


MUNDRA SOLAR LIMITED (MSL)

20000 MT Polysilicon plant in

Mundra, Gujarat


Prefeasibility Report

8th April 2016


	Mundra Solar Limited (MSL)
	20000MT Polysilicon plant

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Acronyms

AGEL	Adani Green Energy Ltd
AHU	Air Handling Unit
APPL	Adani Properties Private Limited
CVD	Chemical Vapour Deposition
c-Si	Crystalline Silicon
DeitY	Department of Electronics and Information Technology
ESDM	Electronics System Design and Manufacturing
FY	Fiscal Year
GOI	Government of India
HDPE	High density poly ethylene
ISO	International Standard Organization
JNNSM	Jawaharlal Nehru Solar Mission
JV	Joint Venture
KL	Kilo litre
Klph	Kiloliter per hour
M-SIPS	Modified Special Incentive Package Scheme
MSL	Mundra Solar Limited
MWp	Megawatt peak
NMP	National Manufacturing Policy
NPE	National Policy on Electronics
NSM	National Solar Mission
PID	Potential induced degradation
PV	Photovoltaic
SEZ	Special Economic Zone
WTO	World Trade Organization

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1. Executive Summary

1.1. Introduction


The Indian **Electronics System Design and Manufacturing (ESDM)** Industry is amongst the fastest growing sector driven by consistent increase in domestic demand of electronic products. The Indian Government has introduced several transparent and investment friendly policies to foster the growth of the Indian ESDM ecosystem that include **National Policy on Electronics (NPE)**; **National Manufacturing Policy (NMP)**; **Modified Special Incentive Package Scheme (M-SIPS)**; **Electronic Manufacturing Clusters (EMCs)** to promote investment in manufacturing sector.

The EMC scheme has been notified on October 22nd 2012, to develop infrastructure in the **Electronics Systems Design and Manufacturing (ESDM) Sector**. The Government is offering a package of incentives to attract domestic and global investments into the ESDM sector within EMCs along with financial support for the development of infrastructure of EMCs.

M-SIPS notified on **27th July 2012** is one more initiative to attract investment in new Electronics Systems Design and Manufacturing (ESDM) units and expansion of capacity/modernization and diversification of existing ESDM Units. The incentives under M-SIPS will be available for those units coming up within **Electronics Manufacturing Clusters (EMCs)** as notified by **Department of Electronics and Information Technology (DeitY)**.


1.2. Profile of Chief Promoters

- **Adani Enterprises Limited (AEL)** is a diversified conglomerate into coal mining and trading, which was listed in 1994. AEL over the years has transformed itself from a pure commodity player to a value enhancer with emphasis on asset creation for long-term sustainability. AEL on its own is the leading player in imported coal trading business in the country. AEL has more than two decades of experience in global trading with established business relationships with the global players. Currently, AEL is the largest importer of coal in India.
- AEL has leveraged on its star trading house experience and execution record of building mega projects to embark on an asset-backed diversification plan to exploit opportunities in infrastructure sector.
- AEL has been designated as Category I power trader (Highest Category in Power Trading Licenses) by CERC till June 9, 2029. AEL's power trading business involves making purchases of surplus power and selling this surplus to energy deficit electricity boards.
- **Adani Properties Private Limited (APPL)** was incorporated on 25th May 1995 as a Private Limited Company. APPL is mainly engaged in the business of let-out and/or lease of immovable properties and wholesale trading of commodities.
- APPL is part of promoter and promoter group of all the listed/to be listed entities of Adani group and holds strategic investment into Adani Enterprises Limited, Adani Ports and SEZ Limited, Adani Power Limited and Adani Transmission Limited.
- APPL has also invested in unlisted group companies which are mainly engaged in Real Estate and Green Energy Business.

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1.3. Proposed Project background

- The project envisages setting up of “**20,000MT Polysilicon plant**” located within a notified Electronic Manufacturing Cluster (EMC) facility of Mundra SEZ under the M-SIPS guidelines. This project will be one of the first such facilities located within an EMC facility to be set up in a Special Economic Zone (SEZ).
- The proposed Solar PV Manufacturing Unit within EMC facility will be located within existing SEZ, and benefits from the following common infrastructure already in place:
 - Mundra SEZ is equipped with a multimodal connectivity which includes road, air, sea and rail linkages.
 - Mundra SEZ is equipped with well-developed social infrastructure facilities for residential, commercial, education, health, recreational and others. In addition to these, the area has special infrastructure services like effluent treatment plants, desalination plant, water treatment plants and others which are ready for use based on the required capacity.
- The proposed facility is located within an EMC facility of **640.89 acre** plot of land within the Mundra SEZ, about 60 KM from Bhuj airport and 65 KM from Kandla airport and well connected with State Highway No.6 and No.48, and National Highway 8A and NH 15 to key cities like Ahmedabad, Mumbai and Delhi.

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2. Project Introduction

2.1. Introduction

Adani Group, currently the largest player in the Private Power sector through **Adani Enterprises Limited (AEL)** and **Adani Properties private limited (APPL)** is planning to expand its operations into renewable energy resources.

- **Adani Properties Private Limited (APPL)** registered in, 1995 is held by Mr.Pranav Vinodbhai Adani, Mr.Kamal Daulal Moondra and registered in Ahmedabad, Gujarat, India.
- **Adani Green Energy Ltd (AGEL)** is a Public Company incorporated in 2015. Directors of Adani Green Energy Limited are Mr.Gautambhai Shantilal Adani, Mr.Rajeshbhai Shantilal Adani and Mr.Vneet S Jaain.

As part of this strategic plan, the Group plans to set up a State of the Art large-scale integrated manufacturing plant to produce polysilicon, crystalline silicon ingots and wafers, solar photovoltaic cells and modules in India through **Mundra Solar Limited (MSL)**, a company with its registered Office in the State of Gujarat, incorporated to undertake, identify, formulate, design, develop, regulate, restructure, re-organise, participate and/or assist in the designing, development, construction, implementation, commissioning, operation and maintenance of solar photovoltaic equipments.

2.2. Holding structure of Mundra Solar Limited

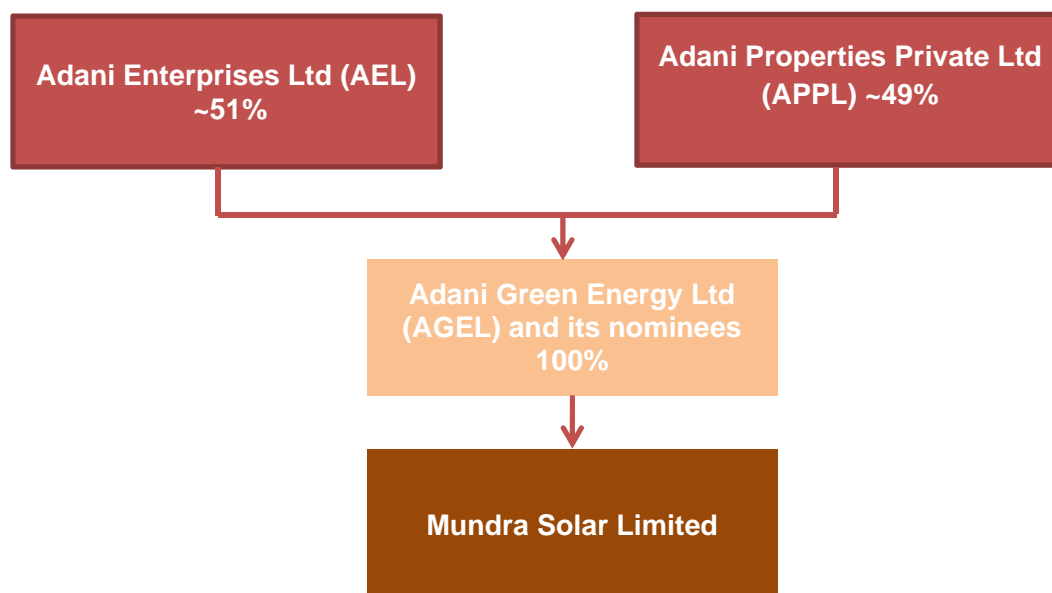



Figure 1: Holding structure of MSL

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2.3. Project rationale

- Gol has recently revised the national target for solar power from 20 GW to **100 GW, to be achieved by 2022**. This target triggers the demand for large scale manufacturing of Solar PV components. Prevailing demand supply gap in manufacturing capacity creates a case for investments in domestic solar equipment manufacturing across the value chain if the national level targets are to be achieved.

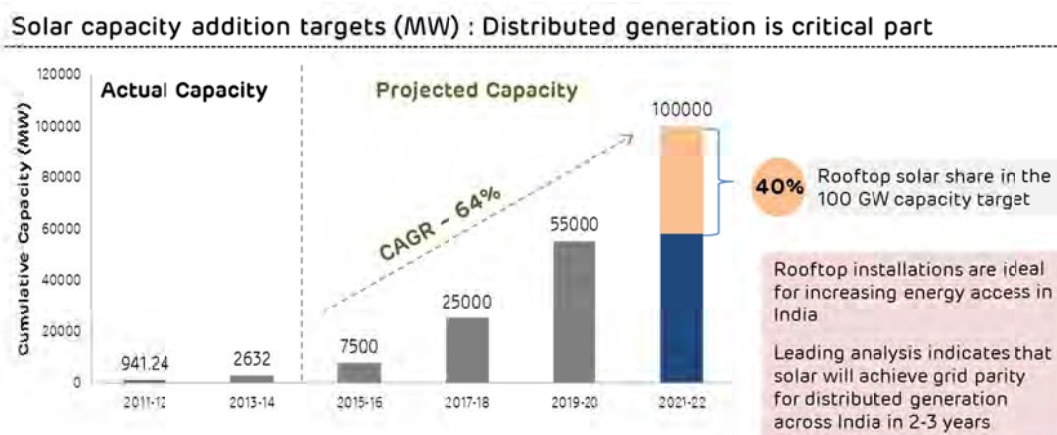


Figure 2. India's aggressive plans for solar generation


- Current installed capacity & Existing manufacturing capacities are extremely small & unintegrated, hence cannot support the desired Solar power generation targets. This implies that the country would need significant manufacturing capacities to meet above demand.

India's current Solar PV manufacturing capacity shortfall							
Projections in MW	FY16	FY17	FY18	FY19	FY20	FY21	FY22
Annual capacity projections	7,500	7,500	10,000	12,500	17,500	20,000	25,000
Cumulative installed capacity	-	15,000	25,000	37,500	55,000	75,000	100,000
Domestic production - cell manufacturing capacity	1,375	1,375	1,375	1,375	1,375	1,375	1,375
Shortfall in domestic capacity (Import dependency)	6,125	6,125	8,625	11,125	16,125	18,625	23,625

Current installed capacity & Existing manufacturing capacities are extremely small & unintegrated, hence cannot support the desired Solar power generation targets

Figure 3. India's current Solar PV manufacturing capacity shortfall

- Launch of **"Make in India"** augments decisions to focus on domestic manufacturing.

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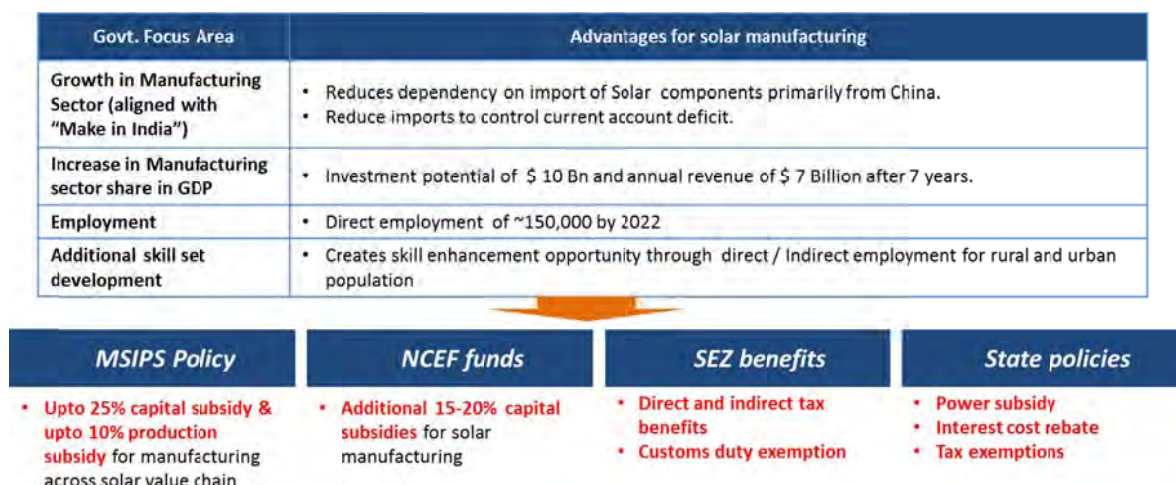


Figure 4. Policies promoting domestic manufacturing

- While poly silicon is the most critical raw material in the value chain, India does not have any polysilicon manufacturing capacity.



- Internationally, polysilicon supplies are concentrated in China and US and hence there is a strong case for manufacturing in India.



Figure 5. Polysilicon production : BNEF

- Given strong solar demand, the polysilicon consumption is expected to increase in future.

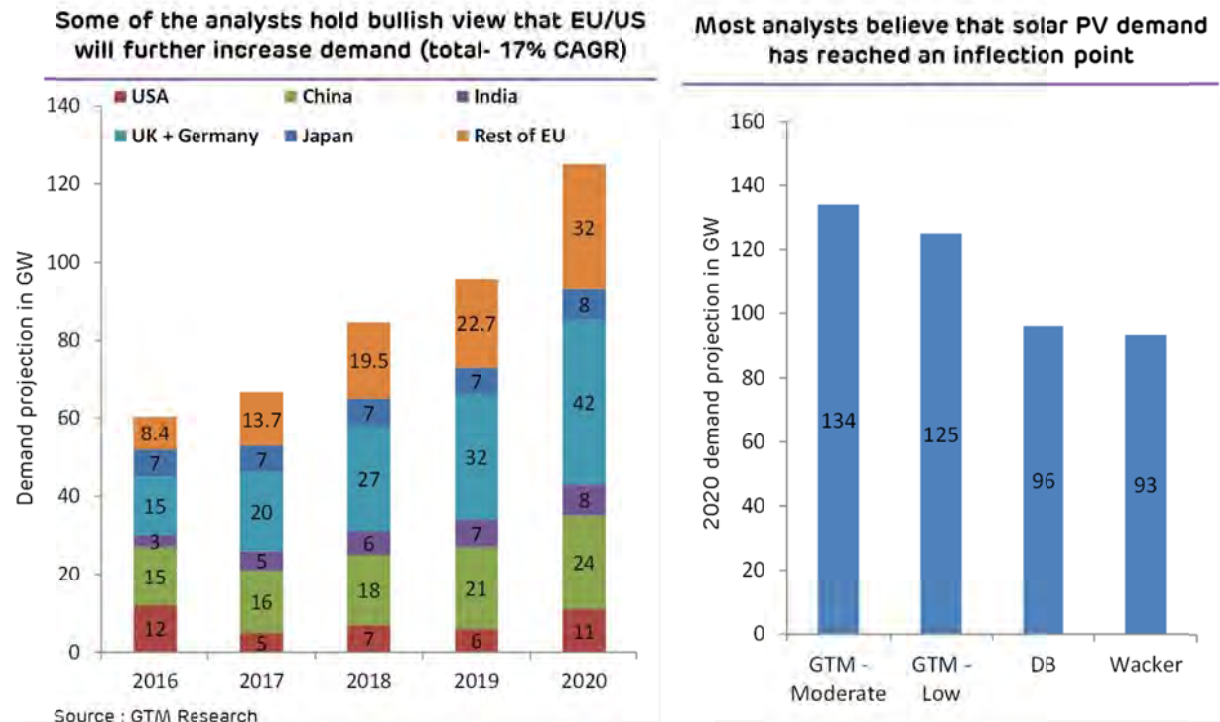


Figure 6. High PolySi / Solar demand expected

- While the global capacity addition scenario is expected to be weak.

