HPQ – SILICON
RESOURCES

# *Becoming the World's Leader in Producing Low Cost Green Solar Grade Silicon Metal*

***AGM - June 21, 2017***

***TSX-V: HPQ***

# DISCLAIMERS

## This presentation includes certain "forward-looking statements"

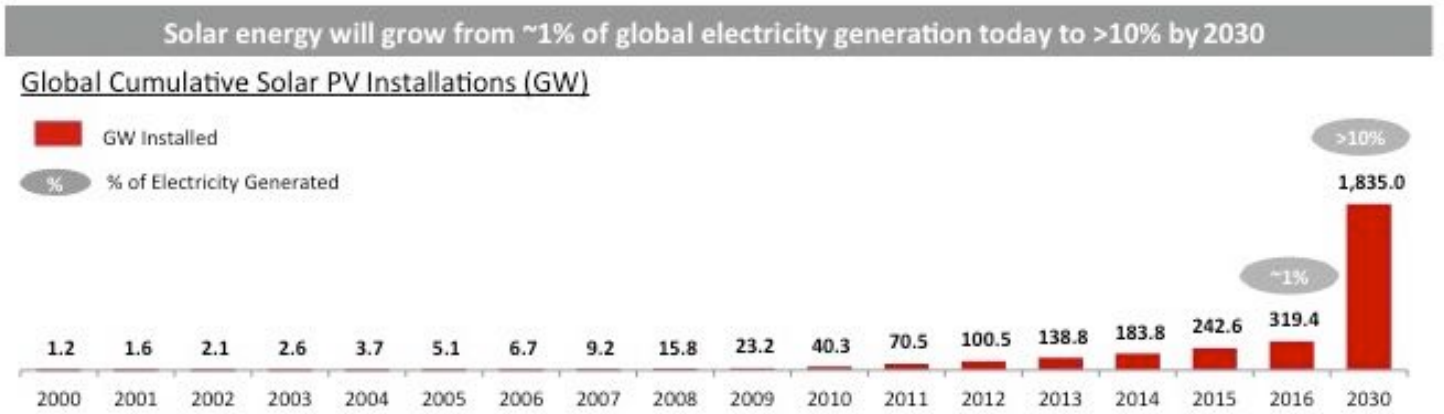
All statements, other than statements of historical fact, included herein, including, without limitation, statements regarding future plans and objectives of the company, are forward-looking statements that involve various risks, assumptions, estimates and uncertainties, and any or all of these future plans and objectives may not be achieved. The terms SGSI, Solar Grade Silicon and Polysilicon are used interchangeably and refer to high purity silicon used in the solar panel industry, with 99.999% purity, also referred to as "5N".

These statements reflect the current expectations or beliefs of HPQ-Silicon Resources Inc. ("the Company") and are based on information currently available to the Company. There can be no assurance that such statements will prove to be accurate, and actual results and future events could differ materially from those anticipated in such statements. All of the forward looking statements contained in this presentation are qualified by these cautionary statements and the risk factors described above. Furthermore, all such statements are made as of the date this presentation is given.

An investment in the Company is speculative due to the nature of the its business. The ability of the Company to carry out its plans as described in this confidential presentation is depending on obtaining the required capital. There is no assurance that the Company will be able to successfully raise the capital required or to complete each of the growth initiatives described. Investors must rely upon the ability, expertise, judgment, discretion, integrity and good faith of the management and Board of the Company.

# Investment Environment

## *HPQ IS DEVELOPING THE Disruptive Technology in GREEN Solar Grade Silicon Metal (SoG Si) required to meet the growing demand for Solar Energy*




Source: Canadian Solar

## Each new GW of Capacity requires 5,000 tonnes of SoG Si

- Reaching 10% goal represent 540 K TPA annual demand for SoG Si
- Worldwide economically viable supply capacity is only 350 K TPA
- Building new supply Capacity is subject to significant Barriers to Entry
  - Depending on process CAPEX cost for 10 K TPA Plant Range from US$ 700 M to US$ 1 B
  - Low margin, Cash Cost between US $ 10 K to US$ 17 K, sales from US $13 K to US$ 16 K
  - Environmental permitting barriers are high because of nasty by-products (Hydrochloric acid (HCl) / H2 /Silicon Tetrachloride (SiCl4)) produced

# Investment Proposition

## HPQ is developing the PUREVAP$^{tm}$ Quartz Reduction Reactor (Patent Pending)

**Present Day Processing - Followed by Downstream Manufacturing**

| Silica Quartz SiO2 | PROCESS #1 Smelter | Metallurgical Grade Silicon Metal MG Si | PROCESS #2 Refining | Solar Grade Silicon Metal SG Si | PROCESS #3 Crystallisation | Polysilicon Brick / Ingots Wafer | Step 1 | Solar Cell | Step 2 | Solar Module | Step 3 | Solar System |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 99.5% SiO2 | | 98.5 to 99.5 % Si | | 99.999 % Si and Higher | | 99.999 % Si and Higher | | | | | | |






**HPQ PUREVAP™ QRR Aims to Combine Two Process and Transform Quartz Directly to Solar Grade Silicon**

| Silica Quartz SiO2 | PROCESS #1 & 2 PUREVAP QRR | Solar Grade Silicon Metal SG Si | PROCESS #3 Crystallisation | Polysilicon Brick / Ingots Wafer | Step 1 | Solar Cell | Step 2 | Solar Module | Step 3 | Solar System |
|---|---|---|---|---|---|---|---|---|---|---|
| 99.5% SiO2 | | 99.999% Si and Higher | | 99.999 % Si and Higher | | | | | | |

## PUREVAP$^{TM}$ QRR is a one step Carbothermic Process expected to:

- Reduce Opex of making SoG Si by as much as 80%
- Reduce Capex Cost of making SoG Si by as much as 95%
- Reduce Carbon Footprint related to producing SoG Si by a minimum of 75%
- Eliminate the production of nasty by-products (Hydrochloric acid (HCl) / H2 /Silicon Tetrachloride (SiCl4))

## The results are radical but the science is simple!

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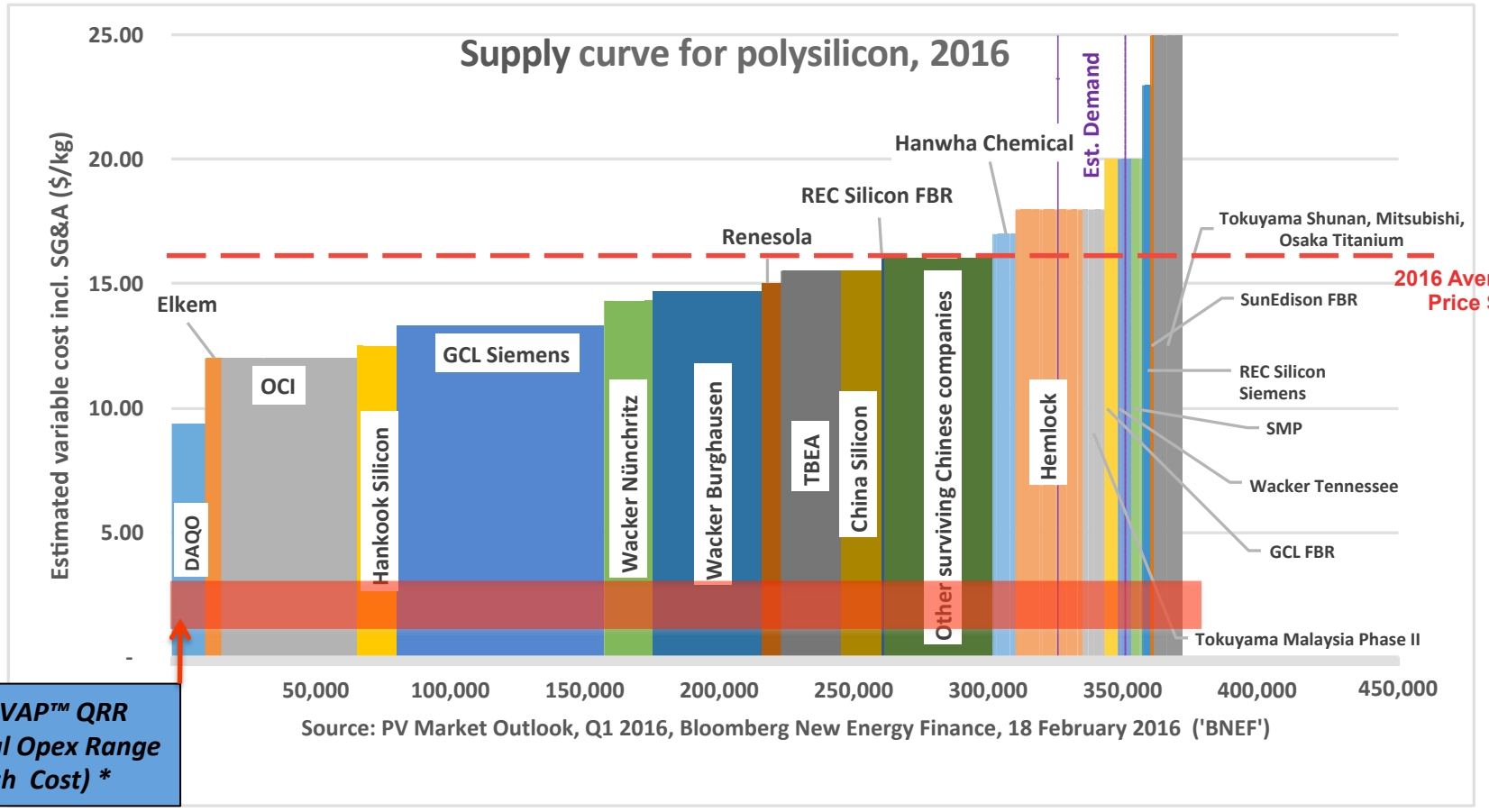
# *PUREVAP™ DISRUPTIVE POTENTIAL*
## *Cash Cost Analysis*

Polycrystalline Silicon Market 2016 – 2025 | © AMMS | Updated: 2 November 2016

**The cost curve for SG SI (polysilicon) suggest that long-term solar-grade polysilicon price below USD 15/Kg is not feasible. HPQ and the *PUREVAP™* will challenge that.**




***PUREVAP™ QRR Potential Opex Range (Cash Cost) ****

*** PUREVAP™ cash costs estimates we be revised after Pilot Plant is operational**

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# *PUREVAP™ DISRUPTIVE POTENTIAL*
## *Capex Analysis*

