system
- Auxiliary specific electricity consumption reduction by renewable energy systems
- Overall recycling of the wastes and by products generated in the post tapping processes

- Quality optimization of the micro silica produced in the off gas system of the furnaces
- Implementation of the slag-free continuous casting process after the commissioning of the plant

26.1.4 Geotechnical Reports

An extensive geotechnical survey of the proposed site should be performed in consideration of the key load factor areas of the site. Refer to Section 18.4.

26.1.5 Metallurgical Testing

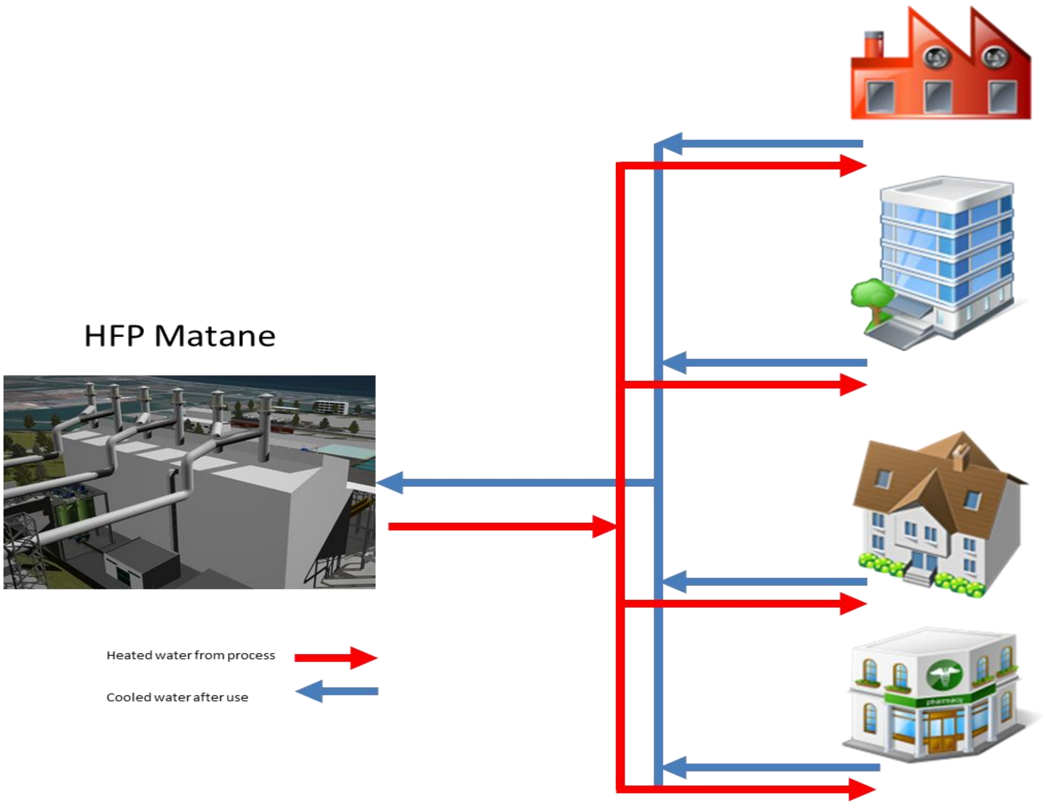
MINTEK duly noted the shortcomings of their initial testing protocol for Langis quartzite in their report. Consequently, they proposed a follow-up evaluation in a larger smelting furnace at their facility. This larger furnace more closely resembles a commercial-scale production environment. Comprehensive evaluation of raw material recipes, mass balances silicon/ferrosilicon yield and silicon/ferrosilicon product quality in the larger furnace should then provide a more accurate starting point for selection of raw materials and recipes in commercial-scale ferrosilicon production for Canadian Metals Inc. The authors of this report support this recommendation by MINTEK.

Further, it is recommended that additional tests be performed in a simulated smelting environment with various blends of Langis quartzite with externally available quartzite to verify Figure 49 and the blending ratios needed to meet customer specifications.

26.1.6 Heat Recovery Options

SMS Siemag has reported that >22% of the electrical power input can be recovered in Si and FeSi processes (CRU, November 2015). With such a large amount of waste heat from the process underutilized, an evaluation should be made at future project stages of the costs and benefits of such heat recovery for the HFP plant in Matane. Heat recovery options may consist of an onsite steam generator that converts waste heat into steam to produce electricity or could consist of district heating systems that use the waste heat from the HFP plant to provide hot water to local homes and businesses via a system of underground insulated pipes.

Figure 188: District heating option



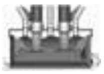
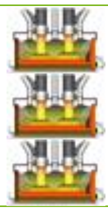
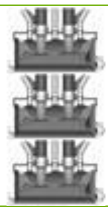
Source: Viridis.iQ GmbH

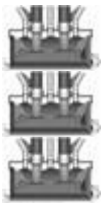
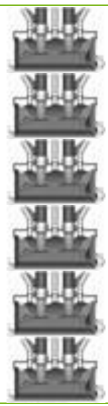
Neither electricity generation via steam generator or district heating options have been considered in this present work and no estimations are made in regards to capital costs; however these options should be evaluated as a offset factor to later project stages when the discount on the L-Rate expires. A full cost and benefit study should be engaged to evaluate the effects of such systems on the financial results of the project.

26.1.7 Expansion Options

Scaling options have been taken into account in the present work such that the maximum scaling can be permitted on the identified base-case site. An expansion phase can be considered at a future date that effectively doubles the production capacity of the plant by the incorporation of 3 additional SAFs in the open space of the current design. The current design and layout for the base-case can accommodate the expansion phase. A comparison of the production output of the two cases is shown below:

Table 80: Phase 1 (3 SAF) versus Phase 2 (6 SAF)

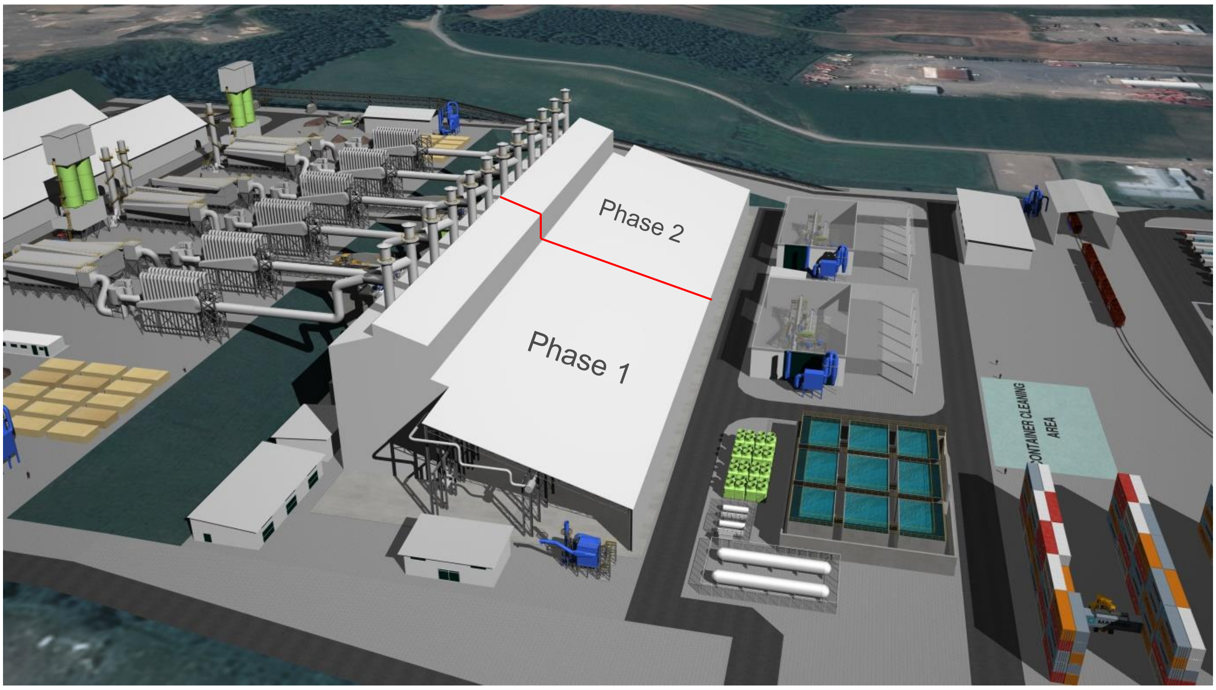
	Flex Mix		Flex MgSi (Base-case)		Flex FeSi	
	mgSi	FeSi	mgSi	FeSi	mgSi	FeSi
Phase 1 only				none	none	
Annual output (primary)	mgSi	35,000	mgSi	50,000	mgSi	none
	FeSi	26,000	FeSi	none	FeSi	75,000
Annual output (secondary)	Silica fume	27,500	Silica fume	24,000	Silica fume	30,000

	Flex Mix		Flex MgSi (Base-case)		Flex FeSi	
	mgSi	FeSi	mgSi	FeSi	mgSi	FeSi
Phase 1 & 2				none	none	
Annual output (primary)	mgSi	70,000	mgSi	100,000	mgSi	none
	FeSi	52,000	FeSi	none	FeSi	150,000
Annual output (secondary)	Silica fume	55,000	Silica fume	48,000	Silica fume	60,000

Source: Viridis.iQ GmbH

The expansion phase of the project is envisioned in the current layout, which was designed to allow for a doubling of the capacity of the project over time and to efficiently utilize the chose base-case site. The expansion of the project would require additional SAFs, bag house, raw material handling systems and other equipment and systems, but can easily be installed in the linear line of the existing structures. The possible expansion of the project can be envisioned in the following figure.

Figure 189: Conceptual expansion phase



Source: Viridis.iQ GmbH

26.2 Geology

The 2015 drilling program by Canadian Metals Inc. was designed to identify around 2.5 million tons of sandstones respecting the specifications for a ferrosilicon plant. As this objective was met, no additional drilling is required for the moment.

If ever needed, additional measured resources could be identified by drilling infill holes in the indicated resources blocks to reduce the drilling pattern from the current 100 meters to 50 meters.

If the quarry is developed, it should be started in the area covered only by overburden. In the quarry, some short holes could be drilled locally, in the floor, to precisely define the underlying contact between the impure transition zone and the Lower White Sandstones which could result in local tonnage gains.

The authors recommend that a small density determination program should be completed on the core of the Lower Sandstones and overlying waste material for better tonnage estimation in a future mining plan.

A recommendation is made that an access be planned to the eastern part of the deposit, where the measured resources area is covered by impure sandstone. The material considered as waste for the ferrosilicon project could be extracted to meet local demand for various uses, as this was shown to exist in the past.

26.3 Quarrying

26.3.1 Geological Modelling

Further the development of a quarrying operation on the property would require a more detailed topographic survey to be performed, due to the contours of the topographic surface from 20 to 20 meters and to provide improved accuracy in the data collection, which can impact the sequencing of the quarry for initial years.

Further testing and development of the inferred resources and exploratory potential of the region can impact future development of the site.

26.3.2 Quarry processing

A more detailed study is recommended regarding the location of structures (processing plant and waste pile) since these positions were indicated in the current work mainly to have better conditions of haulage distance and cost. Health and safety evaluations of these structures also should be studied.

Due to the low value of general slope angle (38°) adopted for the pit operationalization, a more elaborate geo-technical study is recommended at later stages of the project. The silica is a very competent rock and permits the use of higher values of general slope angle.

The current extraction limit of 100,000 tons per year was considered in this work. It is recommended to initiate the permitting process to allow for greater volumes of silica to be recovered from the site.

The current water management plan for the quarry is considered conservative by the authors. A more detailed study regarding the water demand for the quarry must be carried out in further stages of the project.

26.3.3 Minerals Processing and Metallurgical Testing

Since the production of fines (-20 mm) can be considered high (25% of ROM), mineral processing and metallurgical tests would be recommendable in order to define the use of this material as a by-product that can contribute to revenue of the operation.

26.4 Human Resource Analysis

It is recommended to commence detailed due-diligence on available labour pool in Matane and St. Vianney municipalities or within the wider regional catchment area. This work stream could be initiated in parallel to the feasibility study.

26.5 Alternative Sites

Canadian Metals commissioned a preliminary smelter site study by BBA early in 2015, which compared various potential sites in Matane, Baie-Comeau, Bécancour and at the Langis deposit location in St. Vianney.[45] The authors have reviewed the BBA report and concur that the Matane site is one of the best choices, but also see potential value in some of the other sites identified. Nevertheless, the Matane site described in the BBA report has been selected as the base-case for this PEA due to its favorable attributes.

A cursory review of an alternative, brownfield smelter site in Matane, commonly known as Rock-Tenn, was also conducted by the authors and is included below, along with excerpts from the BBA report addressing the applicability of an industrial site in Bécancour.

26.5.1 Rock-Tenn Site Review

The Rock-Tenn site is approx. 2 km away from the base-case industrial site chosen for this work. The site was previously a cardboard paper factory operated by the Rock-Tenn Corporation. The factory was closed in early 2012 and had approximately 80 personnel. The site is approx. 170,000 m^2 in size and has existing light and medium industrial buildings as well as direct railway access.

45 BBA; Analyse des sites potentiels pour l'implantation d'une fonderie de ferro-silicium N° document BBA / Rév. : 3635001-000000-47-ERA-0001 / R00

Figure 190: Rock-Tenn site

Source: Google Earth and Viridis,iQ GmbH

Road and rail access to site is available and a pumping station in the nearby Matane River provided water for the Rock-Tenn equipment. The overall site geography, access, and area appear sufficient for the base-case and expansion phases of the HFP smelter, however further analysis and evaluation will be required to adequately assess the site for the current project, including layout and basic evaluation of utilities and rights. Additionally, proximity of the Rock-Tenn site to residential and downtown areas of the City of Matane raises some concerns regarding potential environmental impact. A direct assessment of this site for factors mentioned, which was not part of the scope of this report, is required to fully understand it's potential.

Figure 191: Aerial photo of previous factory on Rock-Tenn site

Source: City of Matane

Brownfield sites are often considered as potential locations for new factories, especially if there are similarities between the processes of the previous site versus the planned one. The production of cardboard is considered in the author's opinion to be light or medium industrial, while the planned HFP project is heavy industrial.

