Local Made-Up and Mid Stream Contents for Crystalline Silicon PV Industry

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SOLAR SYNERGY

Glimpse of the Future: the Solar City

Agenda

- Understanding Silicon
- Value Chain of Crystalline Silicon PV
- Silica (SiO2) to Metal Grade (MG)-silicon.
- MG-Silicon to Solar Grade Silicon (SoC) Feedstock.
- SoG Feedstock to Ingot.
- Ingot to Wafer
- Wafer to Cell & down the lines
- Marketing prospect
- Q&A Session

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Understanding Silicon

- Silicon is the second most common element on earth (after Oxygen).
- Never occurs free in nature, but only in combination with oxygen, in the form of Quartz rock or Silica sand.

	Metal Grade Silicon (MG-Si)	Solar Grade (SoG-Si)	Semiconductor Grade
% Pure SI	98.5%-99.0%	99.9999% (6N)	99.9999999%(9N)
Impurity (PPM)	15,000 – 10,000	0.5	0.0005

- Metallurgical grade silicon (MG-Si) – 98.5% pure silicon used in metallurgical applications.

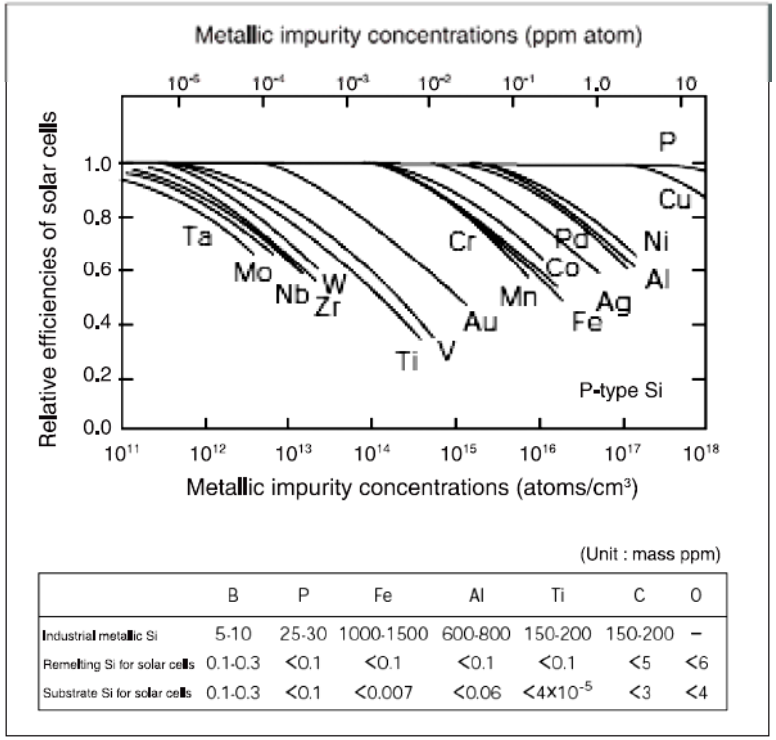
- Solar grade silicon (SoG-Si) – 99.9999% pure silicon; adequately to produce Multicrystalline solar cell

- Semiconductor Grade – High purity silicon, usually over 99.999999% in purity; produced mainly by the capital intensive Siemens process.

Impurities

- Impurities influencing the single crystal silicon solar cell performance and their concentrations found in various silicon raw materials.

- The primary impurities in solar silicon are Phosphorus and Boron, also with number of impurities such as Iron, Aluminium, Titanium, Carbon and Oxygen must be removed from MG-Si in order to satisfied requirements of SoG-Si.



(Unit : mass ppm)

	B	P	Fe	Al	Ti	C	O
Industrial metallic Si	5-10	25-30	1000-1500	600-800	150-200	150-200	–
Remelting Si for solar cells	0.1-0.3	<0.1	<0.1	<0.1	<0.1	<5	<6
Substrate Si for solar cells	0.1-0.3	<0.1	<0.007	<0.06	$<4X10^{-5}$	<3	<4

" Proceedings of the 13th IEEE Photovoltaics Specialists Conference (New York: IEEE, 1978), p.490"

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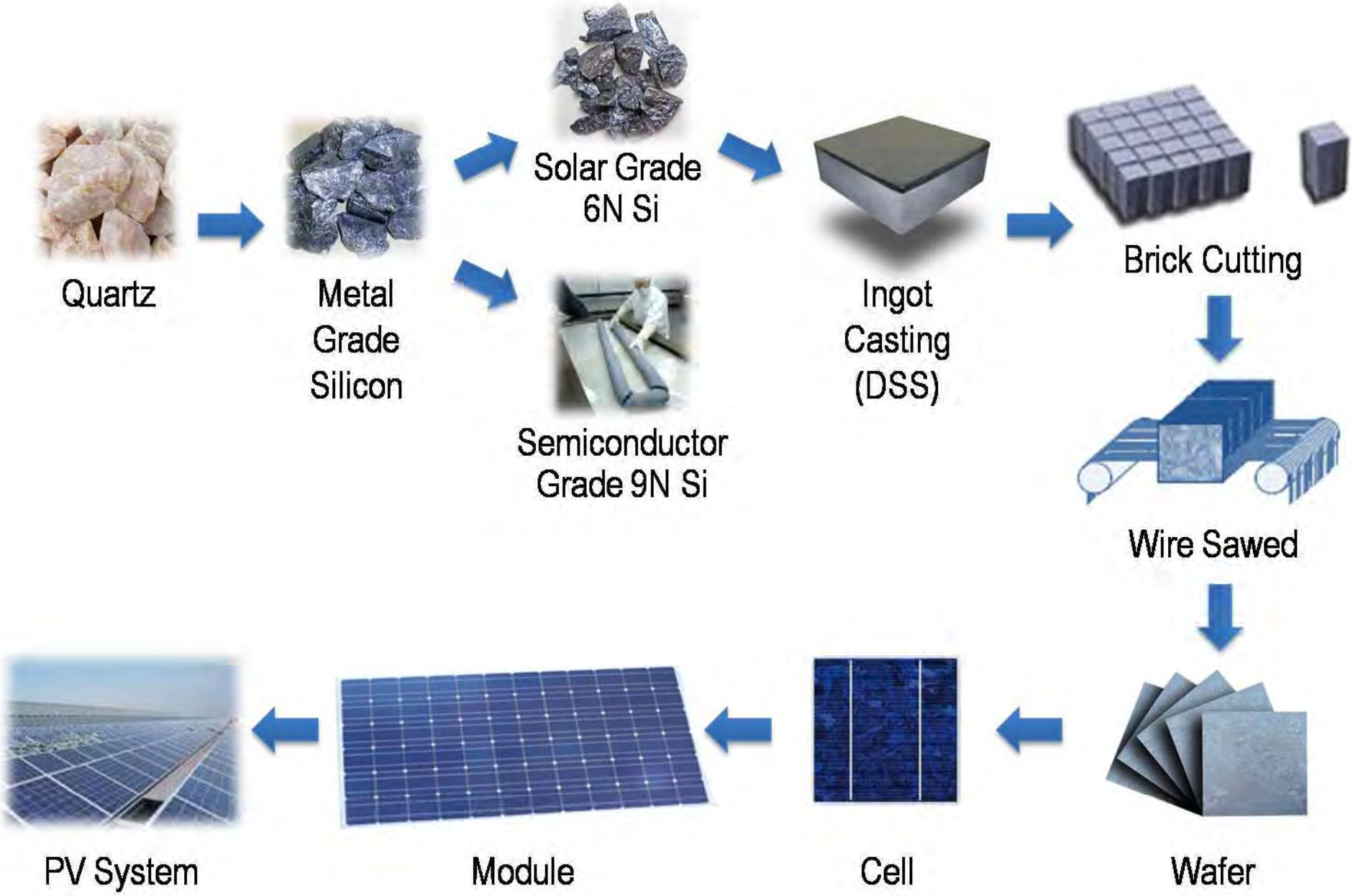
Value Chain of Crystalline Silicon PV



