
Applied Solar Energy

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- Photovoltaic materials: Past and Future
 - Modeling future efficiencies
 - PV and Agriculture
 - Solar thermal systems and solar buildings
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 - PV in a future decentralized energy system
-



Photovoltaic Materials

- **Past: In the beginning there was silicon**
- **Present: It's still silicon**
- **Future: Silicon or ???**



Past

- 1954 First solar cell (Chapin et al.), efficiency 6%
- First applications in space vehicles
- Technology: Chochralski grown crystals, sawed wafers, pn junctions by diffusion



Present

- **Dominance of market by crystalline silicon, with multicrystal growing faster than monocrystal**
- **Supply of silicon is critical. Reliance on reject silicon from semiconductor market leads to shortages. Solar silicon is required**
- **Cell efficiency stands at 24.7% in laboratory and 12 - 16% in production**
- **Efficiency is of great importance because of area related cost**



Mid Term Future: Three potential scenarios

- **Continued dominance by evolution of the present Si single crystal or cast polycrystal technology**
- **New crystalline Si film materials of medium thickness (5-50 μ) either as ribbons or on foreign substrates**
- **Breakthrough of true thin film materials like a-Si or CIS or CdTe**



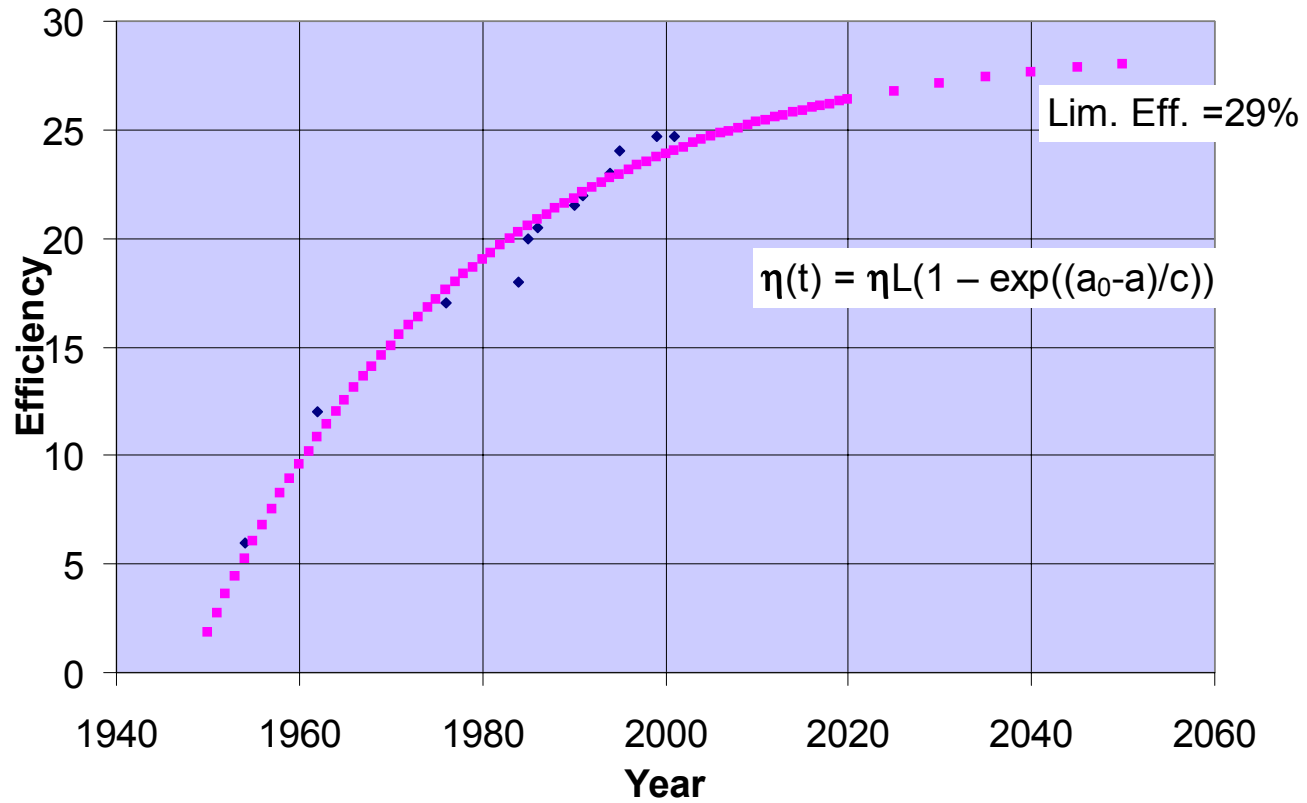
Modeling the past and future development of solar cell efficiency