From a high level assessment, the buildings and structures of the Rock-Tenn site would likely not serve any purpose for the HFP project and the on-site utilities would be substantially less than what is needed for the HFP. The plot is flat and generally well established, thus providing lower construction costs related to earthworks, but no assessment of this savings has been calculated.

The Rock-Tenn site is seen as a possible alternative brownfield site for the HFP project, based on a high level preliminary review of the history and properties of the site.

In the author's opinion, some concerns remain related to the site regarding environmental impacts but the site can be considered as an alternative location for the HFP project at future scoping stages.

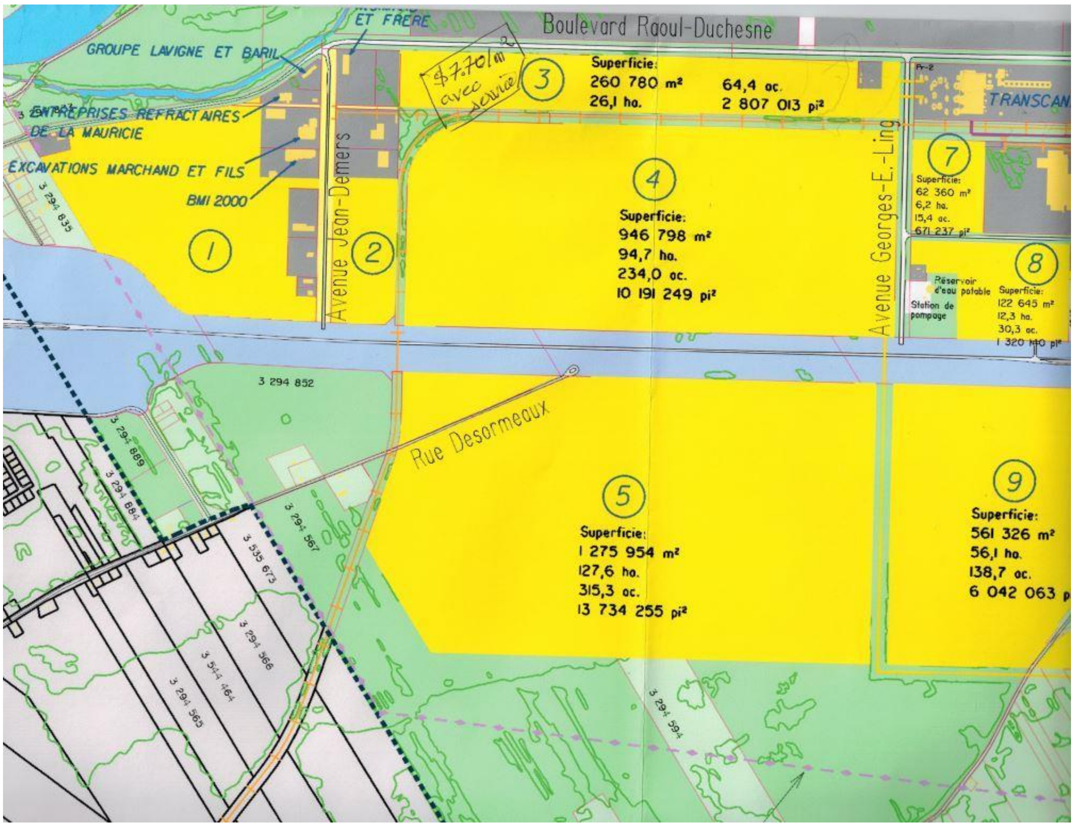
A more detailed evaluation of the Rock-Tenn site is recommended to evaluate any capital costs savings that can be realized from reallocation of existing buildings or structures.

26.5.2 Bécancour Site Review

The authors have not visited the potential site in the municipality of Bécancour but have reviewed the report prepared by BBA, which provides basic information about the potential site and is included herein.

The Municipality of Bécancour, with a population of 12,500 inhabitants, is about 550 km southwest of the Langis mine site along Highways 20 and 132. An industrial site consisting of one block (total 261,000 m^2) was proposed by the municipality to Canadian Metals as shown in Figure 192. The Industrial site is along Raoul-Duchesne Boulevard with direct access to the port of Bécancour, which is located about 6 km from the site. The Alcoa Bécancour smelter is located nearby, as well as a general arrangement of port facilities. The main railway line runs along the site's south side, as does a power line carrying 230 kV.

Figure 192: Industrial site Bécancour from BBA report (just as reference – non std)



Source: BBA

The Bécancour site is a potential alternative site to Matane and may provide some additional value due to the large infrastructure that exists in that region; however, high labor costs and other costs may also increase the project economic metrics. A further detailed study comparing the site with the base-case is recommended at later stages.

26.6 Risk Assessment

Any industrial project contains inherent risks that must be considered from the perspective of the potential operator/investor. The following tables are a risk assessment in an attempt to quantify these risks with the relevant matrices shown. The main definitions used are shown below with the actual risk matrices presented in the appendix. A more detailed and extensive project risk assessment should be undertaken at future project stages to identify and outline mitigation strategies for operations, market and technical risks.

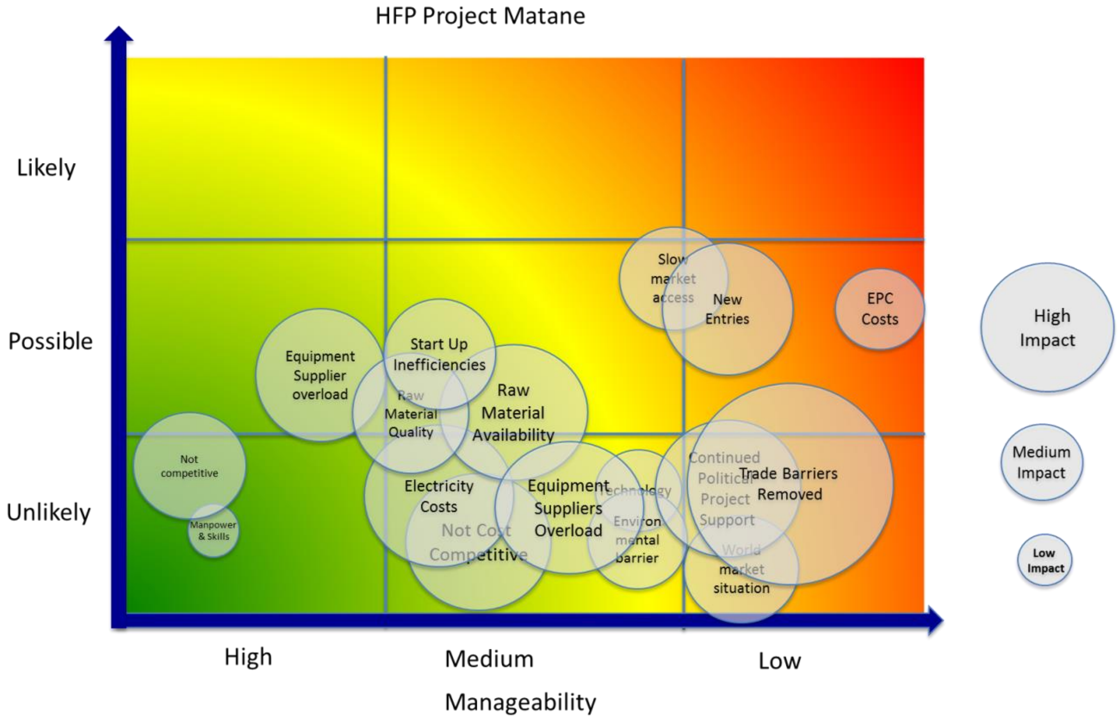
Table 81 Risk definitions

Definitions:

Likely	1 in 2, or greater	
Possible	20 - 50%	
Unlikely	<20%	
low impact	Value schedule quality	<CAD100K <3 weeks minor impact on invest decision
med impact	Value schedule quality	CAD100-500K 3-6 weeks Serious omissions/uncertainties/errors, significant impact decisions/requires additional work
high impact	Value schedule quality	>CAD500k > 6 weeks Cannot make invest decision, or make the wrong decision
Low manageability	Not possible to predict and/or influence/manage, can only react	
Medium manageability	difficult to predict, influencing or managing is not all within our control	
Highly manageable	event/condition is predictable, can be influenced and mitigated	

Source: Viridis.iQ GmbH

Figure 193: Risk matrix



Source: Viridis.iQ GmbH

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End of Report

Appendix I: Genivar – Sections 11 and 13

11.0 SAMPLES PREPARATION, ANALYSES AND SECURITY

11.1 Sample Preparation

All rice bags were shipped by Expedibus from the Lac-au-Saumon terminus to the CTMP laboratory in Thetford Mines, Québec. All samples were received in good standing by the laboratory. The latter sent a list of received samples in conformity with the list of samples shipped.

11.2 Analytical Procedure

The samples from rice bags were processed by CTMP using the following steps:

- Primary crushing to 5 – 10 mm with a Denver 31/4'' x 41/2'' Jaw crusher;
- Secondary crushing to –5 mm with a Denver 12'' Gyratory crusher;
- Tertiary crushing to 0.5 – 1.0 mm with a Denver 10'' x 6'' Roll crusher

Samples for geochemical analysis by XRF (X-Ray Fluorescence) were prepared by producing fused samples for major oxides and pressed samples for trace elements. The CTMP laboratory is not an accredited laboratory however employed acceptable procedures per the following steps:

- Samples prepared by crushing to 0.5 – 1.0 mm were split into ±50 g and then pulverized to -75 µm with a Retsch PM400 grinding mill;
- The samples were then heated in a Lindberg Blue M furnace at 1000°C for one hour to incur loss on ignition;
- For fused samples, 0.6 g was used with 6 g of flux (50% lithium borate, 50% lithium metaborate). This mixture was fused together for 20 minutes in a Claisse M4-30 gas fusion fluxer;
- For pressed samples, 8 g was used with 2 g of binder (Cereox). This mixture was pressed for 1 minute in a 12 ton Carver 4350 L press;
- Both fused and pressed samples were analyzed using the XRF (X-Ray Fluorescence) method with a 4 kW Bruker model S8 Tiger WDXRF (wavelength dispersive) analyzer under the supervision of Jacques Fiset, Chemist at the CTMP laboratory. As detailed in CTMP's report (Appendix A), the method used by the Bruker analyzer allows for the analysis of major oxide concentrations generally from 0.01% to 100%, with detection

limits as listed in Table 6. The standards used are certified reference materials and the documentation provided indicates the concentrations however no certificates were included. The procedure used at CTMP consists of varying the conditions of the analyzer with the verification sample provided by Bruker (BRSTG2). At the beginning of each day three quality control samples (QC_GEOMAJ-01, QC_GEOMAJ-02, QC_GEOMAJ-03) are analyzed and a green light indicates that the results are within the allowable tolerances. To validate this method two samples provided with the standards (GEOMAJ-16 and GEOMAJ-06) were used. The concentrations of these standard samples are listed in CTMP's report.

Table 6: Whole Rock XRF Reporting Limits for CTMP

Oxide	Detection Limits	
	Min. (%)	Max. (%)
SiO_2	0,40	100,00
Al_2O_3	0,04	90,00
Fe_{total} as Fe_2O_3	0,01	40,00
TiO_2	0,01	8,00
Na_2O_3	0,02	11,00
MgO	0,02	100,00
P_2O_5	0,01	20,00
SO_3	0,05	55,00
K_2O	0,05	15,00
CaO	0,02	100,00
MnO	0,01	0,80

Samples for metallurgical tests were processed using the following steps:

- Crushing to 0.5–1.0 mm as per above procedure, then split in two. One half was used for the physical characterization tests which was further divided into 2 kg samples for further processing;
- Screening through 30 mesh on a Gilson screen (F100 -600µm);
- Washing for 5 minutes on a 106µm Sweco screen;
- Vacuum filter both overs and unders with a Whatman 114, 25µm filter, then dry and weighed separately;
- For the composite sample representing PL-13-05, the material passing 600 µm and retained on 100 µm was split into 4 samples to perform 4 separate attrition tests. The remaining material was used for particle size distribution and XRF analysis;

- The material passing 100 µm was pulverized and analyzed by XRF as per the method described earlier;
- Samples were diluted to 75% solids by weight (950g of silica with 320g of water) for a total of 750ml in a 1000ml rectangular container;
- Attrition in a Metso flotation machine converted to an attrition scrubber at 1000 rpm for 1, 3, 5, and 10 minutes;
- Material after attrition was then washed on a 106µm screen (small diameter) fitted with a vacuum plate. The fractions retained on the screen and on the filter (Whatman 114, 25µm) were dried and weighed. A sub-sample of the material retained on 106 µm was analyzed for particle size distribution and the remaining was pulverized and analyzed by XRF. The -106 µm material recovered on the filter was pulverized and analyzed by XRF;
- For the composite samples representing PL-13-01 and 02, they were prepared in the same way except the attrition time was 5 minutes.
- For the 3 composite samples, the washed product retained on 106 µm was then then passed through a wet high intensity magnetic separator (WHIMS) Outotec model 3x4L. At 30% solids by weight the slurry passed through a bed of ½'' balls set at a current of 5.9 amperes, producing a magnetic field of approximately 20 kGauss. Bothe the magnetic and non-magnetic fractions were filtered, dried and weighed. A sub-sample of the non-magnetic material was analyzed for particle size distribution and another was pulverized and analyzed by XRF. The magnetic material was pulverized and analyzed by XRF;

Samples for analysis of roundness and sphericity were taken from the final non-magnetic material after 5 minutes of attrition, from composite samples PL-13-01 and PL-13-05. Three size fractions were prepared as -20+40, -30+50 and -40+70 mesh, typical for frac sand fractions. Photomicrographs of these fractions were used to analyze roundness and sphericity. Samples with better results for roundness and sphericity were chosen to conduct crush resistance tests. Fractions -20+40 and -30+50 were tested with a hydraulic press. Pressure was increased successively from 4000 psi to 8000 psi in 1000 psi intervals. After each test the sample was screened to determine the percentage of fines. The tests conducted for the evaluation of roundness and sphericity and crush resistance are as per the procedures set in ISO 13503-2:2006 (API RP 19C).

For thermal shock resistance, 12 samples were provided by CMI. 3 samples from each drill core (approximately 2'' diameter x 4'' long), as well as 3 samples taken from the surface of the quarry (approximately 4"x4''x4'' cubes) were used. Each were heated in a Lindberg Blue M furnace at 1000°C for 20 to 50 minutes, then cooled to room temperature. Loss on ignition was calculated based on the samples weight before and after thermal shock. Light mechanical breakages were observed. The cooled samples were then screened on 12.5 mm screen opening and the percentage of particles larger than 12.5 mm was determined.