***PUREVAP™ QRR*** US$18.5 CapEx per kg of annual capacity matrix at Pilot Plant phase demonstrate ***the disruptive potential of the technology***

| | | Capital Cost Per Technologies Available To Produce SG Si Material (all $ values in USD) | | | | | |
|---|---|---|---|---|---|---|---|
| | | EXISTING TECHNOLOGY | | | NEW TECHNOLOGY | HPQ TECHNOLOGY | |
| Technologies | Feed Material | Siemens HC | Siemens Hyper Pure | FBR Reactor with Silane | Silicor Aluminum Solvent Refining | PUREVAP QRR R&D Pilot Plant | PUREVAP QRR Commercial plant |
| Capable of Transforming | Si02 to | | | | | Solar Grade Si | Solar Grade Si |
| Capable of Upgrading | MG Si to | Solar Grade Si (4N - 6N) | Electronic Grade Si (8N - 9N) | Solar Grade Si (5N - 6N) | Solar Grade Si (6N - 7N) | | |
| Number of effective competitors | | 7 | | | 1 | 1 | |
| Key Capex matrix | | | | | | | |
| Minimum Capacity Requirement (MT) | | 6,500 | | | 19,000 | 200 | 10,000 |
| Cap Ex per Kg of annual installed capacity (US$/kg) | | 70 (U.S.) 45 (China) | 100 (U.S.) 75 (China) | 100 (U.S.) 75 (China) | 35 | 18 | 4 |
| Capital Cost requirements (US$ million) | | 455 (U.S.) 292 (China) | 650 (U.S.) 488 (China) | 650 (U.S.) 488 (China) | 665 | 4 | 38 |
| SOURCES: | | IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 5, NO. 2, MARCH 2015 | | | Silicor Materials | PyroGenesis Canada Inc (PR August 2, 2016) | Rough Order of Magnitude Study by PyroGenesis |

## Following Pilot Scale Validation of the *PUREVAP™ QRR* process;

- The goal will be to move to a commercial phase, with an objective of building capacity capable of producing 20,000 TPY of SG Si within 5-7 years

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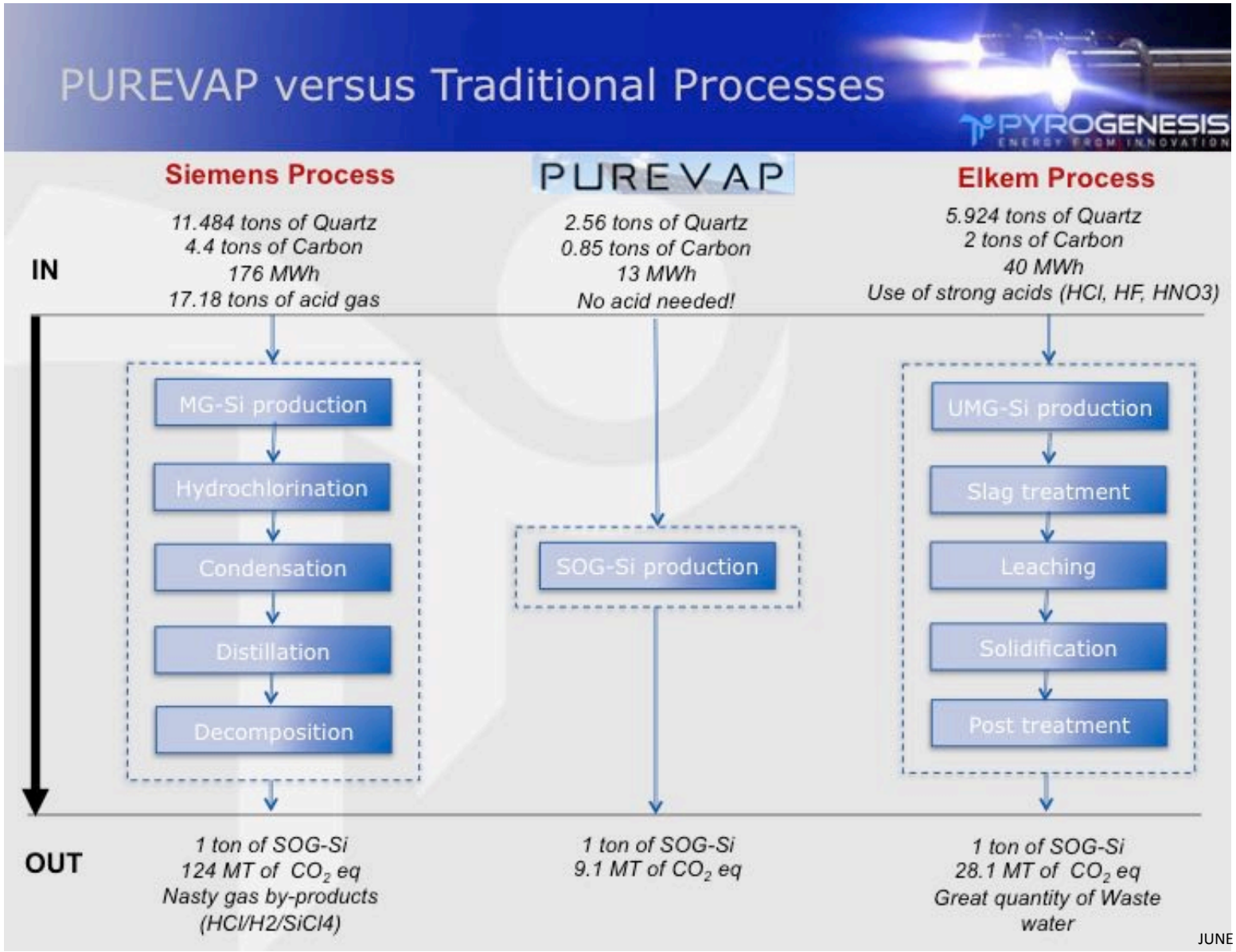
# PUREVAP™
## The Only Environmentally Friendly Option



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# Corporate and Capital Summary

| | | | | |
|---|---|---|---|---|
| **Share Price ( June 19, 2017)** | **$0.125** | **Cash and equivalent in hand** | **$900,000** | |
| **52 Week Low** | **$0.105** | **Cash value of warrants in the money** | **$2,298,679** | |
| **52 Week High** | **$0.305** | **Breakdown of warrants Outstanding** | **#** | **$** |
| **Shares Outstanding:** | **169,469,434** | **$0.07 Strike Price Warrants - Dec. 17** | **6,325,000** | **$442,750** |
| | | **$0.07 Strike Price Warrants - Feb. 18** | **1,800,000** | **$126,000** |
| **Warrants:** | **66,465,139** | **$0.07 Strike Price Warrants - Jun. 18** | **3,915,750** | **$274,103** |
| | | **$0.07 Strike Price Warrants - Aug. 18** | **5,959,000** | **$417,130** |
| **Options:** | **11,650,000** | **$0.07 Strike Price Warrants - Dec. 18** | **7,006,000** | **$490,420** |
| | | **$0.10 Strike Price Warrants - Jul 17** | **232,769** | **$23,277** |
| **Fully Diluted:** | **247,584,573** | **$0.12 Strike Price Warrants - Feb. 19** | **4,375,000** | **$525,000** |
| | | **$0.25 Strike Price Warrants - Jul. 18** | **6,200,000** | **-** |
| | | **$0.25 Strike Price Warrants - Dec. 18** | **6,448,211** | **-** |
| **Market Capitalization:** | **$21,183,679** | **$0.25 Strike Price Warrants - Feb. 19** | **9,411,766** | **-** |
| | | **$0.25 Strike Price Warrants - March. 19** | **2,488,234** | **-** |
| | | **$0.30 Strike Price Warrants - Jan. 20** | **8,000,000** | **-** |
| **Market Capitalization (FD):** | **$30,948,072** | **$0.30 Strike Price Warrants - Oct. 18** | **2,840,909** | **-** |
| | | **$0.35 Strike Price Warrants - March 18** | **1,462,500** | **-** |

## Management

**Bernard J Tourillon, BAA, MBA**
Chairman, CEO and Director

**Patrick Levasseur**
President, COO and Director

**Noelle Drapeau, LLL, MBA, PMP**
Corporate Secretary and Director

**Francois Rivard**
CFO

## Independent Director (*)

**Richard Mimeau, B.Sc.**
Director

**Peter Smith, PhD, P. Eng.**
Director

**Robert Robitaille, B.A., L. Ph., MBA**
Director

**Daryl Hodges H. BSc, M.Sc..**
Director

## Auditors

Raymond Chabot Grant Thornton

## Transfer Agent

Computershares

## Consultants

**Marcel Drapeau, BA, B.Sc. Comm, LLL**
Company Lawyer

**Marc Richer-Laflèche, P. Geo, PhD**
Technical Advisor (INRS- ETE)

## Major Investors

| | | |
|---|---|---|
| Management & Board | ≈ 15% | ≈ 22% (FD) |
| Key Investor Group | ≈ 14% | ≈ 15% (FD) |
| Fancamp | ≈ 3% | ≈ 5% (FD) |
| Institutions | ≈ 4% | ≈ 5% (FD) |
| Taiwanese Group | ≈ 2% | ≈ 3% (FD) |
| PyroGenesis | ≈ 2% | ≈ 2% (FD) |
| **TOTAL** | ≈ 39% | ≈ 51% (FD) |

**Debt free after gold spinout**

* **Independent directors may receive additional compensation for project work.**