- Properties of the modeling function:
 - It starts at a given point in time
 - After long development it reaches an asymptotic value
- The function for efficiency η is:
 - $\eta(t) = \eta_L (1 - \exp((a_0 - a)/c))$

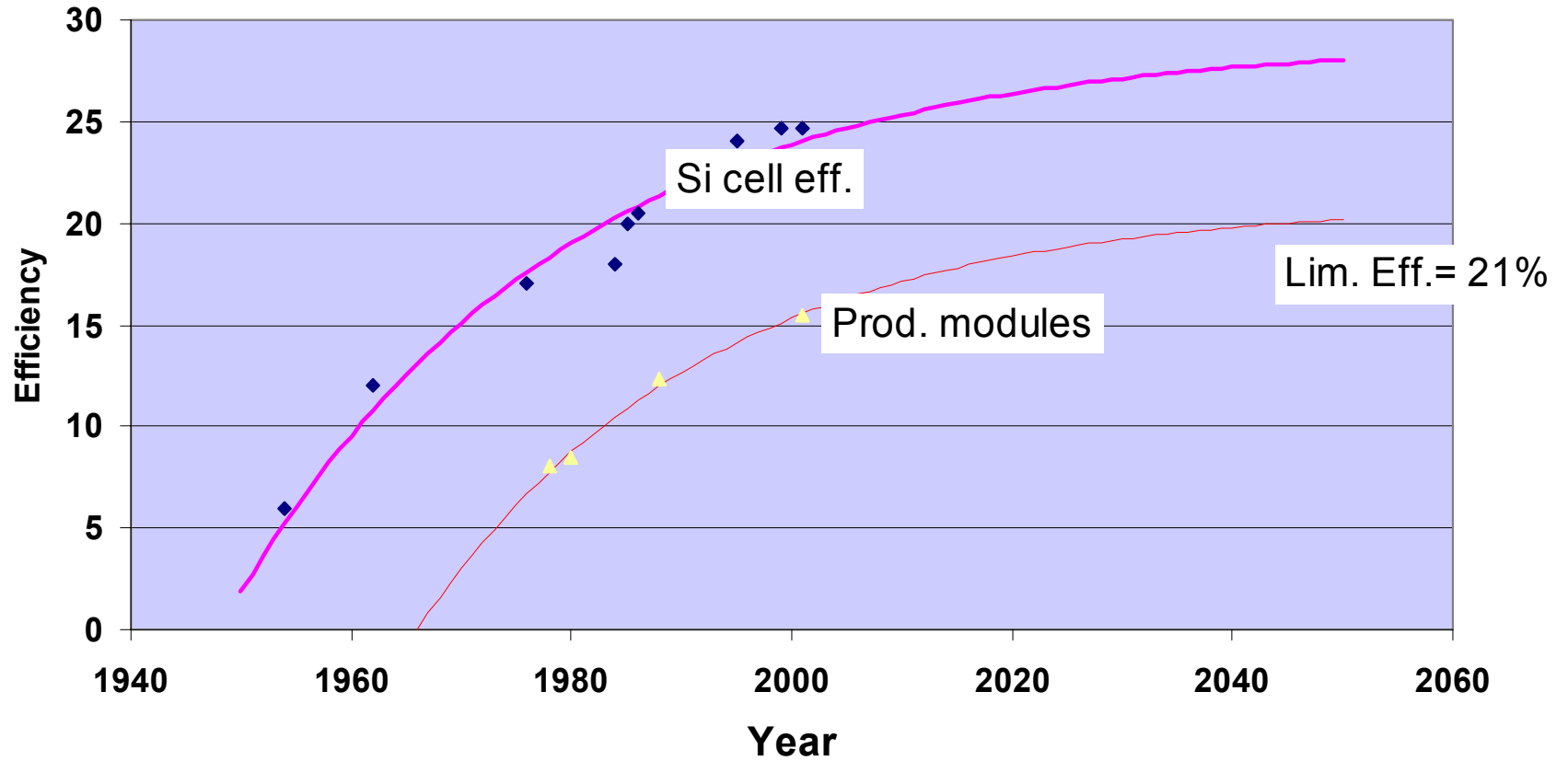
With η_L = final efficiency, a_0 = start of development (year), c = constant. η_L , a_0 , c are empirical constants determined from data



