Solar Energy II

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Mechanical Engineering 496ALT

Alternative Energy

March 10, 2009

California State University Northridge

Outline

- Review last week
- Concentrating solar power
- Passive solar
- Photovoltaics

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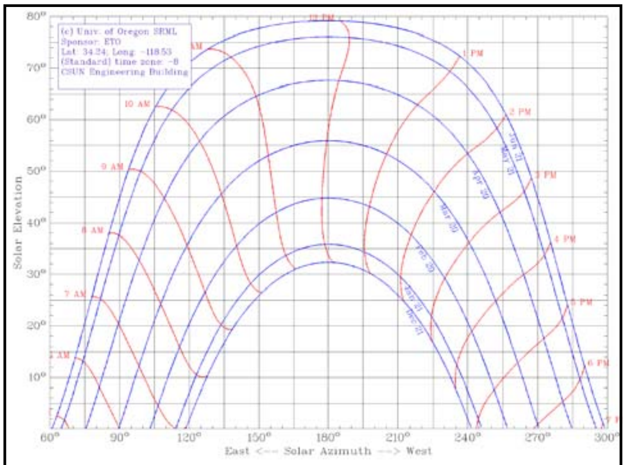

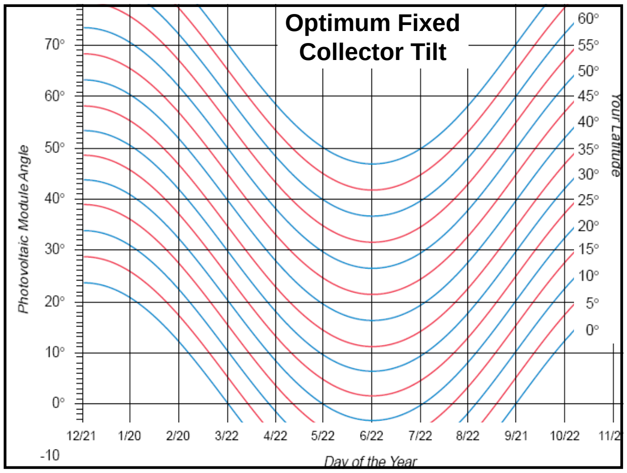

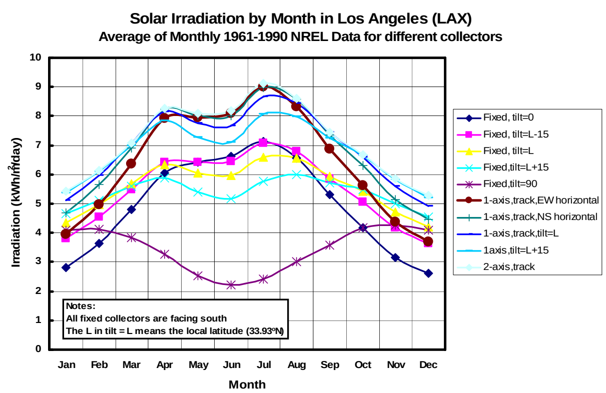

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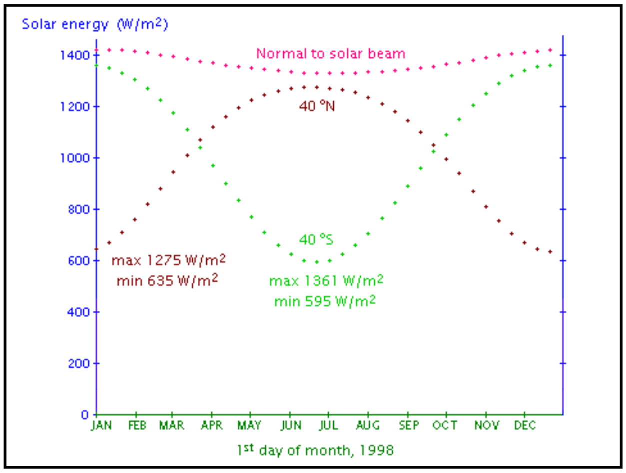

