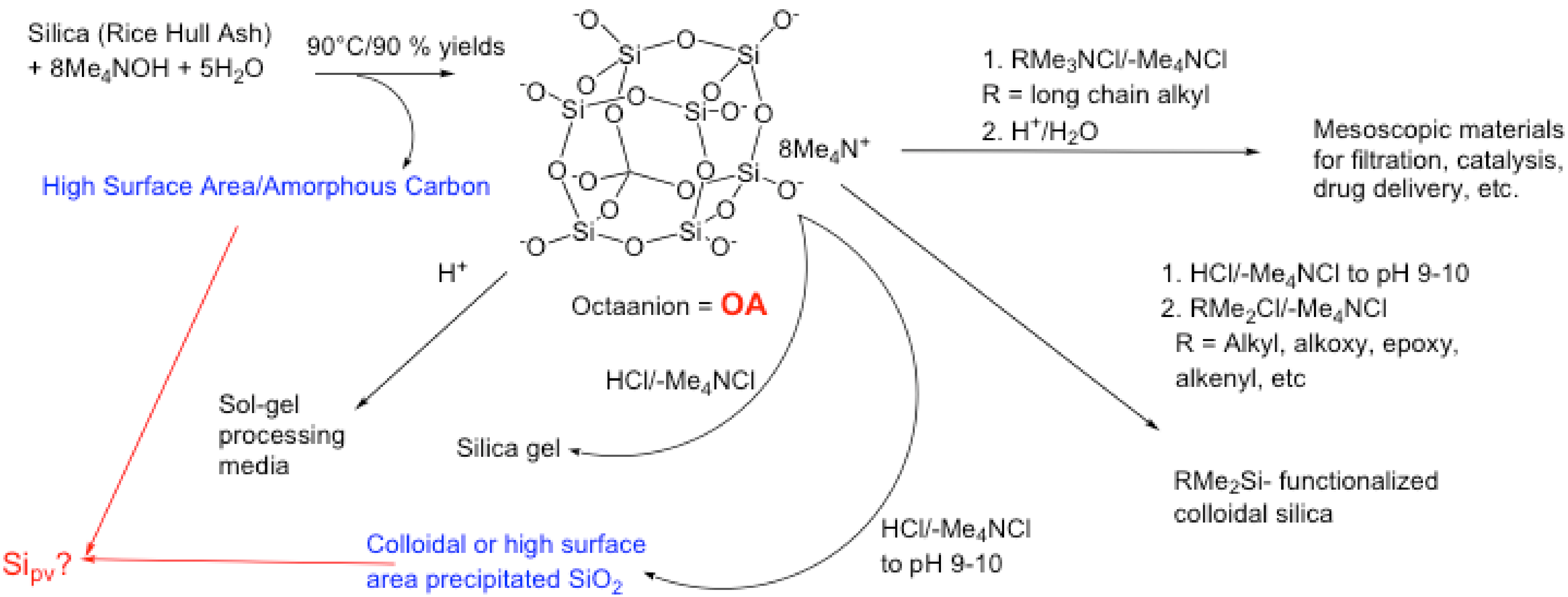

Solar Grade Silicon from Agricultural Byproducts

Program Team (PV, CSP, Systems Integration, Market Transformation)

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04/26/2010

Timeline

- 02/01/2008
- 12/31/2011
- Percent complete 60%

Barriers

Current Siemens process of making Sipv is energy and capital intensive.

We offer to develop a new source of Sipv

- Greener technology
- Lower cost
- Much lower capital cost

Budget

- Total project funding: $1,068,750
  - DOE:$855,000
  - Contractor share: $213,750
- Funding received in FY09: $368,742.60
- Funding for FY10:

  $221652.6

Partners

- Joint venture in negotiation with Wadham Energy, Colusa, CA

Challenges, Barriers or Problems

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

The current Siemens process used to make high purity silicon for photovoltaics (PVs) is energy and capital equipment intensive because:

- It requires multiple steps to purify silicon
- It uses toxic chlorinated intermediates
- It uses multiple high temperature steps.

The latter contributes to the high Si PV costs causing criticism of the solar industry given the ostensibly green nature of using PVs to produce electricity.

The objectives of our project are to develop a new, lower cost route to PV quality silicon using a renewable resource that is also an Agricultural Waste Product.

