Low Cost Multi-Crystalline Silicon
ORNL Workshop on Solar Energy

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Unmet Market Needs Demand net shape "kurfless" Technology

- High cost, wafer is 60% of module cost;
- Low Efficiency, micro cracks, and many sources of contamination;
- Very low yield, lower than 30%
- Untenable Wafer Wire sawing, DOE looking for "Kurfless Technology" causes unavoidable low yield, high costs, micro-cracking;
- Unacceptable energy costs and yield and contamination associated with all bulk melting;
- Incremental improvements to current bulk melting, wire sawing must be replaced with a game change.

Objectives:

Silicon photovoltaic (PV) based solar can perhaps best realize its potential to compete with traditional sources of electricity on a cost basis by reducing the capital cost and operating cost per kWh by 60% or more. Achieving such dramatic reductions in capital and operating cost can only be achieved by addressing specific metrics through manufacturing technologies, but the bottom line must be lower cost per unit of solar module and more importantly greater electrical output per square meter of the solar module:

- Yield on solar grade silicon must be improved from current levels of 30% or less to greater than 90%. It is absurd to think one can achieve desired electricity production costs when one is discarding 70% or more of the materials, energy, labor and overhead;
- Efficiency must be increased from current levels of 17 %. This best leverages the infrastructure of a solar installation which includes glass, aluminum, silicon, inverters, energy and labor, all of which are expensed in capital and operating costs by the number of kWh the unit produced. The higher the efficiency the higher the kWh production of the unit, and therefore, the lower the cost per kWh. It is absurd to think one can achieve desired energy production costs when one is extracting perhaps only 60% of the available energy harvest from the total investment in that unit.

Metrics for success

Cost, efficiency, capital, and operating cost per kWh: Achieving USD 0.10 for PV generated electricity requires that the capital cost per watt be reduced by 60% or more. This can only be achieved by accomplishing these metrics:

- Increase silicon yield from 30% (or lower) to 95%;
- Increase efficiency to greater than 20%;
- Do so by reducing cross section of wafer and net shape manufacture;
- Do so by maximizing the purity of the silicon;
- Do so by reducing the grain boundaries and the impurities they contain;
- Do so by making the PN junction more efficient;
- Do so by making the surface more effective at trapping light;

Introduction of new technology building on prior published work:

- Previously patented and industrialized similar silicon technologies
- Subsequently understood that net shape wafer fabrication could solve all these problems;
- Developing new approach, which is the subject of a series of new patents published and pending;
- We can now introduce this new technology which completes this work and makes it ready.

The leading Requirements:

- Cost!
- This can include higher efficiency;
- But must include:
  - Much higher yield;
  - Much lower energy costs;
  - Elimination of wire sawing;
  - Elimination of bulk melting;
  - Elimination of crucibles

Our Approach:

- Patented and proprietary, but industrially proven, silicon sizing into a powder or slurry;
- Patented approach to net shape fabrication of wafer from properly sized slurry or powder;
- Very short thermal processing reducing energy by more than 99%;
- No contact with air, crucible or long time at liquidus.

Lets consider current market Cost vs. efficiency:

Here is a table of the top producers with regard to efficiency

Company	Production	Efficiency production	Efficiency Lab
SunPower Back Contact	398	22.4	24.2
Sanyo HIT	255	19.9	23
Suniva Artisun	170	18.3	20
Suntech Pluto	48	19	25

Lets consider current market Cost vs. efficiency:

Top 9	50%
1st Solar	1000
Suntech	700
Sharp	600
Q Cells	500
Y Group Energy (SIC)	500
JB Solar	500
Kyocera	400
Terasolar (SIC)	400
Sunpower	400
Total	5000
Industry	10,000

Translated Customer Preferences:

- The Suntech market share is not the high efficiency product so the leaders are leading on cost not efficiency.
- For instance most all of 1st Solar is low out put cadmium telluride which is also an environmental time bomb for them when they have to be disposed.
- The four efficiency leaders are all using single crystal and have a 9% market share.
- All others are using polycrystalline.
- I would say the single crystal group is at 20% average and the polycrystalline is at 17% average.