At no time was an employee of CMIGENIVAR involved in the analytical process.

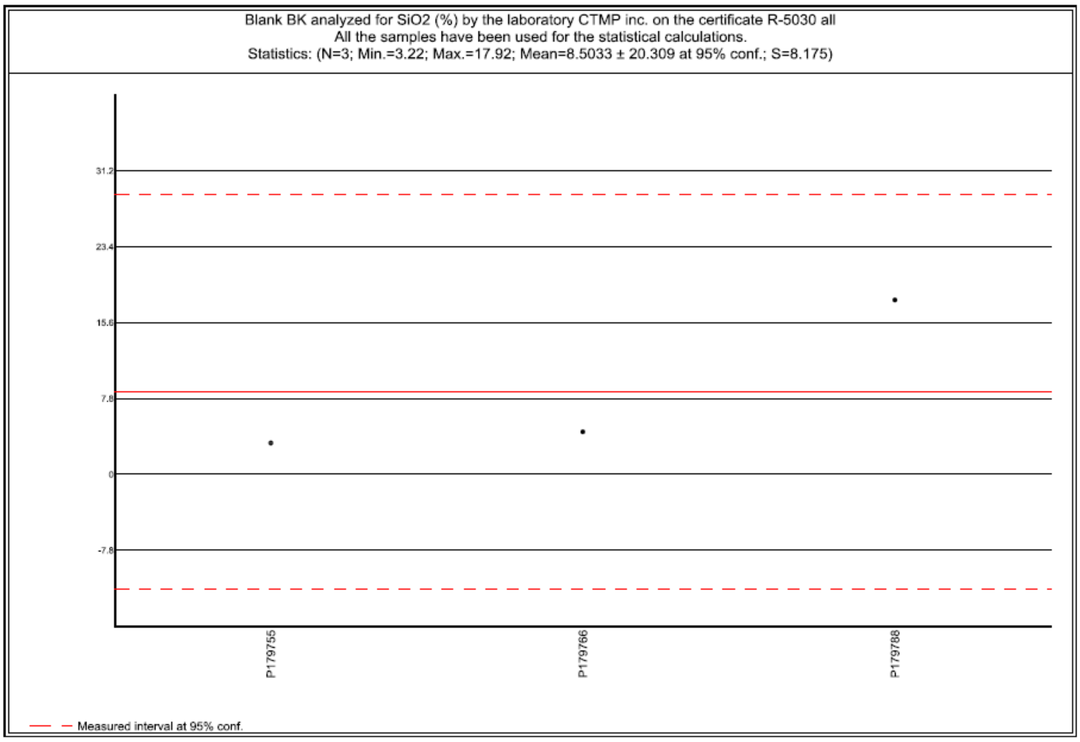
11.3 QA/QC

QAQC at this stage included the insertion in the sample stream of three blank samples and four standard samples for a total of forty-eight (48) samples, e.g. 15% of independent check samples. Blank samples consisted of white marble granulates. Standard samples consisted in silica sand collected from a pile located in the vicinity of the St-Vianney quarry.

11.3.1 Blanks

A total of three blank samples were inserted in the sample stream. Blanks consisted in white marbles supposed to not contain or contain a very low quantity of silica. Figure 11 below shows that SiO_2 measured in all samples varies from 3.22 to 17.92% (P179788). Considering the high deviation of sample # P179788 it would be crucial to perform a reanalysis confirming any contamination during the first assay procedures.

Figure 11: Analyzed %SiO_2 in Blank Samples



11.3.2 Duplicates

Independent duplicate samples were not inserted at this stage by GENIVAR geologist.

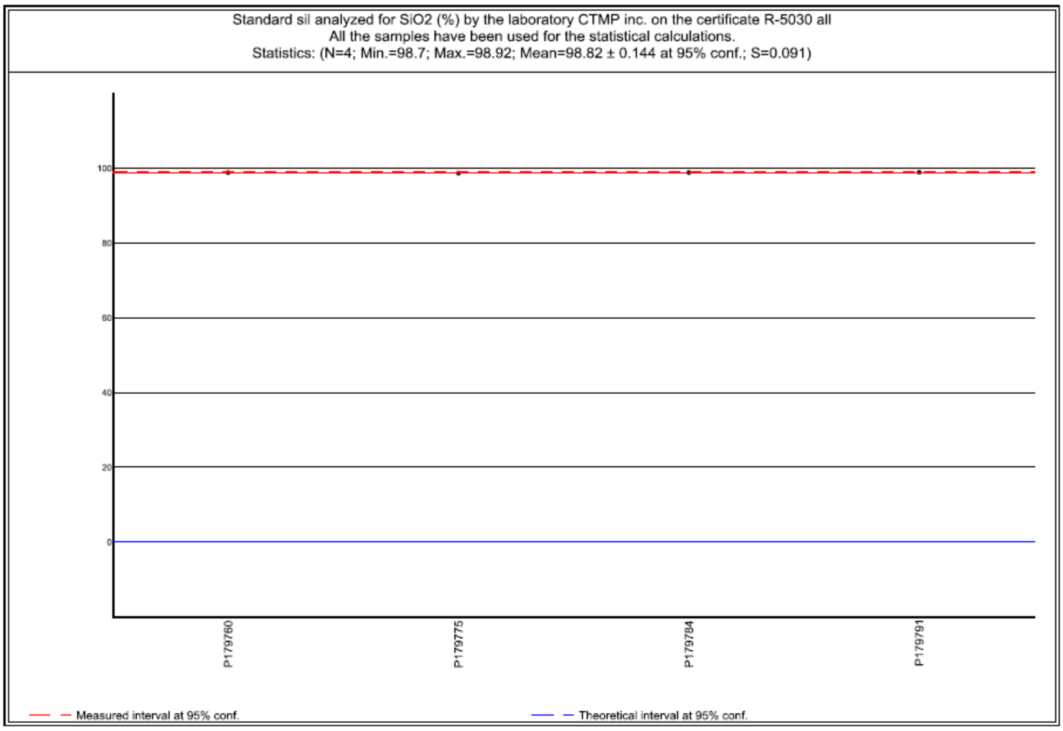
CTMP performed one duplicate assay for major-elements. Sample P179781 and P179781-R return SiO2 tenor of 98.68% and 98.67% respectively.

Duplicates sampling and assaying at a rate of 3-5% should be applied in the next core sampling program.

11.3.3 Standards

A total of four standard samples were randomly inserted in the sample stream by the logging geologist during sampling procedure and were submitted for major and multi-elements assaying. Figure 12 below shows the very low variation of silica content in the silica sand used.

Figure 12: Silica Content in the Silica Sand Used



11.4 QP's Opinion

It is the authors's opinion that sample preparation, security, and analytical procedures put in place by logging geologist and laboratory were adequate for a program at this stage and meet acceptable industry standards. The information can be used for geological resource modeling. The X-ray fluorescence (XRF) method is appropriate for detection of major chemical impurities, however in determining very low levels of oxide impurities contained in the Langis deposit, the XRF method employed by CTMP laboratory has shown that there is an issue of accuracy, therefore it is recommended to use other methods of analysis such as ICP-MS during future test work.

13.0 MINERAL PROCESSING AND METALLURGICAL TESTING

13.1 Introduction

GENIVAR was mandated to conduct a general characterization study of the Property in order to evaluate it as a source of usable silica. A laboratory test plan was recommended that would provide information for its chemical, physical and thermal properties. This information can then be used to help determine which end use the silica can be suitable for. The major uses of silica can be categorized based on the particle size requirements, i.e. lump silica (350mm down to 2 or 3mm), silica sand (2mm down to 74 microns) and ground silica (below 75 microns).

13.2 Laboratory Test Plan

The Centre de Technologie Minerale et de Plasturgie (CTMP) in Thetford Mines, QC was chosen by CMI to performed laboratory test work on three drill core samples of quartz ore taken from the Langis deposit. CTMP is not an accredited laboratory.

One half of the drill cores were used for testing, which comprises two phases:

Phase 1

For chemical properties, X-ray fluorescence (XRF) was used to analyse the major oxides and trace elements of 48 samples taken from 1/4 of the drill cores.

Phase 2

Chemical and physical properties were evaluated on three core samples which were homogenized and crushed and screened to finer than 600 microns. A classification/desliming step was then performed by washing the sand with spray water on a vibrating screen deck with 106 microns opening. Attrition scrubbing was performed on the washed sand to remove more ferrous and clay inlays. The scrubbed sand was washed again on a vibrating screen deck with 106 microns opening and then passed through a high intensity magnetic separator to remove maximum ferromagnetic particles. Chemical analysis by XRF and particle size distribution was performed between each step. Grain shape evaluation for roundness and sphericity as well as crush resistance tests were also conducted.

Thermal properties were evaluated by conducting thermal shock tests on a total of 12 lump samples. Three samples taken from each drill core (approximately 48mm diameter x 96mm long), as well as three samples taken from the surface of the quarry (approximately 100mm x 100mm x 100mm cubes) were used to conduct thermal shock tests. Each sample was introduced in a pre-heated oven at 1000°C and held there for a minimum of 15 minutes, then cooled to room temperature. Light mechanical breakages were observed. The cooled samples were then screened on 12.5 mm screen opening and the percentage of particles larger than 12.5 mm was determined. Above 80% larger than 12.5 mm demonstrates good resistance to thermal shock.

Figures 14 and 15 are generalized flowcharts of the processing steps performed for phase 2.

Figure 14: Test Plan for Lump Silica Applications

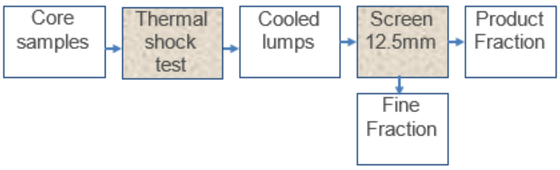
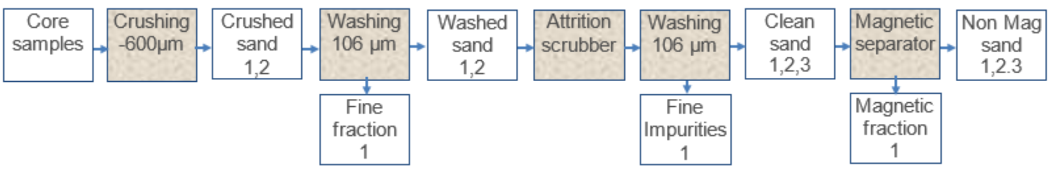


Figure 15: Test Plan for Silica Sand Applications



Analytical procedures applied:

- XRF chemical analysis
- Size distribution (grain size, AFS fineness)
- Roundness, Sphericity

13.3 Characterization of Lump Silica

The criteria for evaluating the deposit as a source of lump silica for high temperature applications are chemical composition, thermal shock resistance and lump size.

Silicon metal production requires lump silica to be very pure with at least 99.5% silica (SiO_2), while specifications for iron oxide (Fe_2O_3) impurities range from 0.05% to 0.10%, alumina (Al_2O_3) from 0.10% to 0.20% and titanium dioxide (TiO_2) up to 0.006%, CaO and MgO impurities must be no more than 0.2% and P and As must be avoided. Resistance to thermal shock is critical and the product should retain at least 80% on a 12.5 mm screen after undergoing thermal shock. The lump silica must not degrade during handling and transportation and is generally 25 to 350 mm in size.

Ferrosilicon production requires silica (SiO_2) content to be at least 98.7%, while specifications for iron oxide (Fe_2O_3) impurities should be maximum 0.3%, alumina (Al_2O_3) 0.6%, titanium dioxide (TiO_2) 0.05%, CaO and MgO 0.2% and P_2O_5 0.1%. Requirements for thermal shock resistance are the same as above.

As a fluxing agent for smelting base-metal ores, the silica sand reacts with iron and basic oxides to form a silicate slag. The silica content of the flux should be as high as possible because silica is the active slagging ingredient. Iron, alumina and other oxide impurities are not critical except that they reduce the percentage of available silica. Silica flux particles are generally 5 to 25 mm in size.

13.3.1 Chemical Composition

Chemical analyses of the composite samples, using the XRF method and per the detection limits as reported by CTMP laboratory, are summarized in Table 8. The average silica grade for the three drill core samples, including loss on ignition (LOI) between 0.3% and 0.5%, is 98.55%.

Table 8: Chemical Analysis of Langis Silica (Including L.O.I.)

		Minimum	Average composite analysis		
		Detection Limit	PL-13-01	PL-13-02	PL-13-05
SiO_2	%	0,40	98,65	98,70	98,22
Fe_2O_3	%	0,01	0,15	0,13	0,14
Al_2O_3	%	0,04	0,44	0,50	0,48
TiO_2	%	0,01	0,05	0,05	0,04
MgO	%	0,02	0,09	0,10	0,23
CaO	%	0,02	0,11	0,05	0,20
MnO	%	0,01	0,01	0,01	0,01
Na_2O	%	0,02	0,06	0,04	0,06
K_2O	%	0,05	0,07	0,08	0,07
SO_3	%	0,05	<0,05	<0,05	<0,05
P_2O_5	%	0,01	<0,01	<0,01	<0,01
L.O.I.	%	-	0,30	0,30	0,52

For industrial applications requiring high temperature metallurgical grade lump silica, the LOI compounds are vaporized and typically extracted to dust collection systems. The remaining compounds are therefore in concentrations relative to the remaining mass. The chemical analyses for the composite samples, corrected for LOI, are summarized in Table 9. The average silica grade then becomes 98.95% SiO_2, 0.14% Fe_2O_3, 0.48% Al_2O_3 and 0.05% TiO_2. This correction for LOI would not be used for sand applications where the silica is not subjected to high temperatures.

Table 9: Chemical Analysis of Langis Silica (Excluding L.O.I.)