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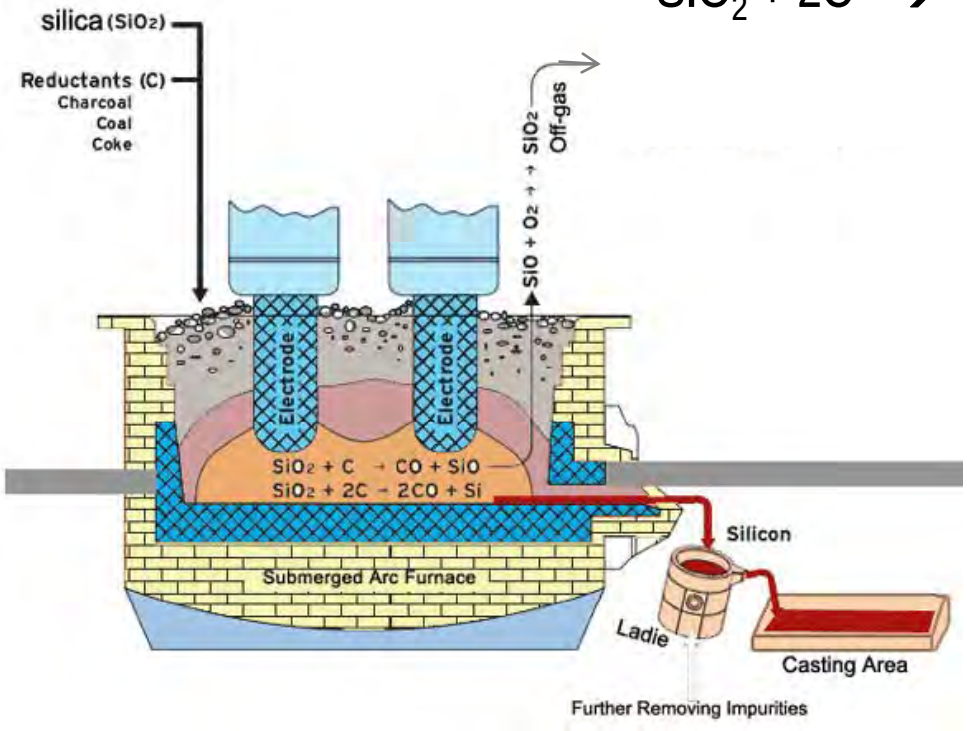
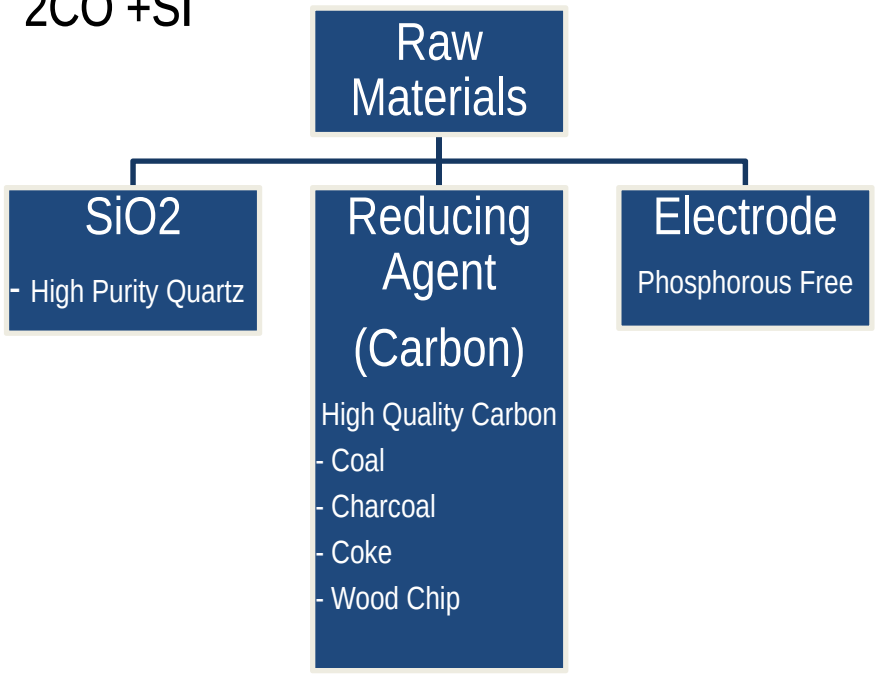
Refining of Quartz into Metal Grade Silicon

Carbothermic Reduction Process

$SiO_2 + C \rightarrow CO + SiO$

$SiO_2 + 2C \rightarrow 2CO + Si$





Challenges: To reduce Phosphorous (P) and Boron (B) impurities in MG-Si.