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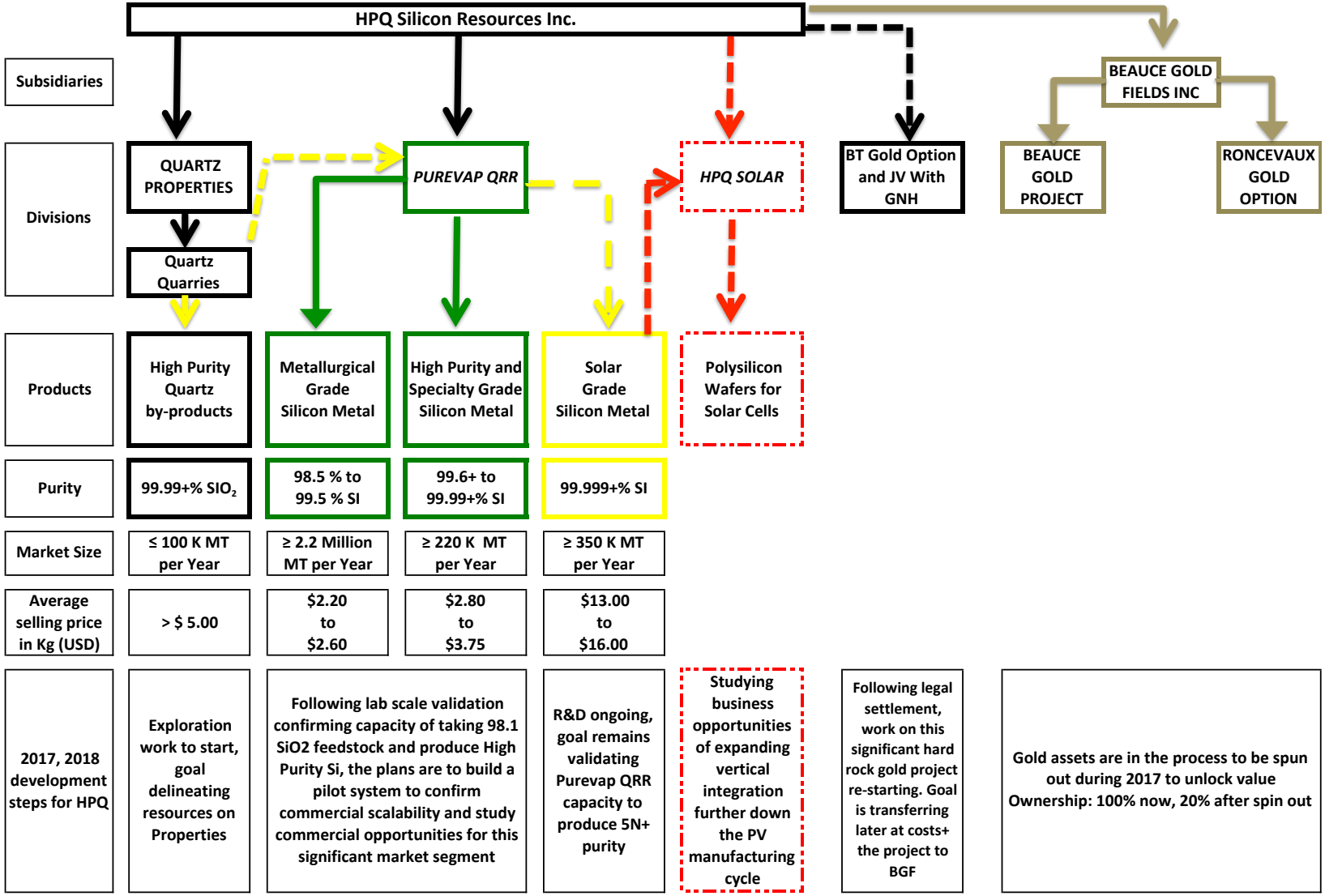
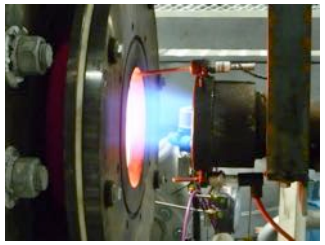
# Corporate Structure and Businesses

## HPQ Silicon plans to become a vertically integrated *Silicon Metal* Company

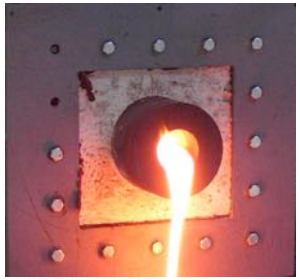


# *Outsourcing R&D And Partnering With The Industry Leader*

PYROGENESIS



| | |
|---|---|
| **INNOVATIVE TECHNOLOGY** | Patented Technology – 18 innovations, covered by 49 patents (issued or pending) worldwide. *USING **PLASMA** LIKE NO ONE ELSE* |
| **INTERNATIONAL REPUTATION** | Montreal based with Industry credibility established through continued relationship with the US Navy and the US Air Force, and cutting edge research credibility with universities around the world |
| **UNSURPASSED EXPERTISE** | Largest concentration of **plasma experts** in the world make up our team of 50 employees, with more then 25 engineers dedicated to technologies development. |
| **CULTURE** | Proven leadership since 1991, ISO 9001:2008 certified since 2007, 2 facilities including a 38,000 $ft^2$ manufacturing facility in Montreal, TSX-V:PYR, OTCQB:PYRNF |



## *STRATEGIC DEVELOPMENT AGREEMENT WITH PYROGENESIS*

- PyroGenesis is developing for HPQ-Silicon's exclusive use the ***PUREVAP™ QRR*** (Patent Pending) a 1 Step, Clean Tech process for making SG Si directly from Quartz, using a plasma submerged arc
- HPQ has acquired the intellectual property rights to the ***PUREVAP™ QRR*** process and will finance the development as it relates exclusively to the production of silicon metal from quartz **(*)**
- PyroGenesis is building and will oversee production from a 200 TPY SG Si R&D pilot plant (Press releases August 2, 2016, September 30, 2015)

* PyroGenesis retains a royalty-free, exclusive, irrevocable worldwide license to use the process for purposes other than the production of silicon metal from quartz

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# *HPQ PUREVAP™ SCALING UP: Making Rapid Progress*

## Proof of Concept Metallurgical Tests Program, Scaling up results

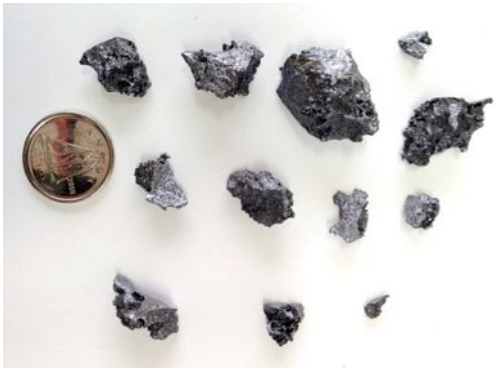
**Thin layer of material produced during first tests**

15 tests later

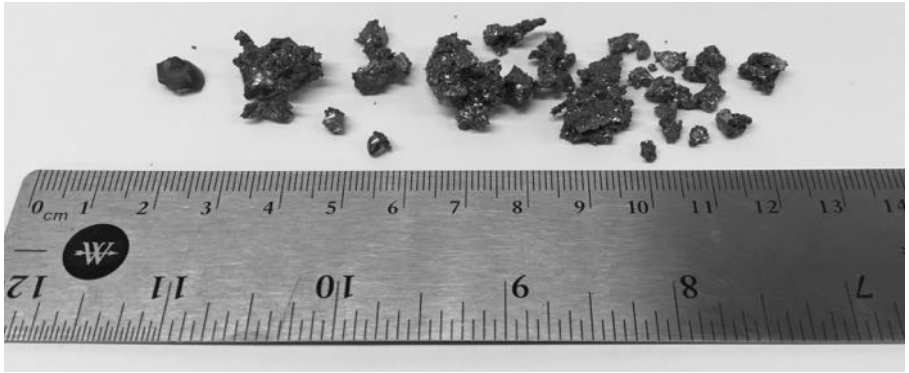
**First nugget of Si (99.97% SI) produced during final proof of concept test (About 0.1 g)**

## Process Characterization Testing Phase, Scaling up results

**Small bead produced during test #24**



**Series of chunks of 99.93 % Si produced during test #32 (8.8 g)**



**Series of chunks of 99.97 % Si produced during test #51 (8.67 g)**

**Modification done to the PUREVAP™ QRR have made it possible for test 51 to produce the same quantity of Si as in test #32, while using smaller batch sizes (55 wt% less)**

**This represent a 531% increase in Yield !**

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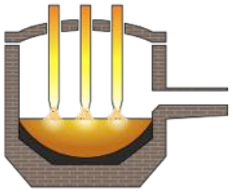
# COMPARISON of TODAY'S PROCESS Vs. PUREVAP™

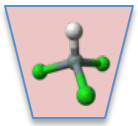
$SiO_2$ 99.5%
Coal - Wood Chips



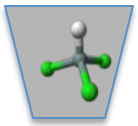
Electric Arc Furnace

MG Silicon Metal
98.0% to 99.5% Si

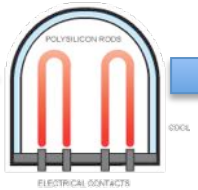
15 % of MG Si Produced Further Refined

MG Silicon Metal Is Dissolved In Hydrochloric Acid To Form Trichlorosilane (HSiCl3)



Trichlorosilane (HSiCl3) is Further Refined



SIEMENS Type Reactor have 90 % Market Share

Solar Grade Silicon Metal
99.999+% Si

## MG SI Key Matrix (98% to 99.5% Si)

| | |
|---|---|
| Market Size (Ton) | ≈ 2.2 Million Tons |
| Market Size (US$) | ≈ 6 Billion |
| Demand Growth | ≈ 6% CAGR |
| Price (US$/kg) | 2.4 to 2.8 |
| Cash Cost (US$/kg) | 1.75 to 2.25 |
| Capex Cost (US$/kg) | 7 to 14 |

**2015 Data (Sources CRU, Ferroglobe, Bloomberg, Viridis.oq, Roskill)**

## Solar Grade SI Key Matrix (5N and Higher)

| | |
|---|---|
| Market Size (Ton) | ≈ 350 K Tons |
| Market Size (US$) | ≈ 5 Billion |
| Demand Growth | ≈ 15% CAGR |
| Price (US$/kg) | 12.80 to 15.67 |
| Cash Cost (US$/kg) | 12.0 to 17.0 |
| Capex Cost (US$/kg) | 75 to 100 |

