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Photovoltaics: the path from niche to mainstream supplier of clean energy

Solar Power 2006

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SunPower Corporation

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OUTLINE

- Wafered Silicon's Past
  - Continual cost reduction
- Wafered Silicon's Future
  - Continual cost reduction

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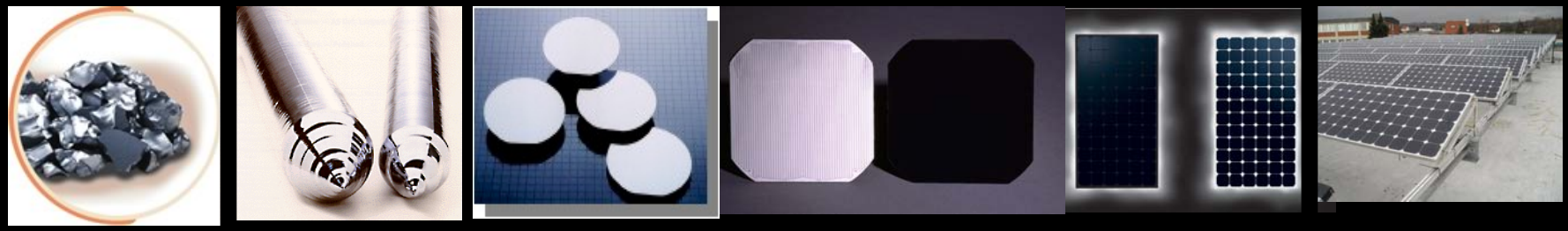
PV Situation in 1975

Wafered Silicon Process



Polysilicon → Ingot → Wafer → Solar Cell → Solar Module → Systems

- $300/kg
- 3 inches in diameter
- Sawn one at a time
- 0.5 watts each
- $100/watt
- $200/watt

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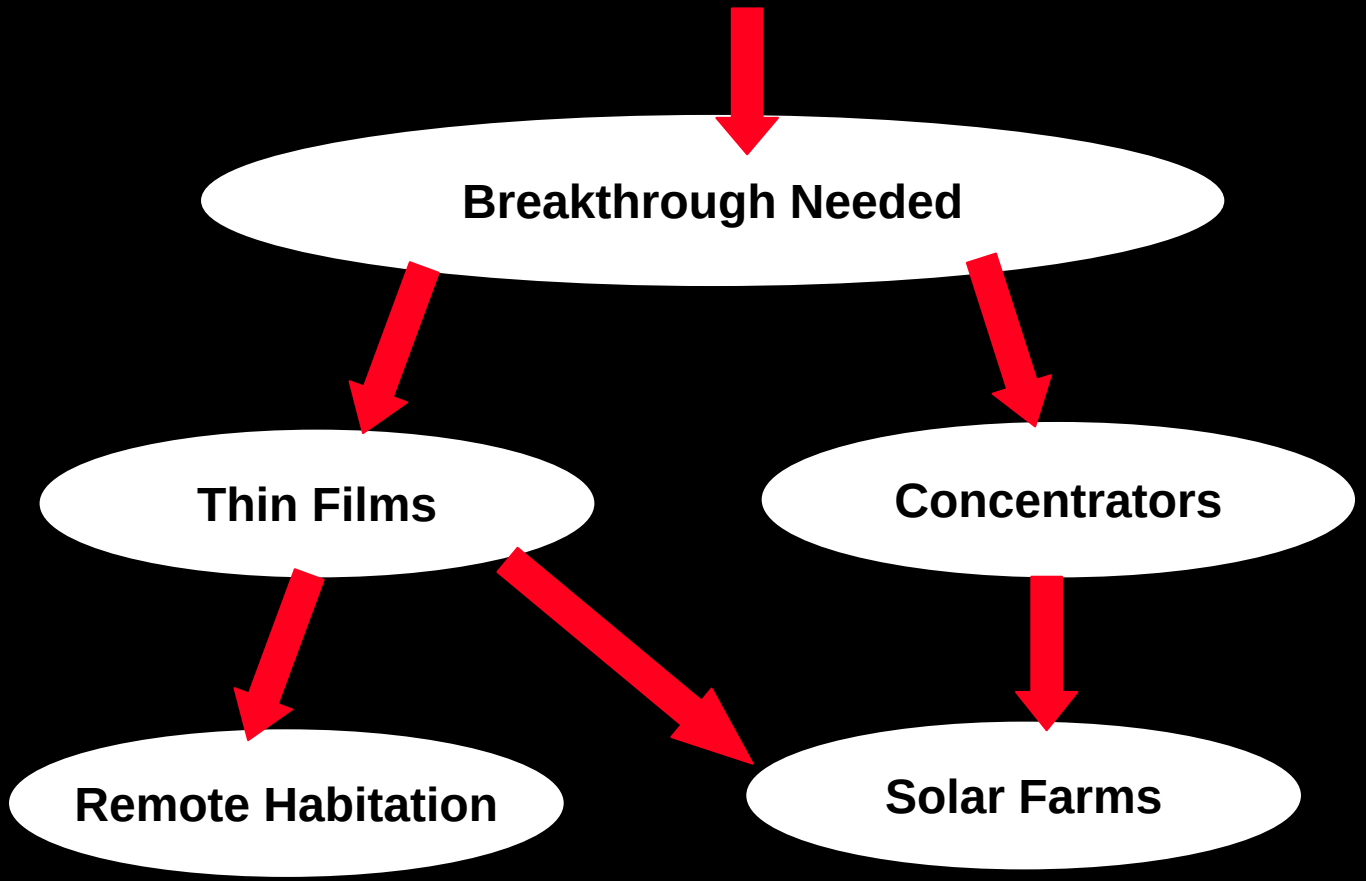
1975 View