- Phosphorous including : 45% in SiO_2 , 45% in Carbon, 10% in Electrode
- Boron including : 39% in SiO_2 , 61% in Carbon

Target is to have lowest level of impurities as possible, especially for B (<7 ppmw) and P (< 25 ppmw)

MG-Silicon to Solar Grade Silicon (SoC) Feedstock

Impurities in MG-Si and Refining Target (ppmw)

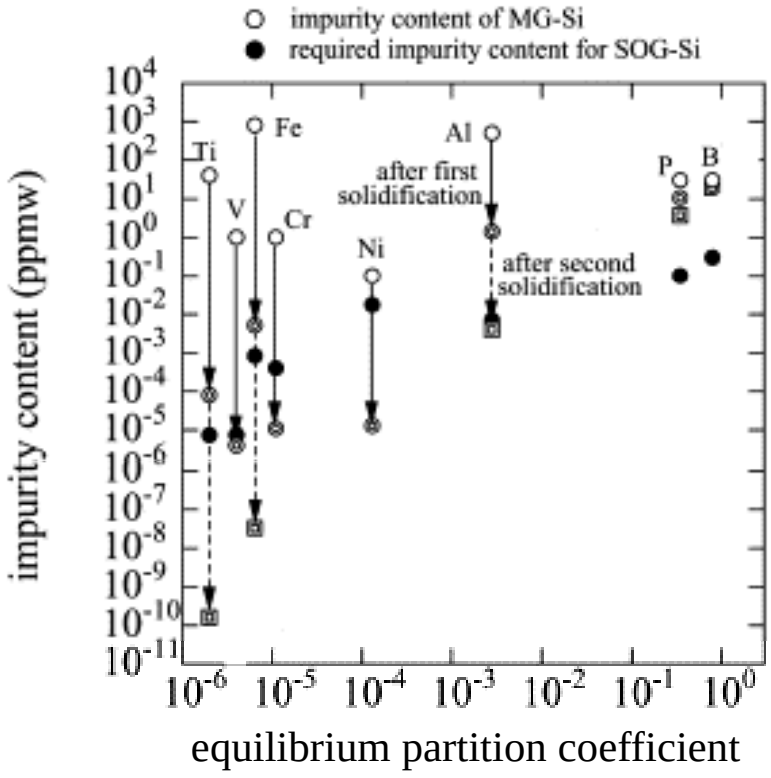
	P	B	Fe	Al	Ti	C
MG-Si	25	7	1,000	800	200	5000
SoG-Si	<0.1	0.1~0.3	<0.1	<0.1	<0.1	<0.5

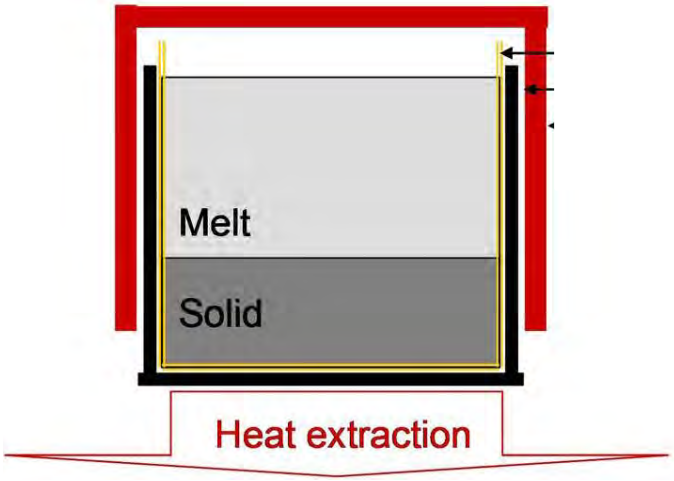
Solar Synergy developed a metallurgical processes, possible to produce high-purity SoG-Si from metallurgical grade silicon.

- **Directional Solidification**: Removal of Metal Impurities in Molten Silicon.
- **Electron Beam**: Evaporation of Phosphorus in Molten Silicon in Vacuum.
- **Plasma with Reactive Gases System**: Boron Removal in Molten Silicon.

Removal of Metal Impurities in Molten Silicon by Directional Solidification

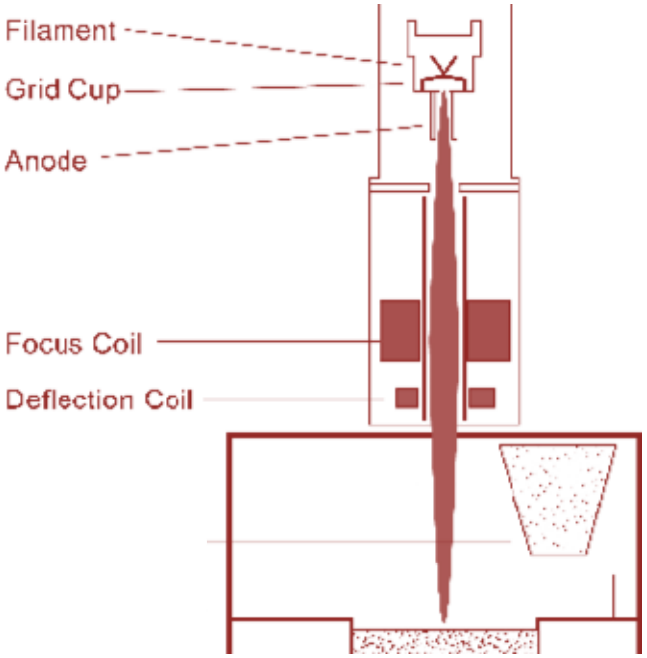
- Effectives mean of removal metallic impurities.
- “Equilibrium partition coefficient” of metals between liquid and solid phase are small.
- Impurity with low equilibrium partition coefficient tends to stay in liquid region. For Phosphorous (0.35) and Boron (0.8) are difficult to remove.



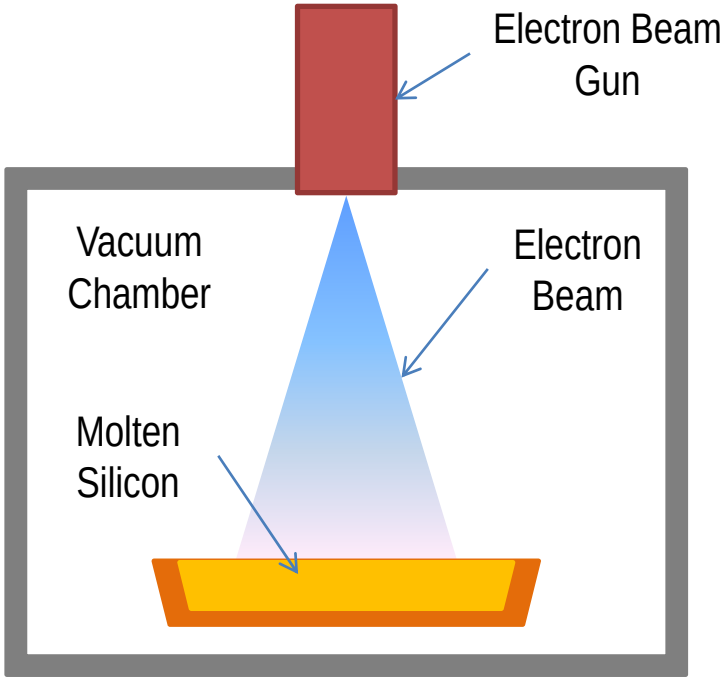


Evaporation of Phosphorus in Molten Silicon by an Electron Beam Irradiation Method

- Equilibrium partition coefficient of Phosphorus is high (0.35), directional solidification is not effective.
- Phosphorus could be remove by evaporation, taking advantage of its high vapor pressure.
- Utilizing Electron Beam (EB) melting dephosphorisation in vacuum chamber, with proprietary technique to manipulate surface flow.