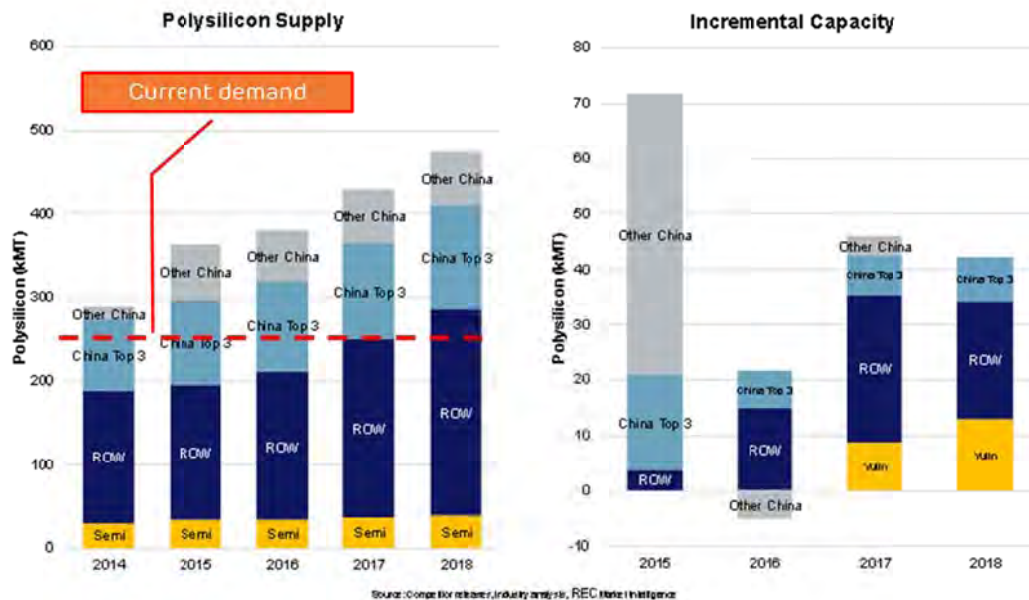



Figure 7. Projected weak supply

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2.4. Employment generation

Manpower planning is very essential for 20,000 MT polysilicon plant of MSL given the fact that it has to consist of right number of people, right kind of people at the right phase and execution of the project and during operations to achieve business goals. MSL's man power utilization rationale is based on the following approach.

- Analyse the current manpower inventory (industry) and make future forecasts based on the project phasing.
- Recruitment of best in the industry team for efficient management.
- Develop employment program for efficient use of resources.
- Design training programmes to enhance skills in line with the industry demands.

2.4.1. Manpower requirements

The manpower requirement includes a mix of Contractors, Engineer Staff and Workmen. The requirement proposed below is during the operation of plant after all the 3 phases are completely commissioned.

The estimation of staff during the operation of plant is based on 3 shifts of 8 hour each as follows

Table 1. Manpower planning -

Description	Polysilicon	Corporate
Contractors	300	-
Up -Front staff	600	-
Engineer staff	92	-
Management	40	46
Admin staff	62	6
Total	1094	52

3. Project Description: 20000 MTPA Polysilicon Facility

3.1. Advantages of the Proposed project location

The manufacturing facility is proposed to be set up in ~97 acre plot located within the EMC facility in Tunda Village (latitude 22° 48' 0.74" N and longitude 69° 31' 37" E) Kutch District, Gujarat. The manufacturing unit is easily accessible by road from NH-8A with extension between Gandhidham and Mandvi towns.

The approach road to EMC facility is through an extension of existing SEZ road (near ANUPAM project) by 1.2 KM approx. including 300m Length Bridge over intake channel. The proposed manufacturing unit will get connected to State Highway (SH-6) via 3.5 KM APSEZ road to SEZ Gate (GATE no. 3A) and continuing up to SH-6 over a distance of 3.6 KM. Further connectivity from SH-6 to NH-8a ext. via Mota Kandagra village over a distance of 7.5 KM exists.

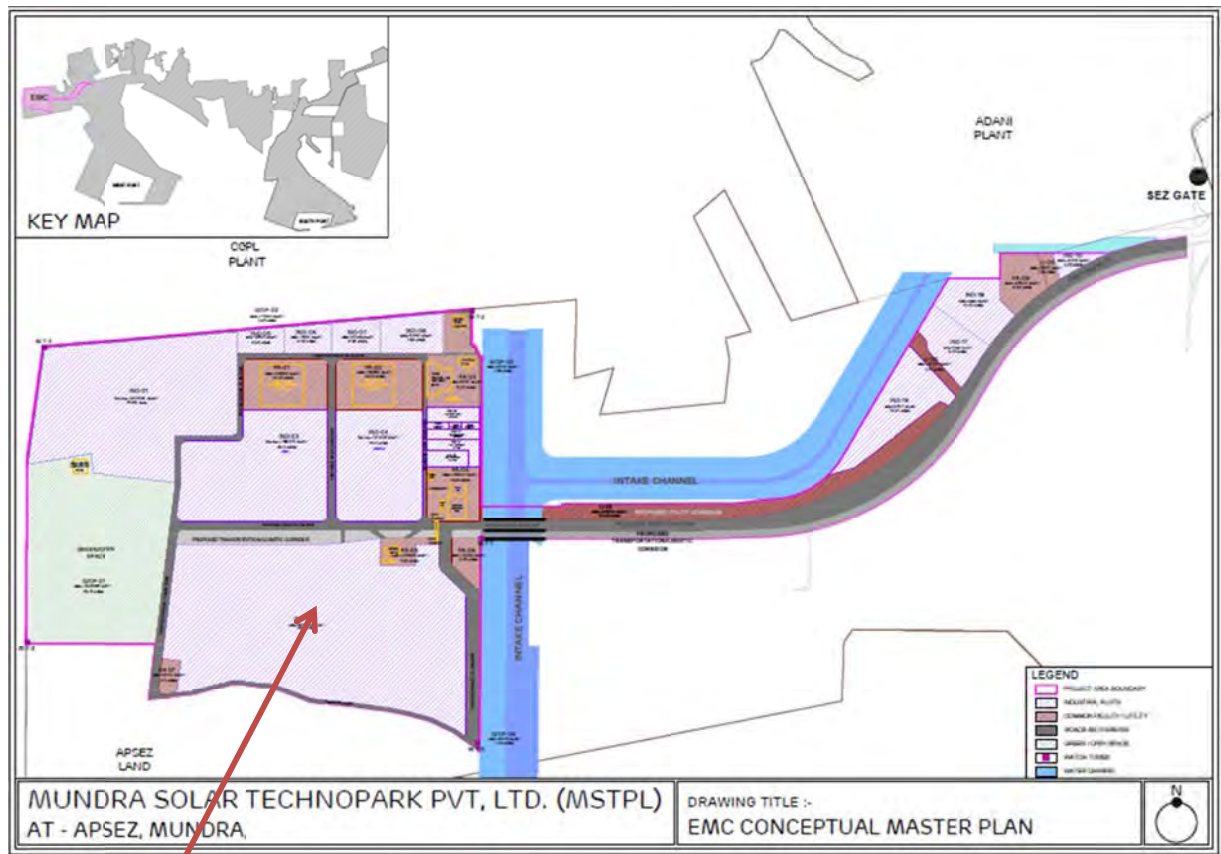



Figure 8 : Lay out of EMC facility

**Proposed location of MSL
20000 MT polysilicon plant**

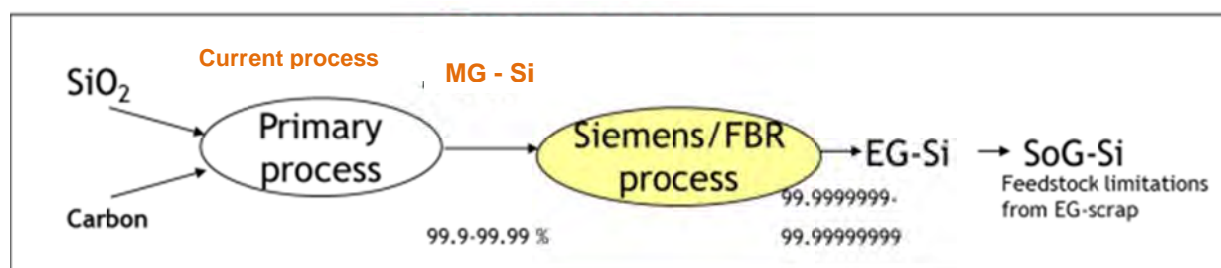
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3.2. Technology for Polysilicon Manufacturing

Polysilicon accounts for about a 30% of the cost of a finished solar panel. Approximately 90% of demand for polysilicon comes from solar PV industry. Polysilicon prices have been volatile earlier, until the construction of new plants in the recent times adding significant capacity supply to the market. Production requires large processing plants that may cost of up to INR 3.5 million per MT to build.

Before silicon rod/boule is cut into thin wafers, the raw material has to be purified, so as to make the “photo voltaic effect” efficient. The process of making low pure **metallurgical grade silicon** from basic raw material of quartz (sand) and carbon through a thermic reduction happens in a submerged arc furnace followed by production of **Chlorosilanes** (basic raw material) by reacting with HCl.

The final stage is **Chemical Vapor Deposition (CVD)** process, where chlorosilanes will be converted into pure silicon. Alternatively high pure Silane (SiH_4) gas is generated from TCS and then converted into high pure Si granules in **Fluid Bed Reactors (FBR)**.



With the patented process of Dynamit Noble expiring, there are few players who offer the package for Hydro chlorination and Siemens based CVD Process and FBR process in polysilicon manufacturing.

Table 2. Major technology players - Siemens and FBR process

	Technology Providers	Technology	Region
1	GTAT (GT Advanced Technologies)	Siemens Based CVD reactor	USA
2	Centrotherm SiTec	Siemens Based CVD reactor	Europe
3	Poly Silicon Technologies (PST)	Siemens Based CVD reactor	USA
4	SCC (Silicon Chemical Corporation) Wacker	Siemens Based CVD reactor	
5	Virasa Technolgies		USA
6	REC Silicon and	FBR	Norway
7	MEMC Silicon	FBR	Singapore


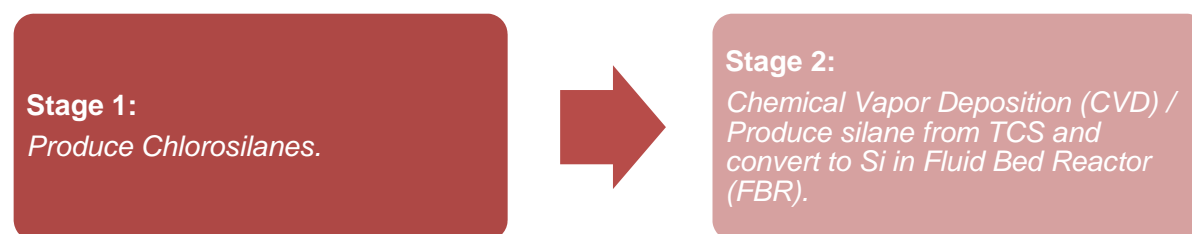
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Table 3. Major technology players in TCS manufacture and technology holders

	Technology Providers	Country of Origin
1	Wacker Chemie, GmbH	Germany
2	DOW Corning Corp.,	Michigan
3	Union Carbide,	Virginia
4	Dynarait Noble	(Later became Huls, Degussa and now Evonik)
5	Osaka Titanium	Japan
6	Chisso,	Japan
7	Shin Etsu Handotain	Japan

The proposed manufacturing process for silicon is done in two stages as shown below.