Wafered Silicon Hopelessly Too Expensive



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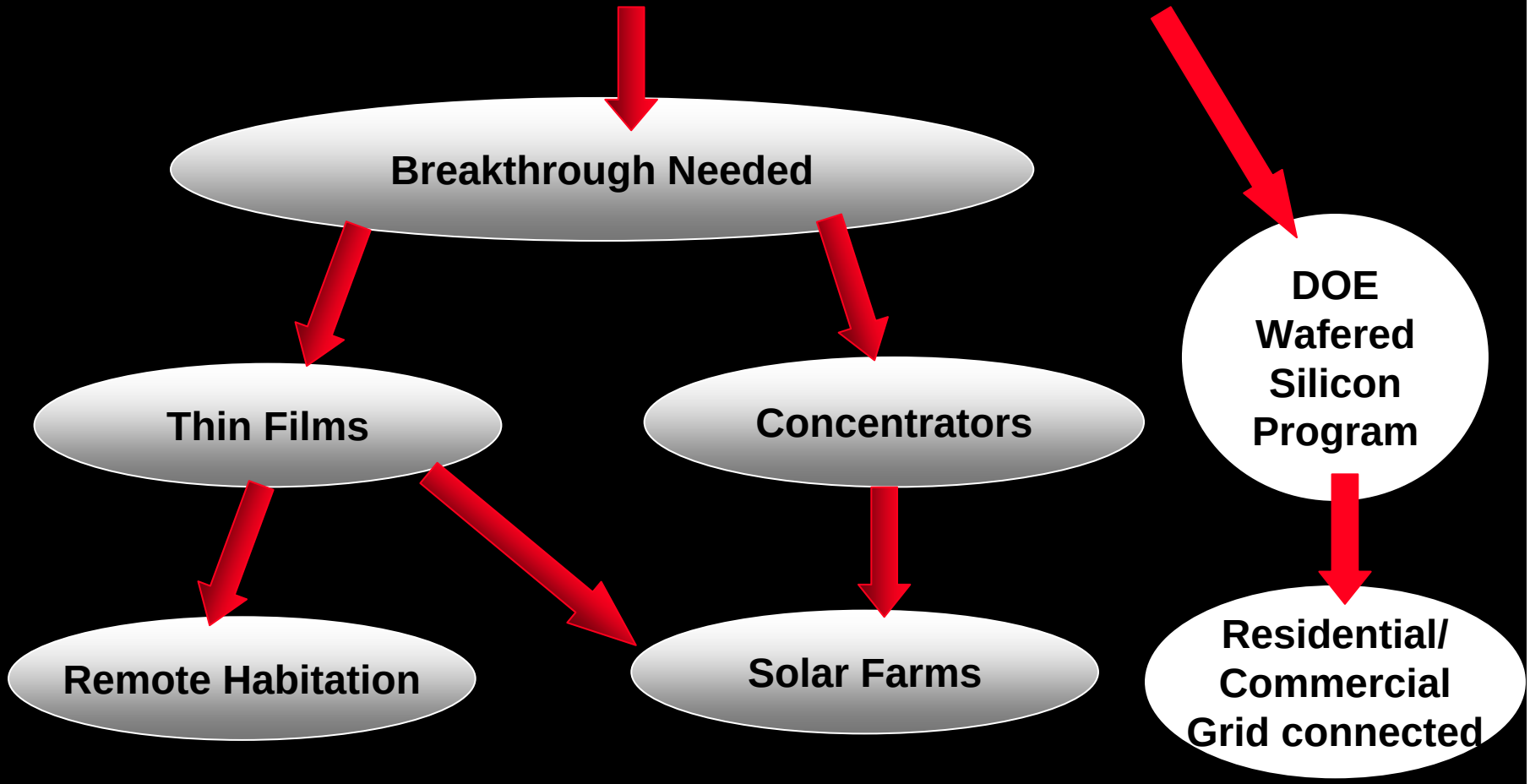
What Actually Happened

Wafered Silicon Emerges as the Dominant Technology



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Residential Roof
Osaka, Japan – 5 kW

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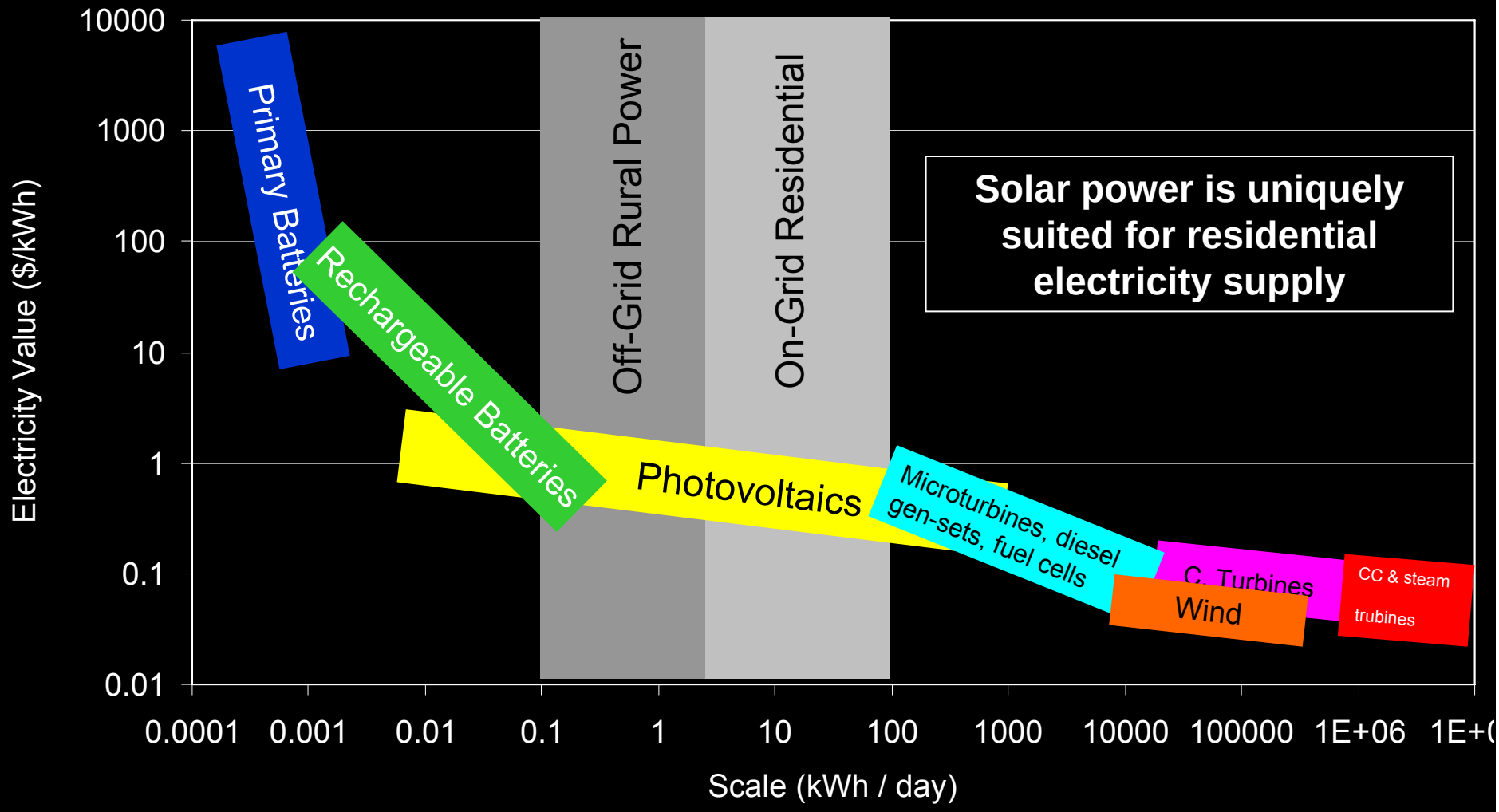
Competing Technologies



