The SunPower Story

The path from R&D concentrator cells to a high volume PV panel and system manufacturer

Dick Swanson
The 1970s oil crises sparked interest in PV as a terrestrial power source

Don’t worry Mr. President, solar will be economical in 5 years!

I can’t believe he said that.

Sun Day, May 5, 1978, SERI
Situation in 1973

Polysilicon: $300/kg

Ingot: 3 inches in diameter

Wafer: Sawn one at a time

Solar Cell: 0.5 watts each

Solar Module: $100/watt

Systems: $200/watt
1975 View

Wafered Silicon Hopelessly Too Expensive

Breakthrough Needed

Thin Films

Concentrators

Remote Power

Solar Farms
What Actually Happened

Wafered Silicon Emerges as the Dominant Technology

Breakthrough Needed

Thin Films

Concentrators

Remote Power

Solar Farms

DOE Wafered Silicon Program

Residential/Commercial Grid connected
Why Wafered Silicon Still Dominates

We never envisioned:

- The dramatic cost reduction potential of wafered silicon
- The dominance of residential and commercial grid connected markets
Historic and Projected Module Cost Reductions

<table>
<thead>
<tr>
<th>Year</th>
<th>Module Price ($/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>$21.83/W</td>
</tr>
<tr>
<td>1990</td>
<td>$6.07/W</td>
</tr>
<tr>
<td>2000</td>
<td>$3.89/W</td>
</tr>
<tr>
<td>2010</td>
<td>$1.82/W</td>
</tr>
<tr>
<td>2013</td>
<td>$1.44/W</td>
</tr>
</tbody>
</table>

Historical

Projected

2002 NREL Roadmap
Comparison to 1977 DOE Projection

Module Price ($/W) ($2002)

Historical
Projected
1977 DOE Projection

1978 1980
$30.14/W $21.83/W

1986
$10.48

128%/pa

1980
$4.88/W

2000
$3.89/W

32%/pa

1986
$1.63/W

39%/pa

2000
$0.65/W

2013
$1.44/W

2023
$0.65

SUNPOWER®
PV Market Growth

Rapid Growth in Subsidized, Grid-Connected Market. 41% CAGR

Early period of rapid innovation and growth
Navigant Forecast History

Industry Shipment Forecast (MW)

- 2007
- 2006
- 2005
- 2003
- 2002
Commercial electricity prices have increased 4.76% each year, on average, for the past 8 years.
Recent Industry Milestones

- **1999**  
  1 GW accumulated module production

- **2001**  
  More square inches of silicon used than in entire microelectronics industry

- **2004**  
  1 GW production during year

- **2006**  
  More tons of silicon used than in microelectronics

- **2008**  
  FPL purchases the first utility-owned PV plant
SUNPOWER
1986 TO 1999

Formation

And

Fund Raising
The Point Contact Cell (27.0% 200x)

- **Low Recombination**
  - Minimal diffused regions
  - Oxide/Alneal passivated surfaces
  - Point arrangement of pn-junctions
  - High injection operation

- **High Generation**
  - Zero grid obscuration
  - High-res, high-tau wafers
  - Good internal optics

- **Low Parasitics**
  - Rear electrodes
  - Double level metallization

- **Photolithographic Features**
  - High-tau FZ wafers
  - Multiple High-tau Tube Diffusions

Photo from M.A. Green, CLEAN ELECTRICITY FROM PHOTOVOLTAICS, eds Mary D Archer & Robert Hill (Imperial College Press, 2001)
My concentrator group visits PG&E, ca. 1982
Fundraising Proved Difficult

US Federal PV Program Spending
($ millions)

1981    133
1982    74
1983    27

Talked with over 40 venture capitalists

Finally in 1990, we put together a triad of funding sources:
  • EPRI
  • DOE, Concentrator Initiative
  • VC’s, AVI and TFI
1990 TO 1992

Enthusiasm
1990: SunPower begins operations
The Cell Pilot Line
First products

200 watt dense array

Fresnel lens cell for EPRI
Tested various concentrator modules
Built 1 kW Segmented Parabolic Dish
1992 was a bad year

- Sandia Concentrator Initiative **Cancelled**
- EPRI Contract **Cancelled**
1993 TO 2000
(7 TO 0 BC)
Survival
Honda Dream
Learning a little about manufacturing
Winning 1993 World Solar Challenge
Surviving on Opto Components
NASA/AeroVironment Helios