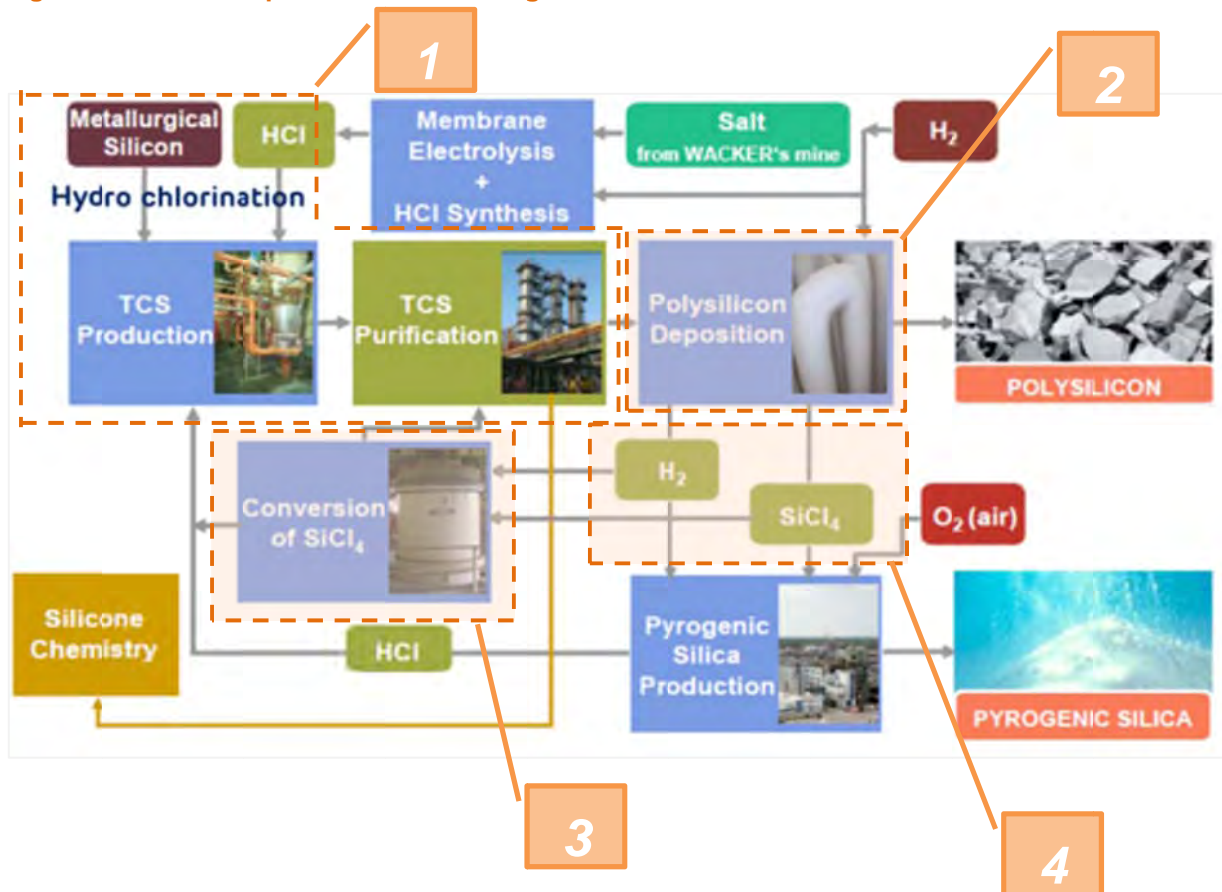
3.2.1. Stage 1. Production process of Chlorosilanes, Chemical Vapor Deposition

The starting material required for the CVD process is pure Chlorosilane (either silicon tetrachloride or trichlorosilane or a mixture of the two) and pure Hydrogen. The simplified chemical reaction with silicon tetrachloride as the source is as below.



For producing such a high purity silicon the starting materials themselves should be very pure. The Solar / Semiconductor grade poly crystalline silicon is obtained by the reduction of chlorosilanes with hydrogen in a chemical vapour deposition reactor. The reactor consists of electrical resistance, heated inverted U5 shaped thin rods, graphites or preferably silicon fixed to a base plate. The reactor is cooled with circulating DI water to keep the walls at the working temperature.

Figure 9. Production process and core stages identified




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Figure 10. Chemistry of various stages of high pure polysilicon production

Synthesis	$\text{Si}_{\text{mg}} + 3 \text{HCl} \rightarrow (\text{HSiCl}_3)_{\text{crude}} + \text{H}_2$
Distillation	$(\text{HSiCl}_3)_{\text{crude}} \rightarrow (\text{HSiCl}_3)_{\text{hyperpure}}$
Deposition	$4 (\text{HSiCl}_3)_{\text{hyperpure}} \rightarrow \text{Si}_{\text{hyperpure}} + 3 \text{SiCl}_4 + 2 \text{H}_2$
Conversion	$\text{SiCl}_4 + \text{H}_2 \rightarrow (\text{HSiCl}_3)_{\text{hyperpure}} + \text{HCl}$
Pyrolysis	$\text{SiCl}_4 + 2 \text{H}_2 + \text{O}_2 \rightarrow \text{SiO}_2 + 4 \text{HCl}$

4 key stages are identified as in **Figure 13** and discussed in the following sections.

3.2.2. Stage 2: Production and Purification stage

3.2.2.1. Production of Chlorosilane

Step 1: Production

Chlorosilanes are produced by direct reaction of Anhydrous Hydrogen chloride with Silicon metal of lesser purity levels (MG-Si grade) along with recycled Silicon tetrachloride for its conversion to Trichlorosilane. This is a cost effective integration of two process steps in to single one that conserves power usage, and same will be introduced in the process of MSL.

The reaction is endothermic and the constituents are required to be heated by external heaters and the resultant gas mixture is passed through for further processing. The chemical reaction in this stage is as below.



- The heating and cooling are done with heat transfer fluids, from which the heat is recovered for use in other areas that requires external heat.
- The off gases containing primarily chlorosilanes and H_2 are subjected to condensation up to 60°C and then to a series of purification steps before subjecting to final scrubbing and disposal.

The product thus collected is subjected to distillation to remove the high boiling impurities and the chlorides of metal to a very low level for it to be used in the downstream process.

Step 2: Purification

The Chlorosilane, are purified by distillation and sedimentation / adsorption. The primary aim of distillation is to remove Chloride impurities such as AlCl_3 , FeCl_3 , TiCl_4 etc and also boron and phosphorous chlorides. The distillation train consists of number of columns. In the first column, the heavy impurities such as TiCl_4 , AlCl_3 and FeCl_3 are removed as bottom products along with the higher boiling residues.

In the subsequent columns the chlorosilanes are further purified and all the chlorides are removed and taken to a high purity levels. Distillation alone may not result in complete removal of the impurities particularly boron and phosphorous. Final purification is achieved by passing the distilled chlorosilanes through a reactor containing activated alumina gel or silicon gel formed in situ as adsorbent. The product coming out of the reactor will be of desired purity.

In order to remove any suspended adsorbent particles, the chlorosilane is subjected to a simple distillation and the pure product is stored in stainless steel storages.

3.2.2.2. Trichlorosilane (TCS) production

The TCS fed to the deposition reactors is produced by reacting finely ground metallurgical grade silicon with anhydrous hydrogen chloride (HCl) gas in a fluidized bed reactor. The reactor produces a mixture of chlorosilanes that are primarily TCS and STC with a small amount of dichlorosilane (DCS) upto a max of 2%. The reactions are:

- DCS reaction: $\text{Si} + 2 \text{HCl} \rightarrow \text{SiH}_2\text{Cl}_2$
- TCS reaction: $\text{Si} + 3 \text{HCl} \rightarrow \text{SiHCl}_3 + \text{H}_2$
- STC reaction: $\text{Si} + 4 \text{HCl} \rightarrow \text{SiCl}_4 + 2 \text{H}_2$

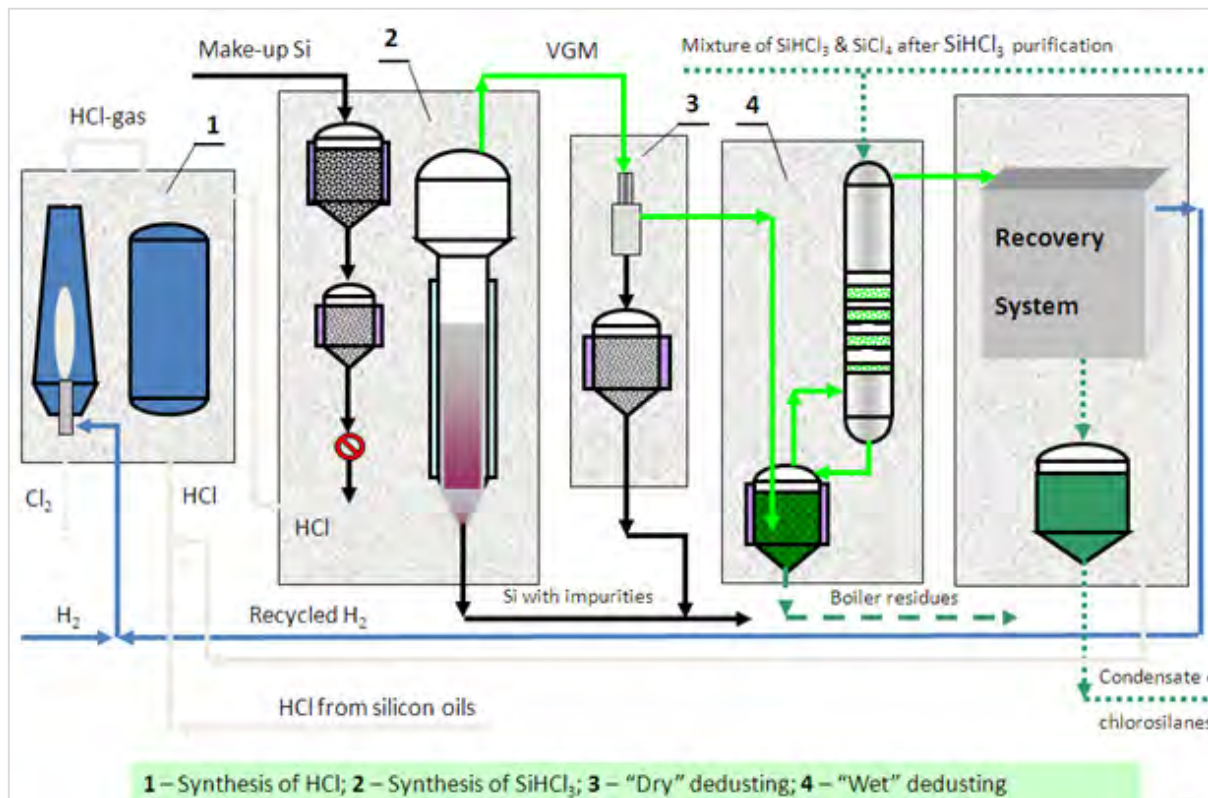



Figure 11. Block diagram for crude production of SiHCl_3

Step 1: Production

This method to produce crude TCS is often referred to as the hydrochlorination process. The crude TCS exiting the reactor contains multiple impurities which must be removed prior to use. The hydrochlorination process produces higher molecular weight chlorosilanes and polysilanes while trace quantities of moisture react with the above compounds to produce siloxanes. Impurities in the metallurgical grade silicon and hydrogen chloride react to produce a number of metal chlorides (primarily aluminum and iron chlorides), hydrocarbons, chlorinated hydrocarbons, and a small amount of methyl chlorosilanes.

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- The off gases from the reactors are first subject to “dry dedusting” by cyclone separators that ensures removal of the unreacted met. Silicon and sends it back to the reactors. Depending on the purity of the feed silicon a slip stream from this will be taken and the material will be purged out to waste.
- A similar purge from the bottom of the reactor will be made to ensure the impurities do not build inside the reactor and do not end in the chlorosilane and increasing the load on the purification stage.
- After the cyclone separators the gases are subjected to dry-dedusting to remove the $AlCl_3$ by maintaining the temp in such a way that they are removed here.
- The gases from the reactor is cleaned by scrubbing the effluent gas, which cools the gas and removes waste liquid and solids called “wet dedusting”.

Off gases are subjected to a three stage condensation to condense all the chlorosilanes, called Crude TCS. The crude TCS liquid requires further purification before it can be fed to the PCS deposition reactors. Effluent gas exiting the scrubber consists of hydrogen, hydrogen chloride, and small amounts of chlorosilanes and reaction byproducts. The TCS production effluent gas can be directed to a dedicated effluent gas recovery system scrubber and dispose the HCl and vent the H_2 to a high point vent as they will not meet the purity levels required in the deposition process.

Step 2: Purification

The crude TCS must be purified before it can be used to produce polycrystalline silicon of sufficient purity for high conversion photovoltaic solar cell or electronic semiconductor manufacturing. The crude TCS is treated via a multiple step separation and purification process as indicated in the process diagram below.

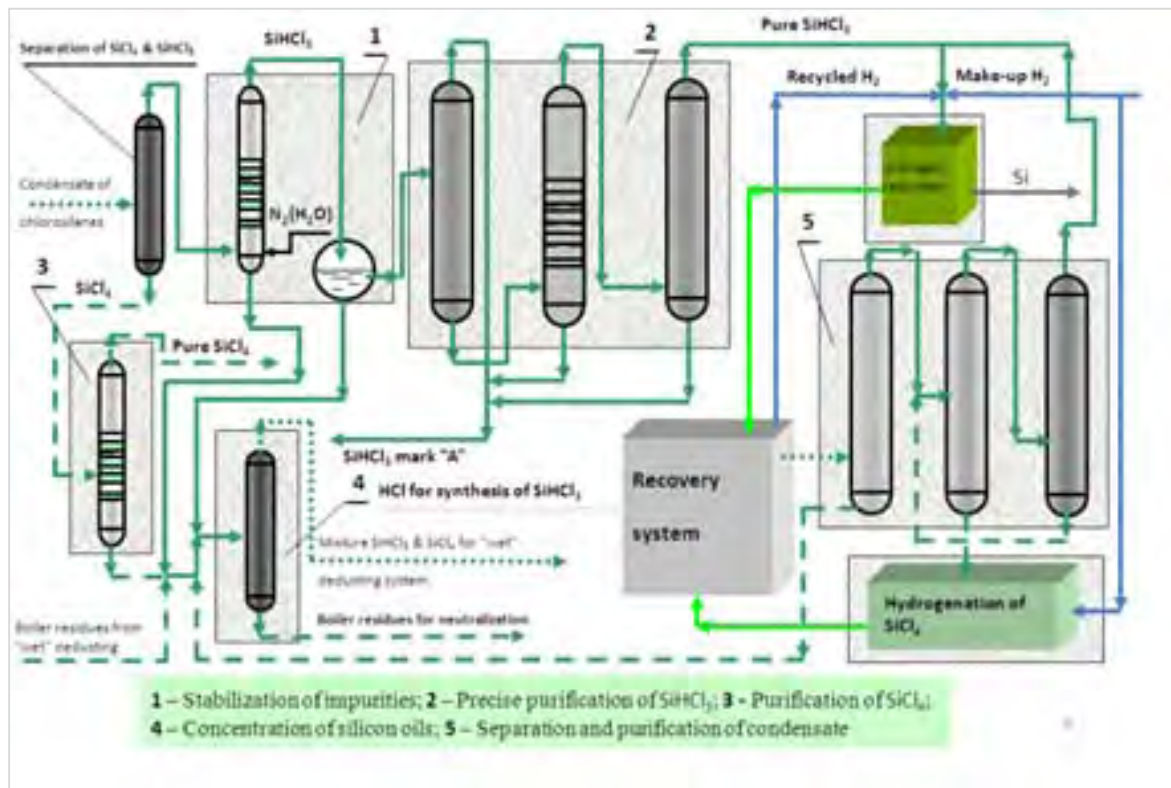


Figure 12. Block diagram for separation of SiCl_4 and SiHCl_3

Purification of the crude TCS removes STC, metal chlorides, higher molecular weight chlorosilanes, polysilanes, siloxanes, and hydrocarbons. In addition the STC is purified for subsequent conversion into TCS. The purification process produces the following streams:

- Purified TCS
- Low grade TCS
- Purified STC
- Heavies waste
- Purification Vent Gas.

