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The Super Highway to Grid Parity

Performance Analysis of Solar Grade Crystalline Silicon Modules

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Performance Analysis of Solar Grade Crystalline Silicon Modules

OUTLINE

- Solar grade Si vs. Conventional Poly-Si
- Comparison between solar grade and conventional crystalline Si solar modules
  - Wafer impurities
  - Reverse breakdown voltage and hot spots
- e-Module and its power station performance data
  - Comparison with conventional module power station
  - Initial light induced degradation
  - Long term performance
- Summary

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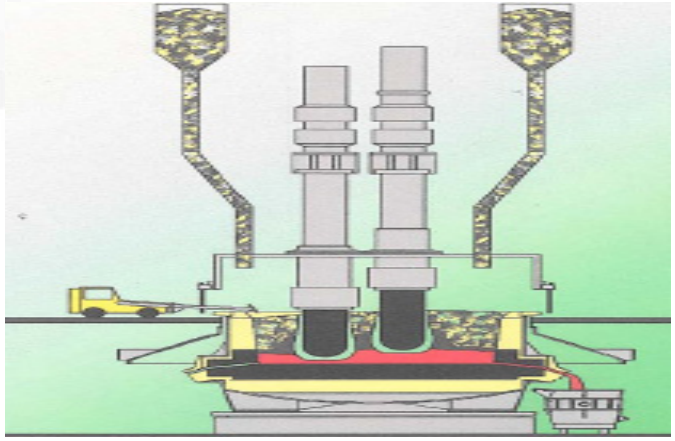
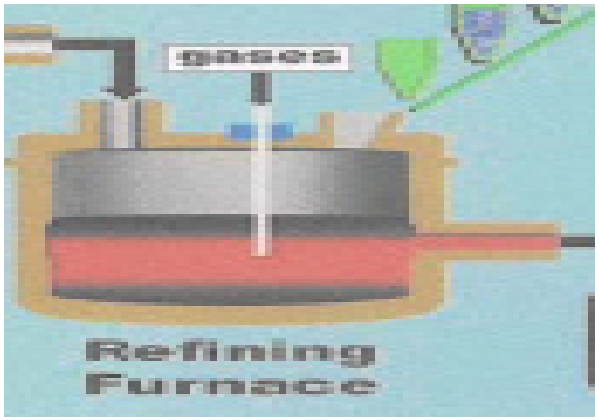
Typical Solar Grade Silicon Process