Some Metrics, industry tonnage:

Company	Location	Metric tons
Hemlock, (Dow Corning lead)	US	36,000
Wacker	Germany	25,000
GCL Poly	Hong Kong	18,000
OCI	South Korea	17,000
MEMC	US	8,000
REC	Norway	17,000
Tokuyama	Japan	8,000
Elkem	Norway	10,000
Total		139,000

Industry wafer tonnage:

In tons	21,000
Starting materials	120,000
Yield on ingot trimming 30%	84000
Yield on carving into loaves 30%	58800
Yield on wire sawing 50%	29400
Yield loss from wafer breakage 30%	20580
Starting weight in grams	2.4E+11
Watts produced	10,000,000,000
Grams per watts	24
Yield on current thickness	0.176

Why Crucibles and bulk melting must be eliminated:

- Both rebonded fuses silica and fuse quartz a major source of contamination:
  - Oxygen in fused quartz and iron from rebonded fuses silica: Fe2O3 **<350** ppm!
  - (At 1600 degrees silicon will steal iron from Fe2O3 in glass!)
- Cost of crucibles, yield, energy, efficiency.

Also true we cannot afford to scale current technology and it is NOT green: Some examples, Silicon:

Silicon			
Tons of silicon used	140,000	560,000	1,194,667
Tons used per MCS process	14,000	56,000	119,467
Tons per GW	11,667	9,333	7,467
Tons per GW per MCS process	1,167	933	747
Cost at USD 5000 per metric ton	700,000,000	2,800,000,000	5,973,333,333
Cost at USD 5000 per ton per MCS	70,000,000	280,000,000	597,333,333
Industry savings per year	630,000,000	2,520,000,000	5,376,000,000

Also true we cannot afford to scale current technology and it is NOT green: Some examples, furnaces and crucibles, polycrystalline:

Furnacing with Crucibles Poly	2010	2015	2020
CAPEX, number of Furnaces	2004	10020	26720
Cost of furnaces	300,000	260,000	220,000
Total Cost of Furnaces	601,200,000	2,605,200,000	5,878,400,000
Number of Crucibles per year	601,200	3,006,000	8,016,000
Unit cost of crucibles	325	325	325
Total Cost of Crucibles	195,390,000	976,950,000	2,605,200,000
Energy @ .06 per watt	720,000,000	3,600,000,000	9,600,000,000
Labor for furnacing @ .08 per watt	960,000,000	4,800,000,000	12,800,000,000
Savings in furnacing	2,281,200,000	11,005,200,000	28,278,400,000
Total Gross Savings	**6,466,542,000**	**29,301,942,000**	**71,725,776,000**

Also true we cannot afford to scale current technology and it is NOT green: Some examples, wire sawing:

Wire Sawing	2010	2015	2020
GW production	12	60	160
Machines in production	2,000	10,000	26,666
Average Cost per machine	600,000	520,000	460,000
Total CAPEX for Wire sawing	1,199,952,000	5,199,792,000	12,266,176,000
Cost per Watt wafering	0.18	0.16	0.145
Total operating cost (billions USD)	2.16	9.6	23.2
Industry Savings per year	3,359,952,000	14,799,792,000	35,466,176,000

Some forecasts by MCS:

CAPEX Cost	**400,000**
Production per hour	5688 watts
Energy use per hour	50 KW
Energy cost per hour	20
Energy per watt produced	**0.0035**
Production per year	45,144,320
Capex with 5 year amort per watt	**0.00177**
Labor cost per watt	**0.0105**

A truly disruptive technology disrupts:

Net Savings	**6,277,302,000**	**28,355,742,000**	**69,202,576,000**
Year	2010	2015	2020
Net Job Creation @ 250k/job	**757**	**3,785**	**10,093**
Net job savings	**25,109**	**113,423**	**276,810**

Published patents and applications; four not published:

Publications:

- These patents apply to the MCS approach to this work:
- US patent 6,638,491 “Method of producing silicon metal particulates of reduced average particle size” issued to John J Carberry 28 October 2003
- US Patent 7,604,696 “Method of making a solar grade wafer” issued to John J Carberry 20 October 2009
- Patent pending May 2010, “Method of making a solar cell” applied by John J Carberry. EFS ID 7672839, Application number 61347904.

Progress Report:

- Industrialization of milling proven;
- Recent trials have proven ability to melt net shape quickly and cleanly with such low energy;
- Characterization of various silicon compositions being evaluated and favor pure materials;
- Economics, yield and efficiency seem to favor using very pure silicon.
- Several further patents being filed or pending;
- Now beginning planning for beta plant.

Our hopes and forecast:

- Maintain high purity in materials preparation: (9 to 11 nines)
- Establish industrialized process for net shape melting in seconds, maintaining purity;
- Establish process for net doping;
- Customize the surface of the melted wafer;
- Integrate cell functions;
- Reduce wafer cost by order of magnitude.

Where, how and who?

- We are in process with Seed Funding at ORNL and ahead of program calendar;
- We are negotiating for space at ORNL;
- We are working on first round;
- We intend to set up a beta line serving a limited customer base;
- We then plan to use this beta facility to launch a broad licensing program, focusing first on Tennessee operations and operators.