Crys. Silicon Efficiencies



Crys. Si + Modules

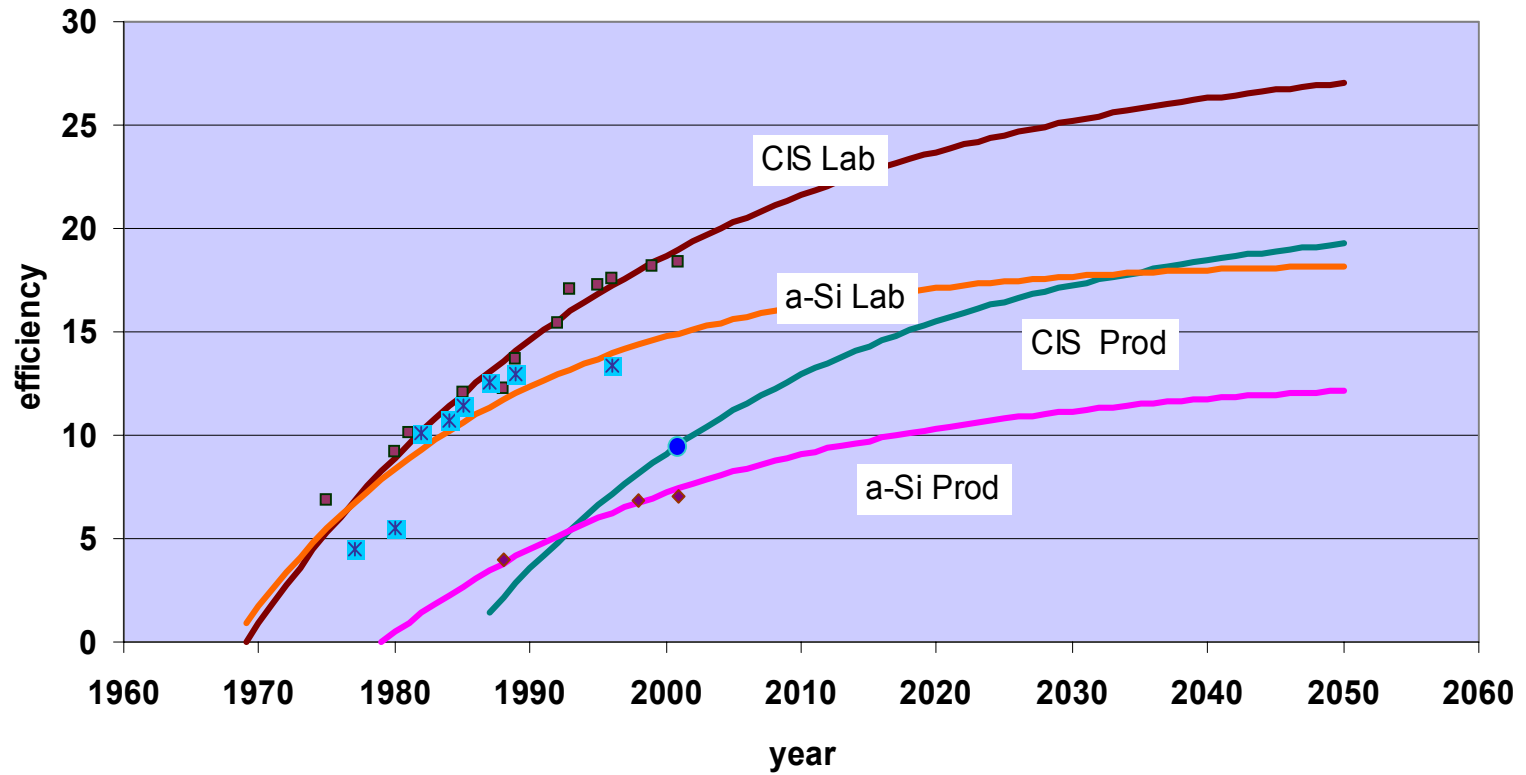


Ongoing development of crystalline silicon

- **Crystalline ribbon and film technologies (commercial)**
 - EFG Ribbons (by ASE)
 - Silicon Film (by Astropower)
 - Evergreen Technology
- **A-Si/C-Si Heterostructures: Very promising development (Sanyo)**
- **Thin crystalline films (5-50 μ) on foreign substrates**
 - Deposition by liquid phase epitaxy (LPE) low temp.
 - Deposition by chemical vapor deposition (CVD) high temp
 - Transfer techniques