The purified TCS is fed to the deposition reactors to make polycrystalline silicon (PCS). The low grade TCS can be sold as a byproduct or further reacted to recover HCl for recycle to the polysilicon process. The purified STC feeds the conversion reactors (STC to TCS) for conversion to purified form of TCS. The heaviest waste goes to waste treatment for neutralization and disposal.

The small amount of vent gas from the purification processes is sent to the vent gas treatment system. To produce high purity TCS, the purification process necessitates that some of the TCS is lost with the un-separated impurities.

Several of these impurities have boiling points which are very close to that of TCS and difficult to separate. These impurities, and the lost TCS, are collected as low grade TCS, which can be either **sold**

as a **byproduct** or incinerated with sufficient hydrogen to produce a fumed **silica byproduct** and recover HCl for recycle to the polysilicon process or chlorinated to produce **silicon tetrachloride** for return to the polysilicon process.

Additional purification of the TCS is required to remove impurities containing phosphorus, boron, arsenic, and iron which can negatively impact the polysilicon product quality even at extremely low levels.

3.2.3. Deposition stage

The basic process equipment for production of polysilicon is intended for deposition of polycrystalline silicon on initial thin (7 x 7 mm) silicon slims of square section produced by longitudinal cutting of rods silicon of big diameter (80 mm - 90 mm). In total a reactor may be fitted with 36 - 48 slims.

Production of polycrystalline silicon is carried out by hydrogen reduction of trichlorosilane. Recirculation contour includes evaporators/vaporizers for preparation vapourgas mixture (hydrogen + Trichlorosilane), reactors for deposition of polysilicon and system of recovery off gases for separation and return chlorosilane, hydrogen chloride and hydrogen back to the process.

- The deposition rate increases with increase in temperature and needs to be controlled to avoid melting. Also the distribution of the TCS and H_2 properly insures better and uniform growth.
- As the surface area available for the growth increases, the reactant flow are to be increased to take the advantage or else it will result in to "starved growth" or "pop corn" patterns. Through out the process the ratio of the TCS and H_2 is

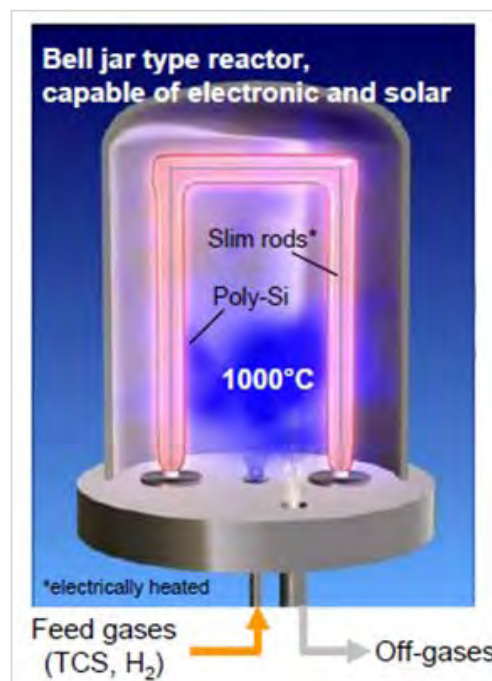


Figure 13. Reactor



Figure 14. Typical Siemens based deposition chamber with Polysilicon rods

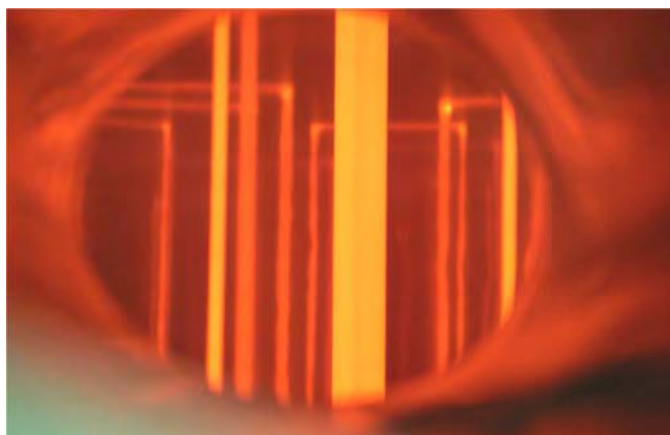
maintained and only the flow is increased as the surface area available for the growth increases.

- The deposition rate increase to the square root of the flow of the re actants into the reactor, In the typical process the deposition will be the highest towards the end and the lowest towards the start up.
(If a simplified process reaction is looked at for every molecule of Si produced two molecule of SiCl_4 is produced and one molecules of HCl is produced and two molecules of SiHCl_3 is used up in the process).
- For all practical purposes the H_2 does not take part in any way in the reaction.

During the above high temperature reaction a small amount of polymers like silicone oils get formed which are flushed along with the Silicon tetrachloride and are better to be neutralized than separating them. A slip stream from the CVD off gas recovery system will be carrying such polymers which will need to be neutralized eventually.

A white to yellow syrupy oil that gets formed is dissolvable in SiCl_4 but in purest form is explosive when touched or rubbed in dry condition. This needs to be borne in mind during taking up the cleaning operation of the reactors. One more yellow powder that gets formed is very quiescent and non dangerous. All these polymers can be doused with water to render them harmless.

- Process of deposition of poly crystalline silicon is carried out in the watercooled reactionary chamber. Distinctive feature of the given design in the above table is the application of hot water with temperature 80°C - 90°C for cooling of internal wall of reactor, and also maintenance of pressure in the reactionary chamber up to 6 bar (g) during process of deposition of silicon. Increase of pressure in the reactionary chamber allows essentially (more than 2 times) to raise deposition rate of silicon in a reactor due to preliminary heating of the incoming gases and allows to increase quantity of initial raw material passed through a reactor.
- Process of deposition of silicon is carried out on a surface of initial slims whose temperature is supported at a level 1090°C - 1120°C with help of electric current.



Preliminary heating of initial slims in a reactor before the beginning of process is to be carried out by a heating system (common for about 4 such reactors). After reaching the desired temperature of the conductor, the temperature on the surface of slim rod is supported by passing electric current continuously. If the initial heating is by Plasmatron then for protection, a small amount of pure hydrogen needs to be passed.

After heating slims, before silicon deposition, etching of surface silicon slims by a mixture of hydrogen and the hydrogen chloride, is to be provided to ensure good, surface for deposition.

During deposition the amount of feeding gas, moving in reactor is adjusted to the surface of silicon rods and changes from minimal to maximal values.

The control loops are to be programmed to ensure the flow and pressure are ensured in the circuit during start up every time.

Higher pressure in a reactor gives a number of advantages, first of all, an opportunity of essential increase deposition rate and, hence decreases of the electric power consumption during deposition of polysilicon.

The high pressure in a reactor allows to increase amount of VGM in a reactor (in comparison with process at normal pressure), and as it was already marked above, moving of VGM to a reactor increases proportionally to growth of a surface of silicon rods. Thus in a reactor forms the significant excessive amount of VGM which is heated up to high temperatures due to a heat transfer by radiation from silicon rods and convection.

Bonds in molecules of trichlorosilane become less strong, that leads to decrease of an energetic barrier for dissociative adsorption of trichlorosilane with formation of chemisorbed layer of silicon dichloride on a surface of silicon rods. The high pressure in a reactor promotes preferable course of reaction as below.



These effects lead to essential increase of deposition rate. Besides increased pressure in a reactor allows passing through a reactor a lot of initial VGM, that also leads to increase of deposition rate. It is necessary to note that increase of pressure in a reactor and in pipelines excludes formation of silicon oils.

The general level of energy consumption during deposition of polycrystalline silicon (kWh/kg) first of all depends on a level of energy consumption in reactor, and the level in a reactor in turn depends of deposition rate of silicon. Therefore achievement of optimum of deposition rate of silicon in a reactor is the important technological problem, in many respects determining technical and economic parameters of process as a whole. The silicon filaments can be purchased or produced on site using vendor provided equipment.

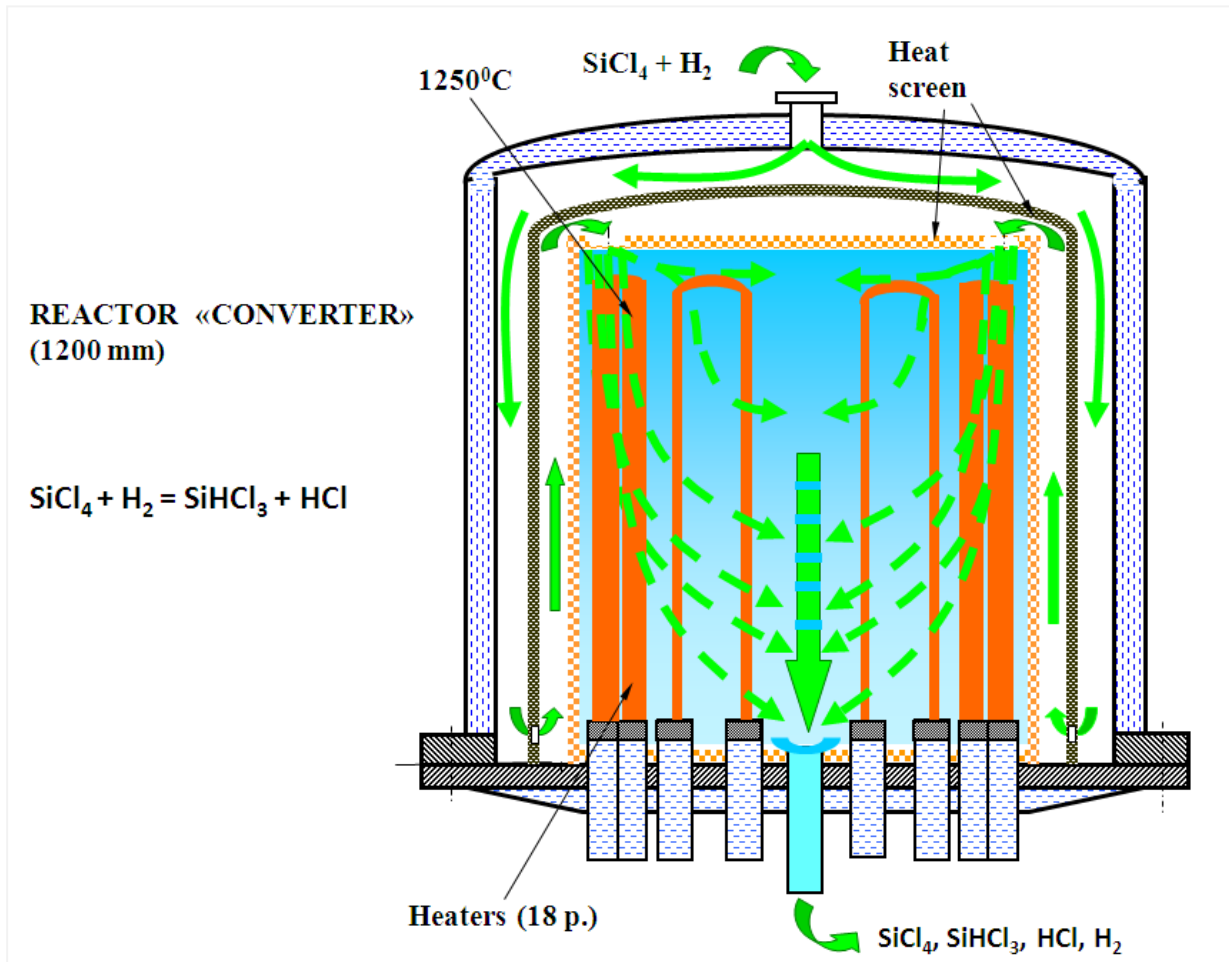
The deposition unit process is supplied with purified TCS liquid and TCS liquid recycled from the PCS deposition and STC conversion effluent gas recovery systems. The TCS liquid is vaporized and mixed with hydrogen gas feed and recycled hydrogen gas from the PCS deposition effluent gas recovery system.

Silicon deposition yields a large quantity of gaseous HCl. The chemical reactions in the deposition reactors also produce a significant quantity of STC and smaller quantities of DCS and other chlorosilanes. Since the deposition reactors are fed with excess TCS and hydrogen, the PCS deposition reactor effluent gas consists primarily of TCS, STC, H₂, HCl, and DCS.

3.2.4. Silicon Tetrachloride conversion to TCS

Poly reactor outlet contains hydrogen, un reacted trichlorosilane, silicon tetrachloride (formed as a byproduct), dichlorosilane and hydrogen chloride, moves to a recovery system similar to the one in the TCS production stream where it separates into components.

Hydrogen and trichlorosilane after separation from silicon tetrachloride by distillation return in process of producing of polycrystalline silicon, hydrogen chloride return in process of synthesis trichlorosilane and



silicon tetrachloride moves hydrogenation to trichlorosilane. Additional STC is obtained from by product plant for conversion to trichloro silane here.

Hydrogenation includes the following basic operation and equipment:

- preparation of gas mixture containing hydrogen and silicon tetrachloride with mole ratio
- Installations of hydrogenation "Converter" in which on surface of carbon heaters at temperature 1250°C there is an interaction silicon tetrachloride with hydrogen to formation of trichlorosilane system of recovery of off gases similar to the one in TCS plant, with return not reacted hydrogen and silicon tetrachloride in a head of process of hydrogenation, trichlorosilane in process of polysilicon production and hydrogen chloride to synthesis of trichlorosilane.

The basic apparatus of hydrogenation process is "Converter" which consists of water cooled cylindrical chamber with an elliptic cover and the flat bottom. At the bottom two thermal screens are loaded for preliminary heating of VGM and 36 electrodes for fastening graphite heaters are located. On the surface of heaters at a temperature at 1250°C hydrogenation reaction takes place.

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The characteristics of reactor "Converter" is as listed in the table below

Sno	Characteristics	Measurement / Value
1	Working temperature on heaters	1250 °C
2	Material of heaters	carbon composite
3	Working pressure in a reactor	6 bar (g)
4	Atmosphere in a reactor	chlorosilane, H ₂ , HCl
5	Percent of SiHCl ₃ producing by one pass	>17 %
6	Mole ratio	H ₂ :SiCl ₄ = 3:1
7	Flow rate of VGM to "Converter"	3000 kg/h
8	Number of heaters	48
9	Specific consumption of power	20 kWh/kg of Poly.

3.2.5. Recovery process

3.2.5.1. Deposition effluent gas recovery

At present the most reliable equipment supplier in this area are CDI who have the comprehensive equipments for separation and re use of various components. Installations of CDI will carry out recovery of off gases from reactors for producing polysilicon and hydrogenation, by consecutive passage through 4 modules.

