PSE Challenges in Solar Research

CAPD Review Sunday March 10, 2013

B. Erik Ydstie

Solar grade silicon	(J. Du)
Float Process for Silicon Wafers	(G. Oliveros)
Dye Sensitized Solar cells	(R. Panella)
Solar and wind on the Grid	(J. Liu)

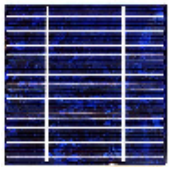
Supply Chain for Silicon Solar Cells

PV System = Solar cell module + Balance of system (BOS)

50% of system cost

30% of module cost

Crystalline silicon → Wafer production → Cell fabrication



Solar-grade silicon

REC Silicon, Moses Lake, WA
Fluidized Bed Si Production:

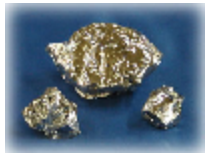
2002–2005	Pilot plant
2005–2007	Demonstration scale
2009	Commercial scale

Aim: $20/kg

$40-60/kg

IC supply chain

Metallurgical grade silicon → $SiCl_3H$ distillation → Decomposition Crystallization → Wafer → Integrated circuit



$3-5/kg

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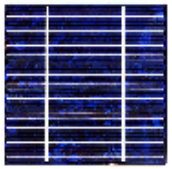

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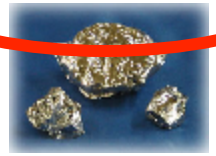

$3-5/kg

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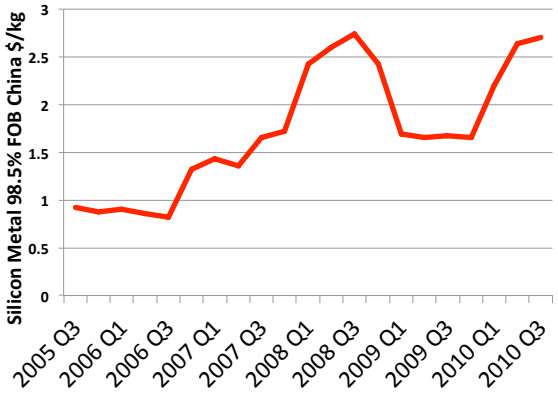
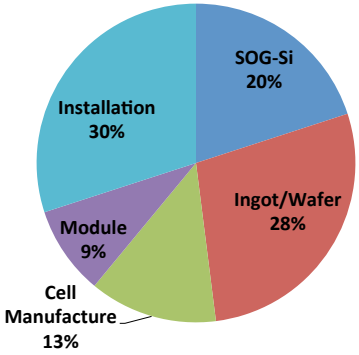
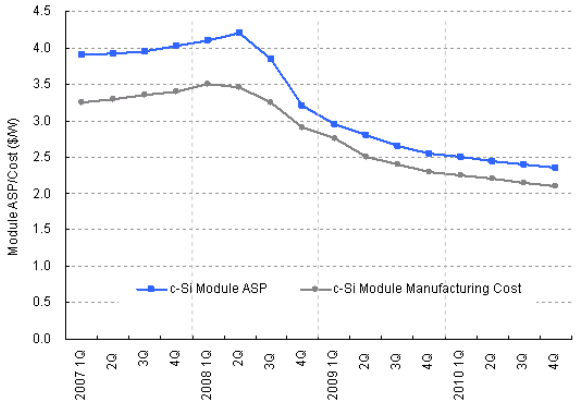
Metallurgical Silicon Production → Poly-Crystalline Silicon Production → Silicon wafers → Solar Cells → Solar Modules