		Minimum Detection Limit	Average composite analysis PL-13-01	PL-13-02	PL-13-05
SiO_2	%	0,40	99,00	99,04	98,76
Fe_2O_3	%	0,01	0,15	0,13	0,14
Al_2O_3	%	0,04	0,44	0,50	0,49
TiO_2	%	0,01	0,05	0,05	0,05
MgO	%	0,02	0,09	0,10	0,23
CaO	%	0,02	0,11	0,05	0,21
MnO	%	0,01	0,01	0,01	0,01
Na_2O	%	0,02	0,06	0,04	0,06
K_2O	%	0,05	0,07	0,08	0,07
SO_3	%	0,05	<0,05	<0,05	<0,05
P_2O_5	%	0,01	<0,01	<0,01	<0,01
L.O.I.	%	-	-	-	-

13.3.2 Thermal Shock Test

A critical aspect of characterizing lump silica for high temperature applications is its resistance to thermal shock. Nine samples from drill cores and three samples from the surface were provided for thermal shock resistance tests. Thermal shock evaluation was based on the "SKW" procedure, in which the sample is introduced into a furnace at 1000° C for at least 15 minutes, after cooling and light mechanical breakage it is screened at 12.5 mm and the percentage retained is determined. A result of more than 80% demonstrates the material has a high resistance to thermal shock. Results from thermal shock analyses of the twelve samples indicate an average value of 95.1%, demonstrating a relatively strong cementation suitable for lump quartz. Depending on the specific producer of ferrosilicon, further detailed tests would be required.

Based on the test work at CTMP, the Langis silica deposit can meet the requirements for the production of ferrosilicon as well as a flux agent for base metal smelting. The chemical composition of this material, however, does not meet the requirements for the production of silicon metal which requires a higher purity silica.

13.4 Characterization of Silica Sand

Sand samples were prepared by crushing the drill cores through a primary jaw crusher, a secondary gyratory crusher and a tertiary roll crusher to finer than 600 µm. The -600 µm homogenized head feed was then processed through a classification/desliming step, an attrition step and a magnetic separation step. Table 10 summarizes the grade and weight recovery of silica (SiO_2) and the major oxide impurities (Fe_2O_3, Al_2O_3, TiO_2) after each process step. The concentration levels of the other oxide impurities contained in the sand product are listed in CTMP's laboratory report (Appendix B, Table B7). For the purpose of this characterization study only the three major oxide impurities are taken into consideration as they determine the quality of most silica sand applications. Appendix B lists the general chemical and physical specifications for different uses of silica.

Table 10: Grade and Weight Recovery of Sand After Each Process Step

Operation Step	Head Feed	Classification		Attrition		Magnetic Separation	
Valuable product	-600 µm	-600 +106µm product		-600 +106µm attritioned		-600 +106µm non-magnetic	
Sample PL-13-01							
Wt Recovery overall (%)	100	75,49		74,04		73,77	
Wt. Recovery per step (%)	100	75,49		98,08		99,64	
Component	Grade (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)
SiO_2	99,03	99,39	75,78	99,58	98,09	99,56	99,66
Fe_2O_3	0,09	0,05	35,48	0,03	89,99	0,03	75,13
Al_2O_3	0,40	0,21	42,64	0,15	94,56	0,16	98,39
TiO_2	0,04	0,03	50,66	0,03	95,03	0,03	98,58
Sample PL-13-02							
Wt Recovery overall (%)	100	77,78		76,13		75,96	
Wt. Recovery per step (%)	100	77,78		97,87		99,77	
Component	Grade (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)
SiO_2	98,91	99,46	78,06	99,53	97,91	99,47	99,78
Fe_2O_3	0,09	0,05	40,24	0,02	77,97	0,04	86,64
Al_2O_3	0,47	0,19	42,23	0,17	88,77	0,15	98,39
TiO_2	0,06	0,03	48,84	0,02	89,32	0,03	98,36
Sample PL-13-05							
Wt Recovery overall (%)	100	84,87		83,21		73,99	
Wt. Recovery per step (%)	100	84,87		98,05		88,92	
Component	Grade (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)
SiO_2	99,01	99,46	84,96	99,58	98,08	99,20	88,93
Fe_2O_3	0,08	0,05	60,90	0,05	93,00	0,01	56,30
Al_2O_3	0,32	0,20	71,82	0,15	89,43	0,17	88,09
TiO_2	0,04	0,03	70,62	0,05	96,58	0,02	86,94
Average							
Wt Recovery overall (%)	100	78,13		76,55		75,91	
Wt. Recovery per step (%)	100	78,13		97,98		99,16	
Component	Grade (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)	Grade (%)	Recovery (%)
SiO_2	98,98	99,44	78,38	99,56	98,01	99,41	99,21
Fe_2O_3	0,09	0,05	40,80	0,03	85,49	0,03	60,50
Al_2O_3	0,40	0,20	46,20	0,16	91,29	0,16	95,50
TiO_2	0,05	0,03	52,84	0,03	93,02	0,03	94,60

13.4.1 Classification/Desliming

The initial classification step removed the -106 µm fines by washing the material on a 150 mesh Sweco screen. This step alone can remove approximately 22% of the material from the head feed. The resulting product contains considerably less impurities thereby producing a higher purity silica sand averaging 99.44% SiO_2. The average iron oxides content was reduced from 0.09% to 0.05% Fe_2O_3, while the average alumina content dropped from 0.40% to 0.20% Al_2O_3 and titanium dioxide from 0.05% to 0.03% TiO_2. As this process is considered more of a desliming step, it is typically performed by hydrocyclones and is a critical step in the purification of silica sand. It also prepares cleaner sand for subsequent steps.

13.4.2 Attrition

Attrition tests were conducted on core sample PL-13-05 to evaluate the effect of attrition residence time. The optimal residence time was then used for samples Pl-13-01 and PL-13-02. The objective of attrition scrubbing is to loosen and disperse coatings of iron oxides, clay minerals and other cementing materials from the sand grain surfaces.

Table 11 shows the distribution of silica and the major oxide impurities for different attrition times on sample PL-13-05. There is an overall increase in silica grade with increasing attrition time. Increasing the attrition time to 10 minutes did not significantly improve the removal of impurities. Taking into account the relative uncertainty with the analysis method, it can be concluded that the removal of iron oxide and titanium oxide impurities were not significantly affected by attrition time. This can be explained by the fact that much of the iron and titanium oxides may be finely disseminated in the silica. On the other hand, the alumina content decreased with attrition time, from 0.19% at 1 minute to 0.13% at 10 minutes.

Table 11: Distribution of +106µm Product at Different Attrition Times

Residence Time	1 minute		3 minutes		5 minutes		10 minutes	
Weight Recovery (%)	98,22		98,12		98,05		98,18	
Component	Grade (%)	Dist'n (%)	Grade (%)	Dist'n (%)	Grade (%)	Dist'n (%)	Grade (%)	Dist'n (%)
SiO_2	99,54	98,24	99,57	98,13	99,58	98,08	99,63	98,19
Fe_2O_3	0,03	94,31	0,03	91,57	0,05	93,00	0,04	95,94
Al_2O_3	0,19	96,05	0,18	95,23	0,15	89,43	0,13	96,30
TiO_2	0,03	97,07	0,03	95,60	0,05	96,58	0,03	95,75

It was agreed to establish an attrition time of 5 minutes as optimal for samples PL-13-1 and PL-13-02. As shown in Table 10, after 5 minutes of attrition and desliming at 106 µm the silica grade for the three composite samples increased from an average 99.44% to 99.56% SiO_2. It was also observed that the average iron oxides content was reduced from 0.05% to 0.03%, the average alumina content was reduced from 0.20% to 0.16%, while the average content of titanium dioxide was left unchanged.

The weight recovery of the product after attrition and desliming averages 98%.

Particle size distributions were analyzed for the +106µm product at different attrition times. As indicated in CTMP's report, there is very little change in particle size distributions with AFS grain fineness numbers ranging from 63 to 67.

13.4.3 Magnetic Separation

Wet high intensity magnetic separation (WHIMS) was conducted on the clean deslimed sand attritioned for 5 minutes. The final non-magnetic material contained an average silica grade of 99.41% SiO_2, while the impurities content in the sand range from 0.01% to 0.04% Fe_2O_3, and 0.15% to 0.17% Al_2O_3 and 0.02% to 0.03% TiO_2. The average impurities content therefore was left relatively unchanged. Nevertheless, a small fraction of magnetic material (less than 1%) was removed indicating that further reduction of iron oxide impurities from the silica sand can be achieved. Again the lack of conclusive results to indicate an improvement in the silica grade by the removal of a small fraction of magnetic impurities can be attributed to the relative uncertainty with which the XRF method was used by CTMP in determining such low levels of oxides. Validation of this step by other methods of analysis is recommended.

13.4.4 Particle Size Distribution

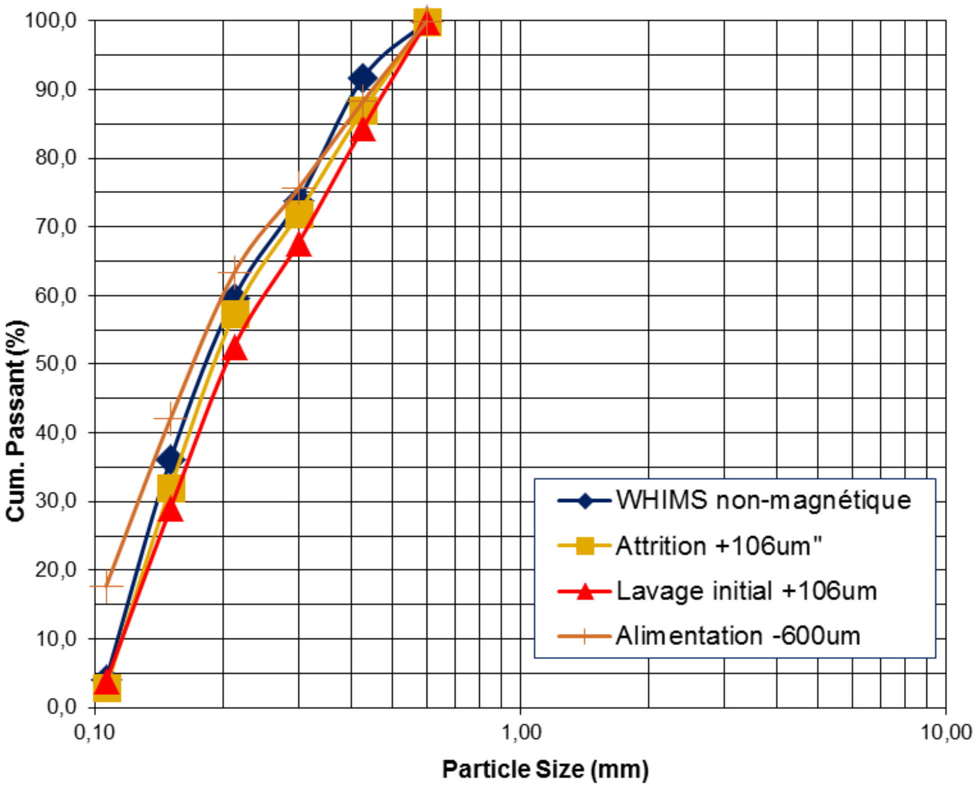
Grain size distribution is an important physical characteristic in determining whether it is applicable to many silica sand uses. The average particle size distributions of the three composite samples, after each process step, are listed in Table 12. It is noted that the size distributions are fairly close for the three composite samples, therefore only the average is illustrated in this analysis. The particle size distributions for samples PL-13-01 (Envoi 1), PL-13-02 (Envoi 2) and PL-13-05 (Envoi 3), after each process step, are included in Appendix B of the CTMP's report. As noted earlier, the classification/desliming step represents the removal of approximately 20% of the head feed. The average AFS grain fineness number is thus reduced from 79 to 66. The average coefficient of uniformity (C_u), which is a measure of grain sorting or uniformity, was calculated to be 2.11, indicating the sand is fairly well sorted. As the value of C_u increases, the material becomes less sorted or uniform. After the initial classification at 106 µm the particle size distribution becomes slightly finer after undergoing attrition and magnetic separation, and becomes a little more uniform with lower Cu values.

Table 12: Average Size Distribution of Sand After Each Process Step

Operation Step		Head Feed -600 µm	Classification -600+106µm product	Attrition -600+106µm attritioned	Magnetic Separation -600+106µm non-mag
(US series)	(mm)	(% Passing)	(% Passing)	(% Passing)	(% Passing)
20	0,850	100,00	100,00	100,00	100,00
30	0,600	99,94	99,85	99,87	99,90
40	0,425	88,24	84,37	86,98	91,68
50	0,300	75,59	67,66	71,95	73,86
70	0,212	63,31	52,58	57,29	59,68
100	0,150	41,99	28,93	31,93	36,04
140	0,106	17,69	3,78	2,89	4,11
Pan					
AFS Grain Fineness No.		79	66	68	71
Cu Coefficient of Uniformity		-	2,11	1,91	1,82

A graphical representation of the particle size distributions for each process step is illustrated in Figure 16.

Figure 16: Size Distribution of Sand After Each Process Step



13.4.5 Roundness and Sphericity

An important physical characteristic for frac sands and foundry sands, is roundness and sphericity of the grains. The core samples were broken down to liberate the individual grains and then screened for various size fractions. Three size fractions were prepared (20/40 mesh, 30/50 mesh and 40/70 mesh) which represent typical sizes of frac sand used as proppants for hydraulic fracturing. A visual analysis of 20 randomly chosen grains for each size fraction was performed based on comparison to the Krumbien & Sloss chart as outlined in the ISO 13503-2 (API RP 19C) standard. Results are shown in Table 13. These observations indicate the roundness of the sand grains averages between 0.3 and 0.5 and thus can be considered sub-angular to sub-rounded, while the sphericity averages between 0.6 and 0.7 and can be considered medium to high sphericity. For frac sand the requirement is 0.6 for both roundness and sphericity, therefore the issue will be roundness even though sphericity may be acceptable. Foundry sand requirements are sub-angular to rounded grains to allow a certain degree of permeability; therefore this product can be applicable to foundry sand based on its grain shape.

Table 13: Roundness and Sphericity of Different Size Fractions

Product	Attrition 10 min, before WHIMS			Attrition 5 min, after WHIMS			Breakage after heating, Attrition 5 min		
Fraction	**20/40**	**30/50**	**40/70**	**20/40**	**30/50**	**40/70**	**20/40**	**30/50**	**40/70**
Roundness	0,4	0,5	0,4	0,4	0,5	0,4	0,3	0,4	0,4
Sphericity	0,6	0,7	0,6	0,7	0,7	0,6	0,7	0,6	0,7

Figures 17 to 20 are photo illustrations of some of the sand fractions evaluated. There are some nice round and spherical sand grains but there are also many angular grains with inclusions and pre-fractures. In addition, there is a significant amount of agglomerates of finer particles (clusters) which, when subjected to high pressures, will tend to break into finer particles.