Our process is less energy intensive & polluting because it uses:

- No chlorinated chemicals, Ag waste & is thus much Greener
- Relatively pure SiO_2 and C from RHA as plants do not imbibe heavy metals.
- Much smaller particle sizes so reaction rates are faster and since electricity is produced to make RHA, the overall process is energy positive.
- Lower process temperatures for purification, lowering costs and
- therefore requires less capital investment (added benefit of making the production more reactive to demand)

Relevance

Objectives:

- **Develop process for purification of RHA**

  Low temperature only

  No hazardous chemicals

  Low cost process only

- **Conversion of RHA into high purity silica and carbon**

  All <100°C

Necessary to lower Si PV energy costs

- **Conversion of RHA-derived intermediates into PV silicon**

  Investigate and optimize kinetic changes brought by these much finer sized intermediates to traditional electric arc furnace (EAF) Si synthesis

  Evaluate alternative processes for Si production

  Scale the production for evaluation of the Si in PV wafer manufacturing

Relevance

Objectives for this period:

- **Optimize RHA purification**

  Identify process effects on individual impurities

  Scale-up purification

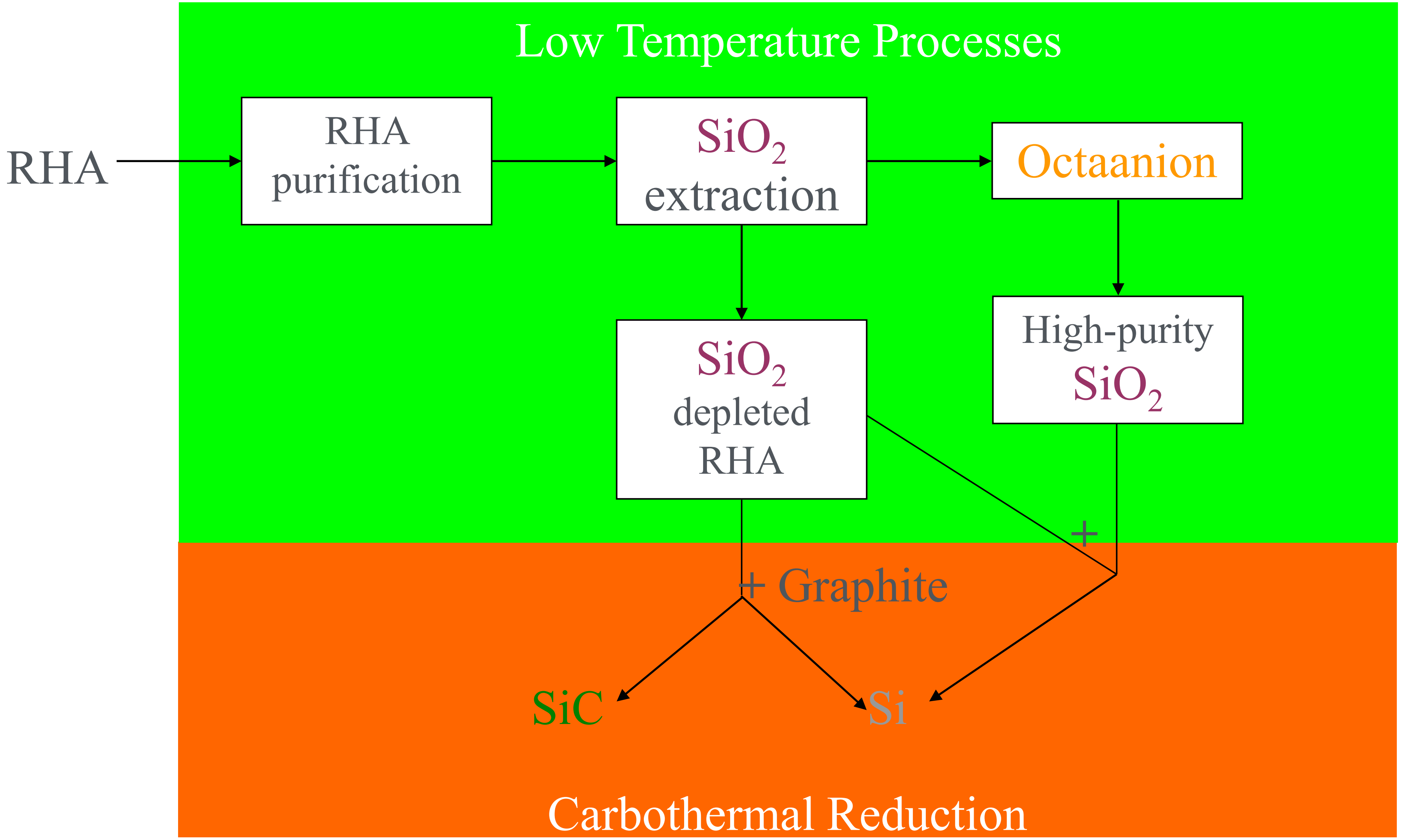
- **Scale RHA conversion to high purity silica and carbon**