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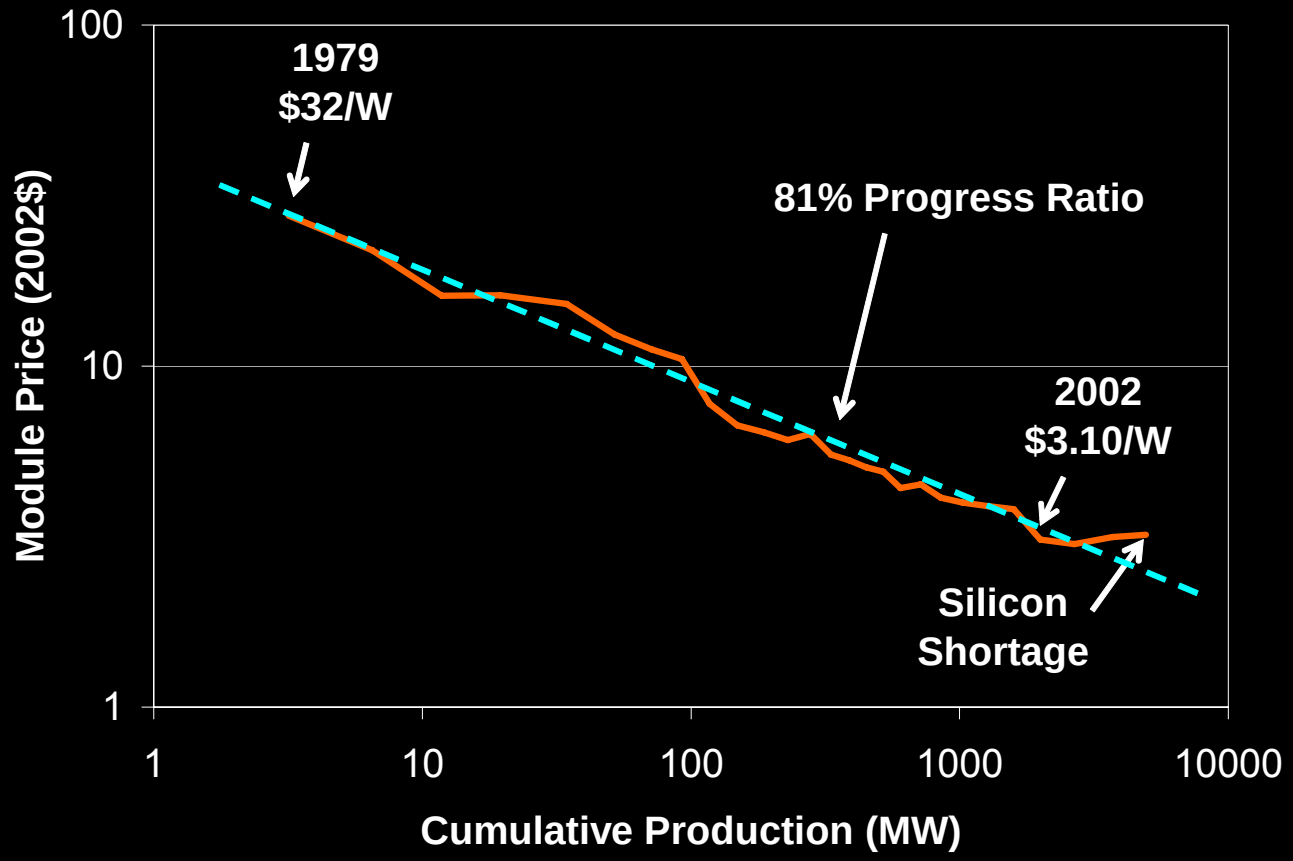
Solar Price Learning Curve

Solar Panel Cost Drops by 19% With Each Doubling in Manufacturing Capacity



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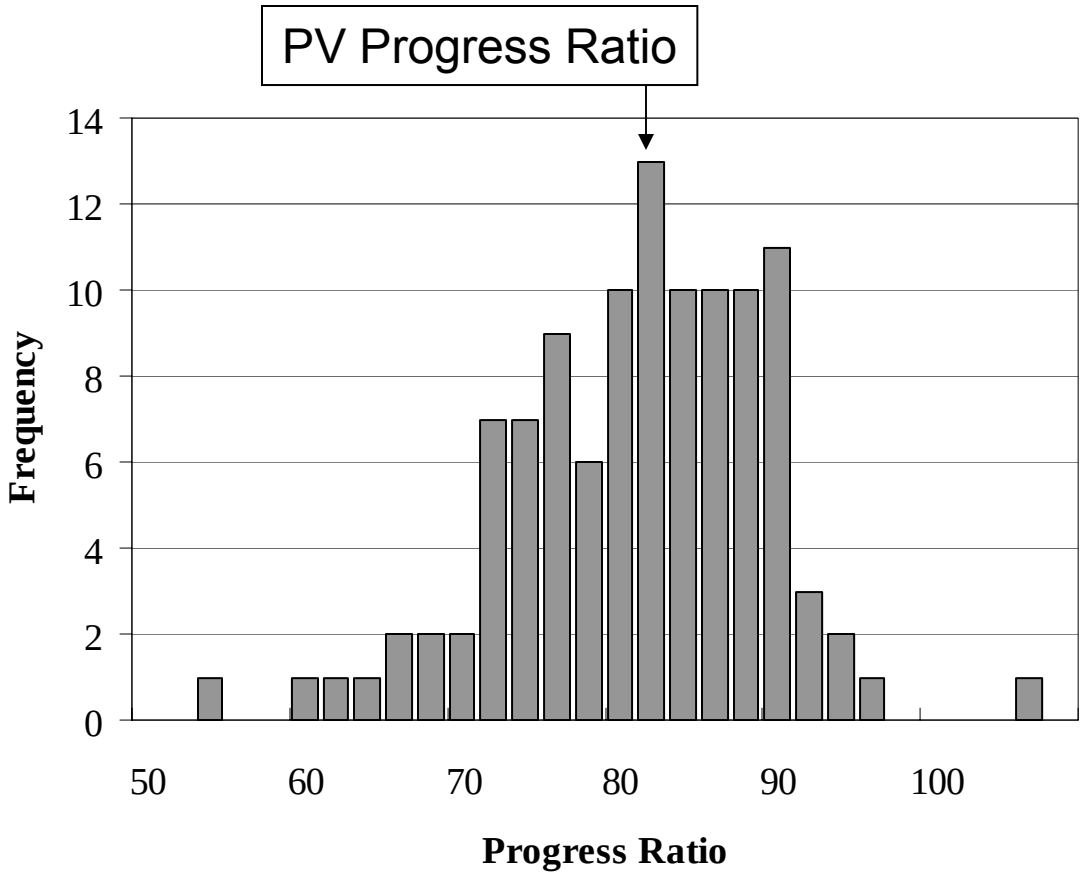
Distribution of Progress Ratios

22 Field Studies (Dutton and Thomas 1984)



Note: These progress ratios are firm level (not industry wide) studies.