13.4.6 Crush Resistance

Crush resistance tests are used to evaluate frac sand. Tests were conducted on the 20/40 mesh and 30/50 mesh fractions of the product after 5 minutes of attrition and magnetic separation and as per ISO 13503-2 (API RP 19C) standard. Results for the 20/40 product showed 26.3% fines at 4000 psi and 32.5% fines at 5000 psi. The 30/50 product showed 21.7% fines at 2000 psi and 40.1% fines at 4000 psi. The API requirement for 20/40 frac sand is 14% fines at 6000 psi. The high amount of fines generated from the crush resistance test can be explained by the presence of agglomerates (clusters) and the angular grains that tend to break apart into fines under high pressures.

Figure 17: 20/40 Mesh Fraction, Attritioned for 10 Minutes, No WHIMS

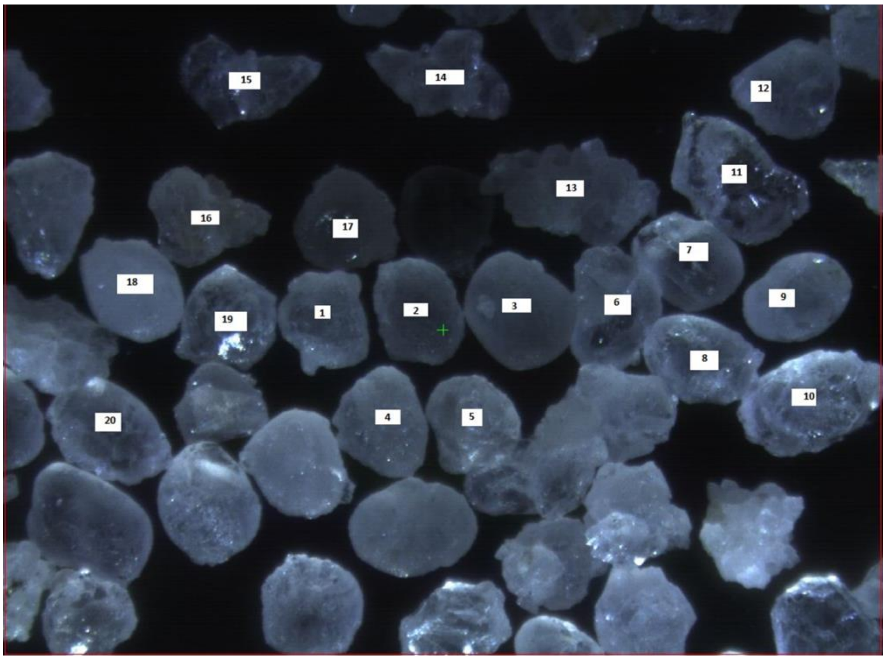


Figure 18: 30/50 Mesh Fraction, Attritioned for 10 Minutes, No WHIMS

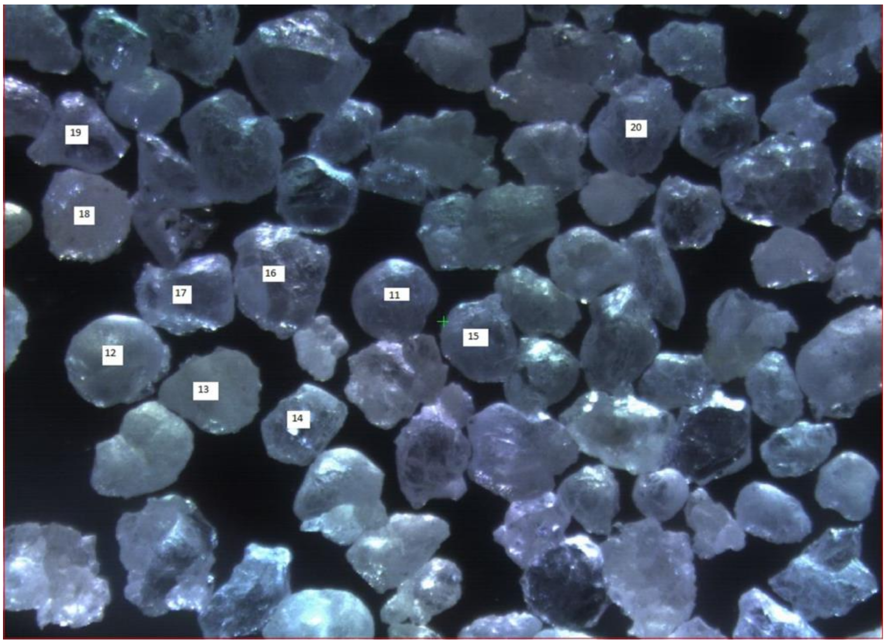


Figure 19: 20/40 Mesh Fraction, Attritioned for 5 minutes, Non-Magnetics After WHIMS

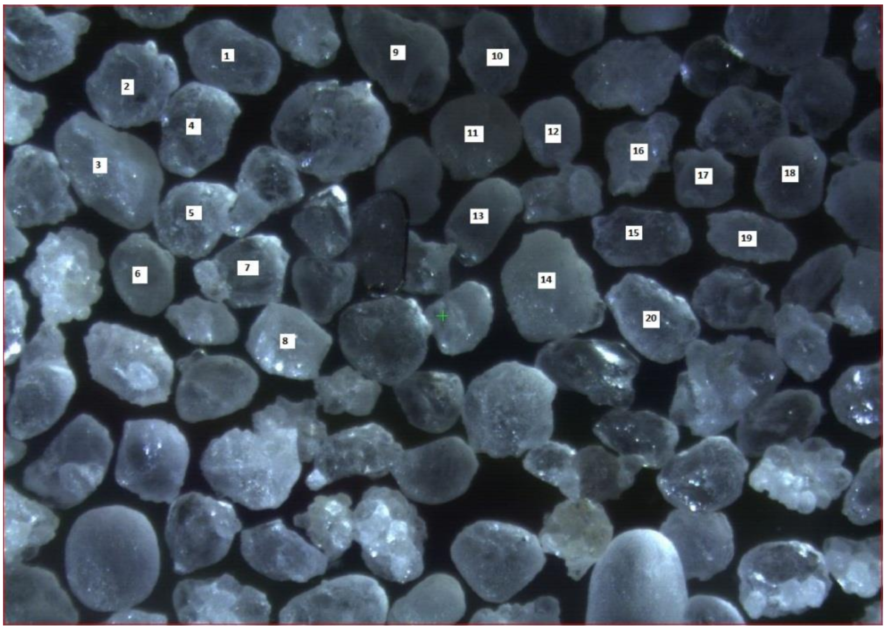
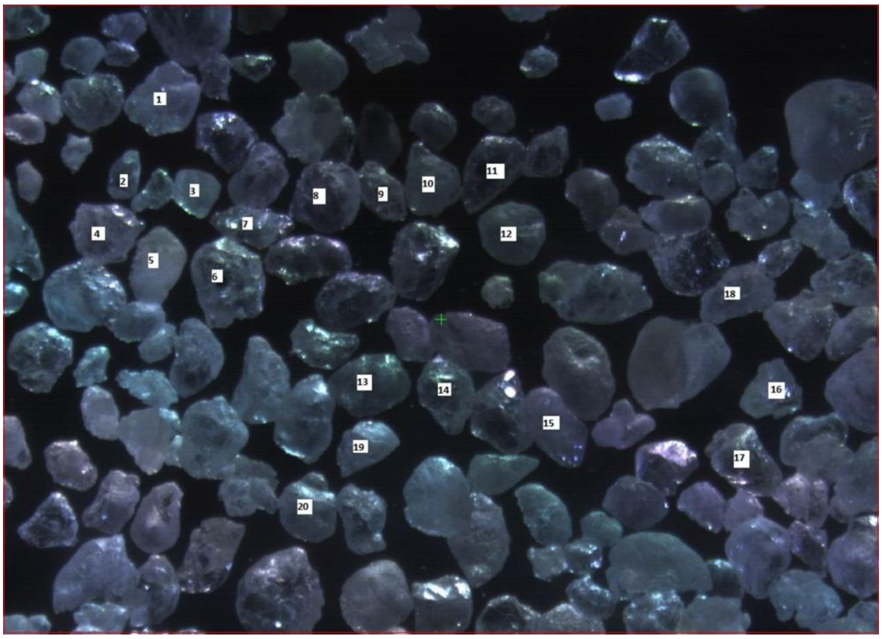


Figure 20: 40/70 Mesh Fraction, Attritioned for 5 minutes, Non-Magnetics After WHIMS



13.4.7 Frac Sand

Evaluation of the material for hydraulic fracturing sand (frac sand) includes, among other requirements, silica grade, size fraction, roundness, sphericity and crush resistance. Most frac sands contain at least 99% SiO_2, therefore the sand from Langis can meet this requirement. Typical size fractions are designated as 6/12, 8/16, 12/20, 16/30, 20/40, 30/50, 40/70, 70/140 and 90% of the sand should lie within those mesh ranges. Samples were evaluated for roundness and sphericity on 20/40, 30/50 and 40/70 fractions. API requirements are at least 0.6 for both roundness and sphericity. The roundness of the Langis sand will be an issue as it lies between 0.3 and 0.5, while its sphericity is acceptable at 0.6 to 0.7. Crush resistance tests of the 20/40 and 30/50 fractions indicate the Langis sand will not meet API requirements. The crushing strength of the sand was lowered due to the presence of agglomerates (clusters), as evidenced from the photomicrographs. Common in sandstone formations, these clusters are typically broken down through attrition and sometimes removed as a coarse fraction +1 to 2 mm after impact crushing. Further tests are recommended to better evaluate this product by a specialized Frac sand laboratory for a suite of API tests including detailed evaluation of roundness and sphericity, crush resistance, acid solubility, turbidity, conductivity, etc.

13.4.8 Glass Sand

The criteria for evaluating the deposit as a source of glass sand are chemical composition, size distribution and trace contaminant levels. Chemical control of the glass batch is of primary importance and as silica sand is the major constituent of the batch composition, it must have a high level of uniformity. The silica content is very important, however it is not the main issue, rather, it is the non-silica contaminants that determine the quality. The principal contaminants include iron, alumina and titania. Other contaminants like calcium, magnesium are present in lesser amounts. Iron oxide (Fe_2O_3) impurities will lead to tinted or opaque glass. Alumina (Al_2O_3) provides greater chemical durability and lower coefficient of expansion, while too much alumina increases the viscosity of the glass, making it difficult to melt and work, and also decreases the transparency of the glass. Titania (TiO_2) colors glass and is more difficult to neutralize than iron. Other impurities such as lime in the form of calcite ($CaCO_3$) and dolomite ($CaMg(CO_3)$) are to be avoided. It is preferable to use lime-free sand and add raw limestone to the glass batch as required rather than rely on daily analyses for lime content. Magnesia (MgO) content up to 1% in sand is generally causes little trouble in glassmaking.

The chemical composition of the silica sand will vary depending on the glass making user. For cler flat glass the silica (SiO_2) content in most glass sands should exceed 99%. The iron content in the form of Fe_2O_3 should be uniform and less than 0.035%, while alumina (Al_2O_3) should be maximum 0.10% and titania (TiO_2) should be maximum 0.02%. For colored container glass the silica (SiO_2) content should be at least 98.9%, while both Fe_2O_3 and Al_2O_3 should be maximum 0.15% and TiO_2 should be maximum 0.10%.

The grain size distribution is controlled simply but screening the coarse and the fine fractions. Again it depends on the end user, however, it should generally pass 20 mesh (0.83 mm) and no more than 5% should pass 150 mesh (0.100 mm). Excessive fines in the sand are undesirable because they tend to carry impurities, cause dusting that can be lost with the flue gases and can also cause foaming in the tanks.

Residual moisture is also considered a contaminant with typical levels requiring less than 0.1% moisture. A drying step will therefore be required if the Langis deposit is to be considered a potential source of glass sand.

Based on the results from the test work the chemical composition of the sand after undergoing attrition and magnetic separation ranges from 99.20% to 99.56% SiO_2, while the impurities range from 0.01% to 0.04% Fe_2O_3, 0.15% to 0.17% Al_2O_3 and 0.02% to 0.03% TiO_2. The particle size distribution lies within the typical target range of 20 to 150 mesh. This demonstrates that the Langis sand could be a potential source of glass sand. It is recommended however to conduct more detailed tests specific to the potential glass making user. If further removal of contaminant minerals is required, flotation techniques to either float the impurities from the glass sand product or to float the clean sand from the impurities can be tested.

13.4.9 Foundry Sand

Molding sand used in foundries should consist of uniform-sized sub-angular to rounded grains of silica. Silica (SiO_2) content can range from 88% to 99%, while oxide impurities can vary greatly. Grain sizes generally lie between 75 and 850 microns, with typical AFS grain fineness numbers between 55 and 65 and the bulk of the sand preferably retained on three adjacent sieves.

Based on the results from the test work the chemical composition and grain shape with respect to roundness and sphericity will qualify the Langis sand as a potential source of foundry sand. Magnetic separation will not be required and suitable sand may be produced even without attrition. The issue will be the particle size distribution as the AFS numbers produced from the prepared samples (average 66 after initial desliming) are somewhat higher than the normal range for typical foundry sands. This can be adjusted by classifying the sand at a coarser size in order to meet the specific needs of the potential foundry. Again depending on the foundries, the sand must satisfy further specifications such as refractoriness, permeability, bond strength, acid demand value, moisture, pH and turbidity. Therefore further tests are recommended to satisfy the requirements of potential end users.

13.4.10 Other Uses

Abrasive Sand

The silica at Langis mey be used as abrasive sand in sandblasting applications. General requirements for the silica is that it should be clean and free of adhering clay or coatings of iron oxide and it should not generate dust during handling. The silica (SiO_2) content should be high (up to 99%) so that little waste results from minerals too soft to be effective. Rounded and angular sand grains are typically used for these applications. Detailed tests specific to abrasive sand users will be required.