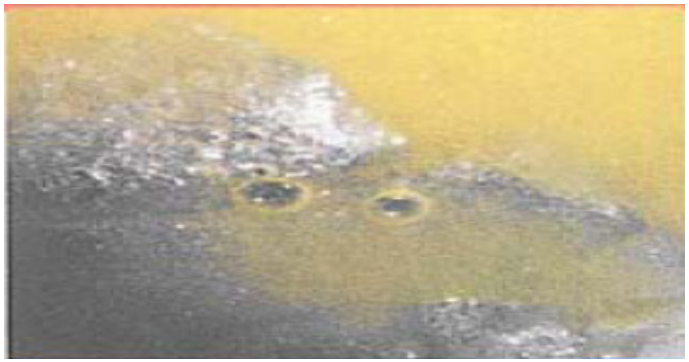
Arc Furnace



Slag Treatment



Chemical Leaching



Solidification and Sorting

Solar grade Si: environmental friendly manufacturing

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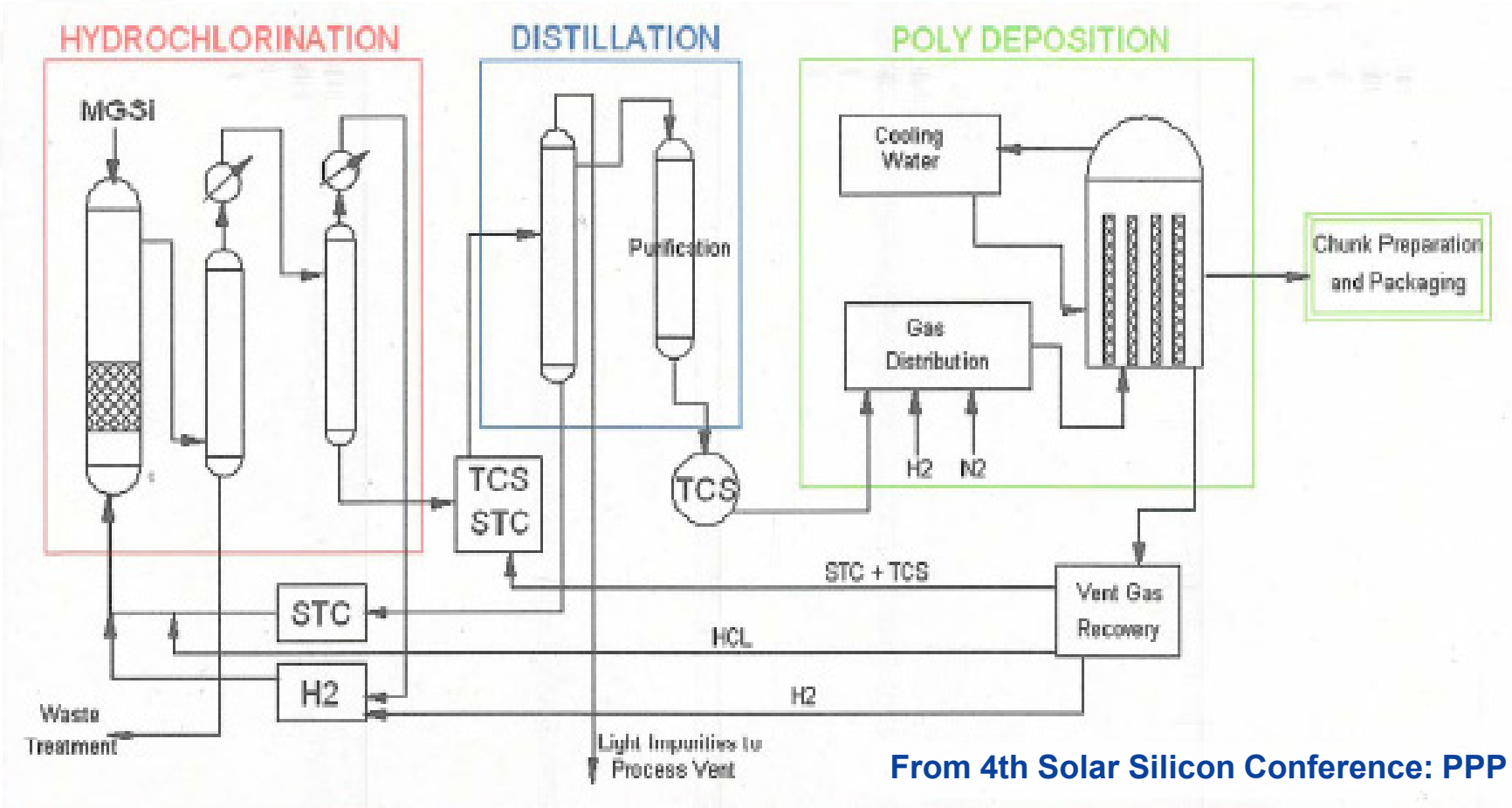
--From 4th Solar Silicon Conference: Silbec, Solmic, Elkem

Modified Siemens Type Poly Silicon Process



From 4th Solar Silicon Conference: PPP

Siemens Type: by-products with environmental concerns

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Solar Grade Si vs. Conventional Poly Si

	Conventional poly-Si	Solar grade Si
Energy consumption (KWh/kg)	80-200	10-20
Environmental impact	High	Very low
Impurity levels* of currently available commercial supply	1) 6N-7N, 7N-8N; 2) 8N-9N; 3) better than 9N	5N- ~6N
Product cost ($/kg)	30-60	10-25
Investment $(USD)M/1000MT	~100	~15
Factory construction period	~2Years	<1Year
Typical multi-crystalline cell efficiency	15-16.5%	14-15.5%

Solar grade Si: Low cost, fast energy payback, environmentally friendly

* Not including O and C

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Manufacturing: e-Modules vs. Conventional

e-Modules

Solar Grade Silicon → Ingots → Wafers → e-Cells → e-Module

Conventional Modules

Conventional Silicon → Ingots → Wafers → Cell → Conventional Module

Same production equipment, enhanced processing

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SIMS Wafer Impurity Analysis