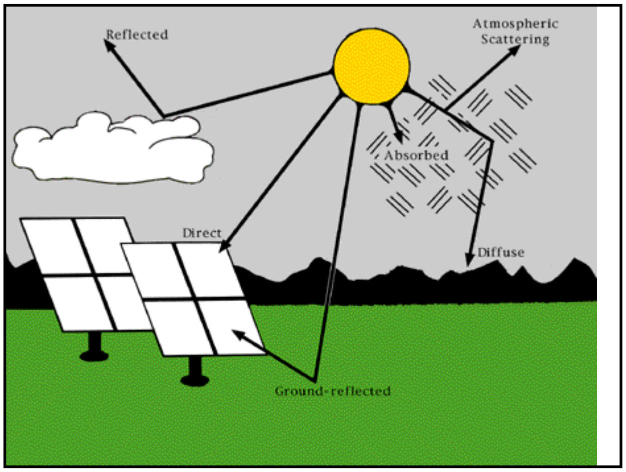

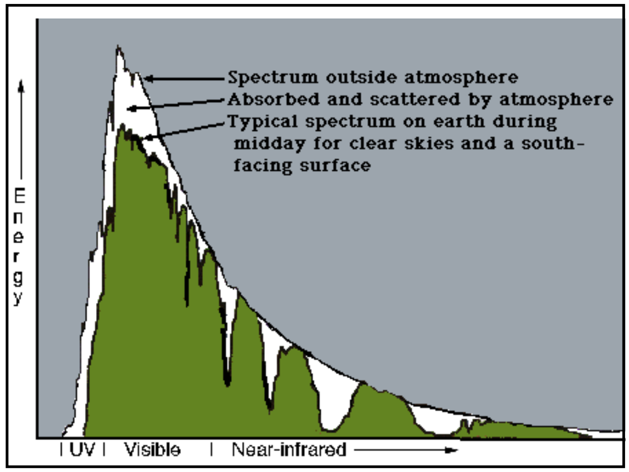

Concentrating Solar Power

- Concentrate solar beam to produce high temperature heat
  - Parabolic trough systems: long, U-shaped mirrors concentrate heat on oil line at focal point; heated oil used to generate steam
  - Dish-engine systems: like satellite antenna, concentrate solar power on external combustion engine at focus
  - Power tower receives solar energy from a series of mirrors to heat molten salts

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Concentrating Solar Power II

- Typically use “hybrid” systems that combine solar and fossil fuel heat sources
- Heated materials (oil or molten salts) can be stored for heat generation later in day
- Most applications for electric power production

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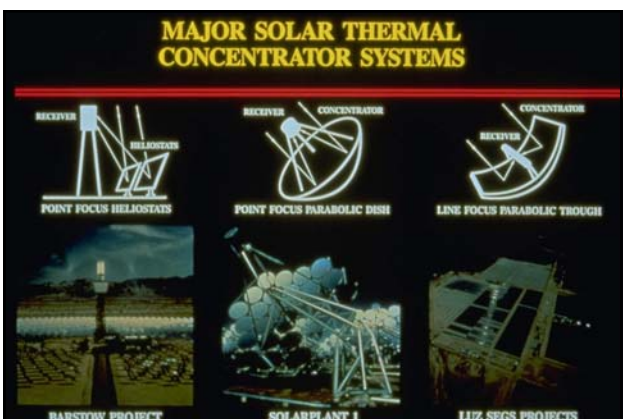
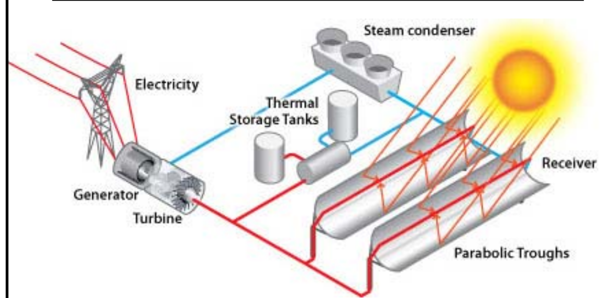