  5 kg scale

- **Convert RHA-derived intermediates into PV grade silicon**

  Scale up the carbothermal reduction

Approach


Low Temperature Processes
RHA
RHA purification
SiO_2 extraction
Octaanion
SiO_2 depleted RHA
High-purity SiO_2
+
+ Graphite
SiC
Si
Carbothermal Reduction

Collaborations

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Wadham Energy

  Operates a power plant that produces 26 MW of electricity/yr by burning rice hulls (RHs). Plant consumes 200,000 tons of RH a year producing.

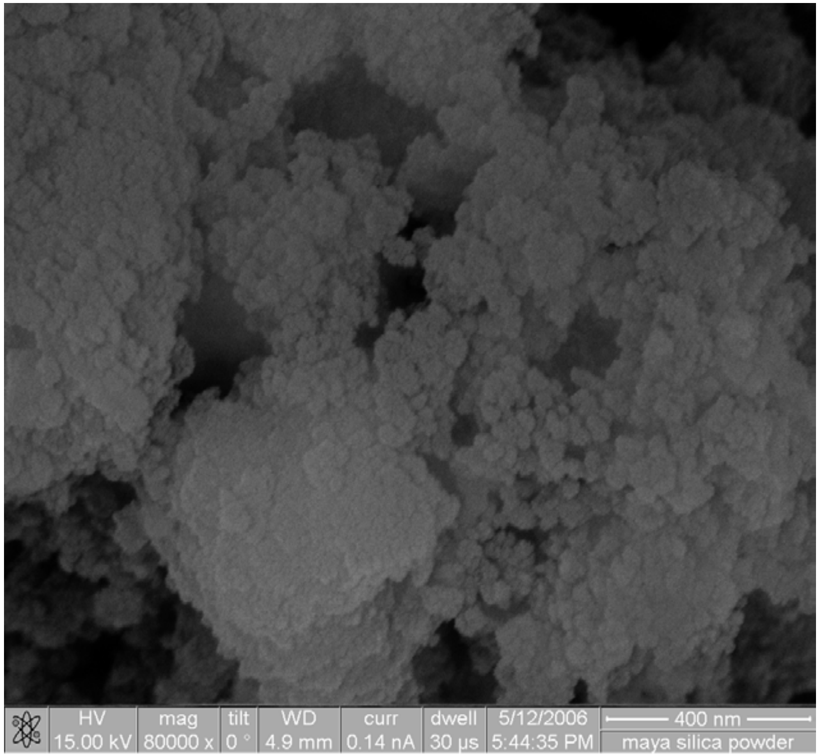
  Developing a working plan with Wadham directed towards a joint venture, with the goal of scaling RHA purification **to 100 tons/day**