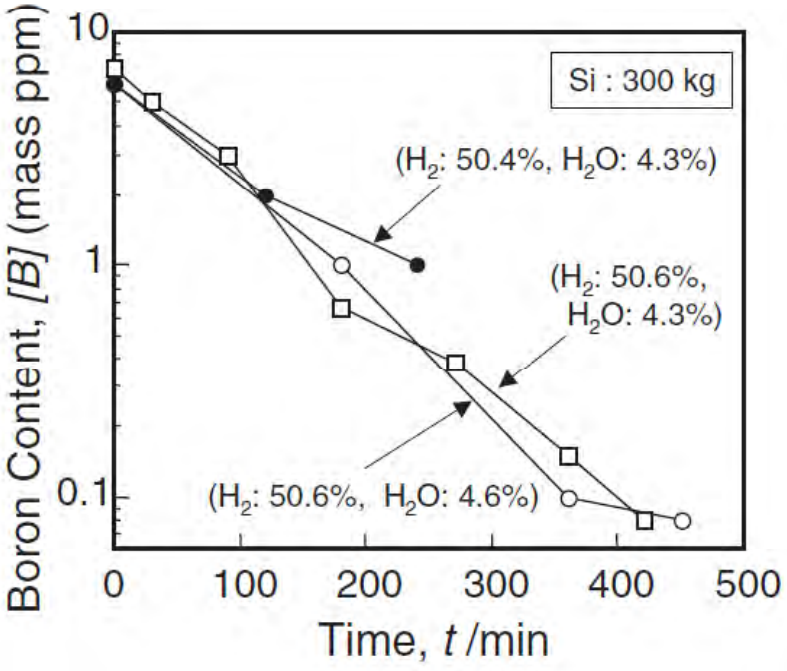


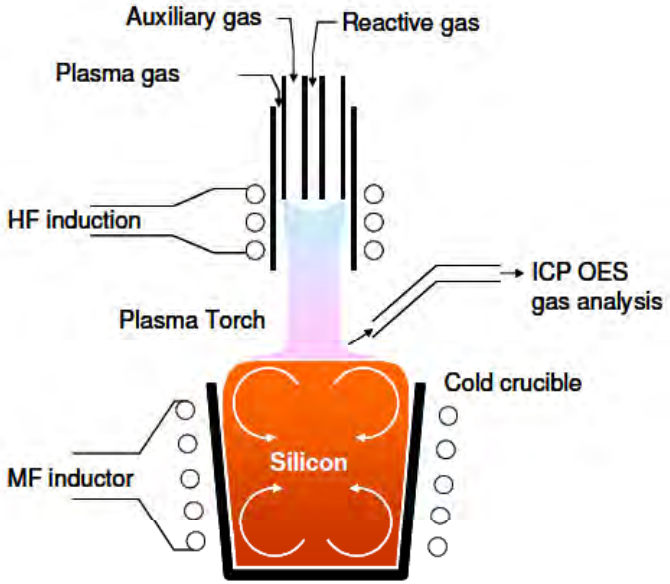
Electron Beam Gun Diagram



Boron Removal in Molten Silicon by Steam-Added and Reaction Gases Plasma

- Boron is difficult to remove by either Directional Solidification or Electron Beam Vaporization, because Equilibrium partition coefficient is at 0.8 with low vapor pressure similar to iron and titanium.
- Oxidation is possible to remove boron from molten silicon, with reactive gas plasma. Increase surface temperature by plasma heating also increase effectiveness of the process.