- **Module 1.** Cools the incoming feed gas 45°C and 1.2 kg/cm² in a scrubbing tower to condense the major portion of the chlorosilanes and silicon oils from the feed gas.
- **Module 2.** Compresses and cools the feed gas to prepare for module 3. Operating conditions are 45°C and 8.9 Kg/cm². Additional chlorosilanes are condensed in this step.
- **Module 3.** Removes and recovers HCl from the feed gas. HCl is absorbed in a 45°C chlorosilane stream at 8.9 Kg/cm². HCl is recovered from the liquid stream by distillation at 7.3 Kg/cm².
- **Module 4.** Removes the remaining HCl and chlorosilanes from the gas stream by adsorption on a special activated carbon. Hydrogen leaving this module contains small amounts of HCl and chlorosilanes. The activated carbon is regenerated by indirect heating and cooling with a heat transfer fluid. The regeneration gas stream is refrigerated to condense chlorosilanes, and then purged to a caustic scrubber for final treatment prior to being vented to the atmosphere.

3.2.5.2. Deposition effluent gas recovery

The off gases from the CVD reactor system is taken to condensers as explained in the TCS off gas section. The chlorosilanes that are condensed are stored in a storage tank of capacity 22 - 50m³ of 5 nos.

- First one collecting the mixed chlorosilanes from the condensers
- One feeding the distillation column that is separating the TCS and STC for feeding the STC to the converters.
- One collecting the TCS from the fractionation column after further purification and absorption. This is sent back to the CVTJ vaporizers.
- One collecting the STC from the fraction action column

- One feeding the STC to the Converters.

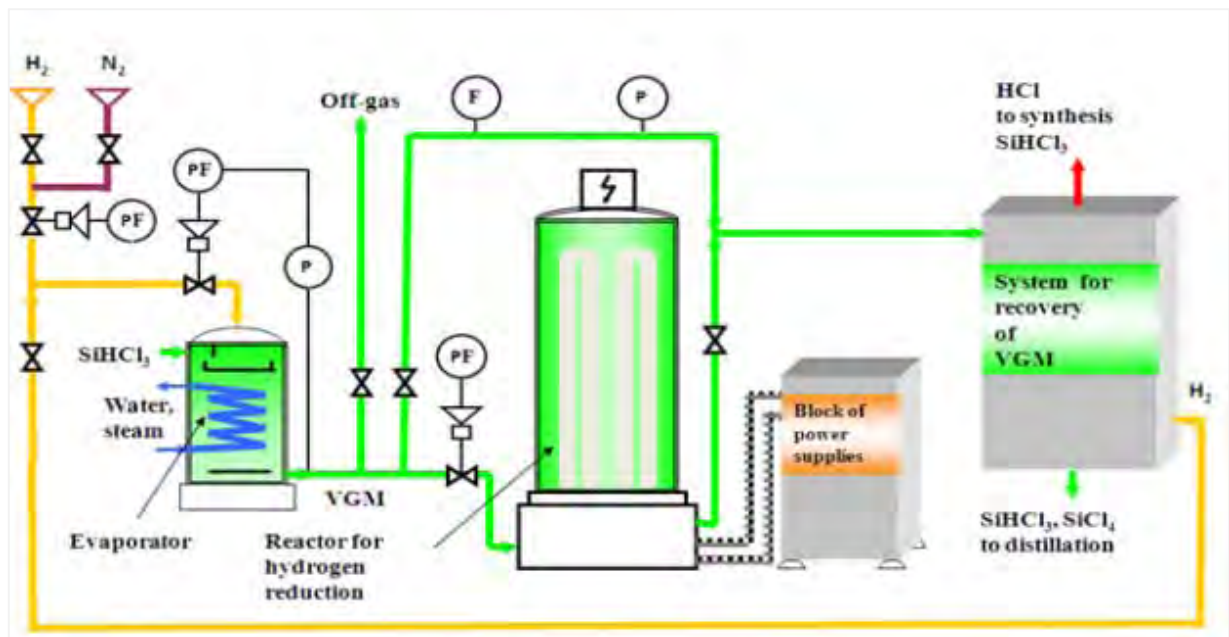
The purification columns in the CVD off gas recovery shall be in 12000 TPA two streams and shall be with two columns, one for macro separation and another for further polishing of TCS before it is fed to the vaporizers again.


- The impurities at this stage will be very less the columns shall be of 11.5 m dia and about 20 - 25m tall max. Operating at about 3 kg/cm² and 70 - 80°C
- The uncondensed gases leaving the condensers are subjected to CDI vent recovery package in two streams of 12000 TPA each and the HCl and H₂ are recycled back to the process. The stages and number of equipment's are similar to the one explained in the TCS section.
- The polysilicon deposition reactors are fed a mixture of TCS vapor and H₂ gas. A relatively low percentage (approximately 15%) of the TCS is deposited as polysilicon. About 30% of the TCS feed reacts to produce large amounts of STC and smaller amounts of DCS and other byproducts.
- Approximately 60% of the TCS feed exits the deposition reactors. This effluent gas contains large amounts of TCS and STC, and significant amounts of H₂, HCl and DCS.

The PCS deposition reactor effluent gas is treated in a multiple step separation and purification processes to allow return of the valued components to the polysilicon production process. Recycle hydrogen is returned to the PCS deposition reactors with excess hydrogen going to the STC conversion reactors. Recycle HCl is sent to the TCS production reactor.

The condensed mixed chlorosilanes are sent to additional process equipment for separation and purification prior to recycle to the PCS deposition and STC conversion reactors. The TCS returns to the PCS deposition reactors. The STC returns to the STC conversion reactors. A low grade STC returns to TCS purification train for additional separation and purification.

Figure 15. Block diagram, process of hydrogen reduction.



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3.2.5.3. STC Conversion Effluent Gas Recovery

The off gases from the Hydrogenator (STC converters) system is taken to condensers as explained in the TCS off gas section. The chlorosilanes that are condensed are stored in a storage tank and tankage requirement for this section is as follows:

- One tank of 1000 cum receives the mixed chlorosilanes and the other one feeding the fractionation column
- One tank of about 1000 cum can be used for storing the STC separated and fed to the big tank in the CVD section or directly fed to the converters.
- One tank of 1000 cum can be used to store the separated TCS and fed back to the CVD section to the vaporizers directly.
- The rejects shall be taken directly to the rejects tank of the CVD distillation section.

The off gases leaving the condensers shall be taken to a two stream of 12000 TPA PCS trains and subjected to removal of HCl and H₂ for recycle back to the process. Since this stream's H₂ could contain some carbon impurities the H₂ is recycled back only to the converters and fresh make up is taken in this stream only as the H₂ atom is added to STC to make it TCS. The HCl recovered at 9 bar (g) is returned back to the TCS FBRs.

The STC conversion process generates an effluent gas stream, which is recovered in a process similar to the deposition reactor EGR. Recycled hydrogen is returned to the STC convertors. Recycled HCl is sent to the TCS production reactor. The condensed mixed chlorosilanes are sent to additional process equipment for separation and purification prior to recycle to the PCS deposition and STC conversion reactors.

The TCS returns to the PCS deposition reactors. The STC returns to the STC conversion reactors. A low grade STC returns to TCS purification train for additional separation and purification.

A mixture of vaporized chlorosilane and hydrogen in suitable proportion is passed through the reactor. The reduction of chlorosilane takes place on the hot surface of the rod on which the silicon produced gets deposited. Thus the rod grows in size with time. Deposition is continued till sufficiently large diameter rods are obtained. The silicon thus obtained is broken down to "Chunks" and stored for further processing.

Once the sufficiently large rods are formed the reactor is taken out of production and purged with N₂ before they are opened and got ready for the next process.

3.2.6. Fluid Bed Reactor Process (FBR)

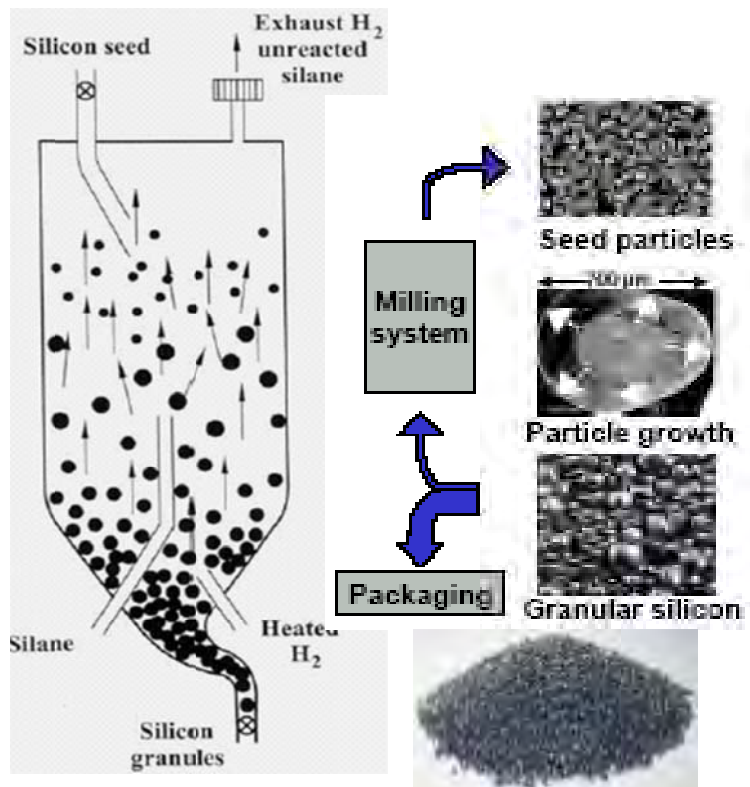
A fluidized bed reactor consists of gas-solid mixture that exhibits fluid-like properties. The bed can be considered to be an inhomogeneous mixture of gas and solid that can be represented by a single bulk density. Furthermore, an object with a higher density than the bed will sink, whereas an object with a lower density than the bed will float, thus the bed can be considered to exhibit the fluid behavior as expected by Archimedes' principle. In fluidized beds, the contact of the solid particles with the gas is greatly enhanced when compared to packed beds. This behavior in fluidized beds enables good thermal and mass transport inside. Similarly due to the good heat transfer, which enables thermal uniformity analogous to that of a well-mixed gas, the bed can have a significant heat-capacity whilst maintaining a homogeneous temperature field.


The increase in fluidized bed reactor use in today's industrial world is largely due to the inherent advantages of the technology.

Trichlorosilane gas produced in the Hydrochlorination process is passed, after purification, through a catalyst which is Amberlyst type which does redistribution of H_2 molecules in the Silicon and yields SiH_4 which is called silane. The silane is further subjected to purification process and then stored in tanks.

In a FBR designed to produce granular polysilicon, tiny silicon particles are fluidized in a SiH_4/H_2 flow, and act as seed crystal onto which polysilicon deposits to form free-flowing spherical particles. The process is carried out at $650^\circ C$. The silicon thus growing on the tiny particles gains weight and travels down the fluid bed reactor and collected at the bottom as Granular Silicon which is known as FBR based high pure POLY SILICON. The size distribution of the particles thus formed is over the range from 0.4 to 3 mm in diameter.

Figure 16. FBR technology.




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Purification of Hydrogen:

The Hydrogen required for reduction is obtained from the in-house water electrolyser to ensure high purity levels in the H₂ gas. This hydrogen is of sufficient purity for Chlorosilane reduction purposes except that it contains some water vapor. The purification of hydrogen, therefore, involves the removal of this vapor. This is accomplished by compression of hydrogen to about 10 - 12 kg/cm² pressure in a two stage non-lubricated hydrogen gas compressor.

When the compressed hydrogen is cooled most of the water condenses and removed. Then they are passed through De Oxo towers to remove the Oxygen and then final traces of the impurity are removed in a dual column adsorption unit with molecular sieves as adsorbents. The hydrogen thus obtained is sufficiently pure to be used for the CVD of silicon.

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3.2.7. Utility systems required to support the polysilicon production process

TCS Production Hot Oil

The Trichlorosilane Production Hot Oil system is a closed loop heat transfer utility used by the trichlorosilane fluidized bed reactors. The loop is designed such that two oil temperatures can be supplied. During initial reactor startup, oil at 350°C is supplied to the reactor to initiate the reaction. The TCS synthesis reaction is very exothermic. Once the reaction is initiated, heating is no longer needed and the oil loop switches operation to become a cooling loop that operates at a temperature of approximately 250 to 300 °C. Note that the TCS reactors are a typical source of heat recovery for the plant.

TCS Purification Hot Oil

The Trichlorosilane Purification Hot Oil system is used to supply hot oil to the distillation column reboilers. The typical operating temperature for this system is 200 to 250 °C. A portion of the heat load for this loop can be obtained from the Trichlorosilane Production Hot Oil loop. To support heat recovery from the PCS deposition and STC conversion cooling water systems, the high temperature TCS purification loads could potentially be supplied from the TCS production hot oil system and low temperature TCS purification loads could be supplied by an oil system at approximately 125 to 175°C.

Process Cooling Water

Process cooling water is a process utility primarily used for the cooling medium in heat exchange processes such as distillation column condensers, process stream coolers, and compressor discharge coolers. The typical operating temperature is 25 to 30°C. The temperature is maintained through the operation of evaporative cooling towers.

Refrigerated Cooling


A refrigerated cooling system provides low temperature heat exchange for the polysilicon production plant. The primary uses are for final condensers on various process systems and storage tank vents. The dual suction pressure system provides cooling at 10°C and 60°C.

PCS Deposition Cooling Water

The polysilicon reactors are serviced by two independent process cooling water systems. The systems recirculate high resistivity water and are supplied make up from the plant DI water system. The two process cooling water systems operate at different supply temperatures. The lower supply temperature system provides cooling for the electrodes and power supply equipment. The higher supply temperature system cools the reactor shell, baseplate, and effluent gas. The supply temperature, resistivity, and flow demands for the process cooling water systems vary between the different deposition reactor providers.

STC Conversion Cooling Water

The STC convertors are serviced by two additional process cooling water systems similar to the systems described for the deposition reactors. The supply temperature, resistivity, and flow demands for the process cooling water systems vary between the STC convertor providers.

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Nitrogen

Nitrogen is a plant wide utility used to provide an inert gas space and to purge process materials from equipment and piping prior to maintenance. Nitrogen is also used in the following locations in the polysilicon production process:

- Pressurizing the Metallurgical Grade Silicon Reactor Feed Tank
- N2 pad for chlorosilanes storage tanks (pressure control and inert gas space)
- Pressure control for certain distillation columns.