Sample ID.	C	O	Al	Cr	Fe
N-A (at/cm3)	4.18E+17	1.01E+17	3.16E+13	<	<
U-C (at/cm3)	3.86E+17	1.13E+17	1.34E+14	<	<
Detection limits	2.00E+16	5.00E+16	1.00E+13	2.00E+13	1.00E+14
Threshold con. *			4.40E+15	1.30E+14	2.50E+14
Sample ID.	Mn	Ni	Cu	Ca	Ti
N-A (at/cm3)	<	<	<	<	<
U-C (at/cm3)	<	<	<	<	<
Detection limits	1.00E+13	2.00E+14	1.00E+14	1.00E+13	5.00E+12
Threshold con. *	1.80E+14	5.00E+15	4.10E+17	-	2.60E+12

* Threshold concentration defined as the impurity level where the impact to cell performance becomes explicit
Source : Davis *et al.*, Impurities in Silicon Solar Cells
N-A: Conventional mc-wafer (from one of the main wafer suppliers)
U-C: Solar grade mc-wafer from Canadian Solar

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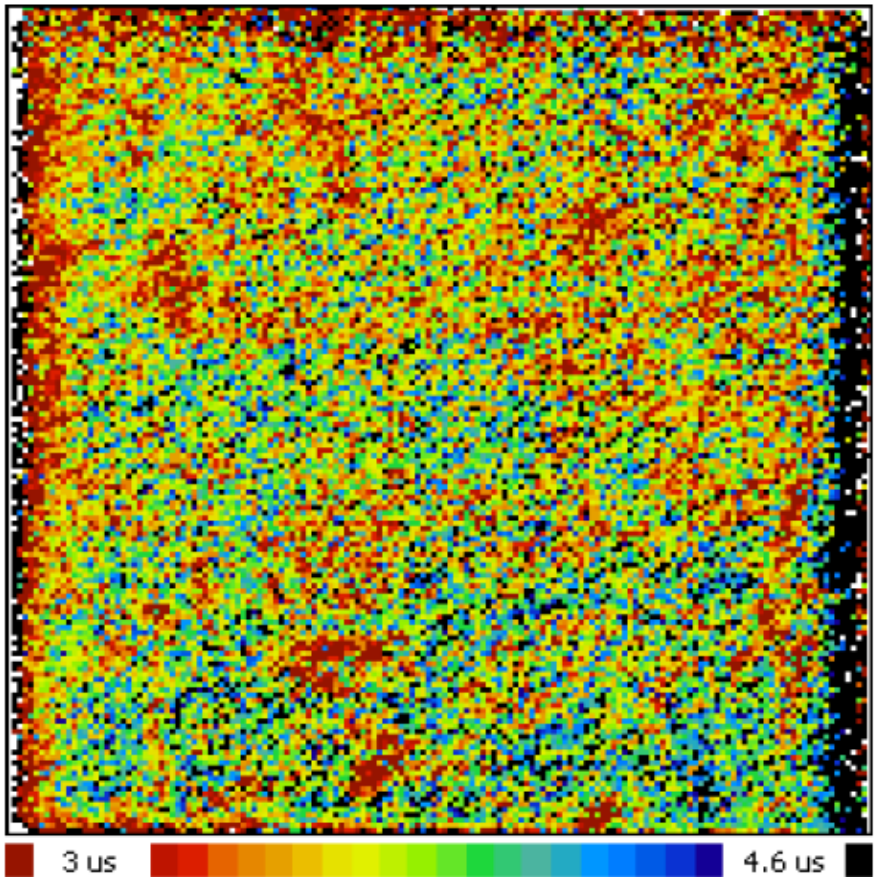
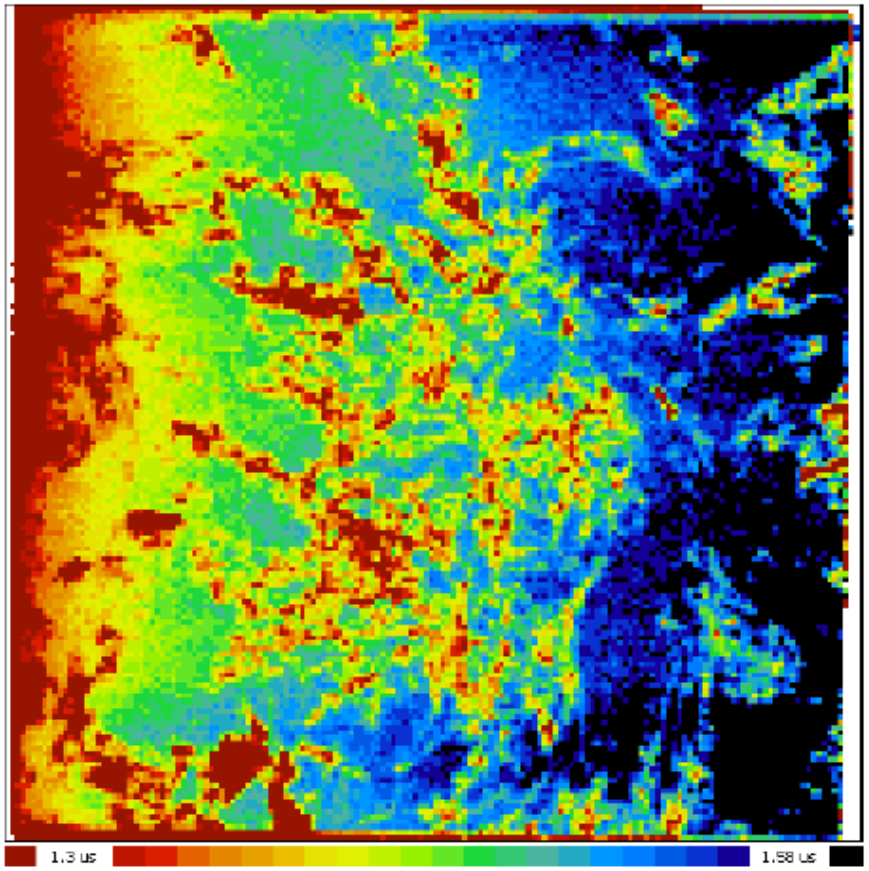
Wafer Minority Carrier Lifetime Mapping