100,000 feet
Record Altitude for an airplane
Solar Powered Airplane Communication Platform

Solar / Electric Plane Network Model

- Multiple aircraft can be used to create atmospheric voice/data network
- Star topology used with gateway connections to terrestrial or satellite networks

Autonomously Controlled Station-Keeping Mode

Airborne Standby

Common Maintenance & Control Facility

Precision Coverage Areas
Concentrator Cells for Solar Systems, Pty.
Concentrator Cells for Honda

- Lower Cost
- Higher efficiency
- Higher capacity factor, more kWh/kW
- Easily scalable to the gigawatt level

Fresnel Concentrator System
Project Mercury: Develop a low-cost back-junction cell

Textured front surface

240 µ thick monocrystalline silicon wafer
Fateful Decision:

Abandon Concentrators and Concentrate on Flat-Plate PV

(Throw away the lens)

Lession: Keep it simple
2001 TO 2008

Success
Fundraising 2000

- No VC or investment banks interested in funding SunPower’s move to flat-plate cells.
- February, 2001: TJ Rodgers, CEO of Cypress Semiconductor, writes $750,000 personal check to SunPower to keep the company alive
- May, 2002: Cypress buys controlling interest in SunPower
- 2002 to 2005: Cypress invests $150 million to develop cost effective cell process and build manufacturing line-- without knowing if the cell could be manufactured at low cost:
  - high minority carrier lifetime
  - Higher process complexity
Cypress Synergies

Highest efficiency solar cells:

- Strong technical expertise - 15 years of solar cell R&D expertise
- Solar cells and opto-electronics
- World leader in ultra-high efficiency solar cells

The volume manufacturer:

- Building cost effective products for 20 years
- $1 bn revenue in 2004
- Leading edge, high volume wafer fabs
- Broad portfolio of integrated circuits
2002; SunPower Goes to Texas

A300 Pilot Line
Osaka 2003: Introduced the 20% A-300 Solar Cell
2004; SunPower goes to the Philippines
2005: SunPower goes public
Pre-trading, every order is for SPWR
2007 Merger
SunPower Applications

- Residential Retrofit
- Power Plants
- New Production Homes
- Commercial & Public
Going forward

• Efficiency up
• Cost down
Breaking News from the Laboratory

- Sunpower has steadily improved cell efficiency both in the laboratory and in high scale production since the first all back contact cell prototype in 2003.
- The transfer of the >22% Generation 2 product was completed in 2007.
- The development team has manufactured a new record device on a 148.58cm² full area substrate of 23.4%.
Key Activities:
- Continuous Cz ingot growth
- Low-oxygen, high-lifetime material
- Development of hot zone for N-type material
- FBR polysilicon process development and implementation
- Crucible durability

Participants:
Solaicx, Santa Clara, CA
SiGen Direct Cleave Process

Direct Cleave Process

Cleaved Wafers

Silicon Ingot

Same material → 2X to 3X more wafers

• c-Si lifetime

• Excellent Edges/Surface

• High strength

Kerf-Free 50 μm c-Si wafer
Unitary Products and Systems Reduce Installation Cost

Concept Overview:
- Factory manufactured systems
- Module integrated mounting
- Optimized for automated assembly and rapid deployment

Benefits:
- **Lower cost**: Leverage standard manufacturing cost reduction practices
- **Higher quality**: Controlled manufacturing environment
- **Scalable**: Achieve economies of scale at relatively low volumes; fast installation, more productivity
Factory Assembled Unitary Product Reduces Cost
Tracking improves Energy Delivery

15 MW Plant
Nellis AFB

Installation Rate:
1 MW/day
The Next Big Thing

- Large Scale Solar Farms
- PG&E Announces 800 MW of PV Power Purchase Agreements
To achieve 80% CO2 reductions by 2050, PV growth needs to be far less than what is possible, given the rise of other renewables and energy efficiency.

2040: What is Possible – 5000 TWH/yr PV (Moderate Growth case)
What is Needed – 2000 TWH/yr PV

Sources: McKenzie Report, 2007 for starting points and energy efficiency; AWEA for wind; internal SunPower calculations for DPV, CPV, CSP
THANK YOU