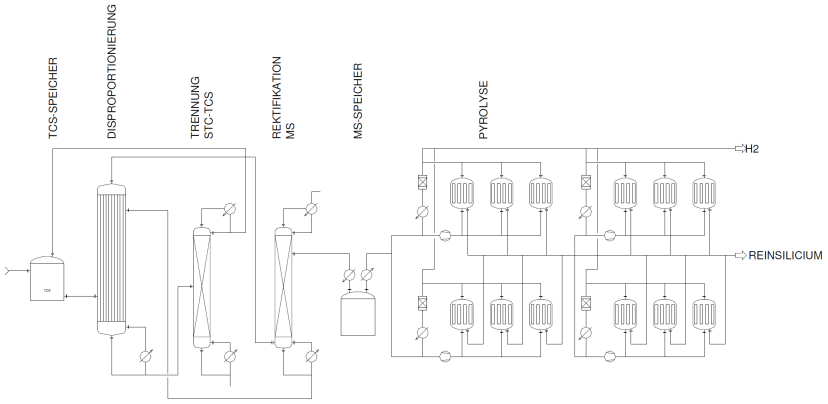


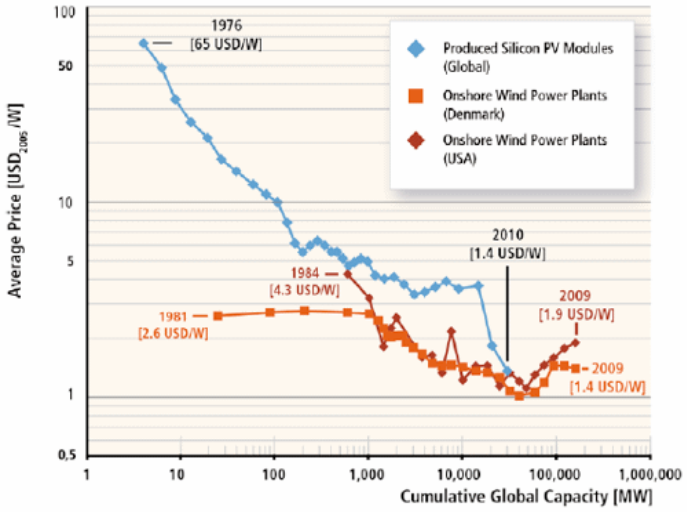


Process flow diagram disproportionation and pyrolysis

$4\ SiHCl_3 \rightarrow SiH_4 + 3\ SiCl_4$

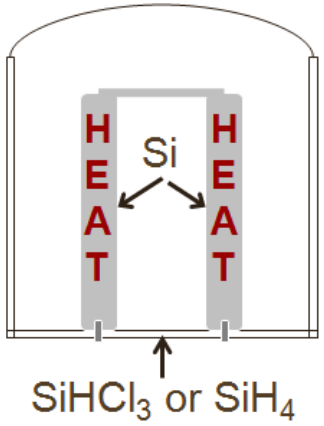
$SiH_4 \rightarrow Si + 2\ H_2$





Design and Control of Solar Silicon FBR process *From Silane to Solar Silicon*

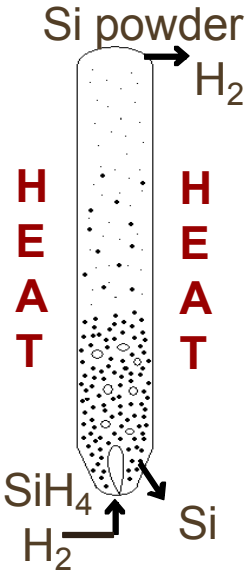
Ron Reis REC Silicon, Paul Ege Reactech
2 PhD students



Siemens Reactor
Batch Process
1100°C (TCS)
650 °C (Silane)

$$SiH_{4(g)} \rightarrow Si_{(s)} + 2H_{2(g)}$$

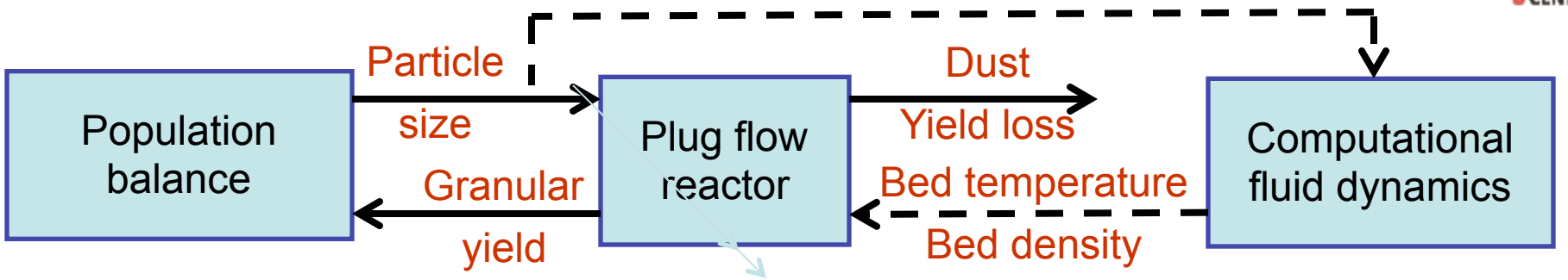
increase throughput
Reduce energy cost



Fluid Bed Reactor
Continuous Process
Large surface area
650 C

Goal: develop scale-up and control models to optimize granular yield and control particle size.