(Without Passivation)



Scale 3.0 - 4.6 us

SoG Si mc-wafer lifetime mapping



Scale 1.3 – 1.58 us

Conventional Si mc-wafer lifetime mapping

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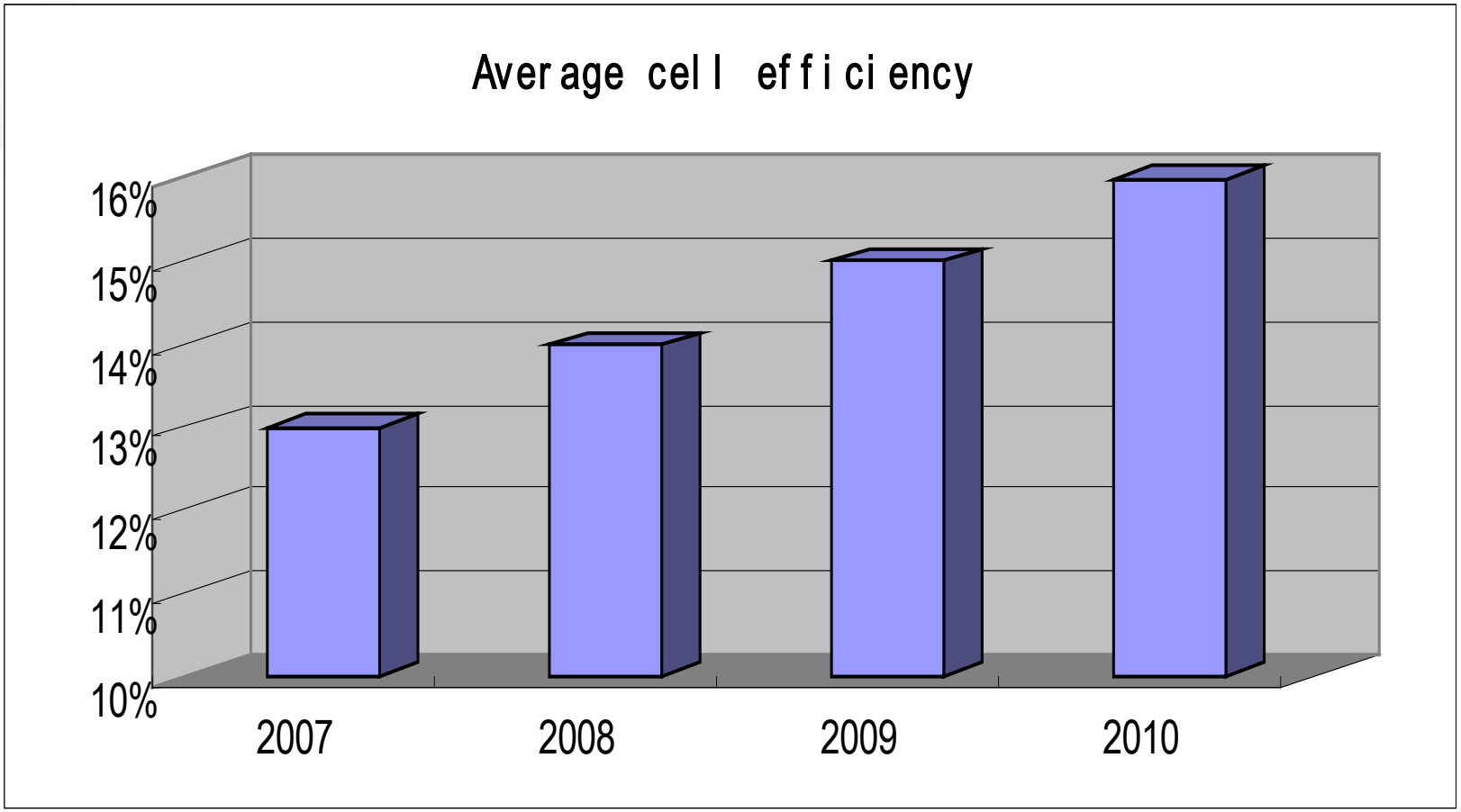
Solar Grade Si Cell Efficiency Footprint & Roadmap



SoG Si cell efficiency will catch up the conventional Si cell efficiency in next 2-3 years

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Reverse Breakdown Voltages and Hot Spots Protection

The relatively low reverse breakdown voltage of SoG Si cells is well addressed through:

- **Materials:** multiple DSS has greatly reduced the metal impurity levels
- **Growth process:** Specially designed ingot growth process has improved wafer crystal quality
- **P-gettering process:** Specially designed P-gettering process reduces impurity level and improves cell quality
- **Control:** Strict cell sorting and specially designed diode configurations keep e-Module performing as reliable as conventional modules

Hot Spots Testing

Single day outdoor hot spots testing

Long term hot spots testing on roof

e-Modules perform normally even over long-term testing

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Performance of e-Modules

Causes of initial degradation:

- **Cell passivation degradation**
- **Light induced degradation (LID)**
- **In some cases: Initial exposure of glass to sunlight can cause an increase of IR absorption**

Initial performance results:

- **Typically LID for SoG modules is 2-4%; stabilized after 3-4 days**
- **Higher than the initial LID of conventional modules (~1-2%)**
- **LID mainly caused by B-O complex; LID results in a reduction of Isc**
- **e-Module flashing is adjusted at factory to compensate the LID**

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Long Term Performance of e-Modules

Isc slow decreasing	FF decreasing
▪ Front side delamination ▪ EVA discoloration ▪ Hot spots cause EVA yellowing spots ▪ Back-side delamination interrupts the heat dissipation and causes the hot spots	▪ Thermal stress induced micro-cracking under ribbon ▪ Delamination caused the hot spots which, in turn, result in micro-cracking under ribbon ▪ Moisture intrusion cause the finger or busbar corrosion ▪ J-box connection corrosion and resistance increasing

	Module-1	Module 2	Module 3	Module 4	Module 5	Module 6	Module 7	Module 8
Pmax(W)*	180.1	189.3	190.16	178.3	177.8	184.94	193.8	190
Pmax(W)**	179.71	188.25	188.2	178.07	175.65	184.69	192.17	189.34
Pmax change	-0.22%	-0.56%	-1.03%	-0.10%	-1.21%	-0.13%	-0.84%	-0.35%