Sodium Silicate

This silica sand may be a potential for the manufacture of sodium silicate. It should contain 99% SiO_2 and less than 0.1% iron, less than 1% alumina (Al_2O_3) and less than 0.5% combine lime and magnesia. Grain sizes should be between 140 and 850 microns. Sodium silicate is used as a chemical agent for detergents, catalysts, pigments, adhesives, paper making, fabrication of calcium and aluminum silicates. It is also be used in the flotation process for the recovery of fine graphite, as it acts as a quartz depressant and slime dispersant. Industrial production is based on fusing silica sand with either sodium carbonate or sodium sulphate and reducing agent such as carbon, at about 1200-1400^{o}C.

Silicon Carbide

This silica sand may also be a potential for the manufacture of silicon carbide. It should contain 99% SiO_2 while iron oxide and alumina should each be less than 0.1%. All sand should be larger than 150 microns. Silicon carbide is generally used as an abrasive, but also used as a refractory. Industrial production is based on melting silica sand and coke in an electric arc furnace at +2200^{0}C.

Ground Silica

It may be possible to produce ground silica, or silica flour with the silica sand from Langis. It will however incur high capital costs for equipment to dry, grind (to below 75 microns), classify and package the fine powder. The general requirements are chemical purity, lack of color or tint (iron oxide must be very low) and particle size. Silica flour has multiple applications such as an abrasive additive in soaps, paints, foundry work, glass, ceramic and clay production. More detailed tests will be required by the potential end user.

13.5 Summary and Conclusion

Based on the preliminary test work by CTMP, basic chemical, physical and thermal properties of the Langis sandstone indicates it has potential to be a usable source of silica. The impurities contained in the core samples are about 1% with a silica grade in the order of 98.55% SiO_2 and a loss on ignition ranging from 0.3% to 0.5%. When corrected for loss on ignition incurred during high temperature lump silica applications, the ore averages 98.95% SiO_2, 0.14% Fe_2O_3, 0.48% Al_2O_3 and 0.05% TiO_2.

Thermal shock tests on twelve representative lump samples reveal that this material has relatively strong cementation, making it a potential source for lump silica applications in high temperature furnaces.

For applications requiring silica sand grains it can be shown that a significant amount of impurities can be eliminated with the removal of fine sand below 100 microns. The residual sand then averages 99.44% SiO_2, 0.05% Fe_2O_3, 0.20% Al_2O_3 and 0.03% TiO_2.

With attrition, iron oxides and clays can be scrubbed from the surface of the sand grains thereby producing a cleaner silica sand averaging 99.56% SiO_2, 0.03% Fe_2O_3, 0.16% Al_2O_3 and 0.03% TiO_2.

High intensity magnetic separation removed a very small fraction of magnetic material with the objective of reducing the Fe_2O_3 content to below 0.03%, however the average impurities content in the sand product was left relatively unchanged.

Physical characteristics of the silica sand were evaluated with respect to particle size distribution, AFS grain fineness numbers, coefficient of uniformity, roundness, sphericity and crush resistance.

It should be noted that the SiO_2 content was calculated from the sum of the assayed results of ten major oxides, twenty four trace elements and loss on ignition, by the x-ray fluorescence (XRF) method. This is a normal method of analysis for a silica deposit such as Langis and was used as an indicator for the purpose of this characterization study. However, in determining such low levels of oxide impurities, this method has shown that there is an issue of accuracy which is evident in the variance of impurities concentration and the basic margin of error as reported by CTMP from the samples analyzed in triplicate.

Based on the chemical, physical and thermal properties observed from the test work at CTMP, by crushing and screening to -120+20 mm lump particles, the Langis silica deposit may be a potential source for the production of ferrosilicon. Further crushing to -25+5 mm particles will also make it a potential source as a flux agent for base metal smelting. The chemical composition of this material, however, does not meet the requirements for the production of silicon metal.

Crushing to -600 microns and deslining the -100 microns fines as well as attrition, size classification, dewatering and drying can be considered to provide a potential source of glass sand, foundry sand and other uses like abrasive sand, sodium silicate, silicon carbide. The material was also tested for frac sand and based on an initial evaluation, the presence of many clusters as well as the issue with the grains' roundness should be considered a stumbling block for its potential as a source of frac sand. Further tests are recommended to better evaluate this product by a specialized frac sand laboratory.

Appendix II: Local construction cost references

Reference Costs

Item	Unit	Amount (USD)
Labor Costs		
Engineer	h	34,74
Steel Works, and Construction Technician Labor Costs	h	24,53
Construction and Assembly professional Labor Costs	h	18,23
Specialized Commissioning Professional	h	150,00
Material Costs		
Forged Cooper including manufacturing costs	kg	29,86
Stainless Steel Aisi 316 plate	kg	6,35
Stainless Steel Aisi 304 plate	kg	3,95
Stainless Steel Pipes	Kg	5,80
Cupper Pipes Internal Diameter 50mm External diameter 70mm	kg	14,50
Carbon Steel ASTM A36 Plate	kg	2,20
Steel Welded Equipment (finished Costs)	kg	4,48
Cast Iron	kg	2,00
Construction Costs		
Heavy Steel Structure	kg	2,86
Medium Steel Structure	kg	3,67
Light Steel Structure	kg	4,48
Civil work and finishing on steel structure buildings	m2	550,00
Building costs - Offices	m2	1.517,24
Building costs - Power Stations	m2	1.350,00
Building costs - Warehouse and Crushing	m2	482,76
Building costs - Maintenance	m2	1.172,00
Building Costs - General Sheds	m2	750,00
Building costs - Heavy Steel Structure - Furnace Building	m2	4.172,85
Building costs - Roofage Metal - Furnace Building	m2	106,90
Building costs - Roofage on steel deck - Furnace Building	m2	211,72
Building costs - Medium Steel Structure	m2	1.172,00
Vegetal Suppression	m2	1,20
Earthworks Cut	m3	9,66
Earth-Works Handling and Disposal	m3	1,14
Equipment Costs		
Conveyor Belt 24"	m	1.150,00
Conveyor Belt 36"	m	1.350,00
Flexowell Conveyor 36"	m	1.550,00

source: compilation of public references, Viridis.iQ GmbH estimates

Appendix III: Hydro-Québec Power Rate Simulation

CANADIAN METALS

SIMULATION TARIFAIRE - 2015 (en dollars canadiens)

Voir note ci-dessous

PROJET SILICIUM LANGIS - TARIF GRANDE PUISSANCE L
(en vigueur le 1er avril 2015)

TENSION D'ALIMENTATION :	230 kV	
TENSION DE MESURAGE :	230 kV	

CARACTERISTIQUES :

Puissance souscrite :	100 000	kW
Puissance maximale réelle (kW) :		
Puissance maximale apparente (kVA) :		
Facteur de puissance:	95,0%	

Prix du kW de Puissance ($/kW) :	12,87	*art. 5.2 p. 59 **
Prix du kWh (¢/kWh) :	0,0326	
Prime de dépassement mensuelle d'hiver ($/kW) :	22,590	*art. 5.6 p. 62*

CRÉDIT D'ALIMENTATION — $/kW — *art. 10.2 p. 138*

5 kV, mais inférieur à 15 kV :	0,612
15 kV, mais inférieur à 50 kV :	0,981
50 kV, mais inférieur à 80 kV :	2,190
80 kV, mais inférieur à 170 kV :	2,679
170 kV :	3,540

RAJUSTEMENT POUR PERTE DE TRANSFORMATION ($/kW) : 0,1767 — *art. 10.4 p. 138*

** Les références aux valeurs indiquées correspondent au Tarifs d'électricité en vigueur le 1er avril 2015.*

Tarif	Période du	Au	Puissance mesurée kW	Puissance apparente mesurée kVA	Puissance souscrite kW	Puissance facturée kW	Consommation kWh	Facteur d'utilisation	Facteur de puissance	Prime de dépassement	Montant avant taxes	Prix unitaire du kWh (¢/Kwh)	Nombre de jours	Nombre d'heures
Tarif L	2015-01-01 00:00	2015-02-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %	0,00 $	3 503 461,84 $	4,584	31	744
Tarif L	2015-02-01 00:00	2015-03-01 00:00	107 000	112 631,6	100 000,0	107 000,0	69 027 840	96,0 %	95,0 %	0,00 $	3 164 417,14 $	NA	28	672
Tarif L	2015-03-01 00:00	2015-04-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %	0,00 $	3 503 461,84 $	4,584	31	744
Tarif L	2015-04-01 00:00	2015-05-01 00:00	107 000	112 631,6	100 000,0	107 000,0	73 958 400	96,0 %	95,0 %		3 390 446,94 $	4,584	30	720
Tarif L	2015-05-01 00:00	2015-06-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %		3 503 461,84 $	4,584	31	744
Tarif L	2015-06-01 00:00	2015-07-01 00:00	107 000	112 631,6	100 000,0	107 000,0	73 958 400	96,0 %	95,0 %		3 390 446,94 $	4,584	30	720
Tarif L	2015-07-01 00:00	2015-08-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %		3 503 461,84 $	4,584	31	744
Tarif L	2015-08-01 00:00	2015-09-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %		3 503 461,84 $	4,584	31	744
Tarif L	2015-09-01 00:00	2015-10-01 00:00	107 000	112 631,6	100 000,0	107 000,0	73 958 400	96,0 %	95,0 %		3 390 446,94 $	4,584	30	720
Tarif L	2015-10-01 00:00	2015-11-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %		3 503 461,84 $	4,584	31	744
Tarif L	2015-11-01 00:00	2015-12-01 00:00	107 000	112 631,6	100 000,0	107 000,0	73 958 400	96,0 %	95,0 %		3 390 446,94 $	4,584	30	720
Tarif L	2015-12-01 00:00	2016-01-01 00:00	107 000	112 631,6	100 000,0	107 000,0	76 423 680	96,0 %	95,0 %	0,00 $	3 503 461,84 $	4,584	31	744
Données annuelles							899 827 200			0,00 $	41 250 437,77 $	4,584	365	8 760

Note: La présente simulation tarifaire a été produite sous toute réserve et sans aucun engagement de quelques natures que ce soit par Hydro-Québec.

Préparé par: Bruno Soucy
Délégué commercial principal
Direction Grands Clients
Hydro-Québec Distribution
08-déc-15

Appendix IV: Integrated Financial Model P&L (Years 1-10) – Steady-state base-case

CME's integrated project P&L estimate	Years 1-10 after project initiation									
Thousand USD	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Revenue	**0**	**36,132**	**108,396**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**
COGS	**1,033**	**24,450**	**69,220**	**91,604**	**91,604**	**91,604**	**91,604**	**91,604**	**92,883**	**94,161**
quartzite (SiO2)	0	1,224	3,672	4,897	4,897	4,897	4,897	4,897	4,897	4,897
carbon reductant	0	2,861	8,582	11,442	11,442	11,442	11,442	11,442	11,442	11,442
woodchips	0	1,203	3,610	4,814	4,814	4,814	4,814	4,814	4,814	4,814
electrode	0	4,038	12,114	16,152	16,152	16,152	16,152	16,152	16,152	16,152
Other consumables, miscellaneous production costs	0	795	2,384	3,179	3,179	3,179	3,179	3,179	3,179	3,179
total electricity	0	5,115	15,344	20,459	20,459	20,459	20,459	20,459	21,738	23,016
maintenance - spare parts	0	1,373	4,120	5,494	5,494	5,494	5,494	5,494	5,494	5,494
Total Resources, Consumables & Materials	**0**	**16,609**	**49,827**	**66,436**	**66,436**	**66,436**	**66,436**	**66,436**	**67,715**	**68,993**
Total Production related Labour exenses	**1,033**	**4,132**	**8,263**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**
Depreciation	**0**	**3,710**	**11,129**	**14,839**	**14,839**	**14,839**	**14,839**	**14,839**	**14,839**	**14,839**
Gross Profit	**-1,033**	**11,682**	**39,176**	**52,924**	**52,924**	**52,924**	**52,924**	**52,924**	**51,645**	**50,366**
Gross margin	0%	32%	36%	37%	37%	37%	37%	37%	36%	35%
Operating Expenditures	**9,965**	**11,178**	**13,611**	**5,229**	**5,229**	**5,229**	**5,229**	**5,229**	**5,203**	**5,178**
EBIT	**-10,998**	**503**	**25,566**	**47,695**	**47,695**	**47,695**	**47,695**	**47,695**	**46,442**	**45,189**
EBIT margin	n/a	1.4%	23.6%	33.0%	33.0%	33.0%	33.0%	33.0%	32.1%	31.3%
EBT	**-16,298**	**-10,097**	**12,315**	**35,194**	**35,994**	**36,849**	**37,762**	**38,737**	**38,526**	**38,385**
Corporate Tax	**0**	**0**	**515**	**9,326**	**9,538**	**9,765**	**10,007**	**10,265**	**10,209**	**10,172**
Net Profit	**-16,298**	**-10,097**	**11,800**	**25,867**	**26,456**	**27,084**	**27,755**	**28,472**	**28,316**	**28,213**

source: Viridis.iQ GmbH estimates

Appendix V: Integrated Financial Model P&L (Years 11-20) – Steady-state base-case