Multi-scale Modeling Approach



Particles are well-mixed

Integrate over time for particle size distribution

Gas and powder are plug flow

Integrate over height for granular yield

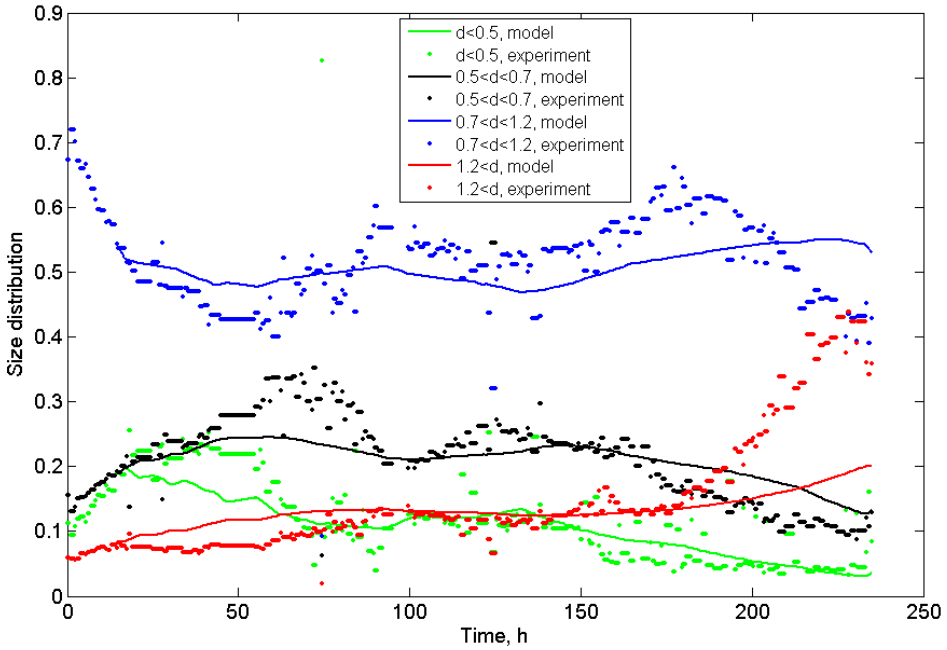
Control fluidization regime

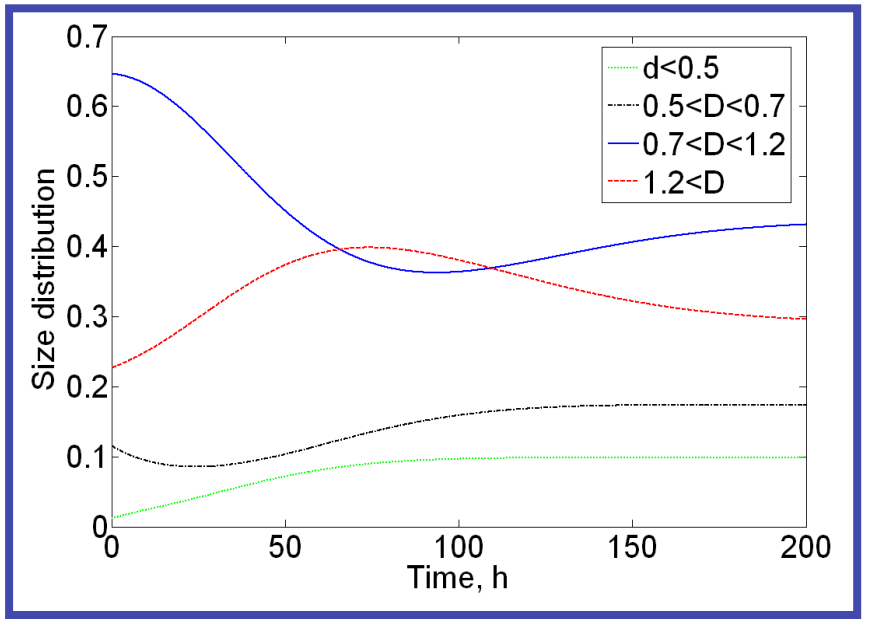
Simulate to obtain model input

Operation challenges

- Fast dynamics – fluidization, reaction
- Slow dynamics – particle size distribution
- Distributed parameters
  - *Particle size distribution*
  - *Chemical reaction, yield loss*
  - *Bed fluidization*