In addition, a major use of nitrogen is the purging of the bell jar reactors (both polysilicon deposition and STC conversion) prior to accessing the reactor internals. The bell jars are similarly purged with nitrogen following any activity which exposes the inside of the bell jar to the atmosphere. The nitrogen must be of very high quality since it does come in contact with process streams and process equipment.


Nitrogen Quality specification

- Purity : ≥ 99.9999 % by volume
- Impurities

Name	Formula	Concentration
Total Hydrocarbons	CH ₄	0.1 ppmv max
Oxygen	O ₂	0.5 ppmv max
Water	H ₂ O	1.0 ppmv max
Carbon Monoxide	CO	0.1 ppmv max
Carbon Dioxide	CO ₂	0.1 ppmv max.

Effluent Gas Recovery Hot Oil System

The Effluent Gas Recovery Hot Oil system is used to supply hot oil to the mixed chlorosilanes distillation column reboilers. The typical operating temperature for this system is 175 to 225°C.

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3.2.8. Typical specifications of Polysilicon

Polysilicon is the essential raw material for the solar and the Electronics industry. Earlier the rejects of Semiconductors was used in the solar industry and the trend has been reversed due to huge capacity additions in the last decade and solar industry alone consumes 90% of the poly produced across the world.

It's one of the purest ever man made material in the world complex and capital intensive manufacturing process.

Based on the Quality/Purity of the silicon, it has categorized into various grades and handled as given below.



Table 4. Polysilicon grading

Grade	Si purity %	# N	Total Impurities (ppm)	Applicable field
MG-Si	98.5-99	1-2	10000 –15000	For Steel application
Silgrain (HQ)	99.7	2	2500 – 3000	Major impurities C, Fe,Ca, Al,
UMG-Si	99.99	4	500 -1000	Same
SoG-Si	99.9999	6	4 – 6	Low amount of Impurities
Pure-Si	99.9999999	9	0.001 - 0.005	High pure for Solar applications

- **Packaging:** Poly silicon is to be packed in polyethylene bag (no additives) of 5.0 Kg weight. A double bag system with clean room packing shall be done.
- **Surface condition:** Product will be clean with no stains, grey, luster free, rough and visible contaminants except the amorphous.



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Table 5. High pure Polysilicon specification

Sno	Description	Specifications
1	Size of Chunk	
1.1	<5mm	<1% by weight
1.2	5 - 45mm	max.25% by weight
1.3	20 - 65mm	max.35% by weight
1.4	10 - 150mm	min.75% by weight
2	Impurities	Maximum Concentration
2.1	Acceptor (B, Al)	< 0.2 ppba
2.2	Carbon	5.0 ppba
2.3	Donor (P, Sb, As)	< 5.0 ppba
2.4	Acceptor + Donor	< 10.0 ppba
3	Other Metals Impurities	Maximum Concentration
	Total surface Metals	30.0 ppbw
3.1	Aluminum(Al)	10.0 ppbw
3.2	Chromium(Cr)	2.0 ppbw
3.3	Copper(Cu)	2.0 ppbw
3.4	Iron(Fe)	10.0 ppbw
3.5	Nickel(Ni)	2.0 ppbw
3.6	Potassium(K)	10.0 ppbw
3.7	Sodium(Na)	15.0 ppbw
3.8	Zinc(Zn)	4.0 ppbw
4	Bulk Metals(Total)	Maximum Concentration
4.1	Fe, Cu, Ni, Cr, Zn, Na	10.0 ppbw

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3.2.9. Proposed plant layout for polysilicon manufacturing

MSL is planning to partner with an established technical company who can establish the process, supply technology, automation and control platform. MSL will use the supplier's experience and process knowledge systems to help MSL plant produce an estimated 20000 tons of polysilicon annually,

The recommended land area for a 20,000 tons state of the art polysilicon plant allowing for use of setbacks, expansion of operations and green space to keep certain operations distant from each other is 325050 Sqm.

MSL proposes to lease an area of approximately 140 acres within an EMC facility in close proximity to water source availability. This will allow for future expansion into manufacture of silicon Polysilicon, ingots and wafers at a future date. This production facility will include the floor space optimized for plant equipment's, change room, raw materials stores, finished goods stores and Waste water treatment plant to ensure a smooth and safe operation. The manufacturing facility will operate in three shifts throughout the year.

MSL as a polysilicon producer is designing the plant with utmost plant safety as the processes are critical. Both the design and the execution of expansion and upgrades to projects are critical as MSL strive for minimal down time so that productivity is not affected in the downstream process. The plant brings in high level of automation - for automatic transport, crushing, classifying material tracking and storage system.

The basis of polysilicon plant design is based on the following requirements.

- Final Process Design and technical partner selection
- Final plot plan
- Detailed Capex estimate
- Detailed Operating cost estimate
- Detailed Project Schedule
- Detailed data for utilities
- QC procedures
- Polysilicon products specifications
- Layout optimised for design capacity

List of buildings planned:

- Metallurgical grade Silicon milling
- HCl generation / Hydrogen generation and purification
- Administration building and quality control lab
- Ware housing- raw material. Finished goods
- Centralised control room
- Tank farm area
- Effluent treatment plant section
- TCS reactor building
- TCS purification
- Poly silicon deposition and STC converter room
- Vent gas recovery system buildings
- Utility Building
- Engineering workshop
- R&D building
- Captive / Emergency power supply

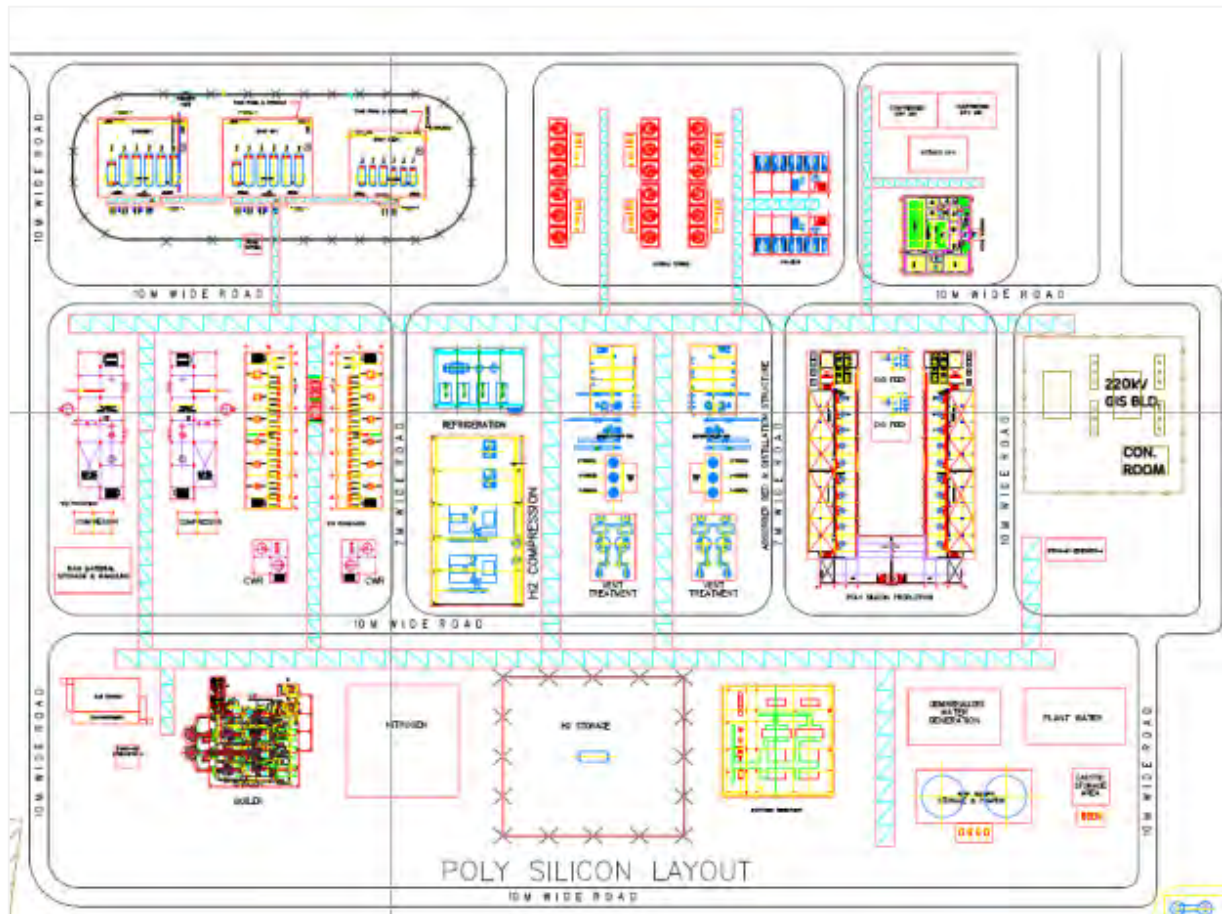



Figure 17. Polysilicon manufacturing plant layout

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3.3. Raw-material

3.3.1. Key raw materials identified in polysilicon manufacturing

3.3.1.1. Raw Material 1 - Metallurgical grade silicon (MGSi)

The polysilicon production process requires metallurgical grade silicon, anhydrous hydrogen chloride, and hydrogen. Metallurgical grade silicon (MG-Si) contains a minimum of 98.5% pure silicon. It is supplied as a finely ground powder and shipped in semi bulk (super sacks) or bulk quantities. The MSL plant will include a material handling system for removing the MG-Si from the shipping containers and transferring it to a storage site. The MG-Si will also be procured as lumps and ground at site to the required size.

Material specifications

- **Particle Size:** 110,373 micro
- **Purity:** ≥ 98.5 % by weight
- **Impurities:**

Name	Symbol	Concentration
Aluminium	Al	4000 ppmw max
Boron	B	100 ppmw max
Calcium	Ca	2000 ppmw max
Carbon	C	1000 ppmw max
Iron	Fe	4000 ppmw max
Phosphorous	P	100 ppmw max
Arsenic	AS	100 ppmw max


3.3.1.2. Hydrogen Chloride

This will be manufactured inhouse using Hydrogen and Chlorine. High purity anhydrous hydrogen chloride gas (HCl) is needed for supply to the TCS fluidized bed reactor.

Material specifications

- **Purity:** ≥ 99.99 % by volume
- **Impurities:**

Name	Formula	Concentration
Hydrogen	H ₂	30 ppmv max
Total Hydrocarbons	CH ₄	1.0 ppmv max
Inorganic Carbon	CO ₂	25 ppmv max
Nitrogen	N ₂	50 ppmv max
Oxygen	O ₂	2.0 ppmv max
Water		1.0 ppmv max
Chlorine	Cl ₂	1.0 ppmv max
Chlorine/Bromine	Cl ₂ /Br ₂	5.0 ppmv max
Hydrogen Bromide	HBr	20 ppmv max
Iron		0.5 ppmw max

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Boron		2.0 ppbw max
Phosphorous	P	3.0 ppbw max

3.3.1.3. Various options on HCl generation units

Hydrogen and Chlorine burning unit:

This system has a very attractive proposition in terms of capital and operating cost as the unit has a pay back of just 3 years with steam generation option at 12 kg/cm² as offered by SGL.

The system's only disadvantage is that the excess H₂ admitted to ensure all the Chlorine is burnt leaves the AHCl with a 0.3% w/w of H₂ or a 56% v/v which may affect the reaction at the TCS fluid bed reactors. Acceptability of such levels of H₂ in AHCl stream needs to be checked with TCS technology providers.

Desorption of aq.HCl 30% - 32%:

There are three options available in this

- **18% - 20% HCl route:** The distillation unit will desorb HCl and leave a 18% - 22% aq.HCl as a byproduct which needs to be again enriched from some other source to 30% - 32% and returned back here.
- **1% route:** The azeotrope of 18% - 22% can be broken with CaCl₂ solution and further distillation is possible until a 1% aq.HCl solution is left for disposal.
- **Twin Tower system:** This system gives a dry HCl and leaves only water which can be taken directly for inland irrigation or for cooling tower make up and is capital intensive.

All the above desorption systems yield HCl with lot of moisture, which needs to be dried further. As the HCl outlet pressure in options 1 and 3 will be at 22.5 kg/cm² the moisture levels will be at about 200 - 300 ppm. With option 2, the generation pressure is at 1 kg/cm² and will have a moisture level of about 1000 ppm.

With the addition of a Sulfuric acid tower after this the moisture level can be dropped to a level of about 50 ppm but leaves one more effluent to be handled that is spent sulfuric acid. All the desorption options require a molecular sieve system to bring down moisture levels to 12 ppm. Capacity of one block shall be at 1.8 - 2.0 MT per hour.

The produced Anhydrous HCl shall be free of moisture and carbon with moisture less than as per the specification discussed, under Raw material and Utilities

- This HCl is mixed with recycled HCl from the plant and compressed in diaphragm compressor to about 5 to 8 kgf/sq.cm and fed to TCS FBR.

The reactor while start up may be required to be operated at peak load till full recycle is established. Till this equilibrium is reached depending on quantity of recycle balance is generated by this reactor. The reactor is capable of having these turn down ratios.

The reactor should be built with safety locks to avoid un reacted chlorine going along with the product by proper ratio controller, Emergency controls should instantly cut down chlorine to appropriate levels.

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Hydrogen

The polysilicon production process requires high purity H₂ with very low levels of moisture and carbon containing compounds.

Nitrogen

Nitrogen is a plant wide utility used to provide an inert gas space and to purge process materials from equipment and piping prior to maintenance. Nitrogen is also used in the following locations in the polysilicon production process:

- Pressurizing the Metallurgical Grade Silicon Reactor Feed Tank
- N₂ pad for chlorosilanes storage tanks (pressure control and inert gas space)
- Pressure control for certain distillation columns.
- In addition, a major use of nitrogen is the purging of the bell jar reactors (both polysilicon deposition and STC conversion) prior to accessing the reactor internals. The bell jars are similarly purged with nitrogen following any activity which exposes the inside of the bell jar to the atmosphere. The nitrogen must be of very high quality since it does come in contact with process streams and process equipment.

Material specifications

- **Purity:** ≥ 99.9999 % by volume
- **Impurities.**

Name	Formula	Concentration
Total Hydrocarbons	CH ₄	0.2 ppmv max
Nitrogen	N ₂	0.1 ppmv max
Argon	Ar	0.1 ppmv max
Oxygen	O ₂	0.1 ppmv max
Water	H ₂ O	0.1 ppmv max
Carbon Monoxide	CO	0.2 ppmv max
Carbon Dioxide	CO ₂	0.1 ppmv max

The raw material requirements & source details are tabulated below:

Raw Material	Quantity	Source	Logistics
Metallurgical Grade Silicon (MG – Si)	~21,600 MTPA	Import from China & other Asian countries	Imported at Mundra port in Jumbo bags through Containers and then by road to plant
Hydrogen	~3200 MTPA	In-house Manufacturing	NA
Chlorine	~4000 MTPA	Domestic	Through Chlorine tonners

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3.4. Utility requirement for Polysilicon plant

Based on the basic engineering and design the connected peak load for the 20,000 MT Polysilicon plant is estimated to be around 1400 MU per annum. The power will be fed by EMC promoter based on the requirement and through the main substation and controlled through distribution transformers and different control centres.