Taken from Robert Margolis' PhD Thesis, 2002

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Factors Driving Past Cost Reduction

- Poly silicon price: $300/kg → $30/kg
  - Recent shortage driving prices up over $60/kg and constraining growth
- Wire sawing: now < $0.25/W
- Larger wafers: 3” → 6”
- Volume manufacturing: 1MW → 100MW plants
- Increased automation: none → some
- Improved manufacturing processes

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Question:

Will the Cost Reduction Continue?

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Answer:

YES

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Now Two New Factors are Emerging:

- **Efficiency as an Important Driver**
  - –Increased efficiency drives value through the entire value chain
- **Thinner wafers**
  - –Reduces consumption of expensive silicon

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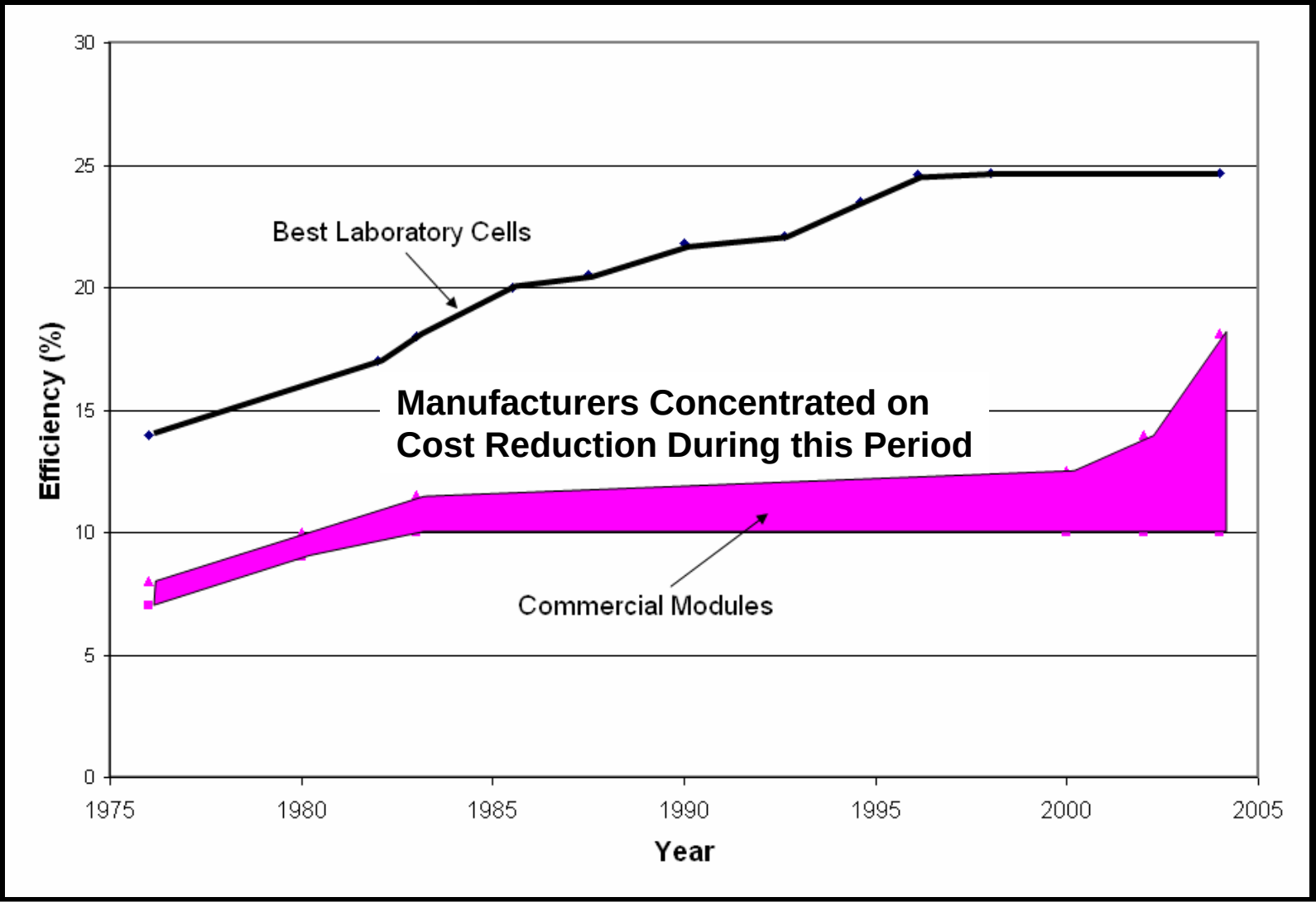
Historical Silicon PV Efficiency



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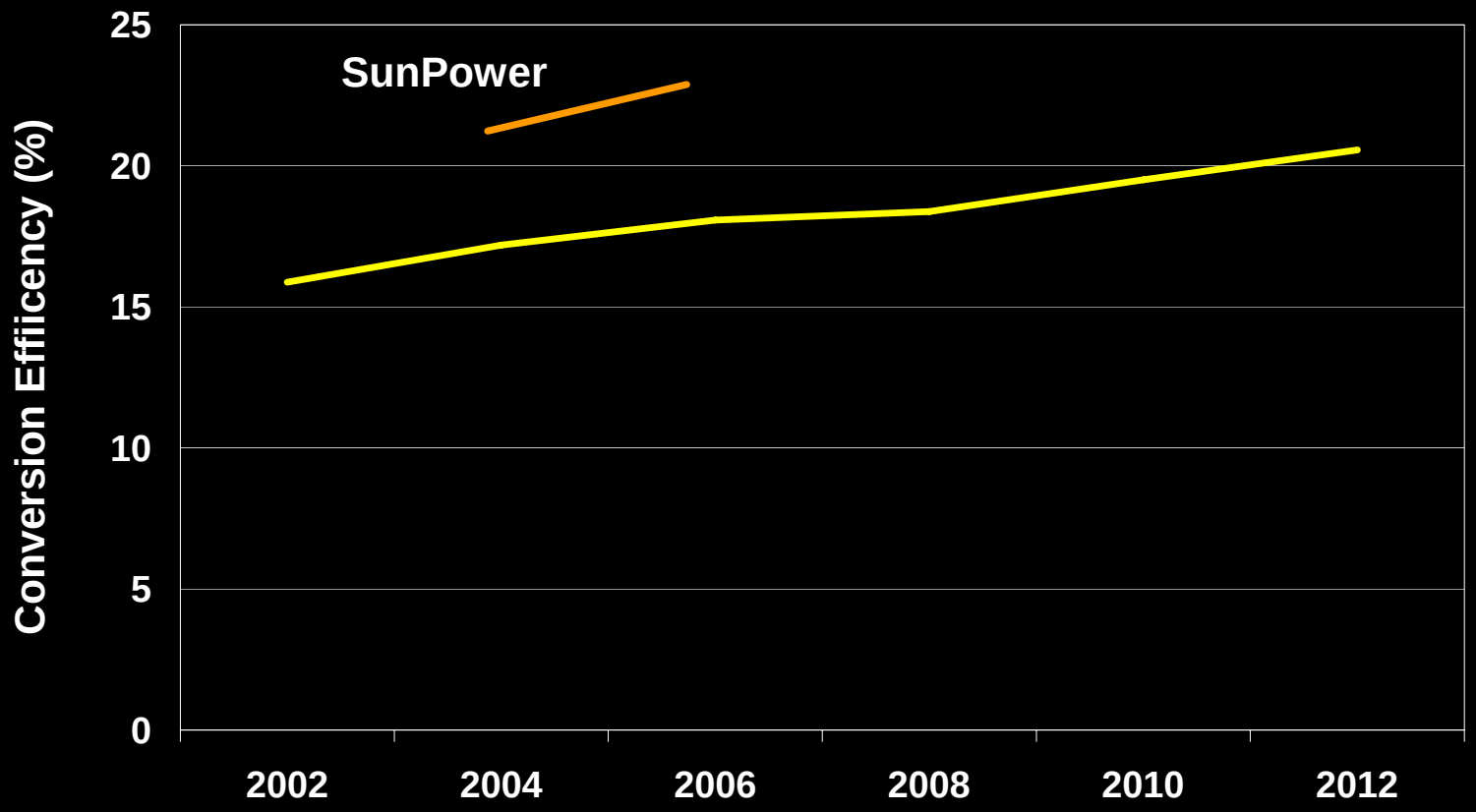
Cell Efficiency Roadmap