Model Verification using Pilot Plant Data



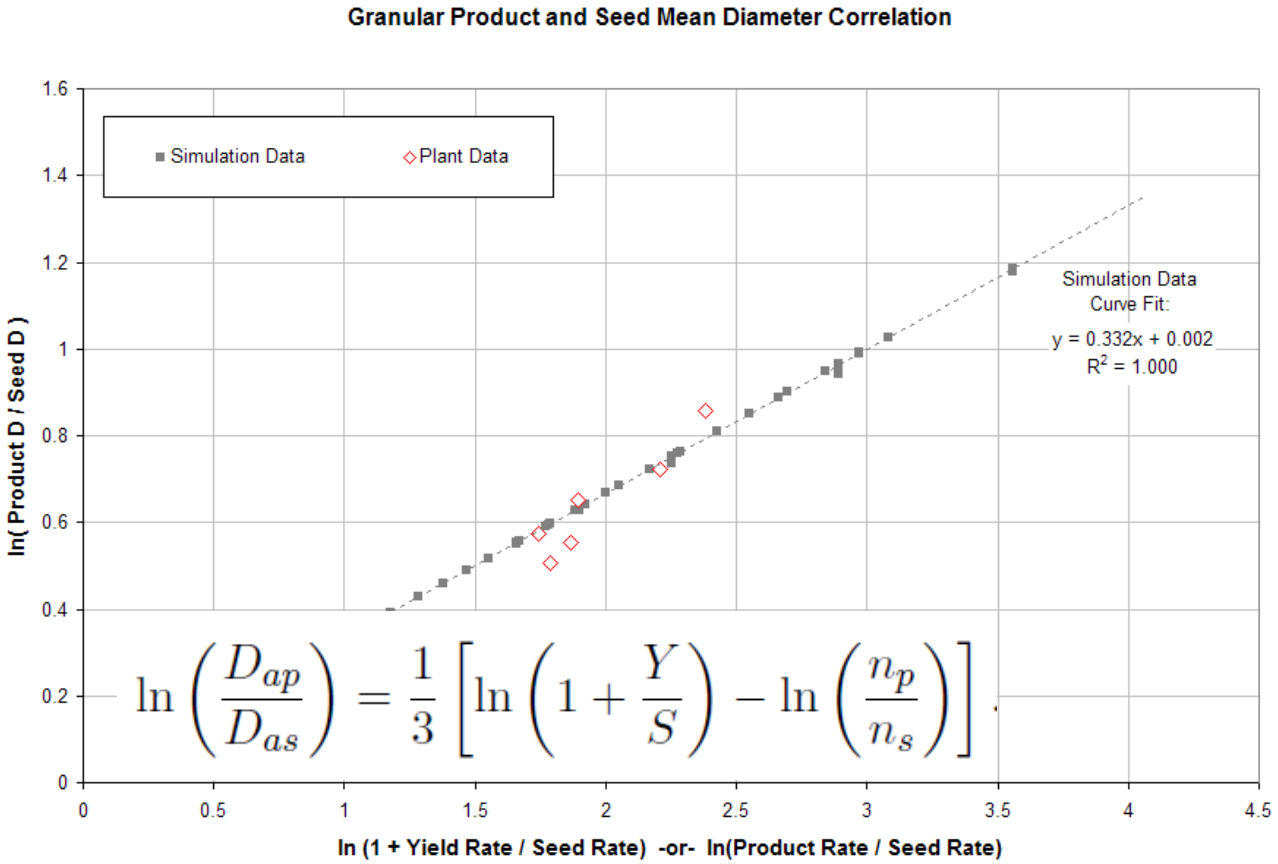


Time constant for particle size distribution about 50 hours.

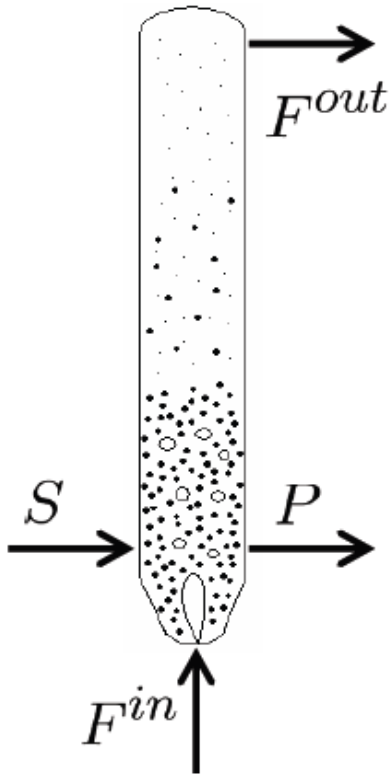
Weak control of distribution function

Difficult to control yield loss (sensitive system)

Scale-up models: from pilot to demonstration plant



$$\ln\left(\frac{D_{ap}}{D_{as}}\right) = \frac{1}{3}\left[\ln\left(1+\frac{Y}{S}\right) - \ln\left(\frac{n_p}{n_s}\right)\right]$$



Y-Yield
S-silane feedrate
D- average diameter(p - product, s-feed)
n- particle feedrate (p -product, s-feed)

Full Scale Production on Moses Lake in 2009

- Multi-scale modeling
  - Captures physics of system (CFD, Chemistry, Population balance)
  - Useful for scale-up and design
  - Predicts process dynamics
- "Natural Discretization" of population balance
- New closure relation
- Stability and control (Juan Du)
- **REC Silicon's $970 million expansion project** in Moses Lake houses 24 fluid bed reactors to produce 6,500 metric tons of polysilicon per year
- Christy's Thesis has been "sold" from the library