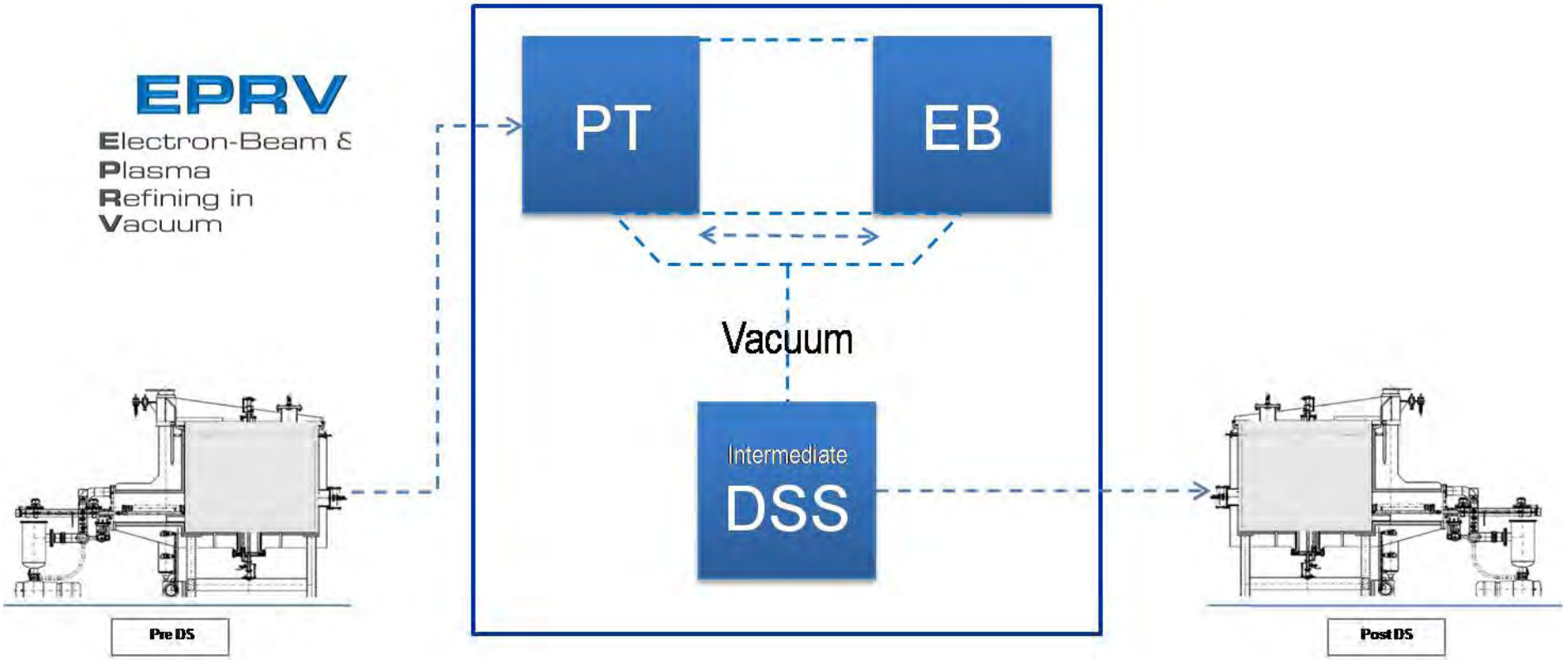




MG-Silicon to Solar Grade Silicon (SoC) Feedstock

Our Goals

Minimized Energy Consumption, Reduce Loss between Process and Simplifying Process Continuation, Clean & Non-toxic Processing



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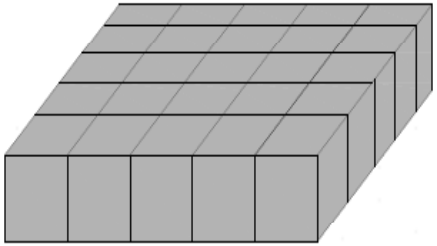
SoG Feedstock to Ingot

- Directional Solidification System (DSS) are stand-alone furnaces for melting and crystallizing of solar-grade silicon into an ingot for subsequent processing into wafers for solar cells.
- Require large dendrite crystal of silicon. Cycle time approx. 50 hours.

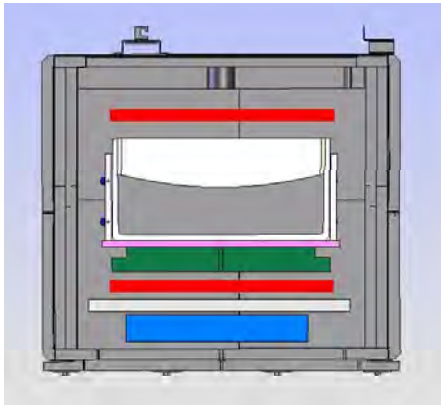
Fused Silica Crucible with Silicon Nitride Coating



Gen 5: 5x5 Bricks
400-450 kg

Ingot

Crucible Filled with Solar Grade Silicon Feed Stock



DSS with 2 Sided Heaters Top and Bottom

After Melting and Crystallization in Vacuum Furnace

SoG Feedstock to Ingot – New Quasi-mono Technology

Alternative for DS Multi-Crystalline and CZ Mono-Crystalline Production

CZ process

- Higher Efficiency
- Higher Cost
- Time Consume

+

DS Casting

- Lower Efficiency
- Lower Cost
- Less Time Consume

=

Quasi-mono Technology

"Best of Both World"

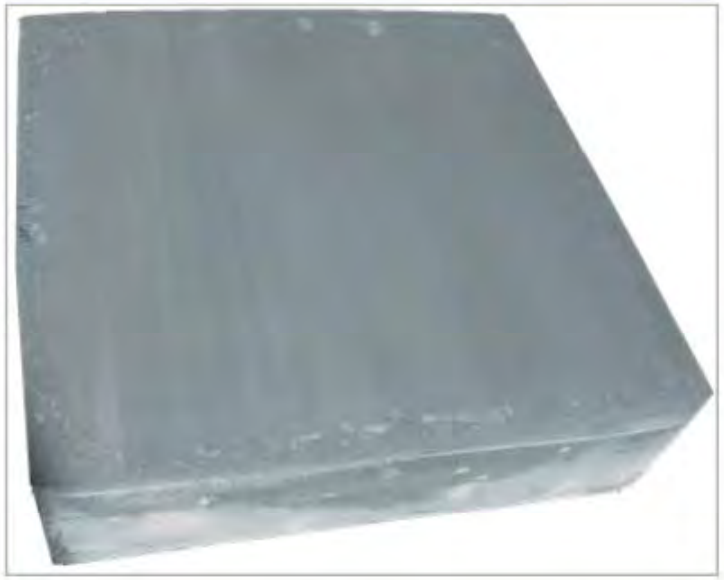
- Production of square mono-crystalline DS ingots, wafers and cells with quality close to CZ method at cost close to DS Casting.

- High Efficiency
- Low Cost
- Less Time Consume

SoG Feedstock to Ingot – New Quasi-mono Technology

Optical Appearance of Quasi-mono Ingots

Quasi-mono Ingot



Cross Section of Gen5 Quasi-mono Ingot

Quasi-mono
Bottom Plate

- Reproducible production of Gen5 Quasi-mono ingots
- > 80% mono-crystalline portion
- All inside brick full mono-crystalline
- Corner bricks have significant multi-crystalline domains

SoG Feedstock to Ingot – New Quasi-mono Technology

Full mono Crystalline Wafer

Mono Area with Small Amount of Multicrystalline Area

Mono Area with Surrounding Multicrystalline Area

Classic Multicrystalline Wafer

Quasi-mono Crystalline Wafer

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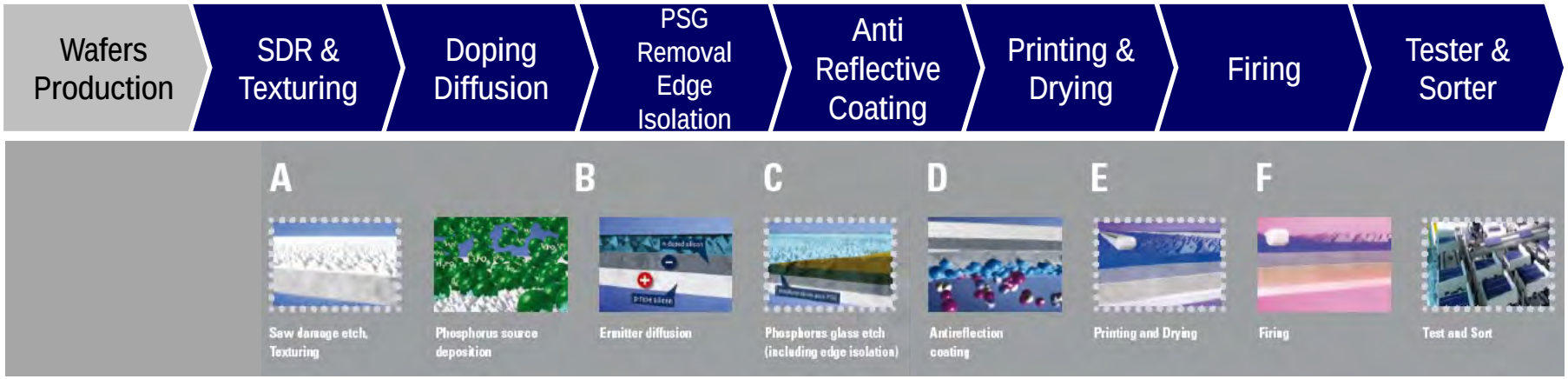
Wafer to Cell & down the lines