Manufacturers are Delivering on Higher Efficiency Cells



Source: 2002 NREL Silicon Roadmap

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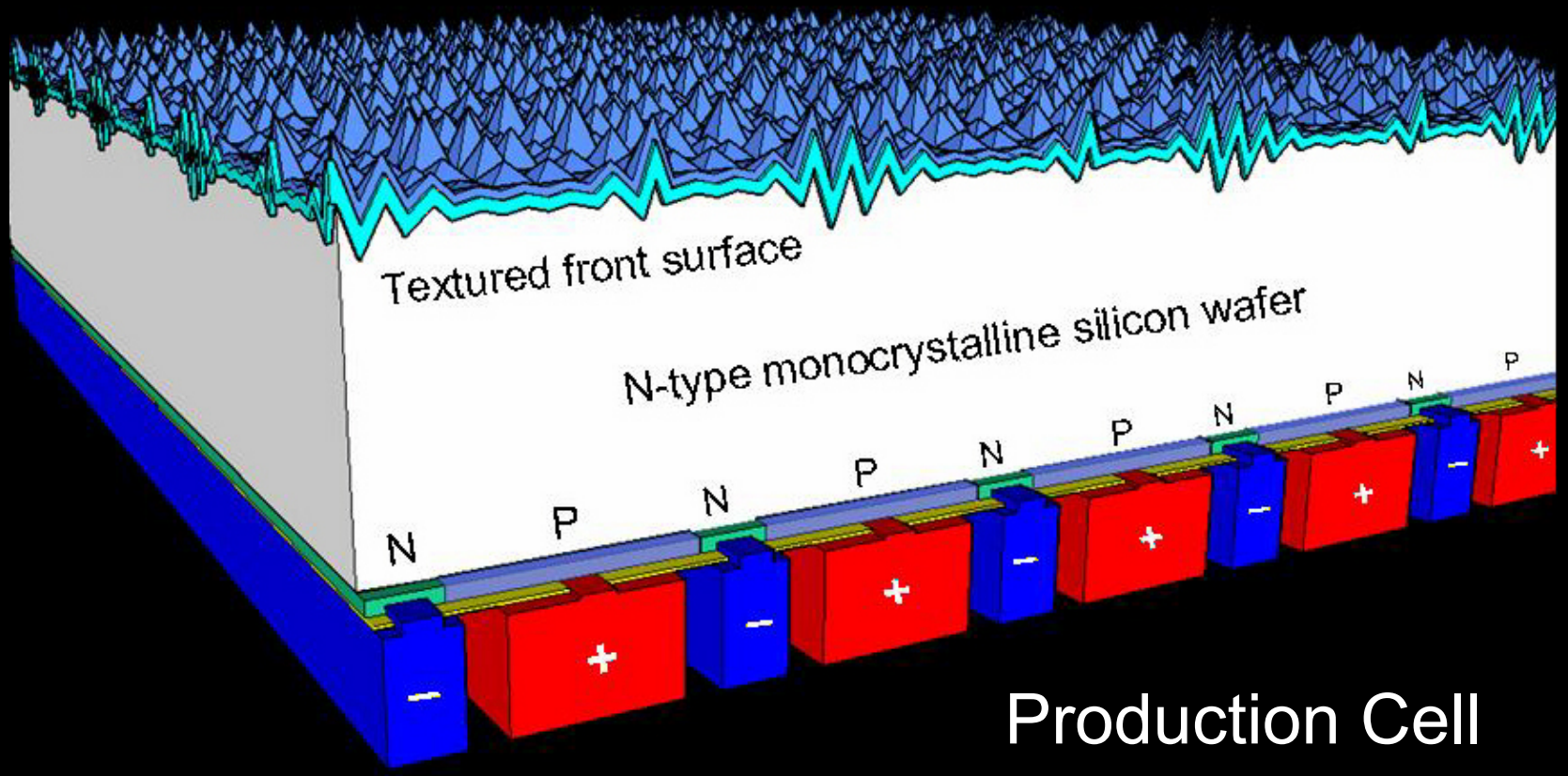
New High Efficiency Concepts