**2015 Data (Sources CRU, GTW, IEEE JOURNAL OF PHOTOVOLTAICS, VOL. 5, NO. 2, MARCH 2015, Bloomberg)**

## PUREVAP™ Quartz Reduction Reactor

***A Proprietary (Patent Pending) One-step Process To Make Solar Grade Silicon Metal***

$SiO_2$ 99.5%
Carbon

***"ELEGANT IN ITS SIMPLICITY"***

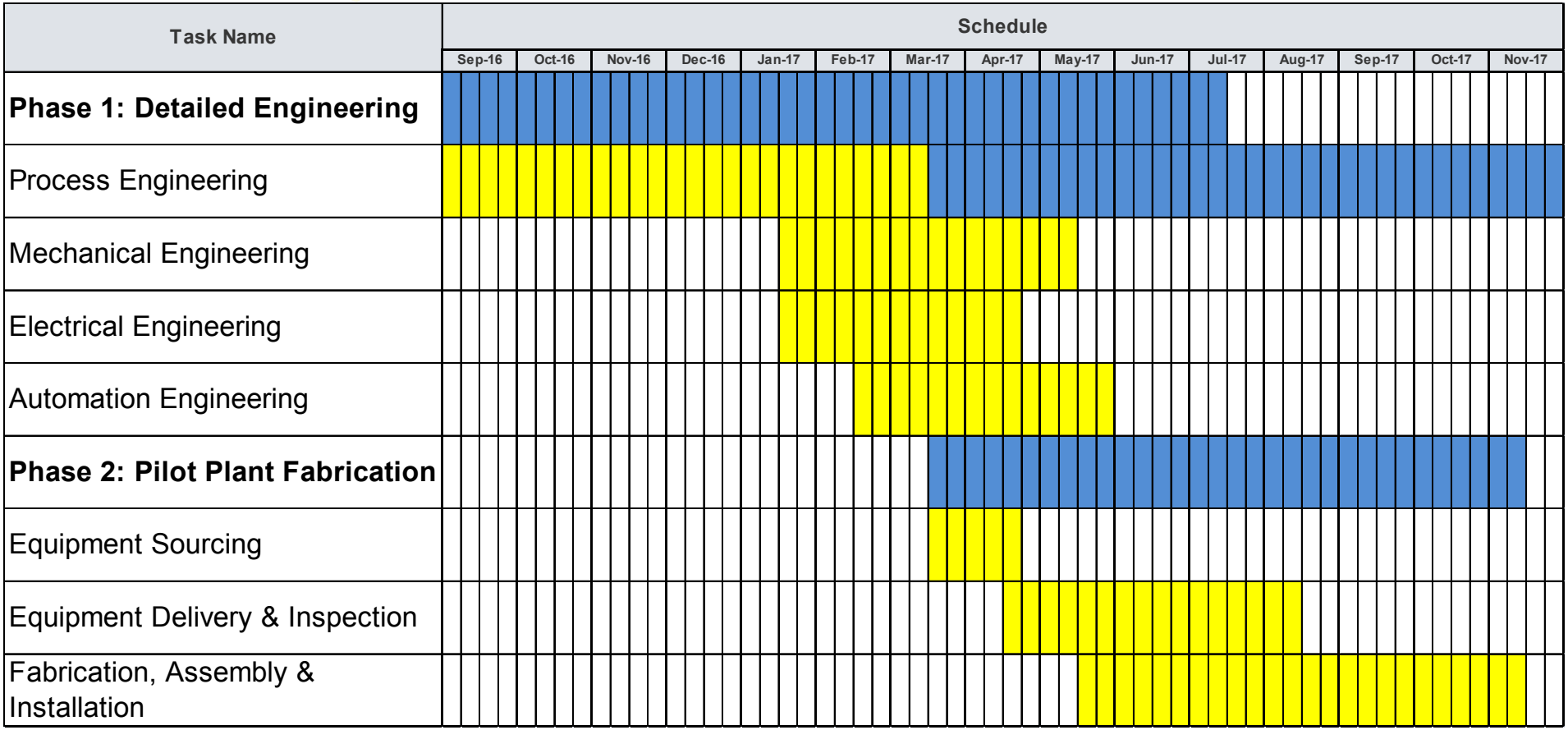
Solar Grade Silicon Metal
"Polysilicon"
99.999 + % Si

## PUREVAP Process Key Working Matrix

| | |
|---|---|
| Combine Market Size (Ton) | >2.7 Million Tons |
| Combine Market Size (US$) | > 11 Billion |
| Demand Growth | > 10 % CAGR |
| Cash Cost (US$/kg) | 1.75 to 2.25 |
| Capex Cost (US$/kg) | 7 (2 K TPY Reactor) |
| Capex Cost (US$/kg) | 4 (10 K TPY Reactor) |

**Capex Cost Sources from PyroGenesis Canada Rough Order of Magnitude Study, (Capex and Opex numbers to be refine after Pilot Plant start operation)**

# Design and Pilot Plant Fabrication Schedule




**Phase 3: Hot commissioning of Pilot Plant schedule from Nov 2017**

**Phase 4: Testing and Operating Pilot Plant schedule from March 2018**

# *PUREVAP™ PILOT PLANT: CAPITAL NEEDS, TIMING*

**The total cost to purchase and commission the *PUREVAP™ QRR* Pilot Plant and related Intellectual Property is CDN$8,260,000 to be invested between 08/2016 en 12/2018:**

- $ 1,000,000 for purchase of the related Intellectual Property **(Completed)**
- $ 4,430,000 for design, fabrication, assembly, and testing **($3,190,200 Completed, $1,239,800 by Nov-2017)**
- $ 520,000 for hot commissioning of the pilot system **(To be paid From Dec-2017 to Feb-2018)**
- $ 2,310,000 for testing and operating the pilot system during 10 months **(To be paid From March to Dec-2018)**

## The Projected Cash call over the next 24 months are:

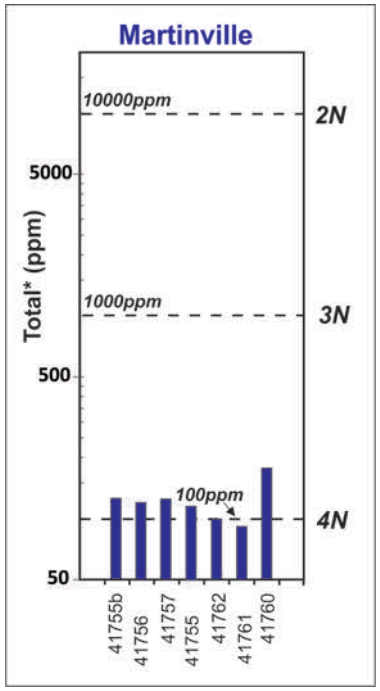
- $1,499,800 for 2017, (To be paid From October 2017 to December 2017)
- $2,570,000 for 2018

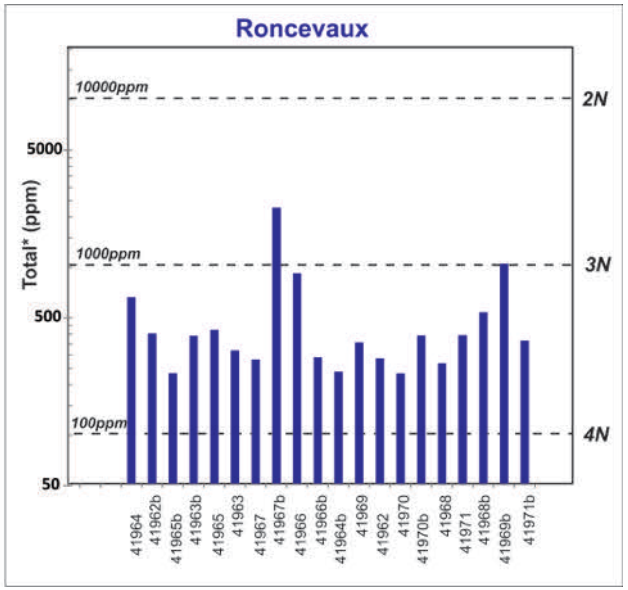
## HPQ Silicon funding advantages:

- The project is eligible for government funding (Provincial and Federal) for 55% to 80% of the cost
  - Discussion with both levels of Government are ongoing, approvals are expected during Q3 2017
- Over CDN$ 2,250,000 worth of warrants are in the money, majority in friendly hands
- The acquisition of PUREVAP™ Intellectual property opens up additional options for financing because investors want to see direct control over the key intellectual property
- Management is exploring several less – dilutive paths for financing the Pilot Plant
  - If the shares prices exceed $C0.40, then over CDN$ 11,2 Million could be raised via warrant exercises
- HPQ will be entitled to R&D research credits on the CDN$7,260,000 investment

# HPQ – PUREVAP™ RAW MATERIAL

- ***HPQ-Silicon* is the largest holder of High Purity Quartz properties in Quebec**, with over 3,500 Ha under claims
- The Roncevaux High Purity Quartz, with it up to 3N purity (99.9% $SiO_2$) samples is in high demand, and has successfully passed rigorous testing protocols of a major silicon metal producer
- The Martinville High Purity Quartz is unique and rare with samples up to 4N purity (99.99% $SiO_2$)

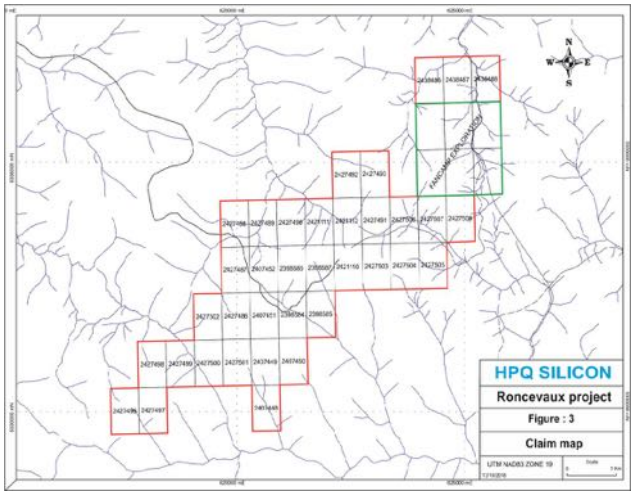



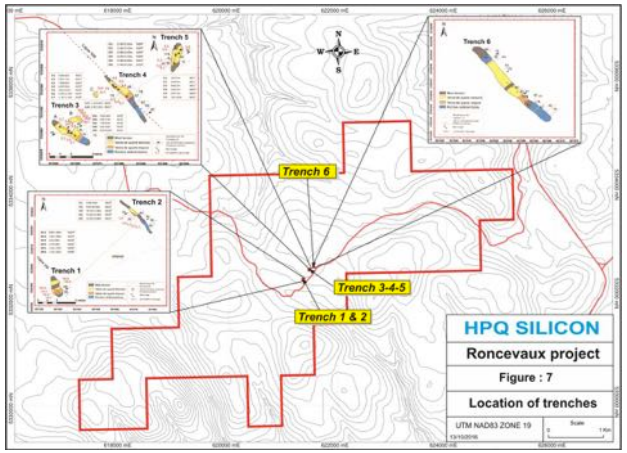

**INRS Test 2016 Results**

# HPQ VERTICAL INTEGRATION STRATEGY

## Plans Are To Establish HPQ Quarry Operations in order to meet our Raw Material Requirement For Future *PUREVAP™ QRR* Plants.