CME's integrated project P&L estimate	Years 11-20 after project initiation									
Thousand USD	11	12	13	14	15	16	17	18	19	20
Revenue	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**	**144,528**
COGS	**95,440**	**96,719**	**89,200**	**89,200**	**89,200**	**89,200**	**89,200**	**89,200**	**89,200**	**89,200**
quartzite (SiO2)	4,897	4,897	4,897	4,897	4,897	4,897	4,897	4,897	4,897	4,897
carbon reductant	11,442	11,442	11,442	11,442	11,442	11,442	11,442	11,442	11,442	11,442
woodchips	4,814	4,814	4,814	4,814	4,814	4,814	4,814	4,814	4,814	4,814
electrode	16,152	16,152	16,152	16,152	16,152	16,152	16,152	16,152	16,152	16,152
Other consumables, miscellaneous production costs	3,179	3,179	3,179	3,179	3,179	3,179	3,179	3,179	3,179	3,179
total electricity	24,295	25,574	25,574	25,574	25,574	25,574	25,574	25,574	25,574	25,574
maintenance - spare parts	5,494	5,494	5,494	5,494	5,494	5,494	5,494	5,494	5,494	5,494
Total Resources, Consumables & Materials	**70,272**	**71,551**	**71,551**	**71,551**	**71,551**	**71,551**	**71,551**	**71,551**	**71,551**	**71,551**
Total Production related Labour exenses	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**	**10,329**
Depreciation	**14,839**	**14,839**	**7,320**	**7,320**	**7,320**	**7,320**	**7,320**	**7,320**	**7,320**	**7,320**
Gross Profit	**49,088**	**47,809**	**55,328**	**55,328**	**55,328**	**55,328**	**55,328**	**55,328**	**55,328**	**55,328**
Gross margin	34%	33%	38%	38%	38%	38%	38%	38%	38%	38%
Operating Expenditures	**5,152**	**5,126**	**5,278**	**5,278**	**5,278**	**5,278**	**5,278**	**5,278**	**5,278**	**5,278**
EBIT	**43,936**	**42,683**	**50,050**	**50,050**	**50,050**	**50,050**	**50,050**	**50,050**	**50,050**	**50,050**
EBIT margin	30.4%	29.5%	34.6%	34.6%	34.6%	34.6%	34.6%	34.6%	34.6%	34.6%
EBT	**38,320**	**38,335**	**47,058**	**48,505**	**50,050**	**50,050**	**50,050**	**50,050**	**50,050**	**50,050**
Corporate Tax	**10,155**	**10,159**	**12,470**	**12,854**	**13,263**	**13,263**	**13,263**	**13,263**	**13,263**	**13,263**
Net Profit	**28,165**	**28,176**	**34,588**	**35,651**	**36,787**	**36,787**	**36,787**	**36,787**	**36,787**	**36,787**

source: Viridis.iQ GmbH estimates

Appendix VI: Integrated Financial Model BS (Years 1-10) – Steady-state base-case

CME's integrated project BS estimate Years 1-10 after project initiation										
Balance Sheet	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Assets										
Property, plant & facility - BV	43,061	120,570	172,243	172,243	172,243	172,243	172,243	172,243	172,243	172,243
Depreciation - cumulated	0	2,153	8,612	17,224	25,836	34,449	43,061	51,673	60,285	68,897
Net property, plant & facility	43,061	118,417	163,631	155,019	146,407	137,794	129,182	120,570	111,958	103,346
Equipment - BV	18,797	52,633	75,189	75,189	75,189	75,189	75,189	75,189	75,189	75,189
Depreciation - cumulated	0	1,880	7,519	15,038	22,557	30,076	37,595	45,114	52,633	60,152
Net asset value equipment	18,797	50,753	67,670	60,152	52,633	45,114	37,595	30,076	22,557	15,038
Net PP&E	**61,858**	**169,170**	**231,301**	**215,170**	**199,039**	**182,908**	**166,777**	**150,646**	**134,515**	**118,384**
Account Receivables	0	4,950	14,849	19,798	19,798	19,798	19,798	19,798	19,798	19,798
Inventories	0	6,929	20,788	27,718	27,718	27,718	27,718	27,718	27,718	27,718
Cash & cash equivalents	41,543	21,192	14,655	39,692	70,508	101,151	131,610	161,873	191,006	218,994
Total Assets	**103,401**	**202,241**	**281,593**	**302,378**	**317,063**	**331,575**	**345,903**	**360,035**	**373,037**	**384,893**
Equity	25,458	40,414	68,916	94,783	121,239	148,323	176,078	204,550	232,866	261,079
Long-term project debt	77,944	155,887	194,859	183,837	172,066	159,494	146,067	131,728	116,413	100,057
Accounts payable	0	5,940	17,819	23,758	23,758	23,758	23,758	23,758	23,758	23,758
Equity & Liabilities	**103,401**	**202,241**	**281,593**	**302,378**	**317,063**	**331,575**	**345,903**	**360,035**	**373,037**	**384,893**

source: Viridis.iQ GmbH estimates

Appendix VII: Integrated Financial Model BS (Years 11-20) – Steady-state base-case

CME's integrated project BS estimate Years 11-20 after project initiation										
Balance Sheet	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Assets										
Property, plant & facility - BV	172,243	172,243	172,243	172,243	172,243	172,243	172,243	172,243	172,243	172,243
Depreciation - cumulated	77,509	86,121	94,734	103,346	111,958	120,570	129,182	137,794	146,407	155,019
Net property, plant & facility	94,734	86,121	77,509	68,897	60,285	51,673	43,061	34,449	25,836	17,224
Equipment - BV	75,189	75,189	75,189	75,189	75,189	75,189	75,189	75,189	75,189	75,189
Depreciation - cumulated	67,670	75,189	75,189	75,189	75,189	75,189	75,189	75,189	75,189	75,189
Net asset value equipment	7,519	0	0	0	0	0	0	0	0	0
Net PP&E	**102,253**	**86,121**	**77,509**	**68,897**	**60,285**	**51,673**	**43,061**	**34,449**	**25,836**	**17,224**
Account Receivables	19,798	19,798	19,798	19,798	19,798	19,798	19,798	19,798	19,798	19,798
Inventories	27,718	27,718	27,718	27,718	27,718	27,718	27,718	27,718	27,718	27,718
Cash & cash equivalents	245,821	271,472	294,747	317,731	340,403	385,802	431,201	476,601	522,000	567,399
Total Assets	**395,590**	**405,110**	**419,772**	**434,144**	**448,204**	**484,991**	**521,778**	**558,565**	**595,352**	**632,139**
Equity	289,244	317,420	352,008	387,659	424,446	461,233	498,020	534,807	571,594	608,381
Long-term project debt	82,588	63,932	44,007	22,727	0	0	0	0	0	0
Accounts payable	23,758	23,758	23,758	23,758	23,758	23,758	23,758	23,758	23,758	23,758
Equity & Liabilities	**395,590**	**405,110**	**419,772**	**434,144**	**448,204**	**484,991**	**521,778**	**558,565**	**595,352**	**632,139**

source: Viridis.iQ GmbH estimates

Appendix VIII: Integrated Financial Model FCFF (Years 1-20) – Steady-state base-case

CME's integrated project BS estimate	Years 1-10 after project initiation									
FCFF	1	2	3	4	5	6	7	8	9	10
EBIT	-10,998	503	25,566	47,695	47,695	47,695	47,695	47,695	46,442	45,189
Depreciation & Amortization	0	4,033	12,098	16,131	16,131	16,131	16,131	16,131	16,131	16,131
EBITDA	-10,998	4,536	37,664	63,826	63,826	63,826	63,826	63,826	62,573	61,320
Normalized Tax	0	131	6,681	12,463	12,463	12,463	12,463	12,463	12,136	11,809
Invest in Working Capital	0	5,940	11,879	5,940	0	0	0	0	0	0
Operating Cashflow	-10,998	-1,535	19,104	45,423	51,362	51,362	51,362	51,362	50,437	49,511
Capital expenditures	61,858	111,345	74,230	-12,030						
FCFF	-72,856	-112,880	-55,126	57,453	51,362	51,362	51,362	51,362	50,437	49,511

CME's integrated project BS estimate	Years 11-20 after project initiation									
FCFF	11	12	13	14	15	16	17	18	19	20
EBIT	43,936	42,683	50,050	50,050	50,050	50,050	50,050	50,050	50,050	50,050
Depreciation & Amortization	16,131	16,131	8,612	8,612	8,612	8,612	8,612	8,612	8,612	8,612
EBITDA	60,067	58,814	58,663	58,663	58,663	58,663	58,663	58,663	58,663	58,663
Normalized Tax	11,481	11,154	13,079	13,079	13,079	13,079	13,079	13,079	13,079	13,079
Invest in Working Capital	0	0	0	0	0	0	0	0	0	0
Operating Cashflow	48,586	47,660	45,584	45,584	45,584	45,584	45,584	45,584	45,584	45,584
Capital expenditures										
FCFF	48,586	47,660	45,584	45,584	45,584	45,584	45,584	45,584	45,584	45,584

source: Viridis.iQ GmbH estimates

Appendix IX: Tax Model – Steady-state base-case

CME's integrated project BS estimate	Years 1-10 after project initiation									
	1	2	3	4	5	6	7	8	9	10
EBT	-16,298	-10,097	12,315	35,194	35,994	36,849	37,762	38,737	38,526	38,385
depreciation	0	3,710	11,129	14,839	14,839	14,839	14,839	14,839	14,839	14,839
EBTD	-16,298	-6,387	23,445	50,033	50,833	51,688	52,601	53,576	53,365	53,224
Federal Tax @ 15%	0	0	292	5,279	5,399	5,527	5,664	5,811	5,779	5,758
Province Tax @ 11.5%	0	0	224	4,047	4,139	4,238	4,343	4,455	4,430	4,414
Effective Tax	**0**	**0**	**515**	**9,326**	**9,538**	**9,765**	**10,007**	**10,265**	**10,209**	**10,172**
effective tax rate	0.0%	0.0%	4.2%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%

CME's integrated project BS estimate	Years 11-20 after project initiation									
	11	12	13	14	15	16	17	18	19	20
EBT	38,320	38,335	47,058	48,505	50,050	50,050	50,050	50,050	50,050	50,050
depreciation	14,839	14,839	7,320	7,320	7,320	7,320	7,320	7,320	7,320	7,320
EBTD	53,159	53,175	54,378	55,825	57,371	57,371	57,371	57,371	57,371	57,371
Federal Tax @ 15%	5,748	5,750	7,059	7,276	7,508	7,508	7,508	7,508	7,508	7,508
Province Tax @ 11.5%	4,407	4,409	5,412	5,578	5,756	5,756	5,756	5,756	5,756	5,756
Effective Tax	**10,155**	**10,159**	**12,470**	**12,854**	**13,263**	**13,263**	**13,263**	**13,263**	**13,263**	**13,263**
effective tax rate	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%	26.5%

source: Viridis.iQ GmbH estimate

Appendix X: Results of Supply-Chain-Analysis

Supplier	Shipping Location	Conformity to Specifications	Shipment Tonnage	Shipment Frequency	Shipping Cost	Indicative Price
Quartzite for FeSi						
Langis quarry	St.-Vianney, QC	Good for FeSi, not for mgSi at 100%	25	16/day	USD 2.5	USD 20.1/t delivered
Quartzite for mgSi						
Reliance Mining	Alexandria, Egypt	Good. Low Fe and Ti for mg-Si blend	25,000	2 - 3/year		USD 110/t CFR Montreal
Elmore Sand and Gravel	Alabama, USA	Good. Low Fe and Ti for mg-Si blend				USD 44/t FOB plant
Blackburn Quartz (now Polycor)	Fermont, QC	Good. 92% therm. stab. by SKW test			TBD	CAD 45/t FOB plant
Sitec Quartz	Saint-Urbain, QC		Not contacted, reportedly owned by Globe; known to supply Globe/Bécancour and Elkem/Chicoutimi			
Imerys Ceramics		Good. QDD, QDM & QSL grades for mg-Si blend	Not contacted			
Unimin			Oriented to silica sand, not lump; contacted through website, no reply			
Midatlantic Minerals		Good, but unknown therm. stability	Trading company, not contacted for this material			
Fairmont/Forestville	Québec	Fe and Ti too high for mg-Si blend	N/A due to high iron and titanium content			
Alabama Sand and Gravel	Alabama, USA	Low Fe and Ti for mg-Si blend	Not contacted, owned by Globe			
Shabogamo Mining	Labrador	Fe may be slightly higher than desired	Not contacted, reportedly owned by Ferroatlantica; known to supply Globe/Bécancour			
Atlantic Silica	New Brunswick		Not contacted, appears they only supply sand and aquarium gravel			
Canadian Silica (Laprarie Group)	Alberta		Not contacted, appears they only supply sand and road-construction aggregates			

Supplier	Shipping Location	Conformity to Specifications	Shipment Tonnage	Shipment Frequency	Shipping Cost	Indicative Price
Heemskirk Canada	BC		Not contacted, only supply sand			
Coal for FeSi						
Carbon Partners (Elkhorn seam)	Toledo, OH, USA	Higher fixed carbon than FeSilero, but TiO_2 slightly high			USD 28/t	USD 187/t CIF Matane
Carbon Partners (FeSilero coal processed by ENERCO)	ARA	Best, TiO_2 OK	9,000 to 20,000	Adjustable	USD 20 to 30/t	USD 140 - 150/t CIF Matane
Patmond Energy	Baranquilla, Colombia	TiO_2 higher than desired	6,000 12,000	4 - 5 per year 2 - 3 per year		USD 144/t USD 129/t CFR Québec
Novadx Ventures			Not contacted			
ThyssenKrupp			Not contacted			
Coal for mgSi						
Carbon Partners (CPI low ash)	Toledo, OH, USA	TiO_2 and SO_3 higher than desired			USD 28/t	USD 243/t CIF Matane
Carbon Partners (CPI low ash, low B)	Toledo, OH, USA	TiO_2 and SO_3 higher than desired			USD 28/t	USD 259/t CIF Matane
Carbon Partners (Silero)	ARA	Best, TiO_2 and SO_3 OK	9,000 to 20,000	Adjustable	USD 20 to 30/t	USD 185 - 195/t CIF Matane
Patmond Energy (Venezuelan)	Belefast, No. Ireland	TiO_2 and SO_3 higher than desired	6,000 12,000	4 - 5 per year 2 - 3 per year		USD 182/t USD 170/t CFR Québec
Patmond Energy (Columbian)	Belefast, No. Ireland	TiO_2 and SO_3 higher than desired	6,000 12,000	4 - 5 per year 2 - 3 per year		USD 182/t USD 170/t CFR Québec
Novadx Ventures			Not contacted			
ThyssenKrupp			Not contacted			

Supplier	Shipping Location	Conformity to Specifications	Shipment Tonnage	Shipment Frequency	Shipping Cost	Indicative Price
Charcoal for mgSi and FeSi						
Norsilva (Grade W)	South East Asia	TBD	10 minimum of 40 FT HC containers	TBD	~40% of indicated price	USD 500/t CIP Montreal
Norsilva (Grade C)	South East Asia	TBD	10 minimum of 40 FT HC containers	TBD	~40% of indicated price	USD 475/t CIP Montreal
Norsilva (Grade M)	Brazil	TBD	10 minimum of 40 FT HC containers	TBD	~40% of indicated price	USD 590/t CIP Montreal
Chabon Engineering	ARA		Not contacted			
Green Petroleum Coke for FeSi (less desirable alternative to coal)						
Carbon Partners	ARA	1.5 - 2.5% SO_3	9,000 - 20,000	2 - 3 per year	USD 20 - 30	USD 220 - 230/t CIF Matane
Carbon Partners	ARA	4 - 5% SO_3	9,000 - 20,000	2 - 3 per year	USD 20 - 30	USD 160 - 170/t CIF Matane
Petroleum Coke Industries Co.	Kuwait	May only supply calcined coke	No reply to 2 inquires			
Kuwait Petroleum Corp.	Kuwait		Not contacted			
Oxbow Corp.			Not contacted			
Koch Carbon			Not contacted			
Hematite for FeSi						
LKAB Minerals	Narvik, Sweden	Good, pelletized	9000	Once/year	USD 30/t	USD 90/t FOB Narvik
Mimetex	Australia					USD 110/t FOB
Various	Mexico					USD 40 – 60/t FOB