a-Si + CIS

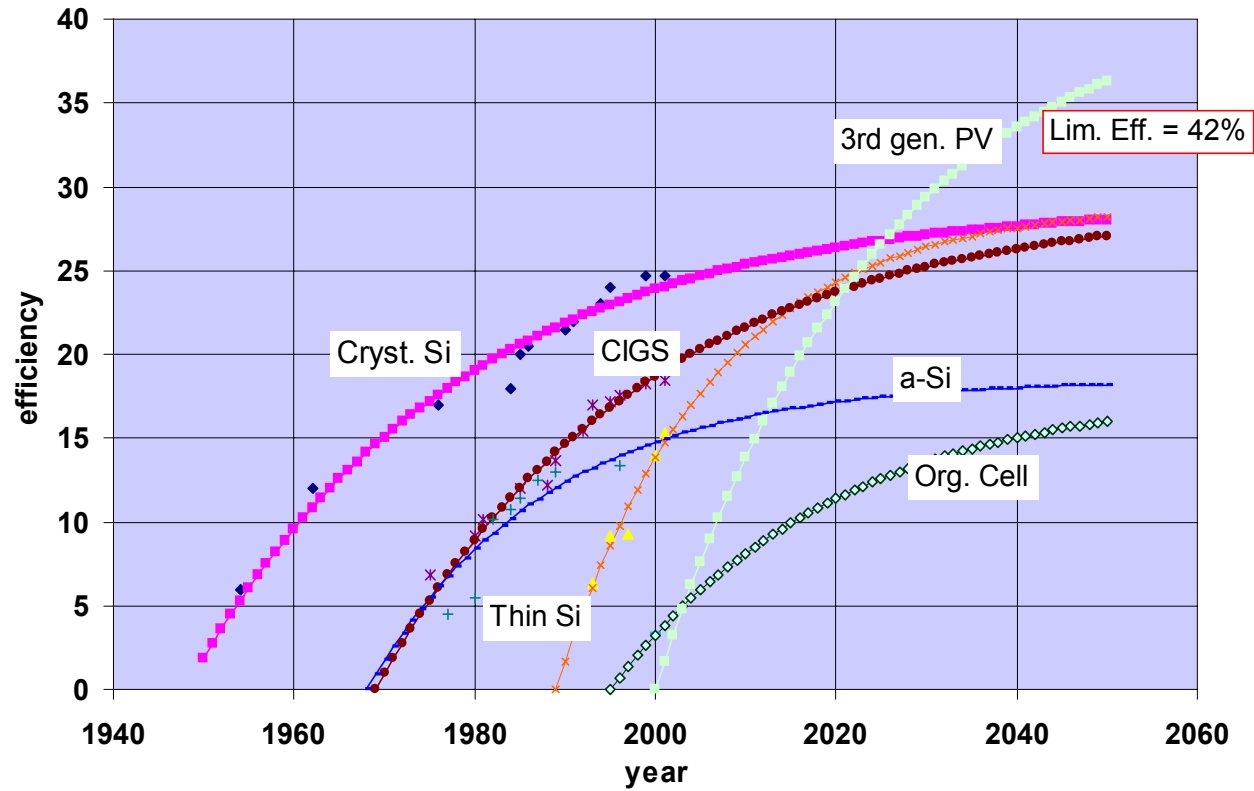


Long Term Prospects

- **Dye sensitized cells**
- **Concentrating systems**
- **Tandem cells**
 - **Stacked thin film solar cells with different bandgaps**
- **Polymer (organic cells)**
 - **Low efficiency but potentially very cheap**
- **Third generation materials and technologies**
 - **Intermediate band material, Multiple carrier generation material, Hot carrier cells, Thermophotovoltaic devices, Micro antenna cells, etc.**



Efficiency for all technologies



Applications of thermal solar energy

- Domestic hot water heating
- Space heating
 - Combi-systems (water + space heating)
 - Seasonal storage in large scale storage units
- Air conditioning
 - High efficiency collectors are available
 - Adsorption system operate at temperatures $\sim 100^{\circ}\text{C}$



Collector Technology

Original Technology	Present Trends
Cheap, unreliable, low efficiency	High quality, high efficiency, proven lifetime
Production: Wet chemistry, environmentally hazardous	Now: Vacuum technologies
Standard product cover glass	Low iron glass with anti-reflective surfaces



Solar Architecture

- Originally: Passive solar energy, components and design for thermal comfort only
- Today: Integrative systems approach, heating, cooling, ventilation, daylighting, PV integration



The Self Sufficient Solar House



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Summary 1: PV

- Presently cryst. silicon is the dominant solar cell material
- Modelling of past efficiencies: → prediction for the future
- Many options exist for future improvement of efficiency and cost



Summary 2

- Collector technology is mature
- Passive Solar has developed into Solar Architecture
- PV and agriculture are compatible
- PV fits well into a future decentralized energy system