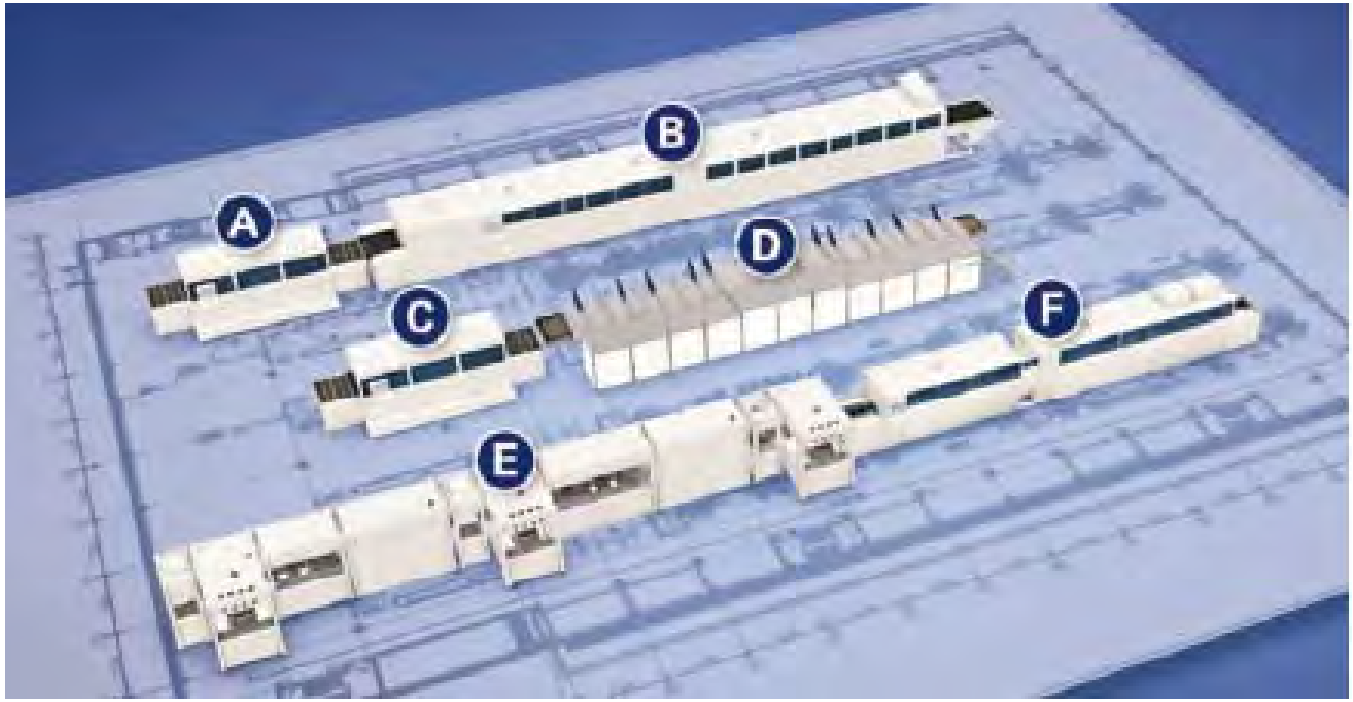
Wafer Line

Mono / Multi Silicon Production	Cropping	Block Cutting	Grinding, Gluing	Wafer Slicing	Pre-Clean Separating Wafers	Final Cleaning	Measuring & Sorting Wafers