- For 2017, HPQ plans on developing the Roncevaux Quartz Potential:
  - **Key goal, delineating a significant resource**
- A Preliminary Economic Assessment (PEA), based on the fact that the PUREVAP™ QRR process is the only process in the world that can transform 98.1% $SiO_2$ into 99.9+% Si will be undertaken in 2018
- Until its completion, all our financial models will be based on purchasing the raw High Purity Quartz required for the plants, in the open market at market prices
- Upon successful start of quarry operations on Roncevaux, HPQ Silicon will be a fully integrated Silicon Metal Producer



# Why Invest in HPQ Now?

## HPQ Is Canada's Only Public Pure Play Investment In the Growing Solar Grade Silicon Market

- *HPQ Bench Test Success Have Validated That We Have The Only Process In The World That Purifies While Transforming Quartz Into Silicon Metal*
- *Project Graduating To Pilot Plant Phase*

### *HPQ PUREVAP™ Proprietary Disruptive Technology*:

- **Low Opex, Low Capex, Minimal Carbon Footprint and Environmentally friendly**
  - **Less than 20% of the Industry's cash cost,**
  - **5% of Industry Capex, and**
  - **Estimated 75% reduction in carbon footprint**
  - **No nasty by-products (Hydrochloric acid(HCl)/H2/Silicon Tetrachloride (SiCl4))**
- **200 TPY Pilot Plant almost completed and talking to potential industry partners**
- **The only one step process in the world that can take low quality feedstock (98.1% $SiO_2$) and produce High Purity Silicon Metal (99.97% Si)**

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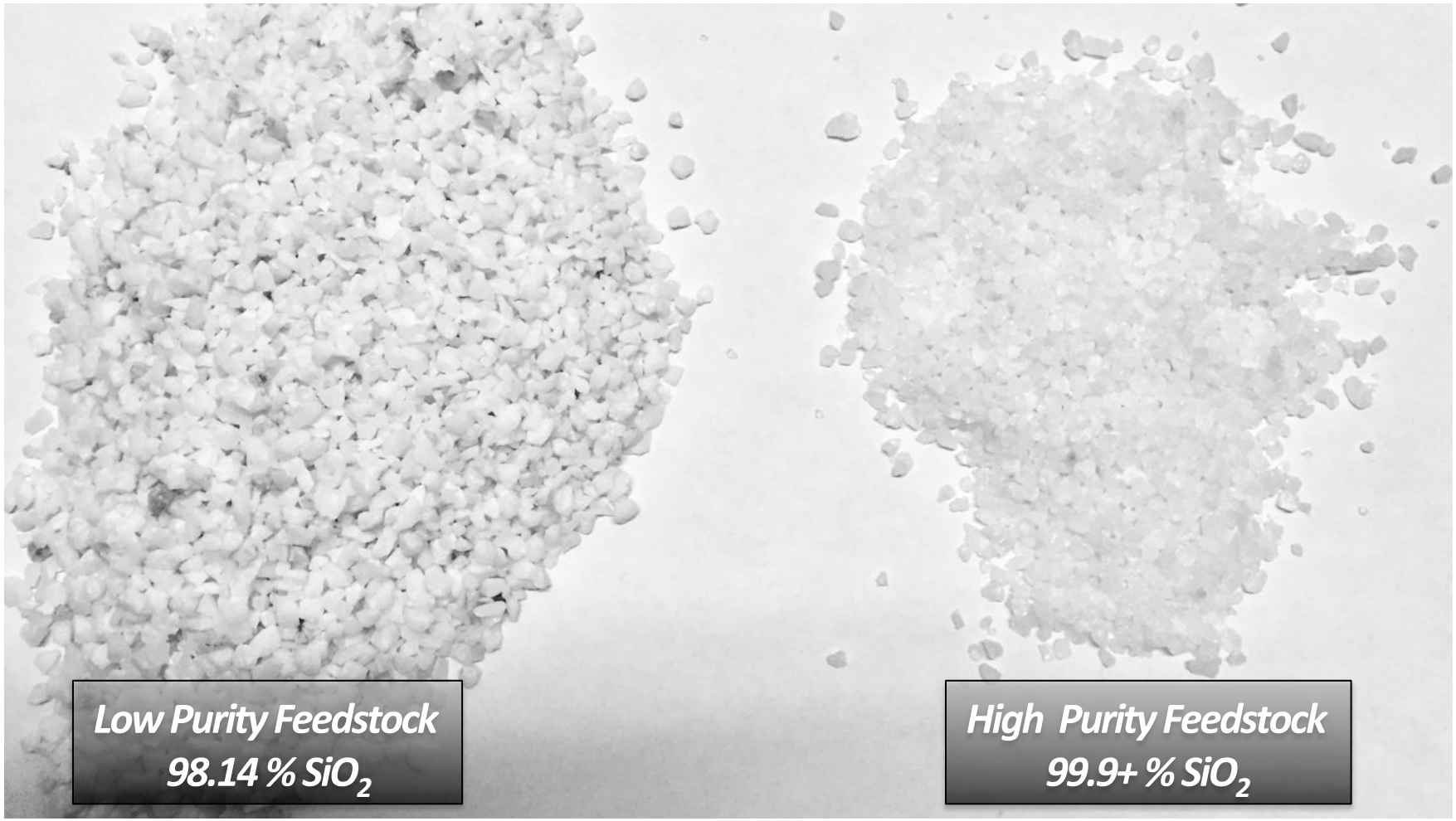
# Appendix: Supporting Slides

*(slides 18 - 32)*




## PUREVAP™

*"Feedstock Flexibility: A Visible Advantage"*

# *Leading Research Paper SoG Si Market projections*

Polycrystalline Silicon Market 2016 – 2025 | © AMMS | Updated: 2 November 2016

**From 2004, PV's growth completely changed the dynamics of the polysilicon industry – visible first by strongly increasing prices and then by over-establishment of production capacity**


Source: "Solar grade silicon: Technology status and industrial trends" by Gøran Bye and Bruno Ceccaroli, Solar Energy Materials & Solar Cells 130 (2014) 634–646 (http://dx.doi.org/10.1016/j.solmat.2014.06.019)

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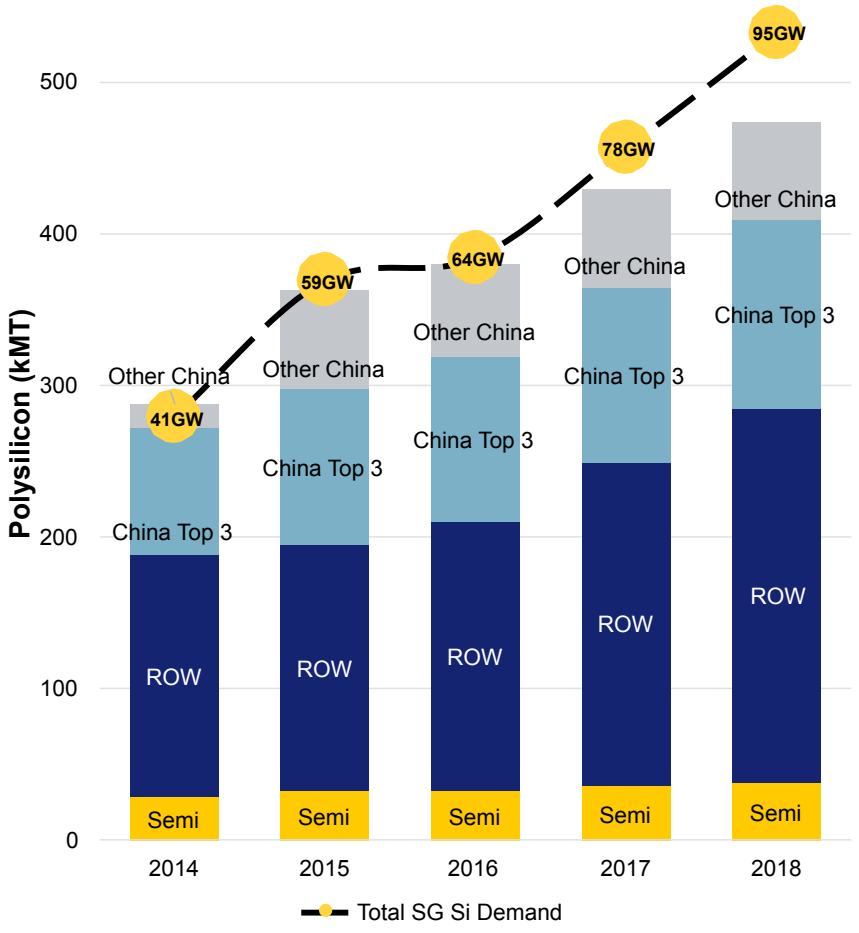
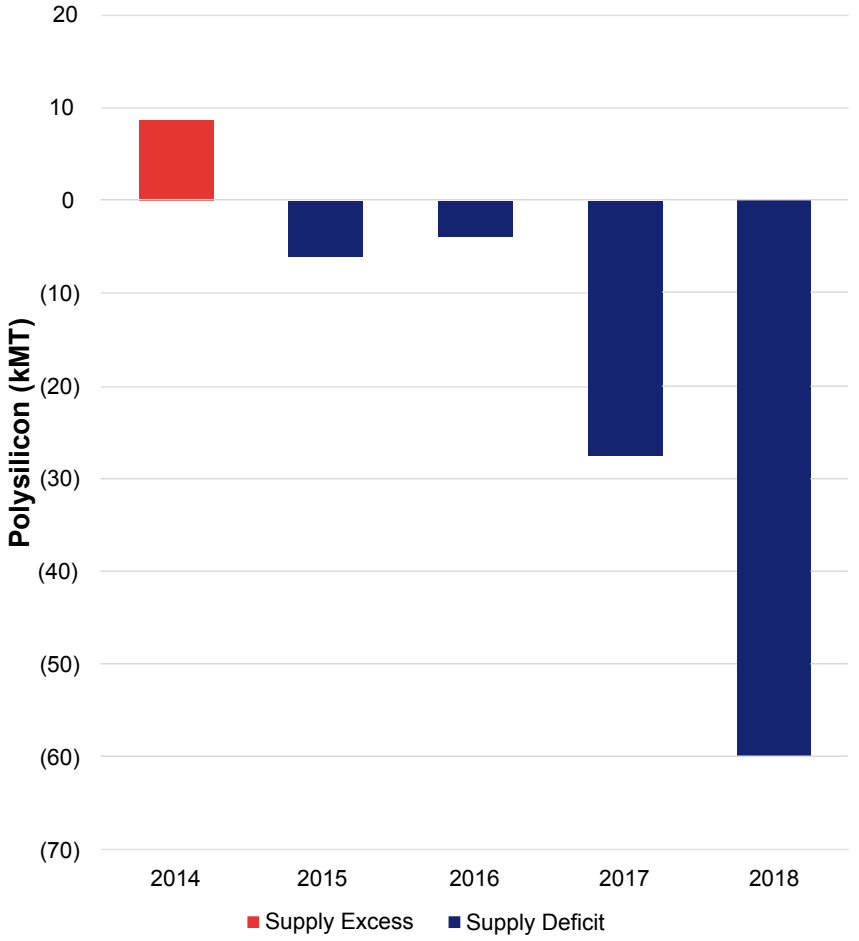
# Low SG Si (Polysilicon) Production Limiting PV Growth