Annual change rate is -0.56%

* Tested after 1 week LID ** Tested after 1y operation in power station

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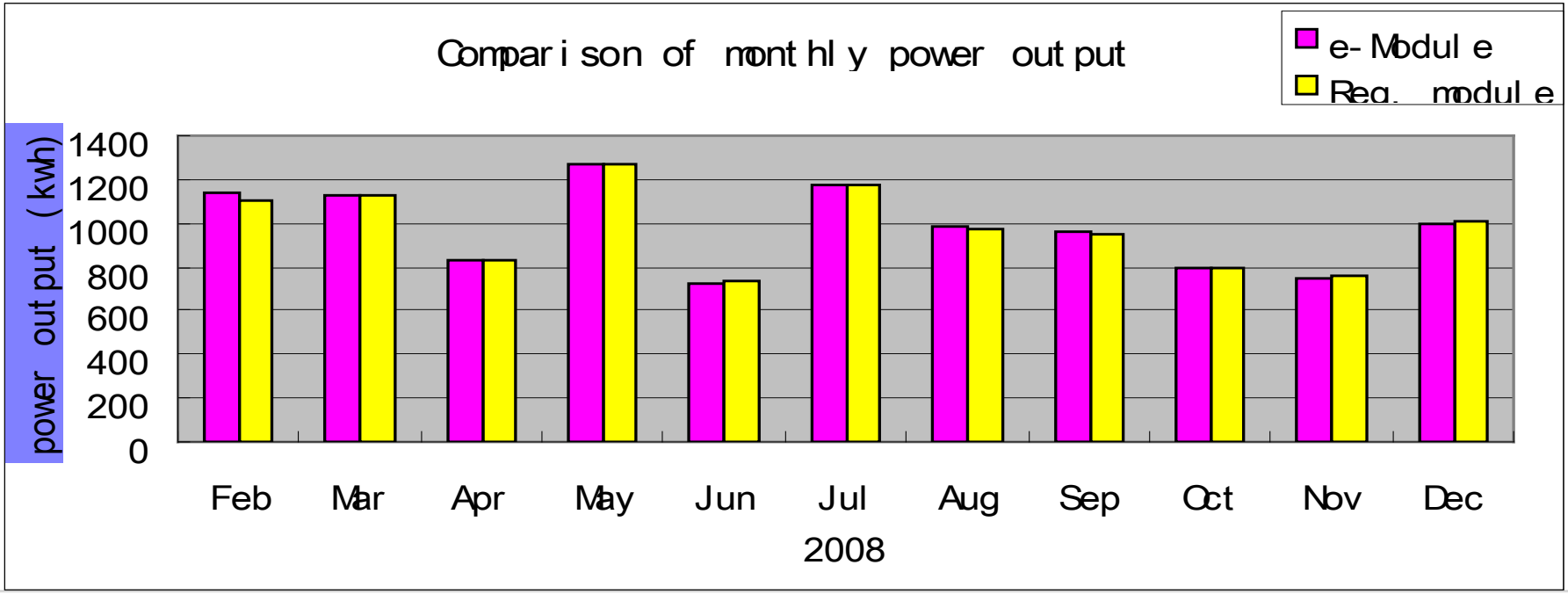
Performance Comparison

e-Modules

Conventional Modules



Equal performance to conventional modules, BETTER at high temperatures (peak pricing periods)