Ground Breaking August 2006

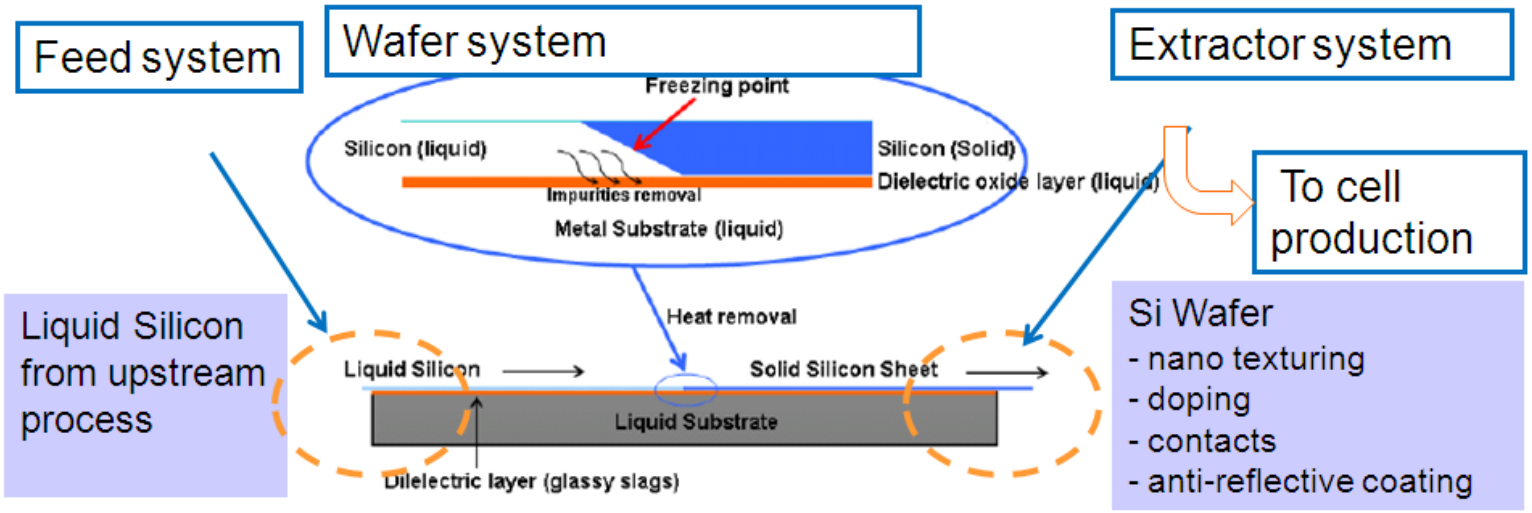
Mar. 2008

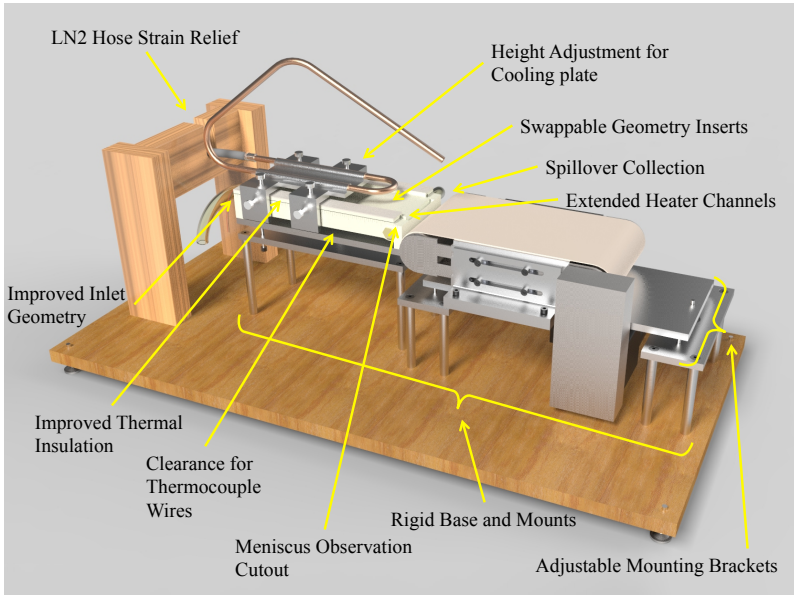
Sept. 2008

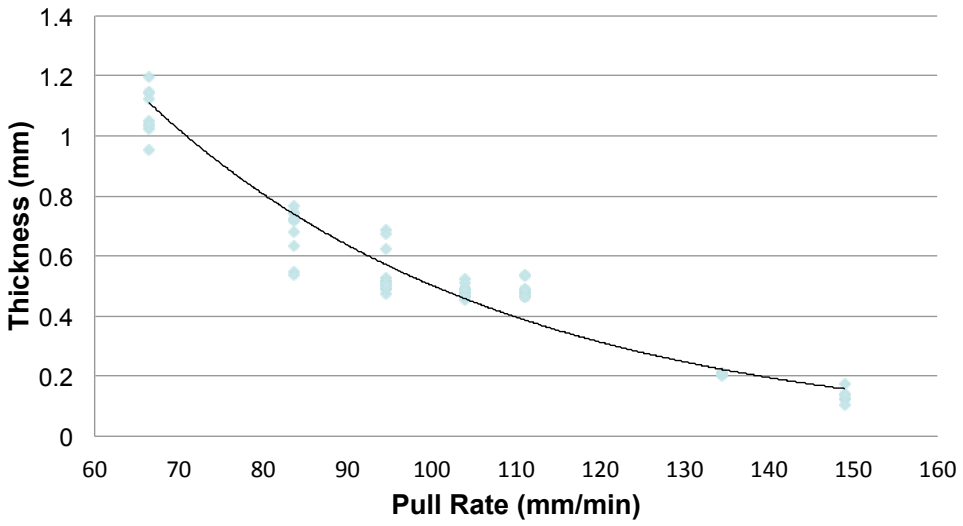
Production Nov. 2009

- NSF Graduate Research Fellowship Program
- REC Silicon
- Reactech Process Development Inc.