## SG Si (Polysilicon) Supply/Demand Forecast



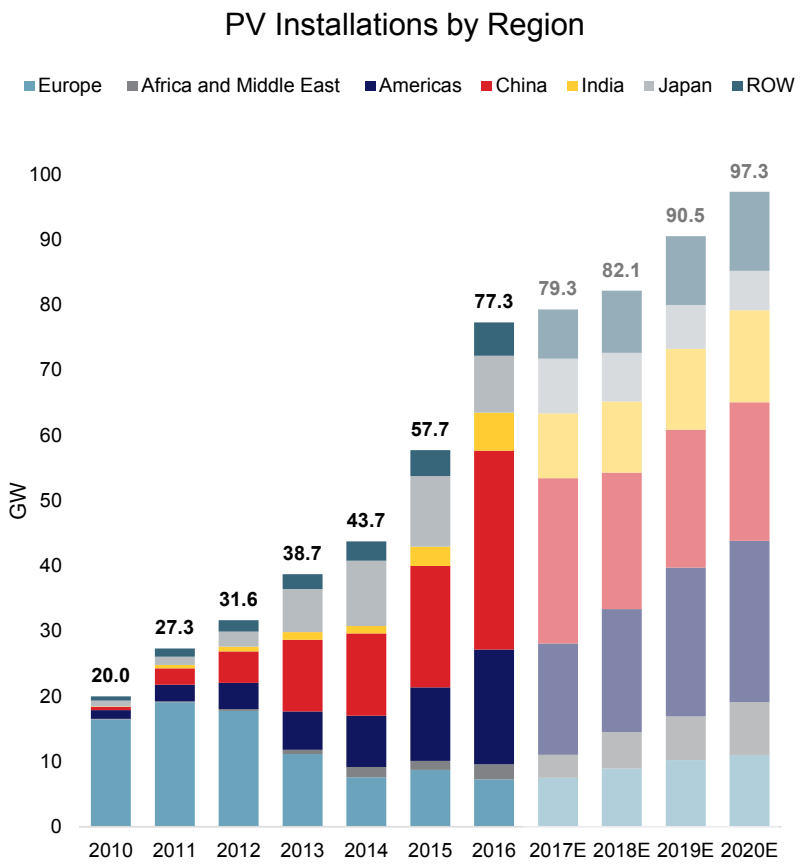

## SG Si (Polysilicon) Market Balance Forecast




Source: Demand Data Installations: GTM Research, PV Pulse, January 2016
Supply Data: Competitor releases, industry analysts, REC Market Intelligence

# Very Strong Growth in PV Demand

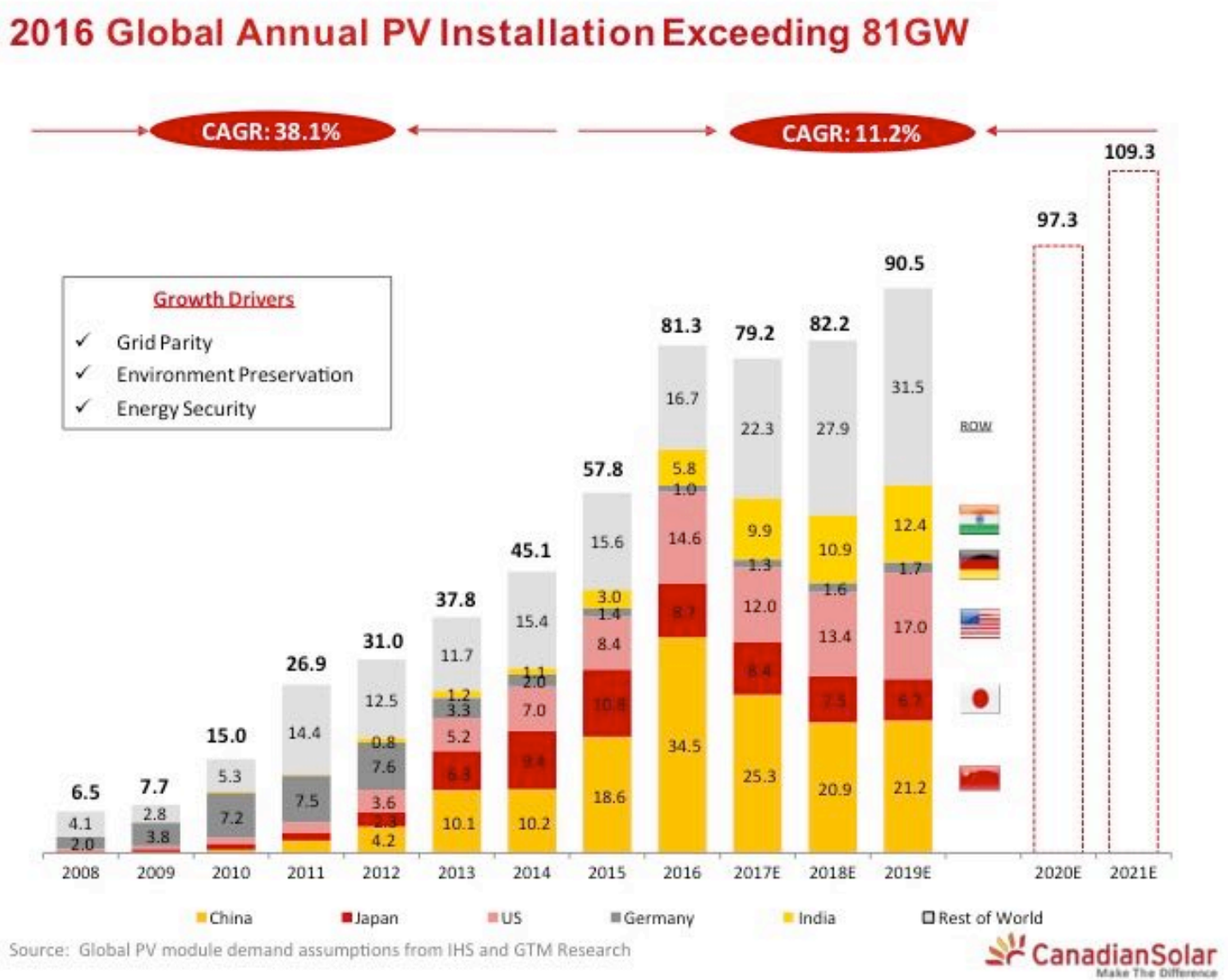
- China still most important market, but reduced installations in coming years
- India and other emerging markets continue to grow
- Long term market outlook is increasingly geographically diversified




Results based on IHS Markit, Technology Group, PV Demand Market Tracker, Q4 2016. This data is not an endorsement of REC Silicon. Any reliance on the results are at the third party's own risk. Visit www.technology.ihs.com for more details.

# Competitors SoG Si Market projections



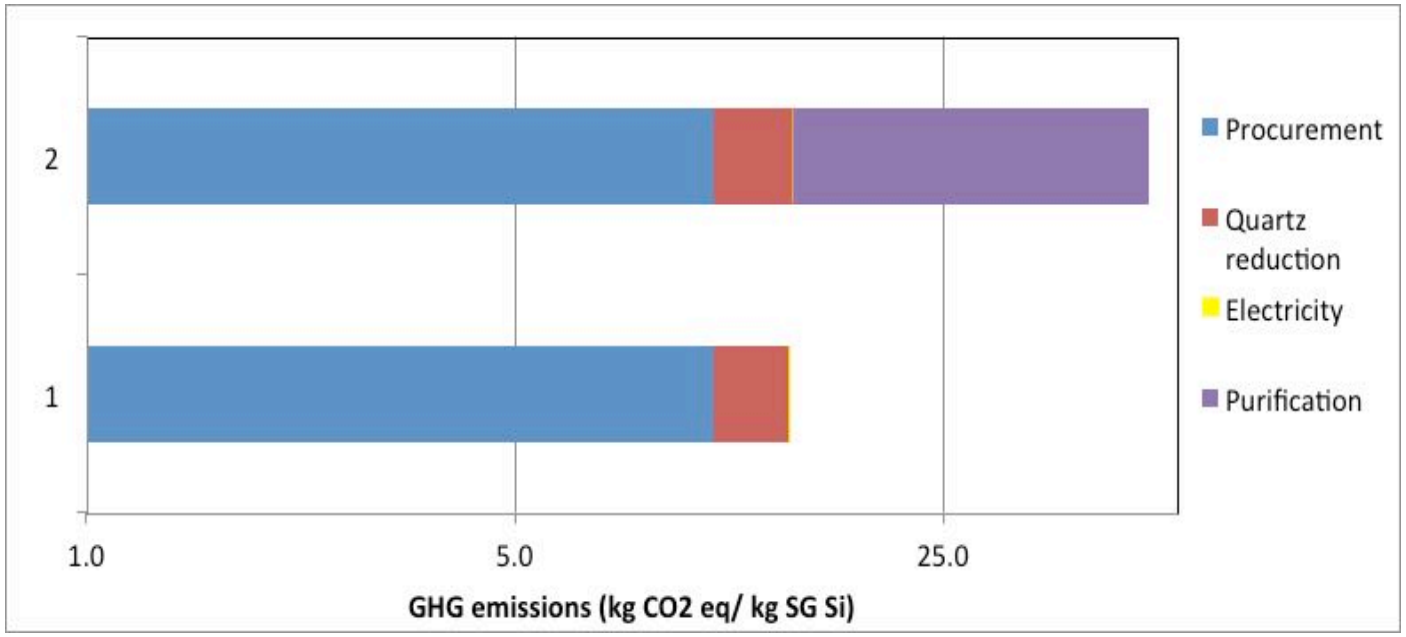
# PUREVAP™
## The Only Environmentally Friendly Option

## Carbon Footprint 75% Lower Than Conventional Process.

The *PUREVAP™ QRR* process is estimated to generate 14.1 kg CO2 eq/Kg SG Si;

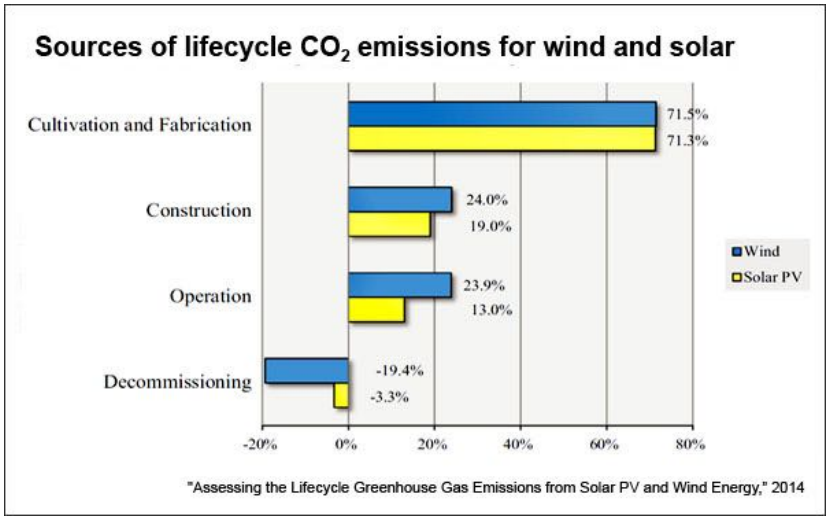
The Siemens process (the industry standard) normally generates 54.0 kg CO2 eq/ Kg SG Si of emissions.*