- EDA

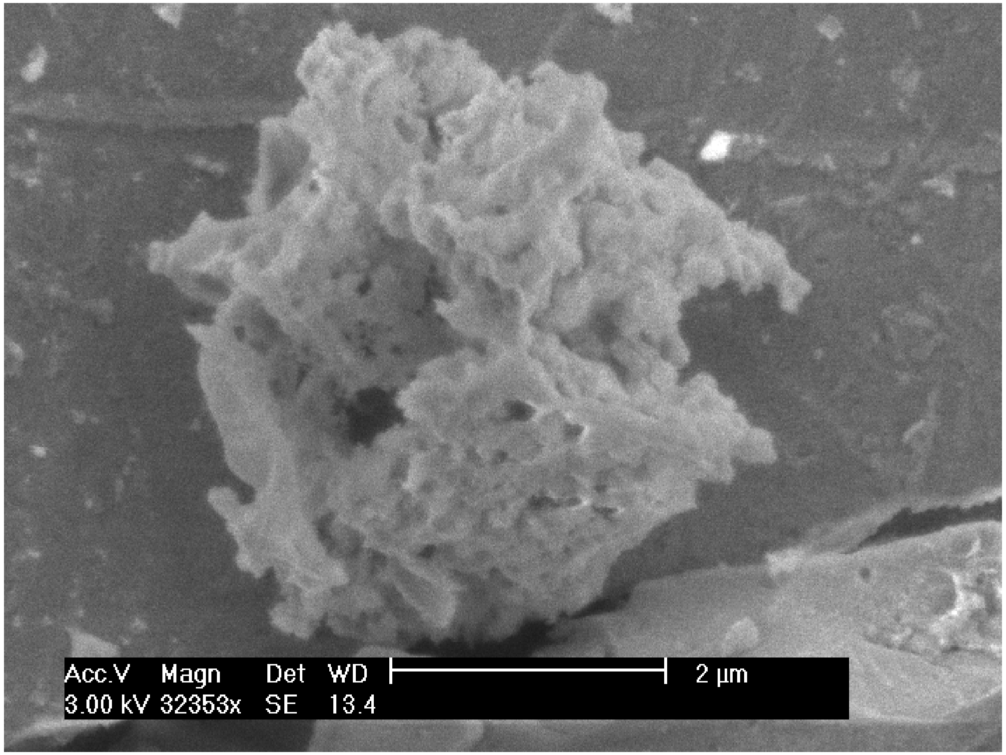
  Scaling plasma processing of RHA to form silane, SiH_4, faces too many obstacles to be solved in the duration of this project. We have ceased efforts here.

Accomplishments / Progress / Results

High purity intermediates with **90+% yield**



Silica nanopowder
(99.999% purity)



Si-depleted RHA
(20%Si/80%C, 99.995% purity)

Now produced in kg quantities

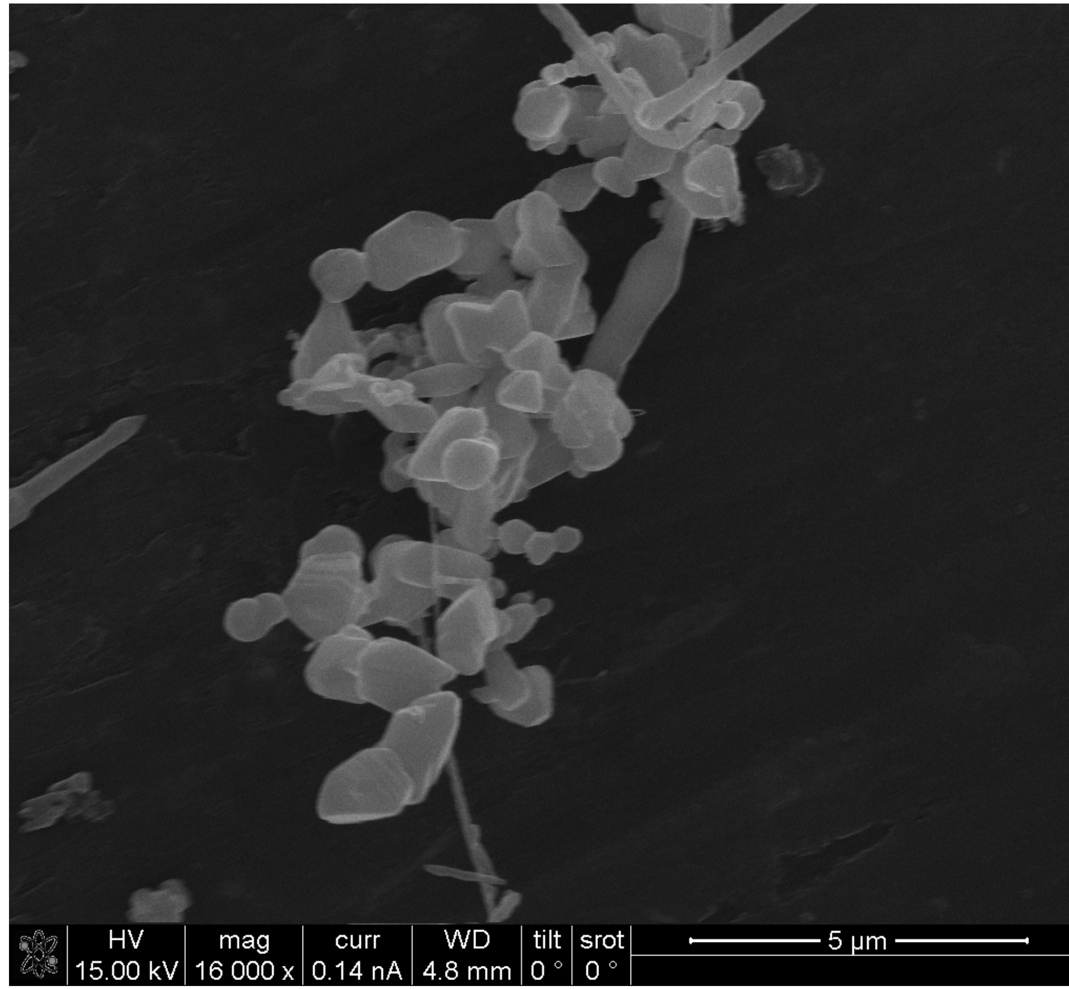
Negotiation for commercialization of the silica nanopowder underway