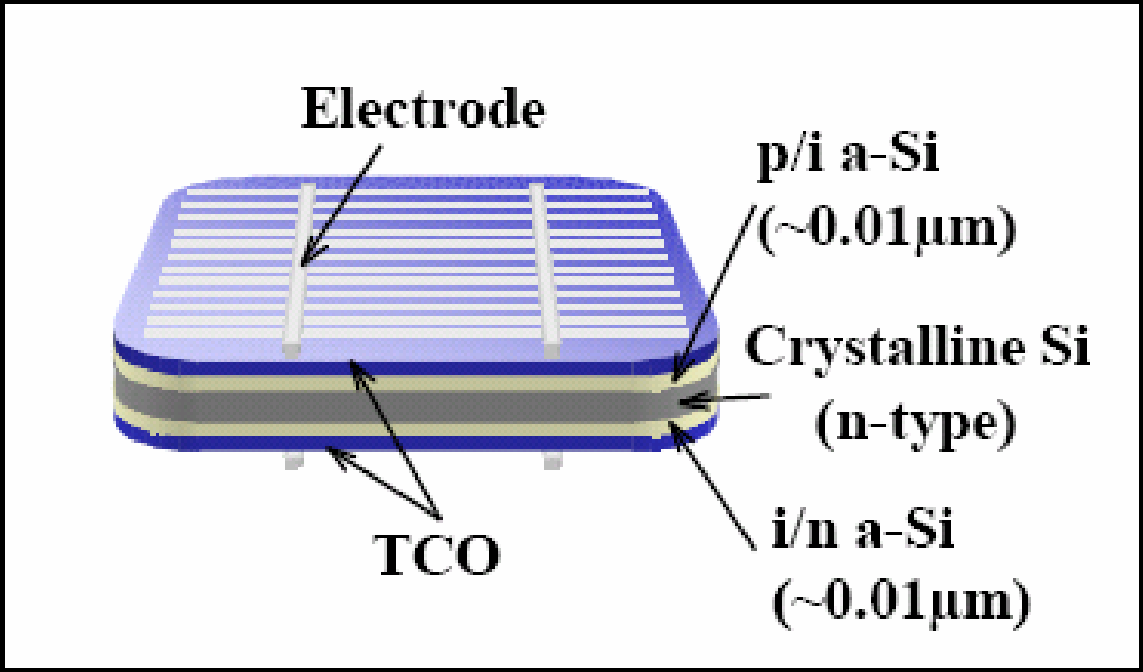
SunPower All-Back-Contact Solar Cell; 22.2% Efficiency



Production Cell

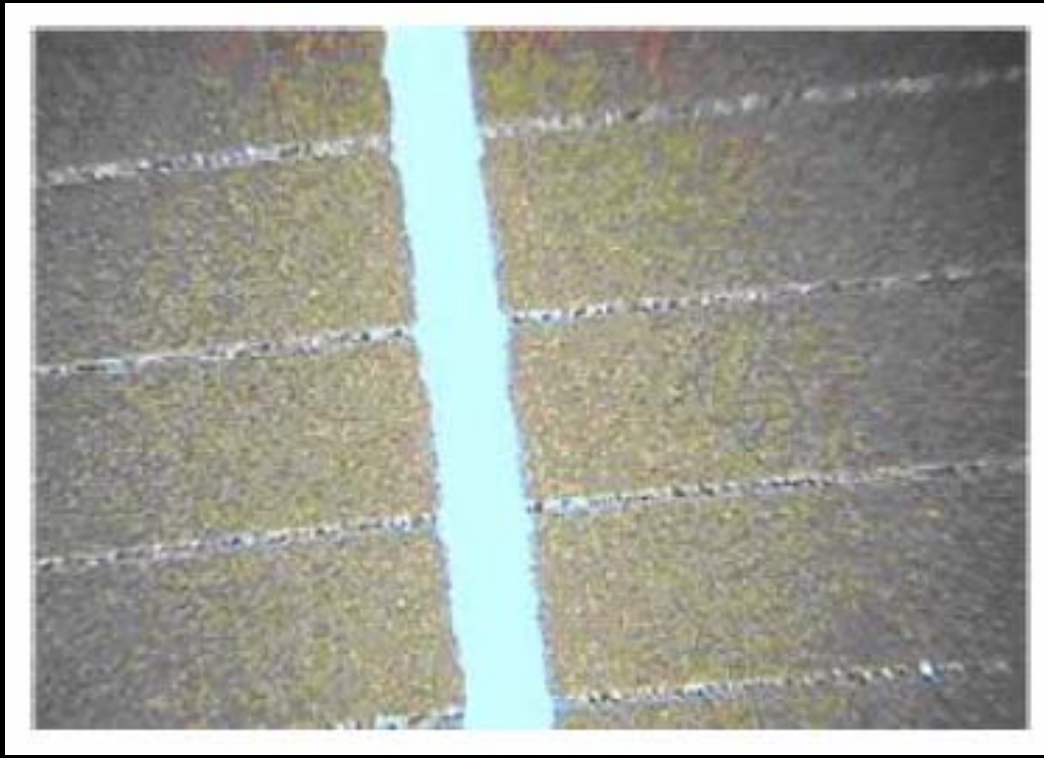
By locating all of the electrical contacts on the back surface, SunPower is able to achieve conversion efficiencies up to 50% higher than conventional solar cells.