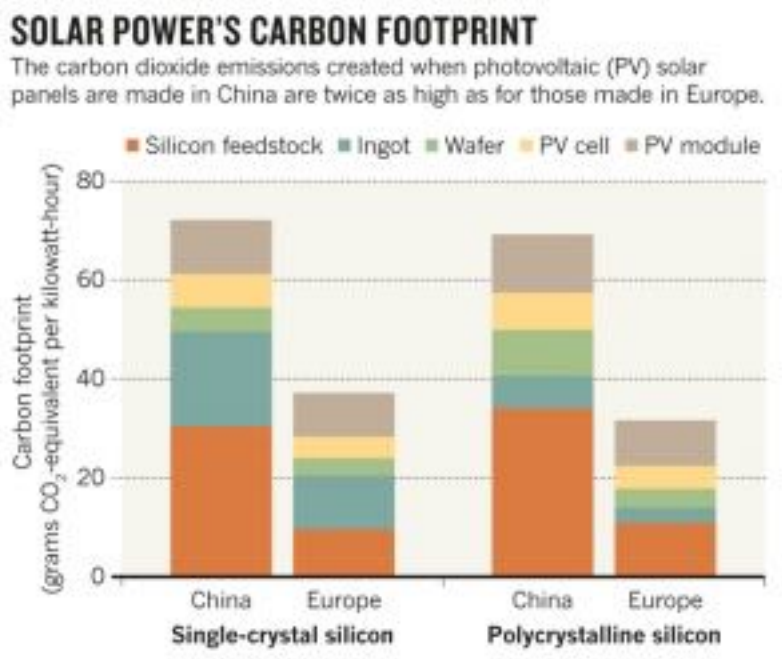
- This represents 75% fewer greenhouse gas emissions, which is justified by elimination of the emissions emanating from the use of chemicals, as well as, energy consumption from the additional purification step.




* Source: R. Glöckner. M. de Wild-Scholten. *Energy payback time and carbon footprint of Elkem Solar silicon*. 27th European Photovoltaic Solar Energy Conference and Exhibition

# PUREVAP™
# Environmentally Competitive Advantage




Traditional process of transforming quartz in solar grade silicon metal represent the biggest contributing source to the lifecycle of $CO_2$ emissions for solar energy

China's coal intensive electricity grid means that making silicon solar panels there – although Cheaper – leaves a carbon footprint almost twice as large as that making it in Europe.

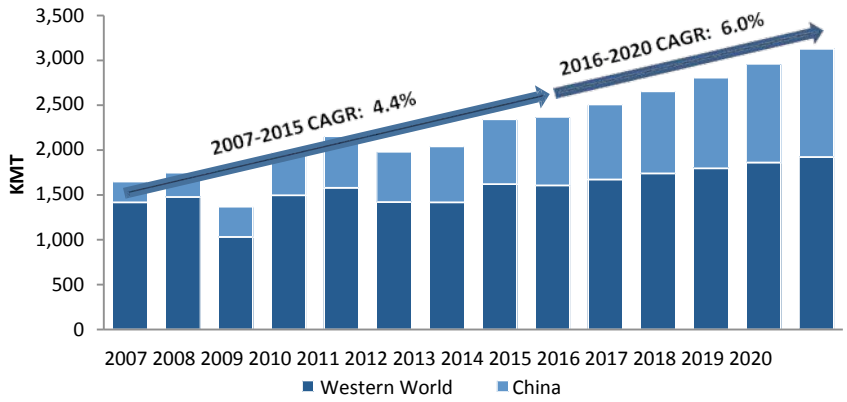
Source: Study led by Fengqi You at Northwestern University (Nature V 510, 19 June 2014)

**ADVANTAGE *PUREVAP™ GOING FORWARD, AS MORE AND MORE SOLAR PRODUCER WILL BE ASK TO CONSIDER THE LIFECYCLE* $CO_2$ FOOTPRINT OF THEIR PROJECTS**

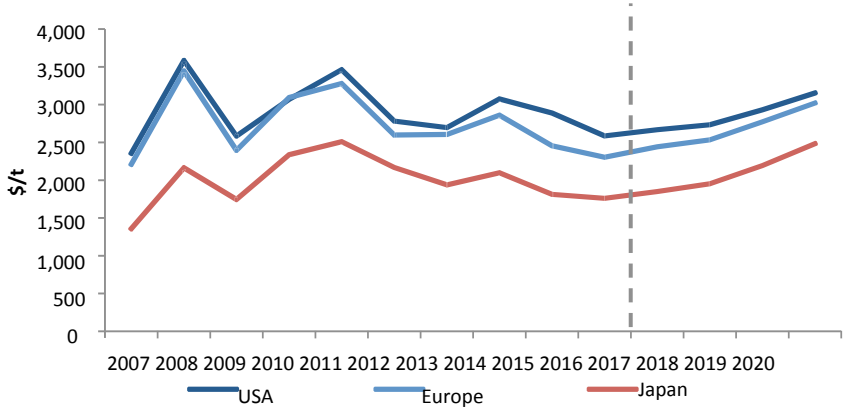
HPQ – SILICON RESOURCES

# GROWING METALLURGICAL GRADE SILICON METAL MARKET

## Growth in MG Si Consumption Expected to Accelerate from Historical Levels




## Rising MG Si Demand Expected to Drive Price Recovery in 2017-2020

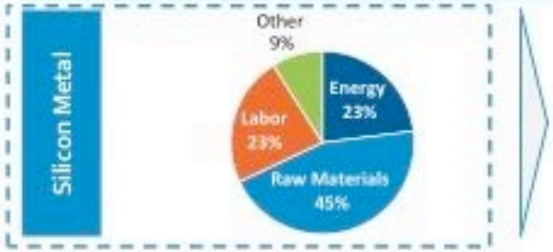



*Source: CRU 2015, Ferroglobe*
*Note: Silicon consumption, pricing, and capacity data are from CRU.*

- MG Si 2015 consumption was 2.2 Million Tons;
  - > $US 6 billion in worldwide sales
- Demand is expected to grow at 6.0% CAGR from 2016 – 2020
- CRU forecasts a 2017-2020 price recovery for MG Si driven by rising MG Si demand
- **In 2015, 15 % of Global MG Si (98.5% Si) production was further refined to Solar Grade Si (SG Si, or "Polysilicon") at 99.999% (5N) purity**
  - 350 K Tons of SG Si was sold in 2015 (≈ $US 5Billion)
- Growth will be largely driven by the growing demand for Solar Grade (SG) Si (Polysilicon) material to be used in Photovoltaic (PV) solar panels
- Each Watt (W) of energy produced by a PV solar system demands ≈ 5 gr of SG Si
- GTM Research estimates that Installed PV demand to growth 15 % - 23 % annually, representing about 10 Gigawatt (GW) per year
- Significant SG Si Deficit are forecast from 2017 on as Gigawatt (GW) produce with Solar panels increases

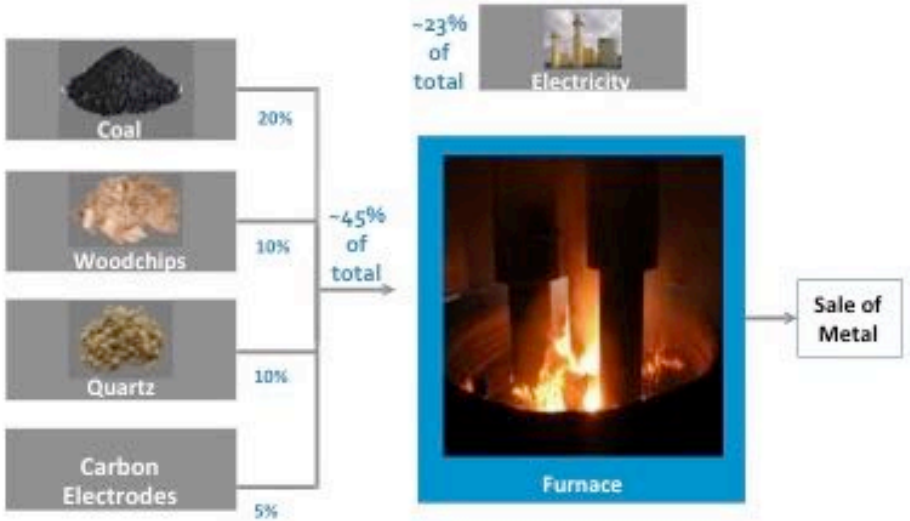
# *HPQ PUREVAP™ QRR Process Is Disruptive In The Traditional Silicon Metal Space With Its Capacity To Transform Low Purity $Sio_2$ Into 3N+ Si*

## Summary of Cost Components




Source: Ferroglobe, CRU

## Overview of Traditional Silicon Production Process

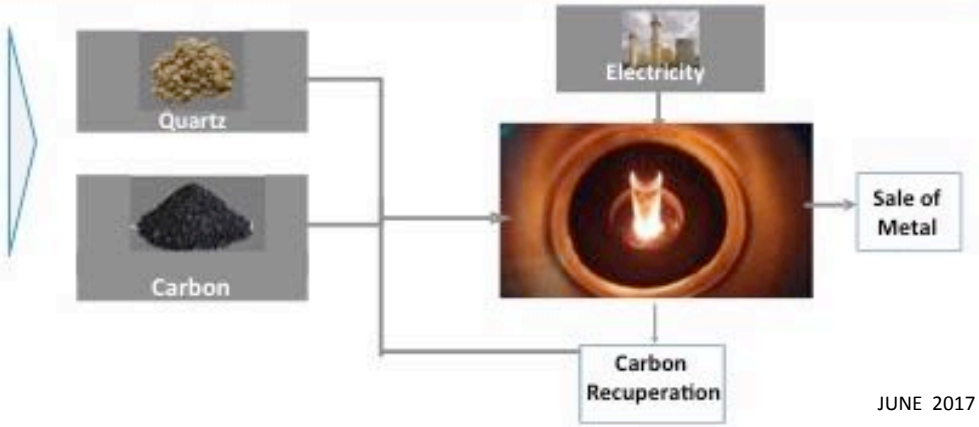



## Estimated Cost Advantages of *PUREVAP™* Process

- Capex Cost of $4 (US$/Kg) annual capacity for 10,000 TPA VS $5 (US$/Kg) for 35,000 TPA
- Eliminating Woodchips usage could reduce Opex cost by US$ 175 per Tonne
- Recycling Carbon from the process could reduce Opex cost by another US$ 88 per Tonne
- Using lower Purity feed stock could reduce Opex cost by another US $15 per Tonne
- Recycling Carbon would render the process green and eliminate the need to buy Carbon credit

Source: Ferroglobe, CRU, HPQ

## Overview of *PUREVAP™* Silicon Production Process



Silicio FerroSolar
Grupo FerroAtlántica

**SilicioFerroSolar, S.L.**

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Fax: +34 981 602354

## Product Data Sheet

## High Purity Silicon

Silicio FerroSolar offers High Purity Silicon for different applications fields such as the ceramic industry (for example ceramic bearings or cutting tools), pyrotechnical mixes, filler for epoxy in microelectronics, sputtering targets and aesthetical applications. Our production technology allow us to offer tailored solutions for each application.