Through a ring main network power will be distributed to the individual blocks of the process area and connected to the equipment. Individual equipment level power requirements at plant level is shown below.

Table 6. Polysilicon plant power requirement

Load requirements for polysilicon plant.		
Equipment Name	Unit	Power requirement
24 Pairs CVD reactor	78	1400 MU
Column	40	
Hydrogen compressor	2	
Hydrochlorination FBR	4	
Adsorber	42	
Cooling tower	4	

Table 7. Polysilicon plant other utility requirement

Utility type	UOM	Requirement
Water	KLD	25,000
Natural gas	NM ³ /a	16,400,000
Steam (1.3 MPa)	Tons / Year	1,300,000

The following plant utility systems required to support the polysilicon production process are provided as a part of the production facility.

- **Compressed Air**

Compressed air is a plant wide utility used for general applications and maintenance activities. This utility will not come in contact with process streams or be connected to process equipment. The typical operating pressure is 650 – 700 kPa (gauge).

- **Instrument Air**

Instrument air is a plant wide utility used primarily to drive valve actuators. This utility will not come in contact with process streams or be connected to process equipment.

- **Steam**


Steam is a potential heat source to be used either directly (or indirectly via hot oil) for heating or vaporizing process streams in heat exchangers throughout the process (e.g. column reboilers).

- **Industrial Water**

Industrial water is a plant wide utility used for processes such as cooling tower makeup, DI water system feed, process hose bibs, etc.

- **Potable Water**

Water used for drinking, washing, eye baths and safety showers.

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- **Fire Water**

A dedicated fire water system is required to support the plant fire protection and fire fighting systems.

- **Hydrant System**

Medium velocity water spray system

- High velocity water spray system
- Low expansion foam system
- Mobile & portable fire extinguishing equipment
- Fire alarm & detection system

The system will be designed in accordance with the requirement for the plant. While designing the fire protection system for this power station its extreme ambient condition will be taken into account. The water for hydrant and water spray system will be met from a dedicated firewater storage tank. All fire hydrants will be provided with necessary accessories and hose houses.

An automatic medium velocity water spray system with heat detection system will be provided for fuel oil storage tanks, cable spreader / trench area. A manual type medium velocity water spray system will be provided for air heaters. Water for the spray system is drawn from the hydrant main ring

- **Thermal Insulation**

Thermal insulation will be provided wherever necessary to minimize heat losses from equipment, piping and other auxiliaries, to ensure personnel protection. Insulation will be held by adequate cleats, wire nets, jackets etc. to avoid loosening. Insulation thickness will be selected so that the covering jacket surface temperature does not exceed the surrounding ambient temperature by not more than 20°C.

- **Cranes, Hoists & Elevators**

Electric Overhead Traveling (EOT) cranes will be provided CVD building & metal grade silicon handling area. The cranes will be used for handling heavy equipment during erection and maintenance of equipment. The cranes will be designed to handle the heaviest piece in that area. Mono- rail hoists of suitable capacity will be installed in areas where the approach of external crane is not possible

- **Workshop Equipment, Stores & Laboratory**


The additional instruments required for chemical laboratory, electrical & electronic instruments for Electrical laboratory and the workshop equipment and accessories as required for general maintenance works will be provided.

- **Protective System**

For protection of equipment against abnormal system conditions, adequate protective devices will be installed in the respective switchgears and/or control and relay panels.

A group of such protective devices would be installed to protect the equipment under different abnormal conditions, arising in the system. Each equipment will be provided with a unit as well as backup protection.

Besides this, protection against lightning surges will be provided with lightning arresters at suitable locations for outdoor equipment over and above the shielding wires and lightning masts. In any case,

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proper discrimination and selectivity will be provided so as to isolate only the faulty elements, keeping the healthy part of the system in service.

- **Plant Communication**

The plant communication system will be provided to facilitate operations by establishing quick communications among the operating personnel stationed at various locations of the plant. The communication system comprises of internal telephone system through an automatic exchange (EPABX), to facilitate communication among the operators, and a public address system for simultaneous transmission of information and instructions. In addition, wireless system will also be provided for operators on the move.

- **Distributed Control System (DCS)**

The instrument and control system will be provided with a microprocessor-based distributed control system (DCS) and a few other analog instruments and control devices. It will perform the functions of monitoring, control, alarm, protection and interlock, diagnosing, accident treatment and maintenance guidance of the unit to meet all requirements at various operational conditions.

- The system will fulfill the following basic functions:
- Monitor all major plant functions inputted to the DCS
- Provide the operator with a central, universal and instantaneous means to monitor the plant.
- Collect and store data for trending of various plant functions. Keep track of various plant events and log them for historical purposes
- Perform required basic calculations for performance monitoring and optimization.
- Produce operating logs for record purposes and post trip review reports.
- Provide sequence of events monitoring and reporting.
- Perform self-checking and self-diagnosis
- Provide capability to add, delete and modify points from the system by means of conversational mode.

The fundamental functions such as control, alarm, monitoring, interlock and protection will be segregated, so that the failure of one does not result in the failure of other functions.

There will be two DCS considered in the project one for the Trichlorosilane Synthesis and for the other parts of the plant.

Error checking will be provided to ensure that accepted message is just the same as that was sent. Redundancy and self-diagnosis will be provided for the control system and communication network. The functions of a failed component will be transferred automatically and bumplessly to the standby processor. The CRT, and the alarm printer will display the failure message. The corresponding input and output circuits are to be programmed in the I/O module.

Sufficient redundancy in the control system will be built to take care of any exigencies and any future requirement and for process optimization.

- **Clean Room - HVAC**

Clean room of cl.10,000 will be made for the CVD reactor section. The ingot preparation room will be to class 1,000.

The final product chunking and packing will be provided with a Class 100 levels to ensure the product is not contaminated during packing operations. The Clean rooms will be provided with dedicated HVAC with sufficient back ups.



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- **Deionized Water**

A treatment system for production of deionized (DI) water purification is needed for reactor filament production, process cooling water makeup, QA lab use, and various other users.

- **Wastewater Collection and Treatment**

Process wastewater from the Vent Gas Treatment final scrubber, the Batch Neutralizer, the Neutralizer Scrubber, and the Emergency Scrubber are sent to the wastewater treatment system.

Wastewater treatment may include pH adjustment, separation of trace insoluble organics, and clarification (removal of suspended particles) as required to meet local discharge requirements.

- **Recycle Water**

Certain waste water streams are segregated, collected, and fed to a recycle water treatment system within the waste water treatment plant. The recycle water is primarily used for processes such as cooling tower makeup.

- **Sanitary Sewer**

A separate sanitary sewer system will be required to service streams from lavatory locations.

- **Plant Cooling Water**

Plant cooling water is a process utility primarily used for the cooling medium for systems outside the main process areas where temperature limitations or tight control is not required.

- **Normal Electrical power**

The plant will be supplied by two independent high voltage electrical sources. The system will provide step down transformers and distribution switchgear to supply power at the appropriate voltages for process equipment. Portions of the electrical distribution system and equipment will be rated for use in a classified (hazardous) environment.

- **Emergency power**

Emergency power will be provided to critical control, safety, and environmental protection systems to maintain operation in the event of a power outage. Selected users of emergency power will be provided with an uninterrupted power source (typically local or centralized battery backup) to ensure continuous operation.

- **Uninterruptable Power**

Uninterruptable power should be considered on systems where a loss of power could result in the permanent loss of critical operating parameters or data. The Distributive Control System computer and compressor PLC's may utilize uninterruptable power.

- **Fuel Gas**

Fuel gas will be used to fire the heating units on the Trichlorosilane Production Hot Oil and Trichlorosilane Purification Hot Oil systems.

- **Plant Safety and Environmental Systems**

The following plant safety and environmental systems are required to support the polysilicon production process.

- **Fire and Hazardous Gas Detection and Monitoring**

Gas detection systems are installed in order to provide early leak detection of chemical releases. Early detection is important to prevent exposure and/or injury to personnel and to minimize

releases to the environment. For the polysilicon plant, both flammable gas and acid gas detection should be installed.

Typically, sensors within the process areas are placed in serviceable locations, away from sample points, in a quantity and density to ensure early detection. Additional sensors are placed on the plant perimeter in order to detect releases going outside the process areas and potentially off site. Gas detection inside buildings will be linked to building evacuation alarms.

- **Liquid Leak Detection and Monitoring**

Liquid leak detection in the process area containment areas are installed for early leak detection of not only process chemicals, but also cooling water and other process utility spills such as hot oil. Placement and activation of these systems must be carefully engineered so that rain water, for instance, will not cause false alarms.

- **Spill Containment and Vapor Suppression**

A spill involving one or more of the liquid chlorosilanes associated with the polysilicon process poses a significant safety and environmental risk to the production plant. Chlorosilanes are flammable and upon release will react with moisture to produce corrosive and toxic compounds. For example, TCS is consider highly flammable with a flash point of minus 28°C and carries the following additional warnings concerning release and improper handling:

- Can form explosive mixture with air
- Reacts violently with water
- Reacts with water and moisture to form gelatinous silicic acid and other corrosive acid(s)
- With water causes rapid corrosion of some metals
- May react violently with oxidants

All areas where liquid chlorosilanes or other hazardous liquids are present will be provided with non-permeable spill containment barriers suitable for long term exposure to the chemicals to be contained. The height of the barriers will be based upon the maximum quantity of liquid which may be present within the containment area.

The area of the individual containment areas will be limited to provide for localized containment and prevent spills from spreading to otherwise unaffected areas of the plant.

The containment areas will be designed, as much as practical, to direct spilled fluids to collection sumps to minimize the surface area of exposed liquid (contributing to vapor release) and facilitate collection and treatment of the fluids. All spill containment areas will be provided with spill/leak detection and alarms.

The outdoor spill containment areas will be designed to address the effects of rainwater collection within the containment area and provide for transfer of collected rainwater to the storm water collection system.

- **Storm Water**

Storm water management systems need to be designed and put in place to handle the accumulation and possible treatment of potentially contaminated rain water.

4. Site Analysis

4.1.1. Locational benefits

The proposed 20,000MT polysilicon plant will be strategically located within north head of the approved EMC Unit which is being promoted and developed by MSTPL with in APSEZ. Located in the Gulf of Kutch, it is bounded by the sea in the south & west and by Rann (salt marshlands) in the east & North.

APSEZ Mundra is also a gateway to Europe, the US, Africa and West Asia. Apart from location, competitive logistics costs to the customer's drives volumes at Mundra port.



The Mundra Port has one of the deepest water draft depths on the west coast of India, ranging from approximately 16 meters to 20 meters berth side, and up to 32 meters at the single point mooring facilities, allowing APSEZ to accommodate capsized container cargo vessels of up to 10,000 TEUs, and VLCCs and ULCCs of up to 360,000 DWTs. The port also has world's largest coal unloading facility with capacity of 60 MMT. It handled 26.76 MMT in FY'13. It has fully mechanized fertilizer cargo complex and steel yard.

APSEZ spread over 15,000 Ha out of which 6656 Ha had already been notified as SEZ in initial phase.

Multi-modal connectivity

APSEZ has multimodal connectivity and it is well connected with the region via existing National & State Highways i.e NH-8A extension & SH-6. Existing APSEZ rail network from Adipur provide connectivity to the national rail network grid which any industrial setup requires; and would help the units in the EMC to reduce the operational cost and improve accessibility to the markets. APSEZ with port facilities has a natural advantage for being the most efficient gateway for land locked hinterland of the country, comprising North and North West India.

APSEZL has developed substantial infrastructure, including two inland container depots, 86 KM of railway track and a network of roads and flyovers connecting the Mundra Port to the regional road network. It is also connected by a railway line that is capable of handling double stack containers to Bathinda and the northern hinterland of India, and by branch lines to the Delhi-Mumbai freight corridor. Its two single-point mooring facilities are connected by pipeline to petroleum refineries in Panipat, Haryana and Bhatinda, Punjab and the regional pipeline network, and port's liquid cargo storage and handling facilities are connected by POL pipeline to Bahadurgarh, near Delhi.

Port connectivity

Mundra Port , India's largest private port is the integral part of APSEZ, has a deep draft which enables large vessels like Panamax and super post Panamax to dock alongside its berth.

The port has associate facilities like warehousing, container freight station (CFS), storage tanks etc. to add value to logistics needs.



Road connectivity


APSEZ is connected to the National & State Highways Road network by NH-8A Extension and SH6 & SH 48. Broad four-lane roads ensure efficient movement of road traffic to and from the port. Four lanes ROB (Rail over bridge) in the SEZ Area of port ensure that the various modes of transportation do not impede each other's movement. APSEZL has developed road network within the SEZ with efficient designed for predominantly freight traffic, in order to provide high-level access to the various zones of APSEZ area like ports, warehousing, CFS, industrial establishments. The major spines run east-west and north-south of APSEZ area connected directly to State highways & National Highways via SH.

Rail connectivity

APSEZ is well connected with national railway network with the exiting BG link with Ahmedabad passing through Gandhidham and Viramgam. This has been facilitated by commissioning the 117 kms BG railway line and includes APSEZ and Adipur connectivity, situated at a distance of 8kms from Gandhidham. APSEZL has developed and operates a private 64 KM double track railway line – largest private railway link in the country between Mundra and Adipur, connecting Mundra Port to the Indian Railways network at Adipur, Gujarat. It has also constructed and operates a 22 KM railway line through Mundra SEZ, connecting Mundra Port to Mundra-Adipur railway line and nearby power plants.

Air connectivity

Fully functional commercial airports are located at Bhuj (about 60 km) and Kandla (About 50km) from Mundra SEZ. A newly constructed airstrip at Mandvi is at a distance of 40 km. APSEZL has its own Airport at an approximate distance of 14.5 KM from the main port location. It is a licensed airport in 'Private Category' with Air Traffic Control (ATC) operated by the Airports Authority of India (AAI). The APSEZL airport has potential to develop commercial modern state-of-the-art international airport capable of serving requirements of cargo hub center, MRO facilities, passenger/baggage handling facility, fuel refilling, aprons, hangers for various kind of aircrafts etc.