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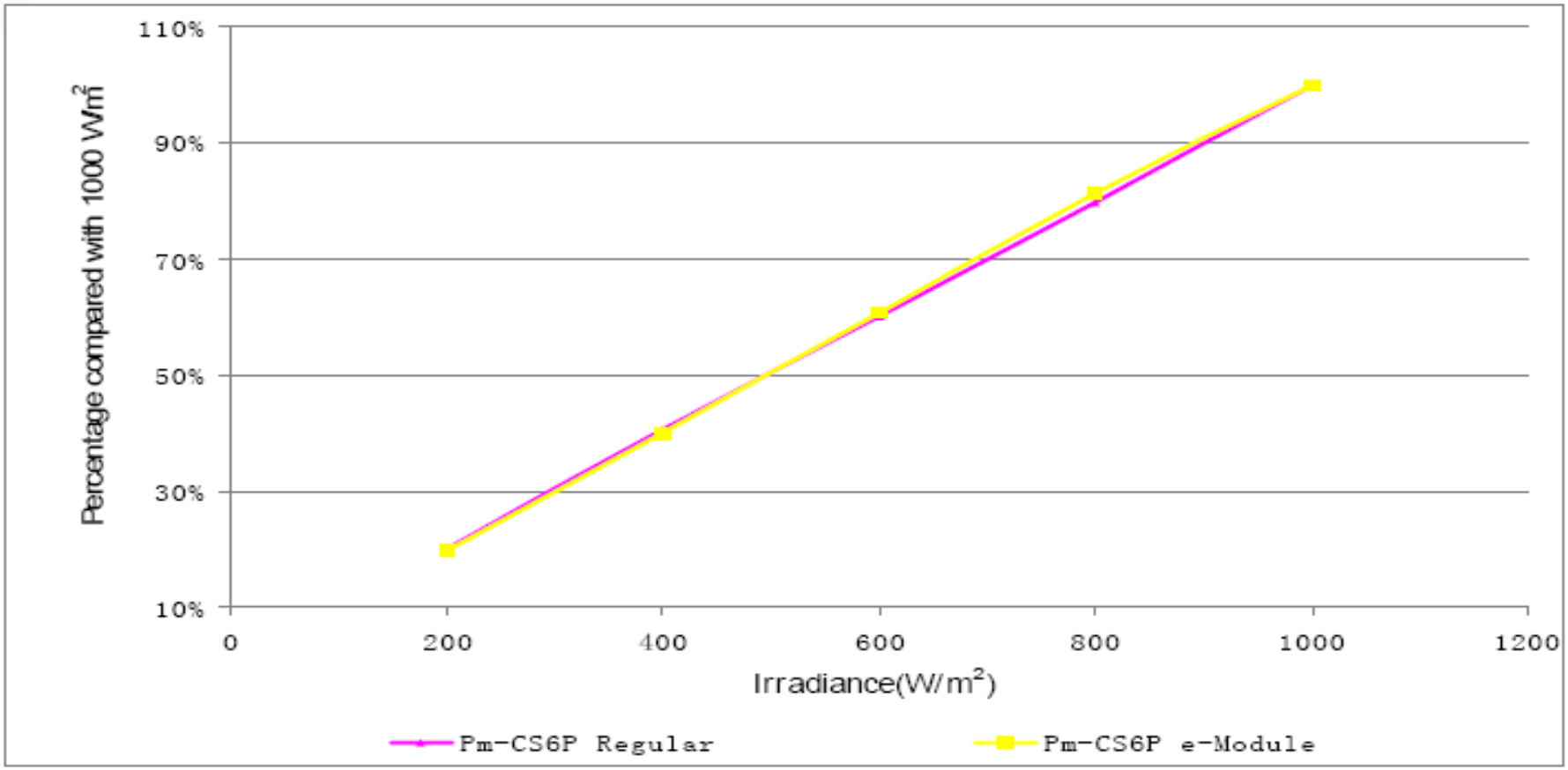
System Output vs. Irradiation