Accomplishments / Progress / Results

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

99.99% pure, fine silicon carbide powder

- Produced at 100 g/3h/batch
- Commercialized for polishing applications



Accomplishments / Progress / Results

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Small scale carbothermal reduction producing Si metal differs greatly from the industrial process:

- 6% theoretical yield
- Reaction temperatures >2400°C

Our process uses:

- Different particle sizes: 1-10 cm (industry) vs 3 μm --> different kinetics
- A different reaction path as intermediate SiO (g) must react rapidly in a small volume reactor.

Using serially built custom EAFs, reaction scaled the several times:

- Increased the power available to the EAF 5 kVA-->9 kVA-->50kVA
- Increased batch size from 7 to 150 g of RHA
- Next scale-up is to 5 kg RH/batch, under construction

Typical Si Produced	1.2	0.09	1.4	0	1.84	0.7	0.1	0.04	<0.1	99.9994%

Budget Status and Potential for Expansion

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DOE total share of budget: $855,000

$523,472.65 spent so far

Mayaterials total share of budget: $213,750

$133,084.06 spent so far

Project is *under budget:*

-Scale up of Si production is time consuming but low cost.

-Need to reach pilot plant scale to interest wafer manufacturer. Larger scale than initially planned

-New spending plan for end date of December 2011

With an increased budget, all processes could be scaled, and purities improved significantly at shorter times.

Future Plans (FY 2011 and beyond)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

FY2010

- Scale RHA processing to 20 kg batches w/ Wadham
- Scale EAF carbothermal reduction to 100 g Si scale
- Commercialize high purity fine SiC powder
- Commercialize high purity silica nanopowder

FY2011

- Scale RHA processing to 50 Kg batches
- Scale EAF carbothermal reduction to pilot plant scale
- Commercialization of medium purity silica nanopowder

Future Plans (FY 2011 and beyond)

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Milestones FY2010

- 99.999% Si purity reached with B < 1 ppm
- Projected cost <$12/kg (goal of $15/kg)
- Down selection of process: EAF selected
- Increase Si production to 10 and then 100 g/batch scales underway

FY2011 New milestones

- Increase Si production to kg scales
- Increase purity of all phases of process to 6 nines.

Mandatory Summary Slide

- We have produced 5N's pure nano-silica in kg quantities

  Working agreement towards a joint venture with Wadham Energy. Significant investment in Q3 2010 for further scale-up

  Commercialization planned for Q2 2012

  Energy required for this process is a fraction of the Siemens project

- Produced 4N's pure SiC fine powder in 100 g quantities

  Commercialization initiated

- 5N's pure Si with B <0.1 ppm made in 1 g quantities

  Projected costs < $12/kg

- Scaled EAF four times from 7g to 150 g to optimize process. EAF as practiced commercially uses 1-10 cm particles, we use 3 μm.

  Project must reach kg batches of Si for further testing in the solar market