### Chemical composition

| | 2N Spec. | 3N Spec. | 4N Spec. |
|---|---|---|---|
| Si Content (%) | >99 | >99.9 | >99.99 |
| **IMPURITIES (%):** | | | |
| Fe | <0.50 | <0.05 | <0.005 |
| Al | <0.20 | <0.01 | <0.001 |
| Ca | <0.05 | <0.01 | <0.001 |
| Ti | <0.02 | <0.005 | <1ppmw |
| P* | 5-20 ppmw | 5-20 ppmw | 5-20 ppmw |
| B* | 25-35 ppmw | 25-35 ppmw | 25-35 ppmw |

*These are the typical range values for B and P. Any target value could be produced.

**Other trace elements on request

### Particle size

Sizes could be adapted to the different needs.

sfs@ferroatlantica.es

# SoG Si Purity by Process

Polycrystalline Silicon Market 2016 – 2025 | © AMMS | Updated: 2 November 2016

**Siemens reactors were originally developed for electronics; FBRs' granular product is in general*) sufficiently pure for PV; upgraded MGS demands some adaption of downstream processes**

| Impurity | Siemens (Solar) (value range) | FBR (value range) | U-MGS (value range) |
|---|---|---|---|
| P (donor) | 0.3-5 ppba | 0.3-20 ppba | 300-1,000 ppba |
| B (acceptor) | 0.1-5 ppba | 0.3-20 ppba | 500-2,000 ppba |
| Total metals | 20-50 ppbw | 30-1,000 ppbw | 100-1,000 ppbw |
| C | 0.25-1 ppma | 0.5-10 ppma | 50-200 ppma |
| O | 0.5-5 ppmw | 10-100 ppmw | (100 ppmw) |
| Gas inclusion | | $H_2$ | |

- Higher Metal concentration → affects life time minority charge carriers→ lower cell efficiency
- Oxygen →forms pair with B → affects Light Induced Degradation (LID)
- Oxygen, Carbon, metals→ form inclusions which may destroy single crystal structure (CZ)
- High dopant (B, P) concentration → compensation→ reduced material yield → risk of LID → risk of reverse current breakdown

Source: "Solar grade silicon: Technology status and industrial trends" by Gøran Bye and Bruno Ceccaroli, Solar Energy Materials & Solar Cells 130 (2014) 634–646 (http://dx.doi.org/10.1016/j.solmat.2014.06.019)

*) Sun Edison in their now shuttered US FBR-facility regularly made electronic grade polysilicon and their Korean JV ("SMP") also, reportedly, is capable of producing electronic grade product

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# UMG SoG Si Competitors Process (Elkem - 2013)

## Elkem Solar production process

Silicon → Slag treatment → Leaching → Solidification → Post treatment

- **Silicon:** metallurgical silicon is produced from quartz in an electric arc furnace, at temperatures above 2,000 degrees C.
- **Slag treatment:** a purification process, in which the molten silicon is mixed with slag, in order to extract further impurities, especially boron.
- **Leaching:** a "wet" chemical refining process that, removes phosphorous and metallic impurities from silicon in solid form.
- **Solidification:** the silicon is melted and directionally solidified through which impurities are segregated and thereafter removed in the subsequent post-treatment process.
- **Post treatment:** surface washing and cutting.

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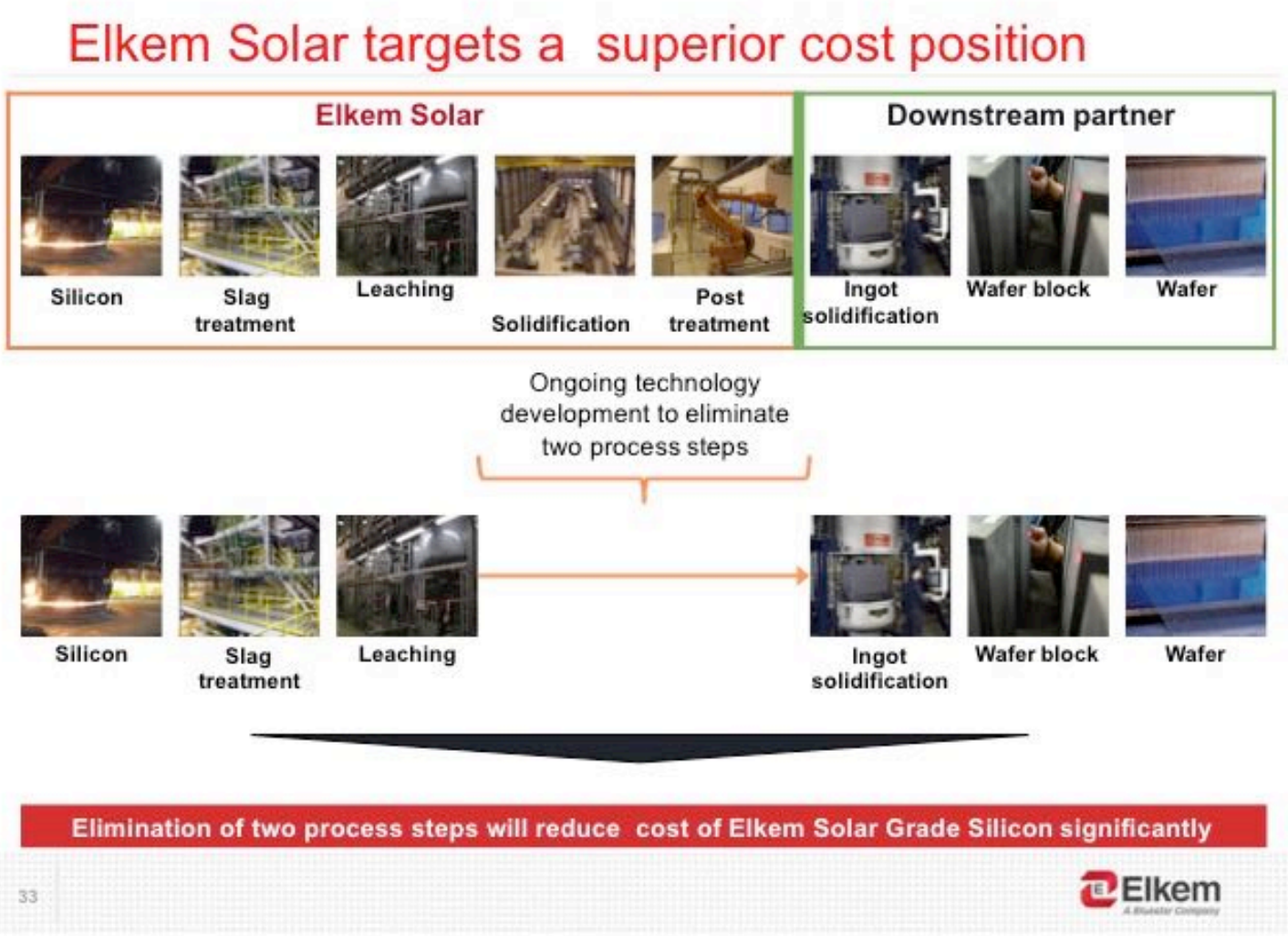
Elkem
A Bluestar Company

# UMG SoG Si Competitors Process (Elkem - 2013)



# SIMPLE PUREVAP™ 1-STEP PROCESS

*"ELEGANT IN ITS SIMPLICITY"*

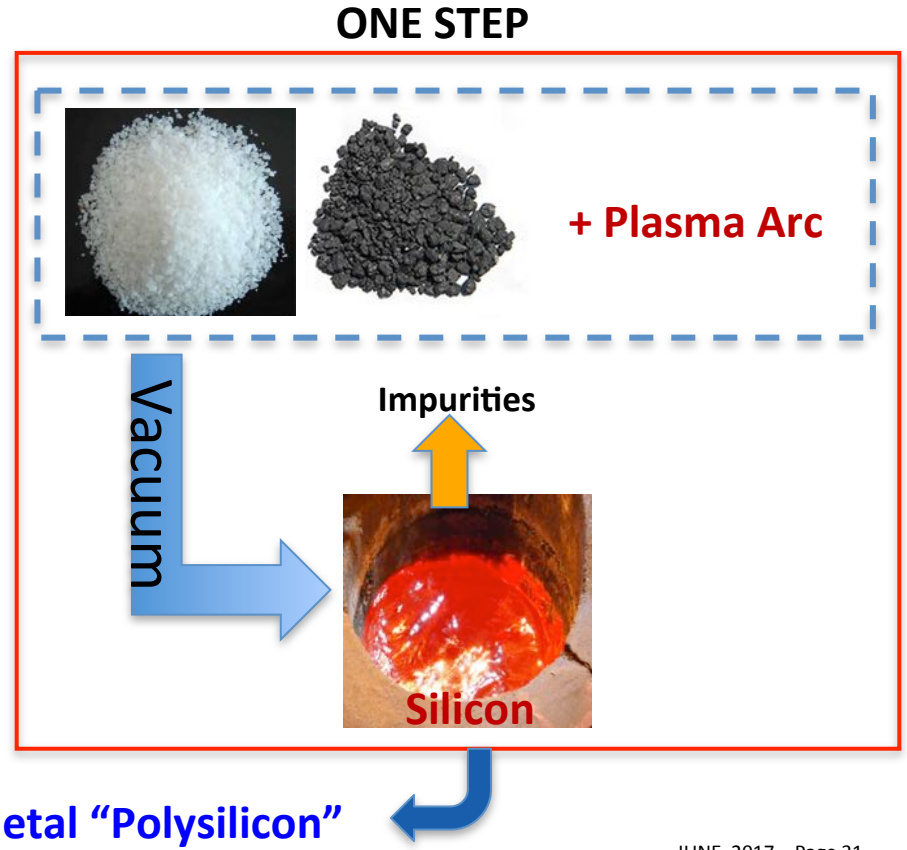
PYROGENESIS

## Quartz Reduction Reactor

- Quartz reduction with carbon using plasma submerged arc
- Silicon refining under vacuum to remove impurities

## Vacuum Arc Furnace

- **Reaching very low air pressure level**
  - ✓ (m bar)
- **Very high temperature plasma arc**
  - ✓ +3500 degC
- **Resulting in vaporized impurities before Si can vaporize**
  - ✓ P, K, Mg, Zn, Ca, Mn, Pb, Al, Fe, etc



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