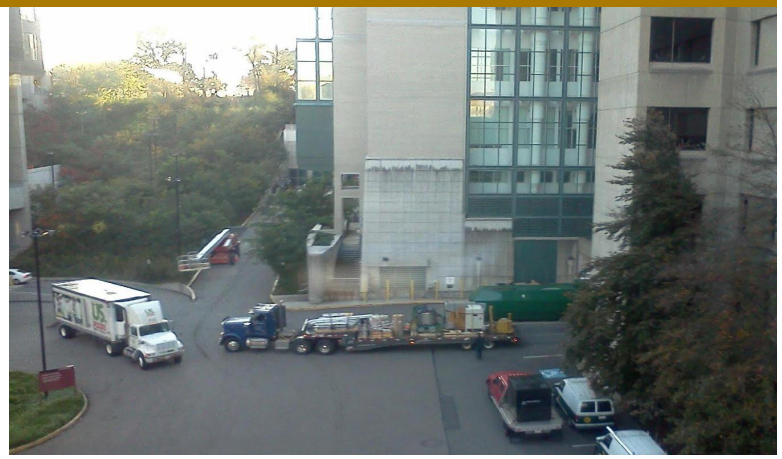
Float Process for Silicon Wafers

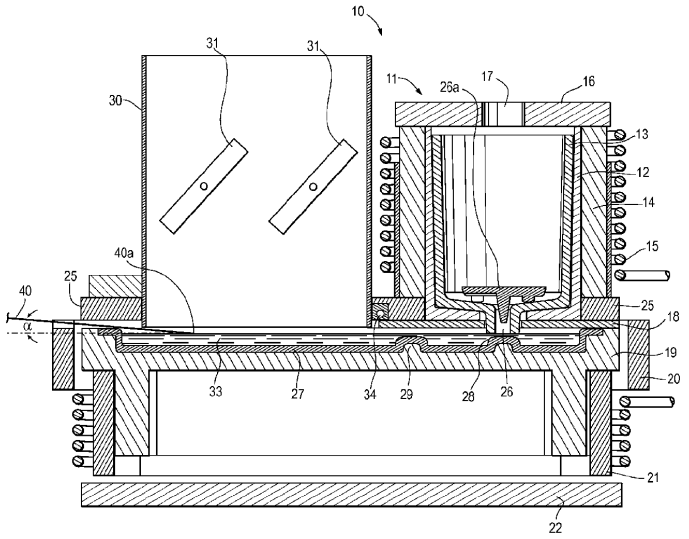






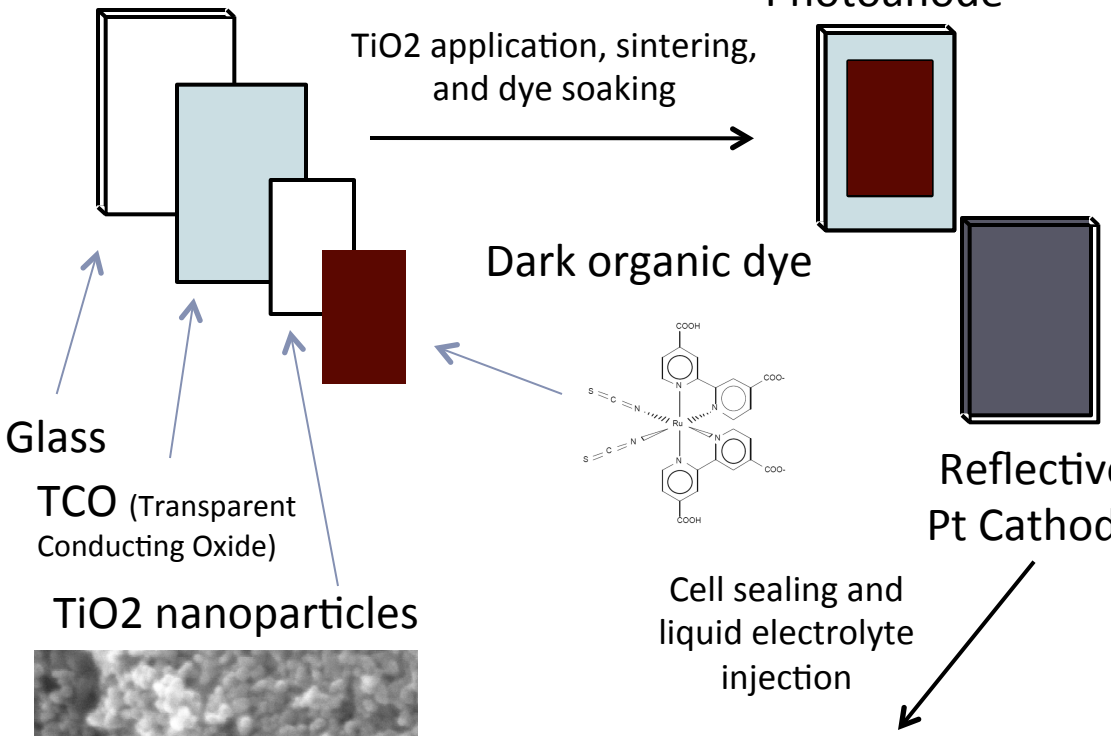
Installation of HRG Pilot Plant at CMU

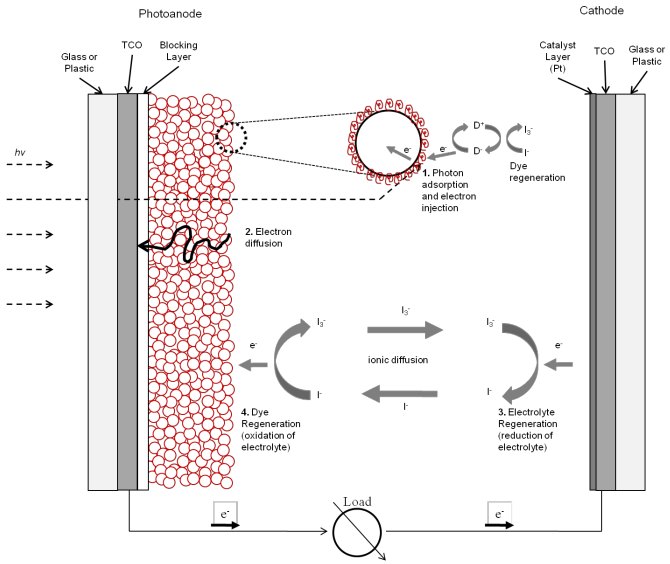


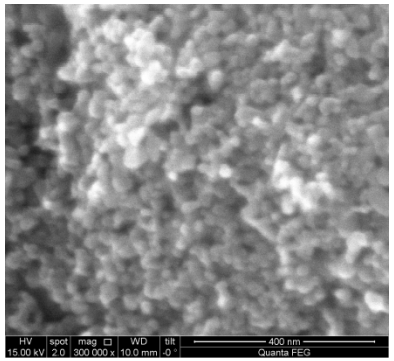


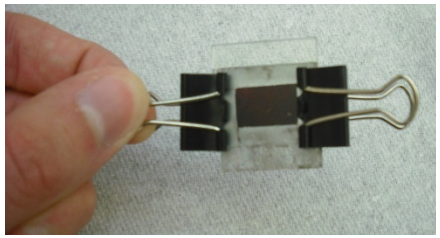
1. ~ $1M investment capital
2. ~$1.5M R&D (modeling small scale,..)
3. 60kW induction furnace
4. 5in wide
5. 10 ft long
6. Ar controlled atmosphere
7. Allen Bradely control system