Supplier	Shipping Location	Conformity to Specifications	Shipment Tonnage	Shipment Frequency	Shipping Cost	Indicative Price
Gindalbie Metals	Australia		Not contacted			
Tata Steel			Requested, no reply			
Scrap Steel or Mill Scale						
Iron Mike (scrap)	Detroit, USA	N/A				USD 30 – 70/t FOB
American Metal Market price (scrap)	Pittsburgh or Detroit, USA	N/A				USD 265 – 280/t local delivery
Ecoex Recycling (scrap)	Montreal		Requested 2 times, no reply			
ArcelorMittal			Not contacted			
QIT (Rio Tinto)			Not contacted			
Limestone for mgSi and FeSi						
Midatlantic Minerals (trading co.)	Québec City	MgO slightly high	TBD	TBD	CAD 35/t by truck	CAD 60/t delivered
Graymont			Requested, no reply			
Unimin			Only supply lime (CaO) and quicklime ($Ca(OH)_2$), not limestone ($CaCO_3$)			
Lydford Mining Co.	Jamaica	Not verified	Not contacted due to location			
Stevin Rock	UAE	Good	Not contacted due to location			
Prebaked Electrodes for mgSi (1320mm/52-inch)						
SGL Group	Germany	Good				USD 2,850/t CIP Matane
Elkem Carbon (Carboindustrial)	Brazil	1146mm/45-inch is largest diameter	N/A			
Energoprom Group	Russia	Poor, high ash and 1272mm/50-inch is largest diameter	N/A			

Supplier	Shipping Location	Conformity to Specifications	Shipment Tonnage	Shipment Frequency	Shipping Cost	Indicative Price
Søderberg Electrode Paste for FeSi						
Rheinfelden Carbon (ELPA 50)	Rheinfelden, Germany	Sulfur slightly high, otherwise good	22 t/container	82 containers/y	EUR 114/t	EUR 654/t
Rheinfelden Carbon (ELPA 30)	Rheinfelden, Germany	Sulfur and ash high, flexural strength low	22 t/container	82 containers/y	EUR 114/t	EUR 604 - 614/t
Elkem Carbon	Various	Type S: flexural strength low				USD 850 CIP Montreal
Elkem Carbon	Various	Type TSR: flexural strength low				USD 850 CIP Montreal
Wood Chips for FeSi and mgSi						
Groupe Lebel	¾-hour drive from Matane	Unknown	15.8	3,800/year	CAD 17.50/t	CAD 117.50/t delivered
Groupe GDS	Sawmills	Unknown	15.8	3,800/year		CAD 90 - 100/t FOB sawmill
Groupe GDS	Matane chipper	Unknown	15.8	3,800/year		CAD 150 - 160/t FOB chipper
Norsilva	Norway		No longer supply wood chips			
Angel Coal Carriers	So. Africa		Not contacted due to location			
Wood Logs for FeSi and mgSi						
Tracy Exports	Illinois, USA		Only premium furniture-grade logs available			
Angel Coal Carriers	So. Africa		Not contacted due to location			

Appendix XI: QP Statements

Date and Signature Page and Certificate of Qualification

Certificate of Qualified Person

I, Etienne Forbes, B. Sc., do hereby certify that:

a) I am a geologist and president of Geoforbes Services Inc., whose place of business is located at 56, du Rosaire street PO BOX 338, Lac-Au-Saumon, Province of Quebec), G0J 1M0;

b) I am the qualified person for the preparation of Sections 11 & 12 of the technical report entitled "*NI 43-101 Technical Report pertaining to: Langis Property, Matapedia area, Quebec, NTS 22B/11 Prepared for Canadian Metals Inc*."dated January 26, 2016 and revised March 21, 2016;

c) I also revised chapters 11 & 12 of the technical report entitled "NI 43-101 Preliminary Economic Assessment on the Langis Silica Deposit and a Metallurgical Silicon Processing Plant in the Matapedia Region, Province of Québec, Canada" dated April 11, 2016 and confirm that these chapters are or include representative excerpts from the report mentioned above in b);

d) I am a graduate from the *Université du Québec à Montréal (UQAM)* with a B. Sc. in geology in 1994.I am a Professional in Geology and registered member of the Ordre des Géologues du Québec (OGQ), permit number 611;

e) I was involved in exploration work on the property since 2013 having the responsibility to oversee the two diamond drill programs as an independent contractor for Genivar (2013) and Canadian Metals Inc. (2015). As co-author, I reviewed various issues related to the property with co-author Alain Tremblay P. Eng. I visited the Langis Property numerous times since 2013;

f) I am independent of the issuer in accordance with Section 1.5 of National Instrument 43-101, Standard of Disclosure for Mineral Projects;

g) I have read the definition of «qualified person» as defined in National Instrument 43-101 («NI 43-101») and certify that by reason of my education, affiliation with a professional association and past relevant work experience, I fulfill the requirements to be a qualified person for the purposes of National Instrument 43-101;

h) I have read the National Instrument 43-101 and Form 43-101F1, and the Technical Report has been prepared in compliance with that instrument and form.

i) As at April 18, 2016, to the best of my knowledge, information and belief, the Technical Report contains all the scientific and technical information that is required to be disclosed to make the Technical Report not misleading.

Signed this 18th day of April, 2016.

____

Etienne Forbes, P. Geo.

BIOFILIA CONSULTANTS EN ENVIRONNEMENT | 20 ANS | AU SERVICE DU DÉVELOPPEMENT DURABLE DE VOS PROJETS

Date and Signature Page and Certificate of Qualification

Certificate of Qualified Person

I, Caroline Lachance, Engineer, of Victoriaville, Quebec do hereby certify:

a) I am an independent engineer with the consulting firm, Biofilia, located at 595 rue Principale, Laval, Québec, H7X 1C7.

b) This certificate applies to the technical report entitled: NI 43-101 Technical Report on the Preliminary Economic Assessment (PEA) for a Vertically Integrated Hybrid Ferrosilicon and Metallurgical Silicon Plant, Province of Quebec, Canada Report (the "Technical Report").

c) I am a graduate of Chemical Engineering from Université Laval, Québec (1988) and master degree in Environmental Management from Université de Sherbrooke, Québec (2011). In addition I have taken specialist training in environmental site assessment and auditing from Université de Sherbrooke in 2003.

d) I am a member in good standing of Ordre des ingénieurs du Québec (OIQ #099587). I have over 20 years of experience in the field of environmental management and studies in industrial process. My relevant experience is environmental management and monitoring programs, auditing, site assessment and management of multidisciplinary environmental investigations that includes years in metallurgical and mining studies. I am a "Qualified Person" for the purposes of National Instrument 43-101 (the "Instrument").

e) I have not visited the study site.

f) I am responsible for the completed "Section 20 Environmental considerations" of the of the technical report entitled "NI 43-101 Preliminary Economic Assessment on the Langis Silica Deposit and a Metallurgical Silicon Processing Plant in the Matapedia Region, Province of Québec, Canada" dated April 11, 2016 and part of Section 1 and 25 (Section 1.8 Summary – Environmental and Social and, Section 25.5 Interpretation and conclusion–Environmental and social considerations).

g) I am independent of Canadian Metals Inc. as defined by Section 1.5 of the Instrument.

h) I have no prior involvement with Canadian Metals and the Property that is the subject of the Technical Report.

i) I have read the Instrument and the section of the Technical Report that I am responsible for has been prepared in compliance with the Instrument.

j) As of the date of this certificate, to the best of my knowledge, information, and belief, the section of the Technical Report that I am responsible for contains all scientific and technical information that is required to be disclosed to make the Technical Report not misleading.

Signed and dated this 18th day of April, 2016 in Victoriaville, Quebec.

Caroline Lachance

Caroline Lachance, ing. M. Env.

Date and Signature Page and Certificate of Qualification

Certificate of Qualified Person

I, Alain Tremblay, B.A.Sc., do hereby certify that:

a) I am a geological engineer working for 2419-1538 Quebec Inc., a company otherwise known as Consultations Géo-Logic, whose place of business is located at 1032 De Fontenay-le-Comte, Quebec City, Province of Quebec, G1Y 2Y1;

b) I am the qualified person for the preparation of Sections 1-10 and 13-27 of the technical report entitled "NI 43-101 Technical Report pertaining to: Langis Property, Matapedia area, Quebec, NTS 22B/11 Prepared for Canadian Metals Inc." dated January 26, 2016 and revised March 21, 2016.

c) I also revised chapters 1, 4-10, 14, 15, 25 and 26 of the Viridis 43-101 of the technical report entitled "NI 43-101 Preliminary Economic Assessment on the Langis Silica Deposit and a Metallurgical Silicon Processing Plant in the Matapedia Region, Province of Québec, Canada" dated April 11, 2016 and confirm that these chapters are or include representative excerpts from the report mentioned above in b).

d) I graduated with a B.A.Sc. degree in geological engineering from École Polytechnique in Montréal in 1979. I am a member in good standing of the Ordre des Ingénieurs du Québec, No. 33996. From graduation until 1994, I worked for public, para-public and public companies and the government in the field of mining exploration. During that time, I conducted or supervised geological studies and exploration programs for gold, base metals and industrial minerals in all geological provinces of the province of Quebec. I founded 2419-1538 Quebec Inc. in 1994 and have since acted as President of the company, which offers geological services for the exploration and development of mining properties.

e) I was not involved in previous exploration work on this property. As co-author, I reviewed the historical data for the property and adjacent areas and discussed various issues related to the property with co-author Étienne Forbes, P. Geo. I did not visit the property recently.

f) I am independent of the issuer in accordance with Section 1.5 of National Instrument 43-101, Standards of Disclosure for Mineral Projects;

g) I have read the definition of "qualified person" set out in National Instrument 43-101 and certify that by reason of my education, affiliation with a professional association (as defined in National Instrument 43-101) and past relevant work experience, I fulfill the requirements to be a "qualified person" for the purposes of National Instrument 43-101;

h) I have read the National Instrument 43-101 and Form 43-101F1, and the Technical Report has been prepared in compliance with that Instrument and Form;

i) As at April 18, 2016, to the best of my knowledge, information and belief, the Technical Report contains all the scientific and technical information that is required to be disclosed to make the Technical Report not misleading.

Signed this 18th day of April, 2016.

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Alain Tremblay, Geol.Eng, OIQ 33996

Date and Signature Page and Certificate of Qualification

Certificate of Qualified Person

I, Valdiney Domingos de Oliveira, M.Sc. Eng., MBA, CEng. do hereby certify that:

a) I have earned the Bachelor degree in Chemical Engineering from "Universidade Federal de Uberlandia", dipl. engineer in 2002. I have also earned the post-graduation degree in Metallurgical Engineering from Universidade Federal de Minas Gerais, Master in 2010. I am a member in good standing of the Chemical Engineering Council (CRQ MG) in Brazil, No. 02301646.

b) I am in good standing professional registered member of the SME – Society for Mining, Metallurgy & Exploration, N.04220598 in Englewood, CO, US. I am also Professional Member in good standing with the status of Chartered Engineering (Professional Member) at the Engineering Council, under the registration N. 63074 in the Institute of Materials, Minerals and Mining (IOM3).

c) I am member of the Canadian Institute of Mining, Metallurgy and Petroleum and also member of the Intelligence and Technology in Mining, N.18862.

d) I am Director of Metallurgy and Engineering at Viridis.iQ GmbH, a German engineering, consulting and technology firm with unique expertise on every step of the silicon based value chain including metallurgical silicon, polysilicon, ingoting, wafering, solar cell and modules, whose place of business is located at Moltkestraße 2-4, Telekom Tower, 78467 Konstanz, Baden Württemberg, Germany.

e) I am the qualified person for the preparation of Sections 17 and 18 of the technical report entitled "NI 43-101 Preliminary Economic Assessment on the Langis Silica Deposit and a Metallurgical Silicon Processing Plant in the Matapedia Region, Province of Québec, Canada" dated April 11, 2016.

f) As Qualified Person of this report, I also revised the chapters 1 to 3, 16, 19 and 21 to 26 of the same report entitled "NI 43-101 Preliminary Economic Assessment on the Langis Silica Deposit and a Metallurgical Silicon Processing Plant in the Matapedia Region, Province of Québec, Canada" dated April 11, 2016, and confirm these chapters are under the norm standards as PEA NI 43-101, applicable disclaimer for specific observations in the review are presented in the sub-chapters 1.9.1 and 21.4.1 in the footnotes 2, 42 and 43.

g) From graduation until today, I worked for private companies in the field of Metallurgy of Silicon, project development in the Ferroalloys area and process design for the very same kind of industry related to this project. I also worked for Brazilian government, teaching classes for engineering and chemistry graduations and post-graduation in the field of Unit Operations, Clean Technologies and Industrial Processes, including laboratory classes.

h) I was not involved in previous exploration work on this property. I reviewed the historical data for the property and adjacent areas and discussed various issues related to the property. I did not visit the property.

i) I am independent of the issuer in accordance with Section 1.5 of National Instrument 43-101, Standards of Disclosure for Mineral Projects;

j) I have read the definition of "qualified person" set out in National Instrument 43-101 ("NI 43-101") and certify that by reason of my education background, past relevant work experience and affiliation with a professional association (as defined in NI 43-101 and mentioned in the Annex 1 of the Form NI 43-101F), I fulfill the requirements to be a qualified person for the purposes of NI 43-101.

k) As at April 18, 2016, to the best of my knowledge, information and belief, the Technical Report contains all the scientific and technical information that is required to be disclosed to make the Technical Report not misleading.

Signed this 18th day of April, 2016.

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Valdiney Domingos de Oliveira
M.Sc. Dipl. Eng., MBA CEng.63074

Chartered Engineer

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