Wafer to Cell & down the lines

Cell Line

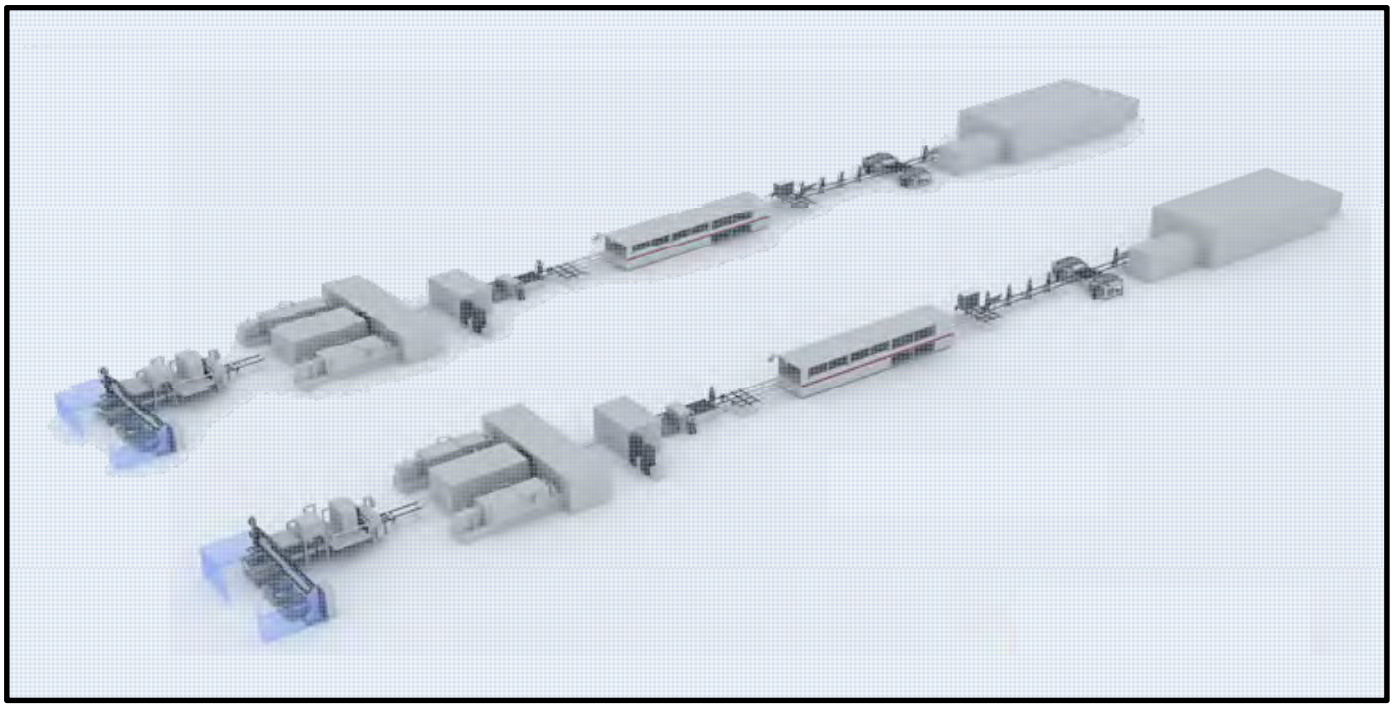




Wafer to Cell & down the lines

Module Line

Cell Production → Glass Handling & Washing → Cell Soldering → Inter Connection → Lamination → Edge Trimming → J-box → Framing → Testing



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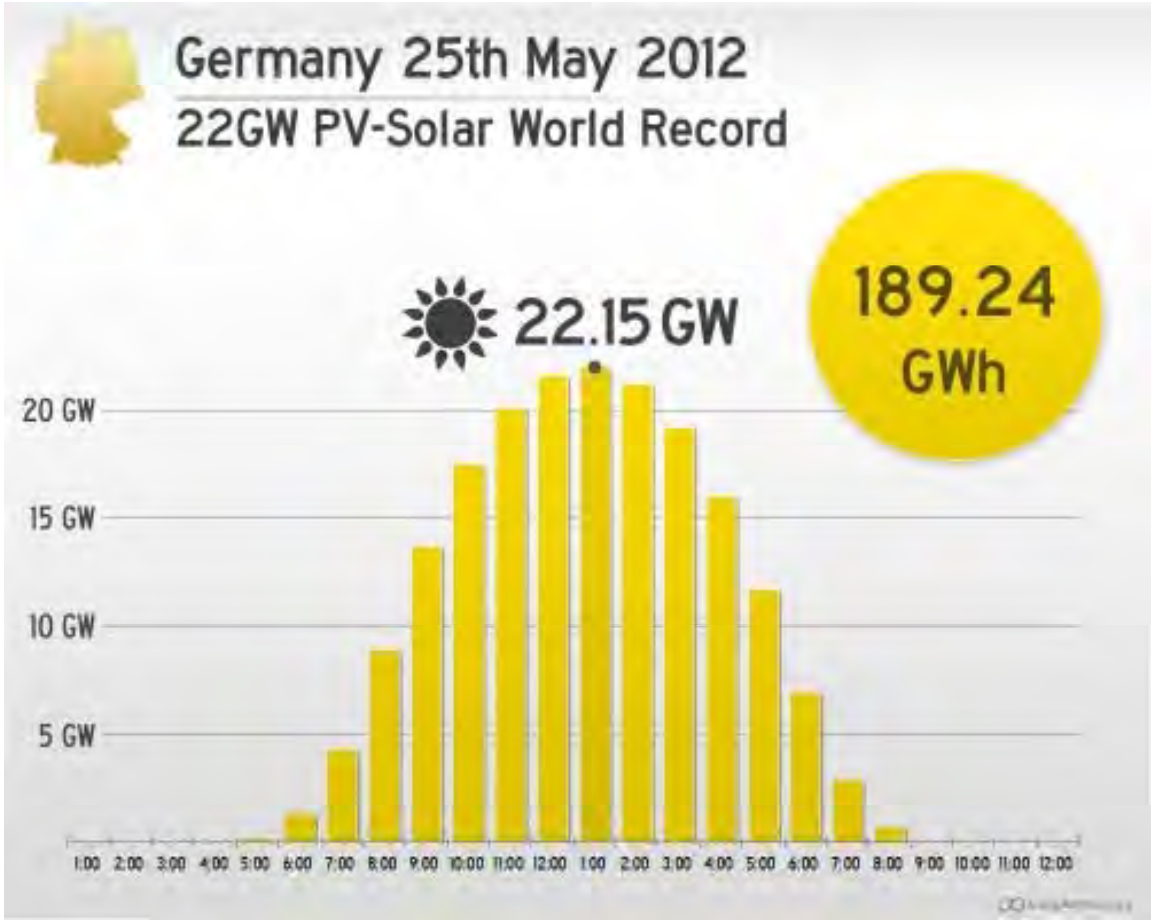
Marketing Prospect

- Reference Germany as present time
- Germany by mid 2012, solar plants' electricity production reach 22 GW or 22,000 MW equal to 20 Nuclear Plants