Equal performance to conventional modules

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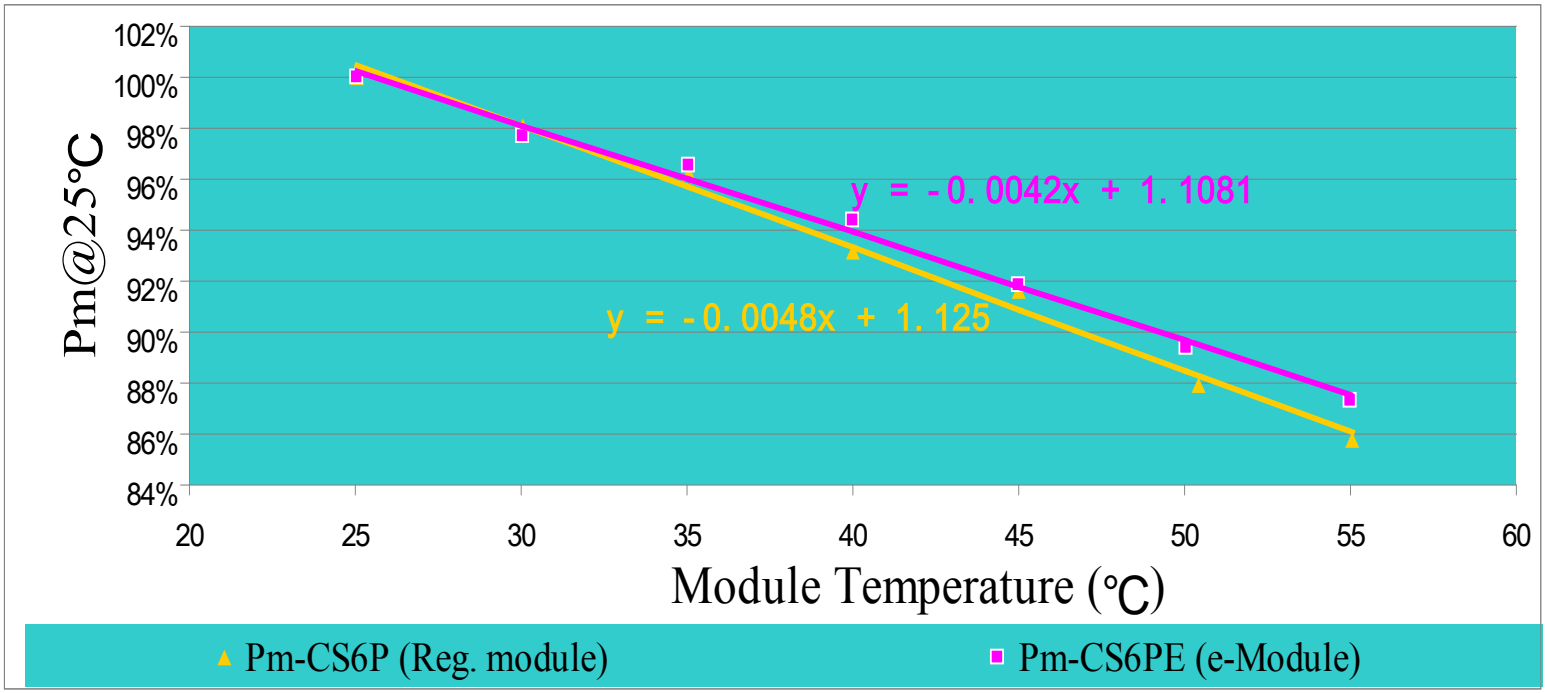
Modules Temperature Coefficients

	α-Isc(%/℃)	β-Voc(%/℃)	γ-Pm(%/℃)
CS6P Reg. module	0.073%	-0.356%	-0.494%
CS6PE e-Module	0.107%	-0.378%	-0.438%



A lower peak power temperature coefficient

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Activities on Long Term e-Module Performance

- A new e-Module power station (shown above) built in Dec. 2008 to monitor the long term performance of the new e-Module products
- 12 e-Modules and 6 conventional modules were sent to PTL (now part of TUV group) for long term performance analysis
- Canadian Solar tracks long term performance for selected e-Module solar projects built all over world

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Summary

- SoG Si: low cost, fast energy payback time, and environmental friendly
- e-Modules demonstrate long term performance equivalent to conventional modules
- e-Modules demonstrate similar annual degradation rates as conventional modules (approx. -0.56%)
- e-Modules demonstrate excellent potential for fast-pace efficiency improvement and cost reduction
- **With performance on par with conventional silicon modules, e-Module will be the first crystalline silicon module to reach thin film price**

Canadian Solar works hard to build the solar super-highway to Grid Parity

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e-Module Project in USA

Project Details			
Location	Visalia, CA	Module Type	e-Module CS6P-PE
System Size	392.645 kWp	Completion	August 2008

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e-Module Project in Germany

Project Details			
Location	Ostfriesland, Germany	Module Type	e-Module CS6A-PE
System Size	111 KWp	Completion	September 2008

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e-Module Project in Korea

Project Details			
Location	Jeong Up-si, Korea	Module Type	e-Module CS6P-PE
System Size	300 KWp	Completion	September 2008

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Thank you !