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4.1.2. Logistics infrastructure

APSEZL also has logistics division which helps in integrating ports with industrial business hubs. It provides logistic services through its wholly owned subsidiary Adani Logistics Ltd. It currently owns and operates six trains of container cars across India. It also operates two rail linked Inland Container Depots (ICD) at Patli, Punjab and Kishangarh, Rajasthan. ICD Patli is a multi-functional logistics park, the single largest in National Capital Region (NCR). Company has developed two container freight stations at Mundra and Hazira.

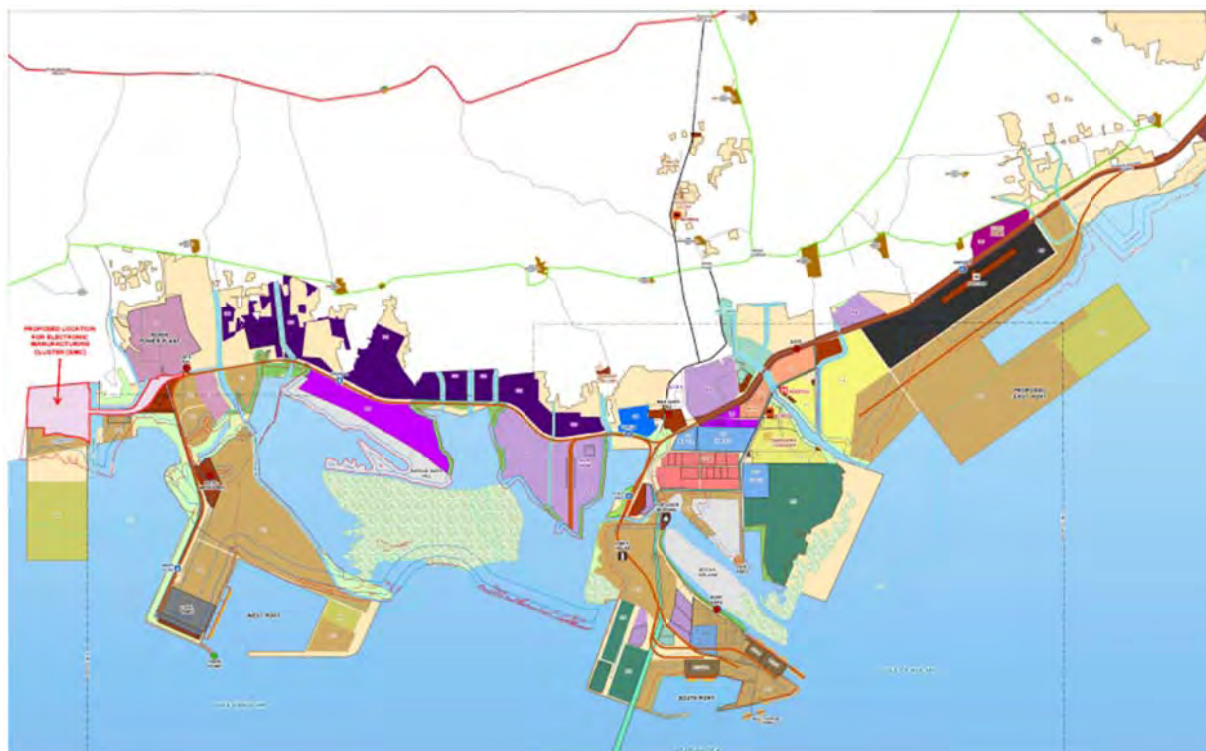


Figure 18: EMC facility within Mundra SEZ

The proposed location of MSL's facility within Mundra SEZ is having advantage of existing well established connectivity and accessible to the nearby region via road, rail and air.

5. Proposed Infrastructure by EMC

5.1.1. Basic infrastructure

a) Internal roads network

The entire road network is divided into four corridors to access any designated area within the entire EMC facility.


- Main arterial road comprising of 40 meter, 30 meter, 18 meter, 12 meter ROW approximately 12550 **meter** four lane/two lane carriageway
- Provision of street light is maintained for the road. The pavement will be designed for heavy traffic movement in arterial roads and light traffic movement in service road
- Pavement marking and road signs will be provided as per standard practice and project specific requirement
- The roads within EMC shall be of flexible pavement road (preferably) i.e. bituminous road. Wherever required, rigid pavement concrete road would be provided. The pavement thickness shall be designed to cater to the desired traffic intensity estimated approx. of 350 to 400 trailers per day. This traffic intensity is expected within EMC.
- Four lane bituminous roads with shoulders and RCC drains will be provided to access all parts of the EMC area. In addition to four lane road, the two lane roads will also be provided with divider as per IRC norms. All storm water drains will be RCC rectangular drains. This would be open at top except at road crossing where precast concrete cover slab will be provided. Kerb Stones are intended to separate surfaces providing physical or visual delineation and containment of the pavement construction and also on either side of roads.



Fig 25. Typical 2 Lane Road with Median

b) Landscaping and Green Belt development

The proposed landscaping and green belt development plan will have an objective such as prevention of land degradation due to activities during construction phase; enhancing the forest cover for increasing the biodiversity of the region; providing aesthetic value to the

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project area and enhancing the ecological equilibrium of the area; and to a large proportion in combating soil erosion.

The development of green belt protects the natural flora and fauna of the area and provides cleaner, improved air quality. The greenbelt development plan aims at overall improvement in the environmental conditions of the region. Approach roads shall be covered under this plan by providing avenue plantation on both sides or at median of the road. Wherever required, guards and barbed wire fencing will be installed for protection of the plants. In addition there shall be roadside plantation in two rows on either side of new roads around the project area and also along existing roads. To maintain the plantation, organic manure and arrangement of water will be done.

c) Street lighting

11 kV/415V Compact Sub Stations (CSS) are proposed to cater power to street light and parking area. LED type lighting fixtures are proposed to save power. Tubular 9m height with single arm/double arm lighting pole are proposed to illuminate internal roads within EMC area. LED lights of 60 W are proposed for Street lighting purpose. Solar Street Lights have been considered over normal street lights due to the following advantages:


- No line voltage, trenching, or metering
- No power outages
- Battery backup for cloudy or rainy days
- Solar street lights are independent of the [utility grid](#). Hence, the operation costs are minimized.
- No maintenance except for the battery: Solar street lights require much less maintenance compared to conventional street lights.
- Since external wires are eliminated, risk of accidents is minimized.
- Environment friendly - 100% powered by the sun, solar panels reduce fossil fuel consumption, eliminating pollution.
- Separate parts of solar system can be easily carried to the remote areas

The solar street lights shall have the following components:

- Solar Panel
- LED Lighting Fixture
- Rechargeable Battery
- Controller
- FRP Pole

d) Storm water drainage system

Storm Water drainage system within EMC shall be designed considering rainfall intensity of 75mm/hr and for 1 hour duration. The cross section and longitudinal slope of drains shall be designed such that the velocity of water shall be equal to or more than self-cleaning velocity. The proposed drainage design shall be revalidated from Indian Metrological data.

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RCC rectangular drains shall be provided. At road crossings, cross drainage work either of RCC box culvert and/or pipe culverts of suitable diameter and class shall be provided.

e) Boundary wall

The boundary wall will be provided on the periphery of the EMC area for only 511.34 acres and the rest additional area would be demarcated along the periphery of the EMC without any boundary wall

- Boundary wall shall be of 2.4m high and constructed with pre-stressed precast panels.
- The wall panels are designed for 2133 mm (L) X 50 mm (B) x 300 mm (D) , 7 no's
- Vertical post with pre-stressed precast concrete will be provided at regular interval.
- The foundation shall have 250 dia piles 6 m depth at 2.253 m³
- The column sections are designed for 200 mm X 200 mm X 2700 mm high
- Metal angle post with RBT wire will be provided over boundary wall as additional protection.
- The total length of boundary wall is around 6.125 kms.



Fig 28. Typical Boundary Wall

5.1.2. Essential infrastructure

To ensure that EMC facility has seamless access to essential basic services like water, power, sewerage and effluent effectively, it is proposed that the essential services be addressed in separate such as those required at the unit level and at the facility level. The requirements for the EMC facility shall be met by the infrastructure already available within the SEZ facility and such details are provided in the subsequent sections. Essential services required by respective units shall be designed and built by respective units as per their needs; however MSTPL will facilitate the requirement for power, water, ETP and other utility needs as when required.

a) Primary power distribution

The power infrastructure is planned to meet the requirements of EMC facility. Initially 11 kV and 66 kV voltage levels are proposed as receiving voltage from local distribution licensee *MPSEZ Utilities Pvt. Ltd. (MUPL)* and a 220 kV substation is envisaged for meeting the future requirement of the anchor and other units. In this regard, MSTPL has already filed an application with MUPL on 07th August 2015 to avail power supply at 11 kV and 66 kV voltage levels.

b) Water Supply

The overall water distribution infrastructure is planned to handle the water requirement estimated at 40 MLD. The initial infrastructure is planned to meet the EMC related water requirements estimated at 2 MLD. Desalinated water to the EMC facilities will be supplied from the existing 40 MLD desalination plant with suitable capacity augmentation.

- Desalinated water will be stored in RCC tank (partly below and partly above ground located within EMC facility area) of capacity 5000 cu.m. This tank capacity is derived considering buffer storage

of 3 hrs of total process water requirement and one hour of total pumping capacity of fire water in line with TAC requirement i.e. 300 cu.m water storage for fire protection system.

- The desalinated water tank shall be designed as per IS 3370. This also includes the water requirement for fire protection systems.
- From the storage tank, three (3) vertical turbine pumps (2W+1S) of capacity 840 m³/hr at 40 mWC head will supply / distribute the desalinated water to various Units/ facilities located within the EMC facility from the storage tank.. The vertical pumps capacity is arrived based on 40 MLD of process water requirement for the EMC. Each facility will have their storage & further treatment & distribution network within their Unit.
- HDPE piping will be used for the water supply system considering high chloride content in desalinated water. This will eliminate internal corrosion in water supply piping.
- Water supply pipe is routed from existing power plant desalination plant to EMC complex via. Water tank located near Main Receiving Sub-Station (MRSS) which is approximately 5 Kms and the water pipe will be routed underground.
- MSTPL is also providing the internal pipeline distribution infrastructure for all the Units located within the EMC facility.
- The water shall be pumped in to the ring main to different units using piped water network.

c) Effluent storage and collection


Effluent/sewage shall be considered as 80% of the water supply. Effluent generated from the individual Units located within EMC facility will be treated by the individual Units and thereby meeting the environmental regulations stipulated by Central Pollution Control Board (CPCB) and State Pollution Control Board (SPCB) norms/regulations.

- Treated effluent from all the Units located in EMC complex will be transferred to common collection RCC sump having approx. 5 hrs. storage and will be located within EMC complex.
- The storage tank capacity of effluent is about 7000 cum. From common collection sump, treated effluent will be pumped to outfall channel through 3nos. (2W+1S) pumps vertical turbine pumps of capacity 700 cu.m. /hr and rated discharge head of 30 mWC.
- Effluent discharge shall be continuous .Treated Effluent meeting the relevant norms will be discharged to outfall through underground HDPE piping. The typical specifications of the HDPE piping are given below
 - Pipe Size : 500 NB
 - Pipe MOC : HDPE
 - Pressure Rating : PN 6
 - Grade : PE 80
 - Design Standard : IS 14333
- In case the discharge norms are not met by individual units, then there will be a provision for retreatment of effluent at the individual units

d) Sewage Treatment System

The sanitary waste streams from toilets of different buildings will be conveyed either by gravity or by pumping to the main sewage receiving sump cum lifting station. Final treated sewage will meet the norms of Environment. Sewage will be transferred to common sewage receiving station through sewage network which will be covered under civil scope.

STP capacity : 2 X 60 KLD (Packaged type)

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Type : Aerobic

Raw Sewage Characteristics:

- BOD₃ 27°C : 350 mg/l
- COD : 500 mg/l
- TSS : 500 mg/l
- Fecal Coliform : 10⁶ - 10⁷, Number per 100 ml

Treated Sewage Characteristics: (Deleted)

- BOD₃ 27°C : 30 mg/l
- COD : 100 mg/l
- TSS : 5 mg/l
- pH : 6.5-8.5
- Fecal Coliform : <1000, Number per 100 ml
- Residual Chlorine : 0.5 mg/l

Treated sewage water will be used in horticulture.

e) Fire protection service

The Fire Detection and Protection System provide a means to control fire hazards in order to provide life safety and minimize property loss in the event of fire.

Water for the fire protection system is supplied from a water storage tank which will have dedicated water storage for fire water supply system. The system consists of water storage tank, main fire water pumps, jockey pumps and yard piping. The fire water mains are provided with necessary sectional isolation valves to permit isolation of a particular section for maintenance while keeping the rest of the system operational. Fire hydrants are installed along the fire main in accordance with TAC recommendations. External Hydrant System shall cover following facilities:

- Admin Building including auditorium and conference facility
- Gate Complex /Security building
- Fire Station
- Canteen
- Training Center
- Warehouses
- Switchyard


6. Project Schedule & Cost Estimates

6.1. Project Schedule

The Project Company will establish Project Management Systems for close monitoring of the Project for quality, schedule and environment. The project will cover activities on all fronts including conflict resolution, drawing necessary expertise and support from Implementation Consultants on regular basis.

A high level schedule of project is provided below:

		Q3-2016			Q4-2016			Q1-2017			Q2-2017			Q3-2017			Q4-2017			Q1-2018			Q2-2018			Q3-2018			Q4-2018			Q1-2019			Q2-2019		
Task Name	Duration [Months]	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
Kickoff Meeting	1																																				
Complete Contract for Silane	1																																				
BE Basic Engineering Package	5																																				
FE Basic Engineering Package	1																																				
Integration Basic Engineering Package	3																																				
BE Proprietary Equipment Procurement	14																																				
FE Proprietary Equipment Procurement	13																																				
Detailed Engineering	12																																				
Site Preparation	4																																				
Non-proprietary Equipment Procurement	13																																				
Bulk Materials, CS Procurement	12																																				
Underground	3																																				
Civil - Foundations, Piling & Supports	6																																				
Electrical Substation & Motor Control Center	5																																				
Structural	5																																				
Set Equipment	7																																				
Piping	7																																				
Electrical to Equipment	6																																				
Instrument Wiring	7																																				
Commissioning	3																																				
Startup	2																																				
Ramp to Capacity	6																																				

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6.2. Project Cost

The approximate project cost is provided below

(In Rs. Crores)	Cost
Particulars	
Land & Site Development	290
Building Cost	600
Equipment and Infra Cost (including EPC)*	5300
Research Equipment	50
Preoperative Cost	150
Contingency @ 5%	320
IDC Expenses @ 10%	671
Total Project Cost	7381