Dye Sensitized Solar Cell – Simple Construction

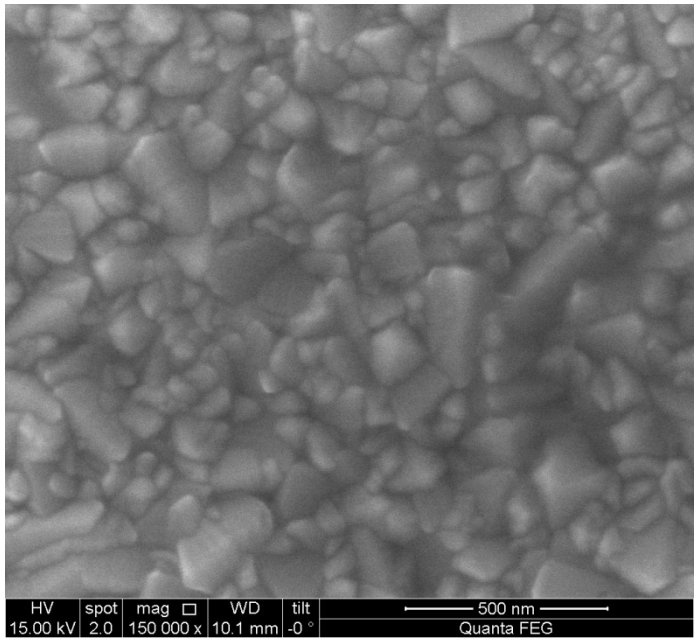




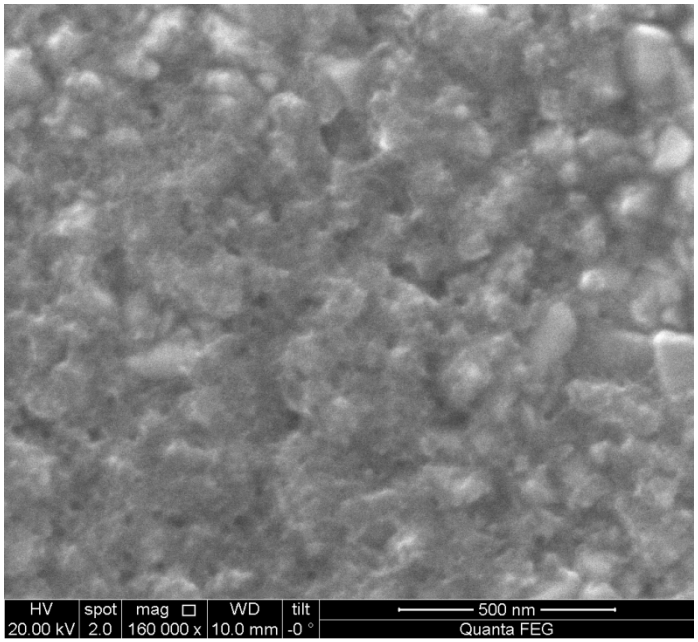




Application of Deposited Particles to Operating Cells



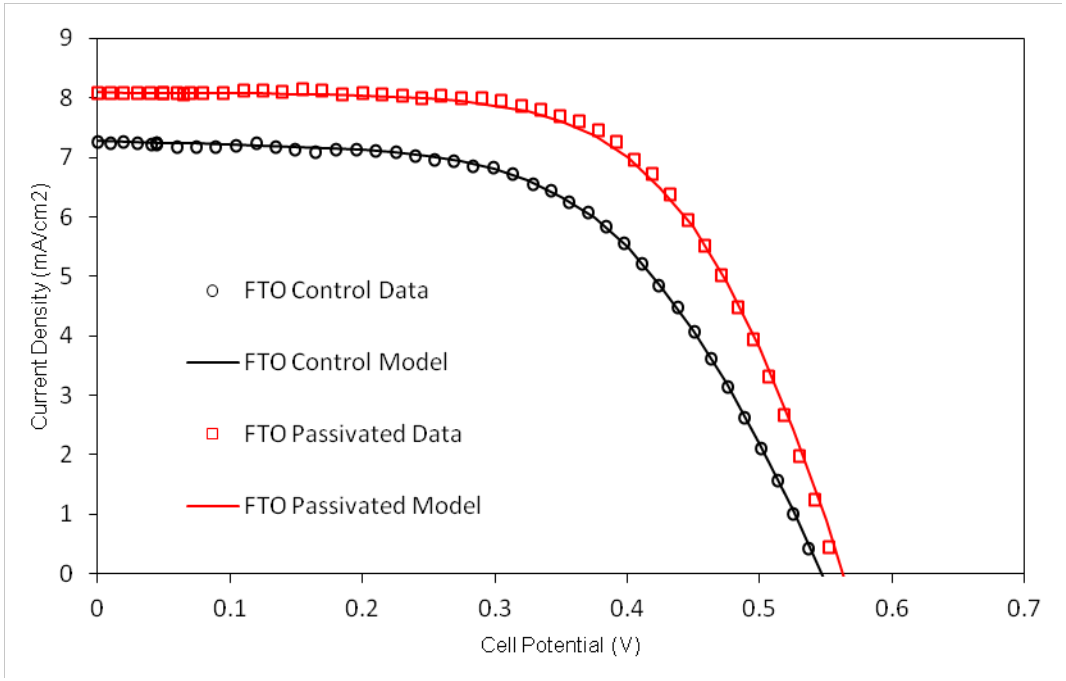
10 Ω/□ FTO under 150k magnification SEM
Crystalline nature encourages light scattering



10 Ω/□ FTO which has been exposed to TiO_2 nanoparticles under adsorbing conditions

Small, 10 nm particles are able to strongly adsorb to the FTO surface

Solar Results



	I (short circuit) mA/cm2	V (open circuit)	Fill Factor	IPCE
"Pre" Coated Cell	2.55	0.46	0.441	0.52%
Standard Cell	1.41	0.33	0.417	0.19%

The pre-coated anode has been treated with an impinging jet with 10 nm TiO_2 nanoparticles.

On top of this, a ~30 µm layer of 25 TiO_2 particles has been applied by doctor-blading and drying a concentrated slurry. The normal anode only has the doctor-bladed layer, not the 10 nm layer.