Sanyo—HIT Cell; 21.8%



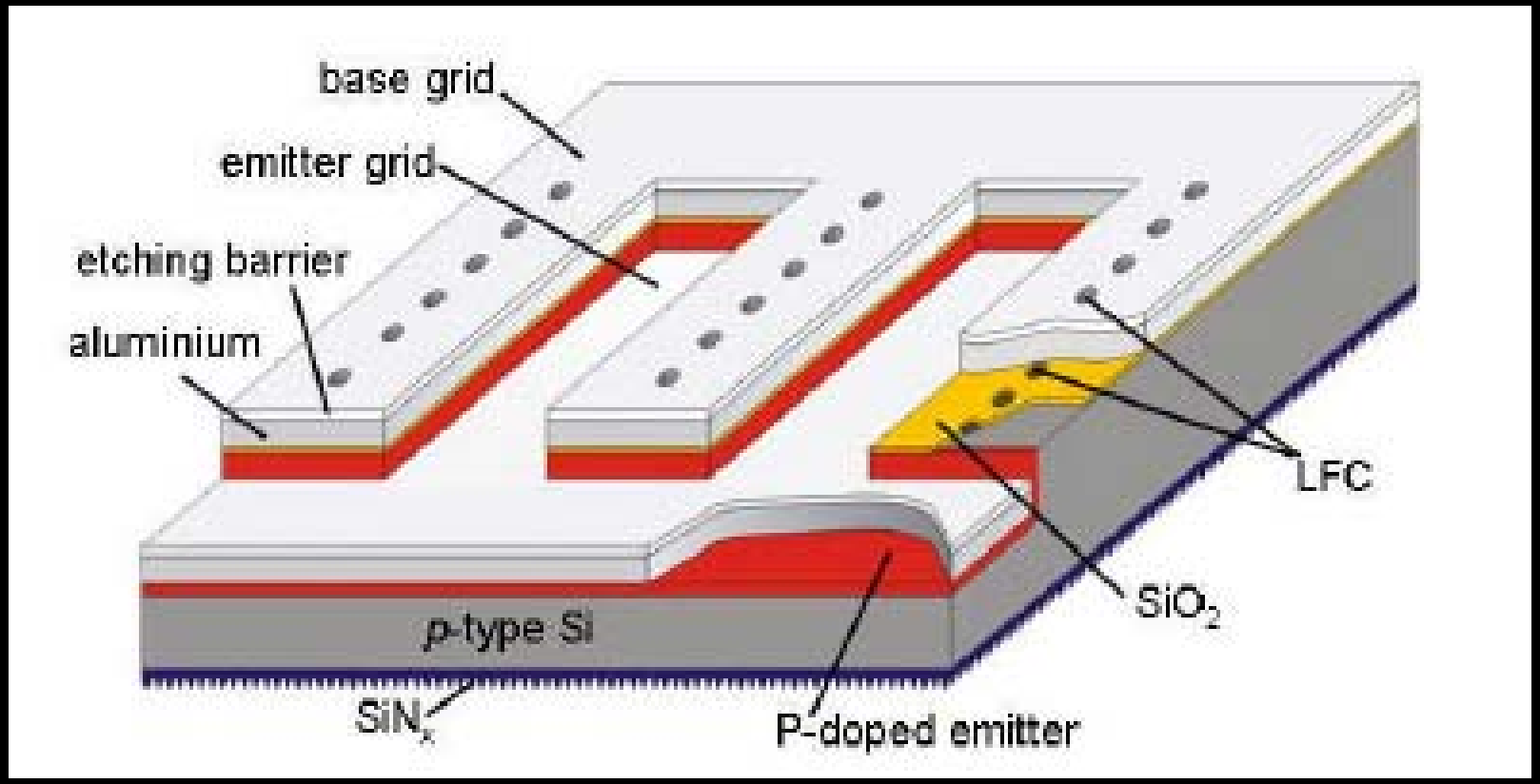
Production Cell

SunTech--Semiconductor Grids



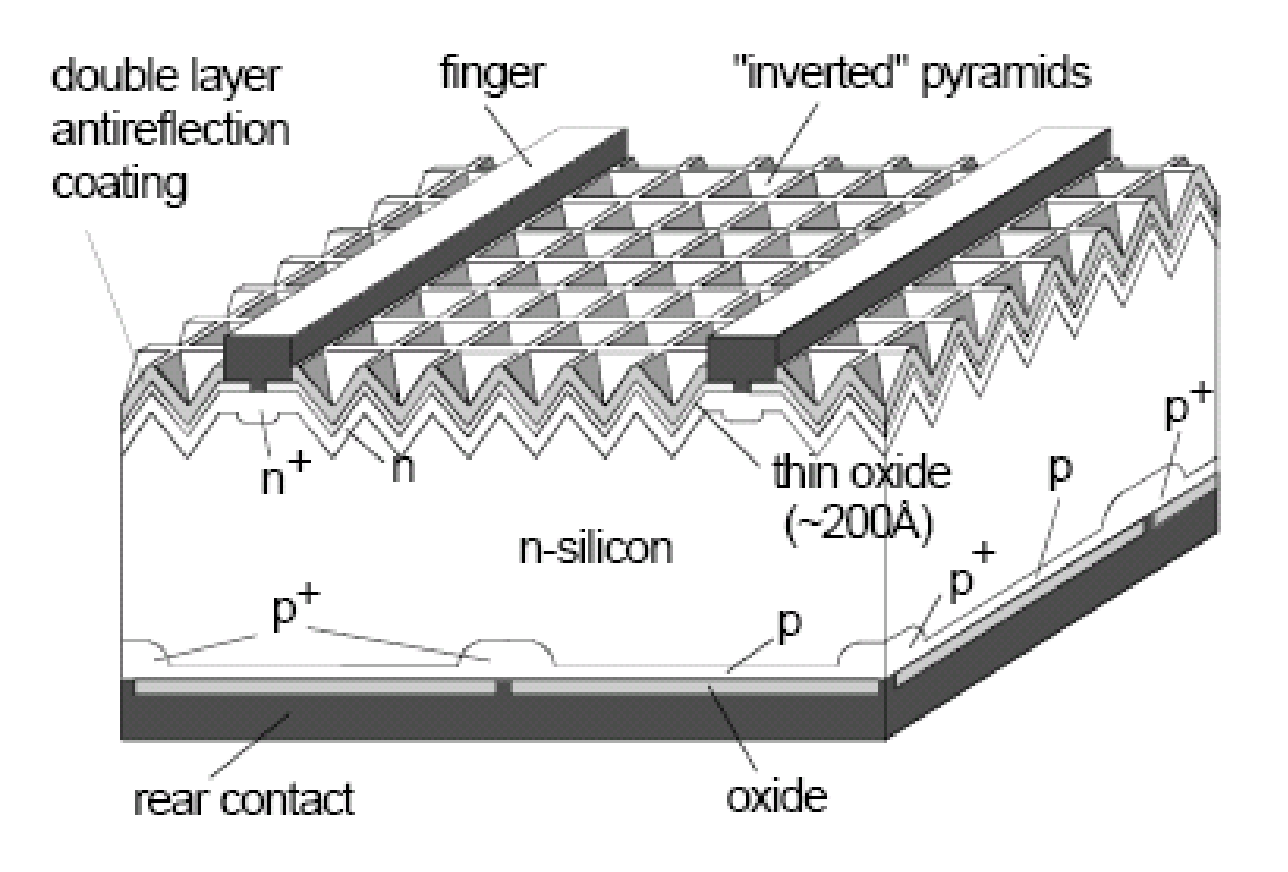
New High Efficiency Concepts

ISFH (Germany)—RISE; 22%



Laboratory Cell

UNSW—n-Type PERL Cell; 22.7%



Laboratory Cell

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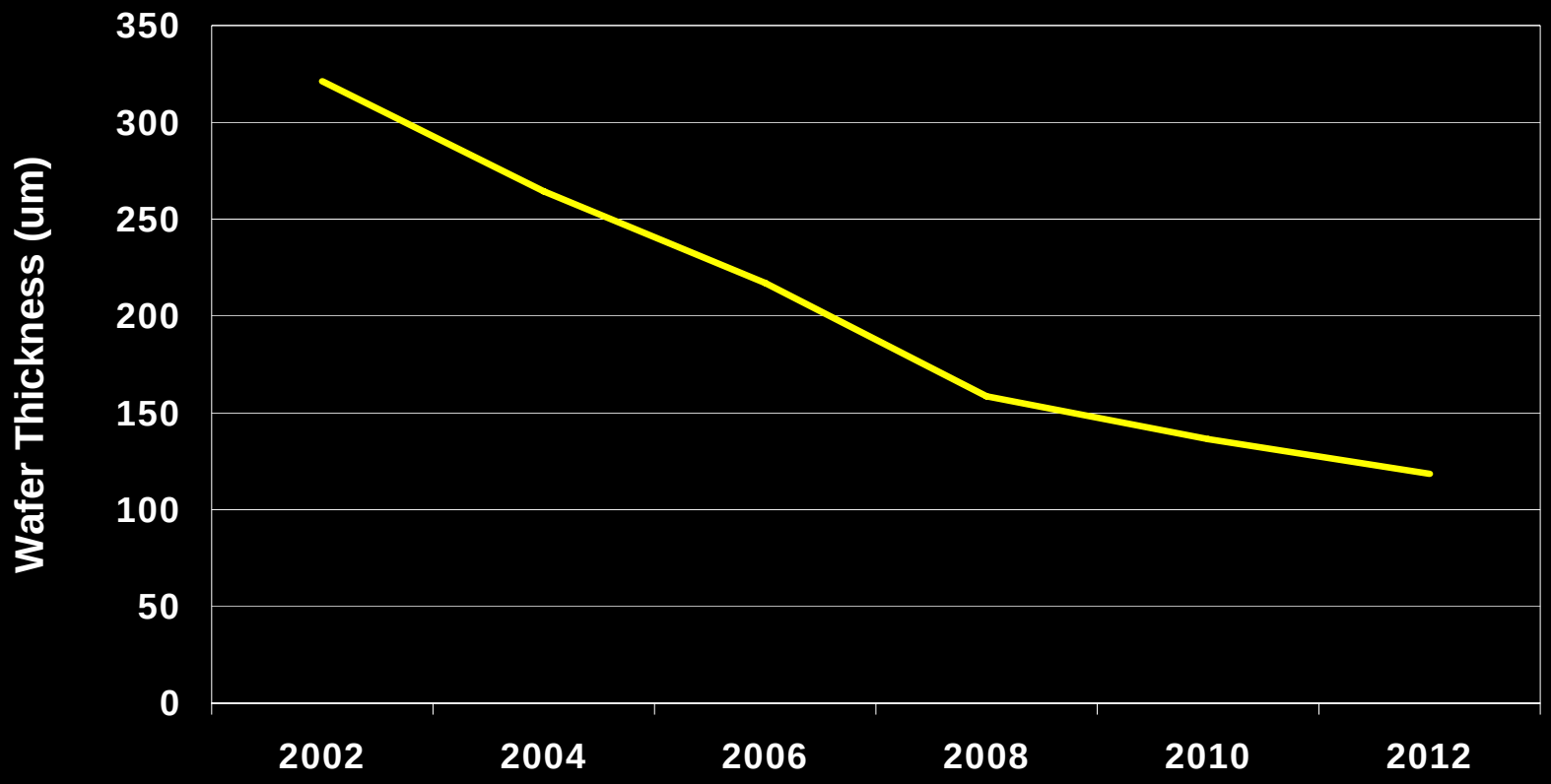
Wafer Thickness Roadmap

Source: 2002 NREL Silicon Roadmap



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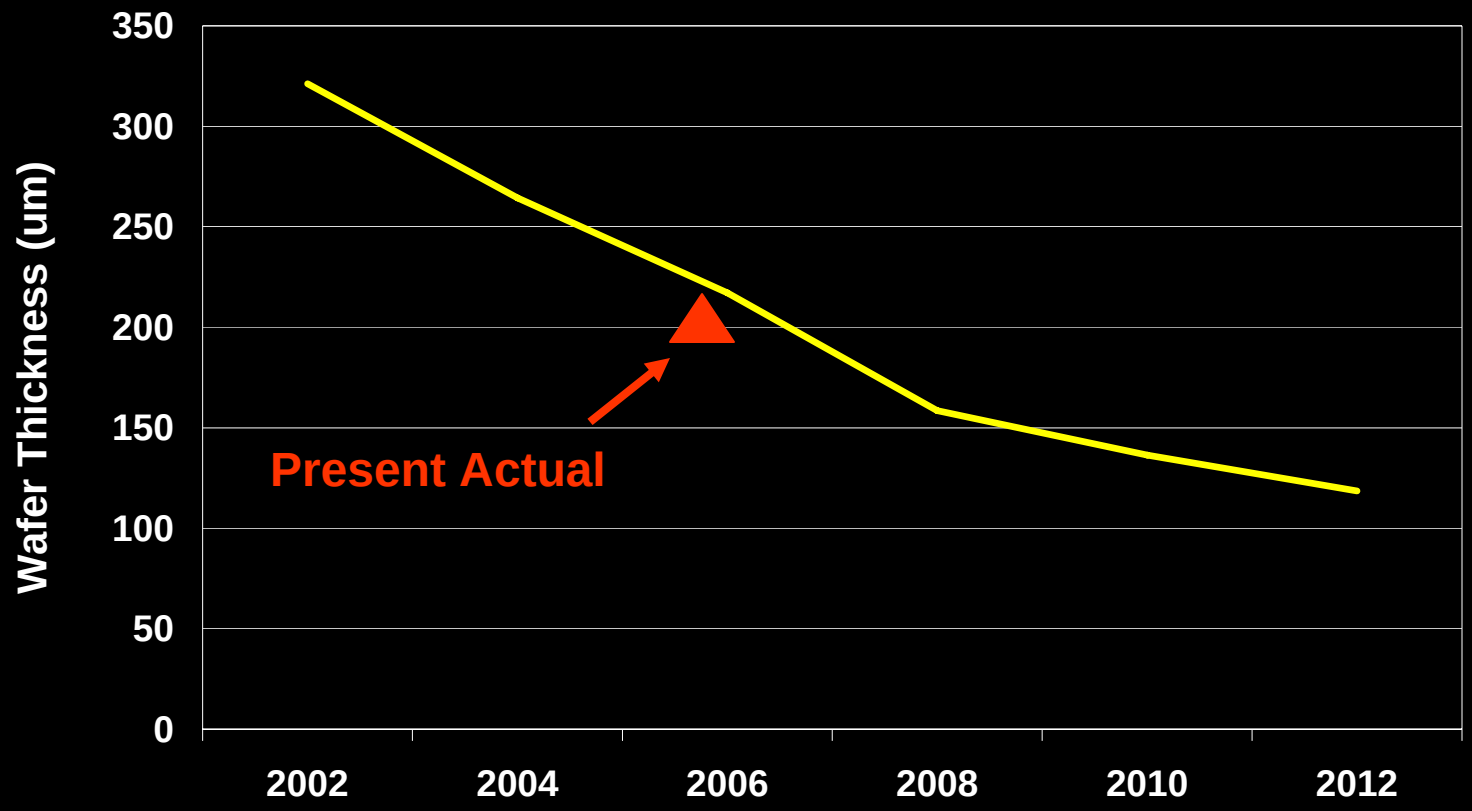
Wafer Thickness Roadmap

Manufacturers are Accelerating the Introduction of Thinner Wafers



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Factors Driving Future Cost Reduction

- Thinner wafers
- Higher efficiency
- Improvements in crystal growth technology
- Improvements in slicing technology
- Improvements in cell processing technology
- New lower cost silicon refining technologies
- Increased manufacturing scale:

  200 MW → 500 MW plant size

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Retail Parity in 7 to 10 years