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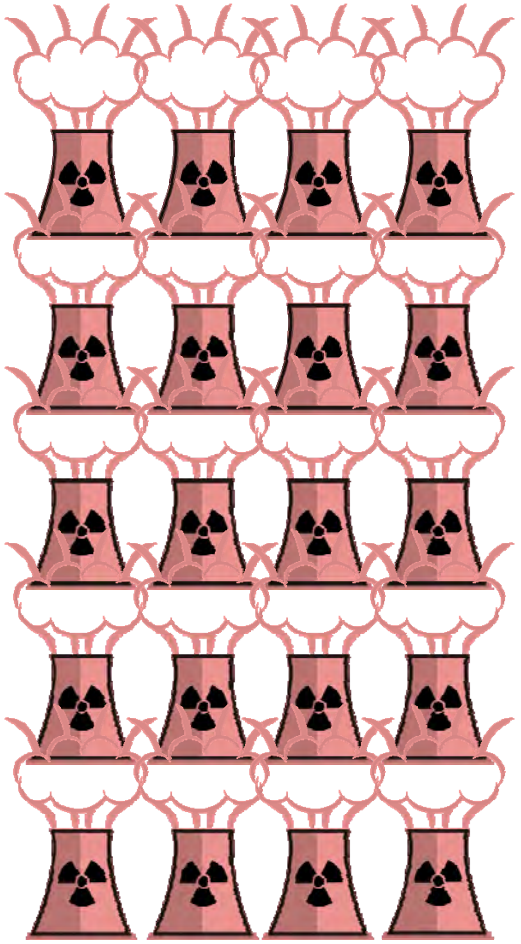
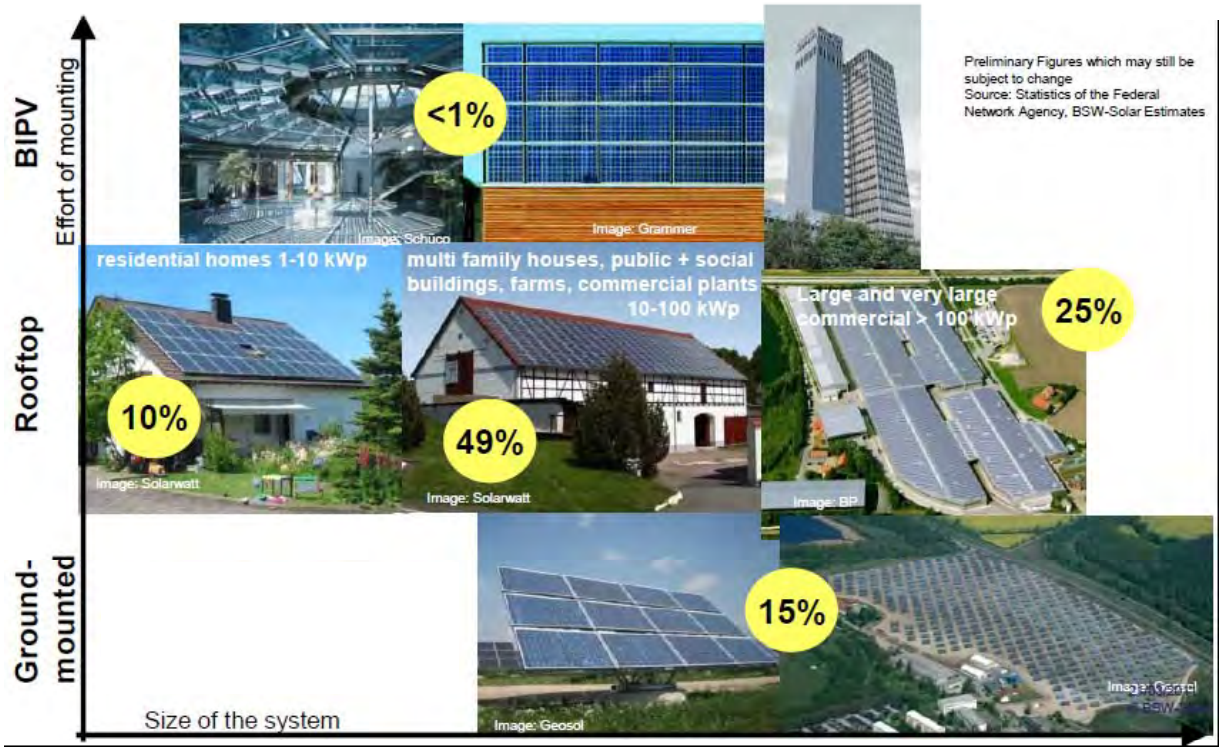


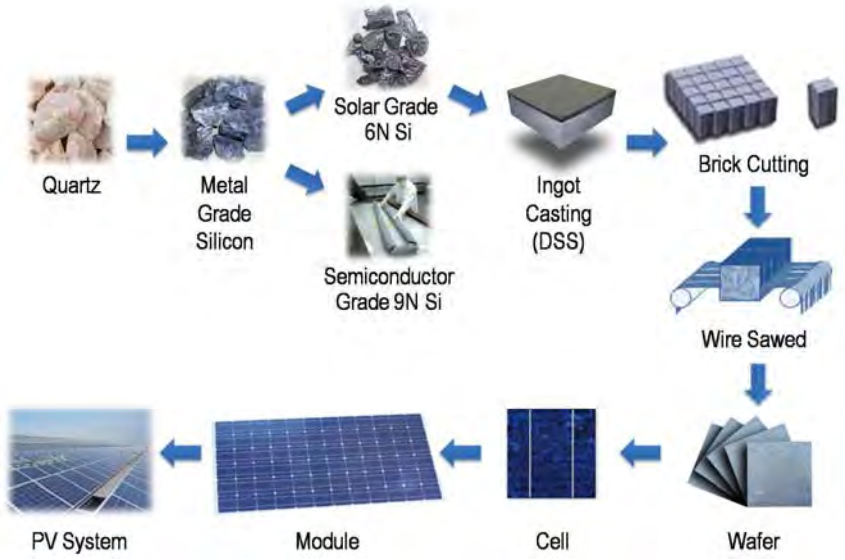
Marketing Prospect



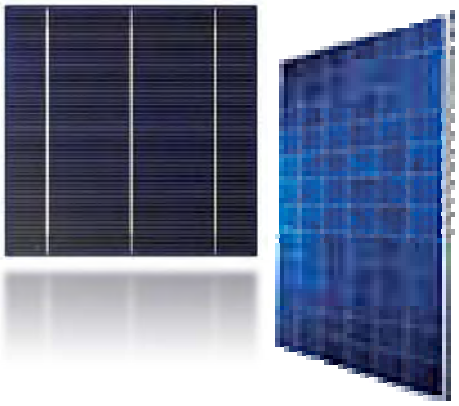
- Our aim is to concentrate in Rooftop installation where by the residential and commercial customers are our targets with affordable installation cost by available local services team.

- For small Solar Farms (VSPP) should be our secondary choice.

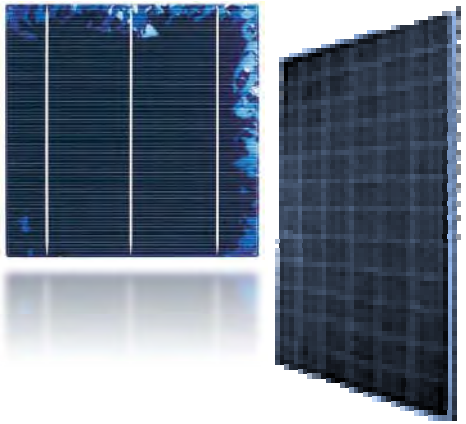
Variety of Choices



Multicrystalline (Poly)



Quasi-mono



Monocrystalline

SOLAR SYNERGY

Are We Ready for AEC 2015?

Time is running up!!

Thailand's local solar industry shall be promoted and ready for upcoming challenges, energy policy should be cleared and supportive to local manufacturers, when we open market to The ASEAN Economic Community (AEC) in 2015

SOLAR SYNERGY


“Clean Energy from the Sun,
is the Future Energy for Our Country”

Thanks for your attention!

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