California State University Northridge 11 http://www.energylan.sandia.gov/photo/photos/3081/308154d.jpg

Parabolic Troughs



- http://www1.eere.energy.gov/solar/linear_concentrators.html

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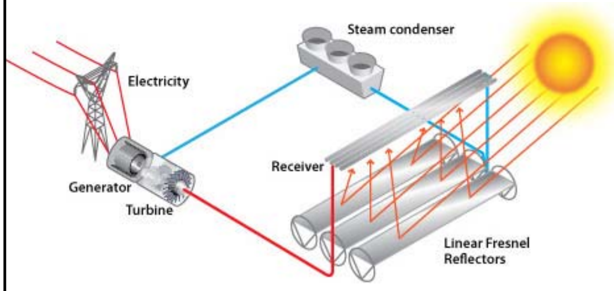
Linear Fresnel Reflectors



http://www1.eere.energy.gov/solar/linear_concentrators.html

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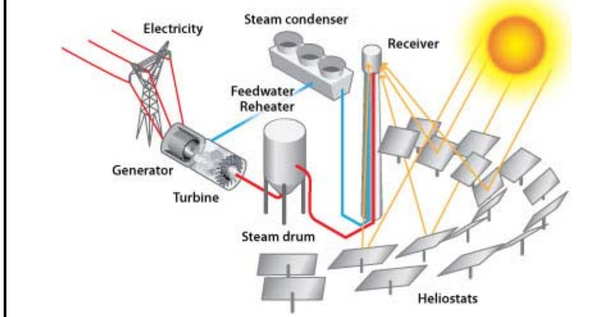
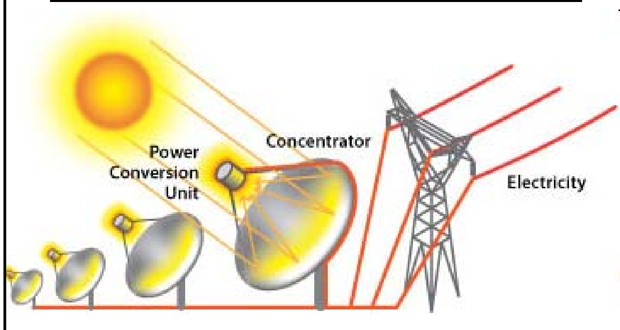
Power Tower



California State University Northridge http://www1.eere.energy.gov/solar/power_towers.html 14

Dish Sterling



California State University Northridge http://www1.eere.energy.gov/solar/dish_engines.html 15

CSP Comparisons 1997

	Parabolic Trough	Power Tower	Dish/Engine
Size	30-320 MW*	10-200 MW*	5-25 kW*
Operating Temperature (°C/°F)	390/734	565/1,049	750/1,382
Annual Capacity Factor	23-50%*	20-77%*	25%
Peak Efficiency	20%(d)	23%(p)	29.4%(d)
Net Annual Efficiency	11(d')-16%*	7(d')-20%*	12-25%*(p)
Commercial Status	Commercially Available	Scale-up Demonstration	Prototype Demonstration
Technology Development Risk	Low	Medium	High
Storage Available	Limited	Yes	Battery
Hybrid Designs	Yes	Yes	Yes
Cost			
$/m^2	630-275*	475-200*	3,100-320*
$/W	4.0-2.7*	4.4-2.5*	12.6-1.3*
$/W$_p$†	4.0-1.3*	2.4-0.9*	12.6-1.1*

Values indicate changes over the 1997-2030 time frame.

$/W$_p$ removes the effect of thermal storage (or hybridization for dish/engine). See discussion of thermal storage in the power tower TC and footnotes in Table 4.

(p) = predicted; (d) = demonstrated; (d') = has been demonstrated, out years are predicted values

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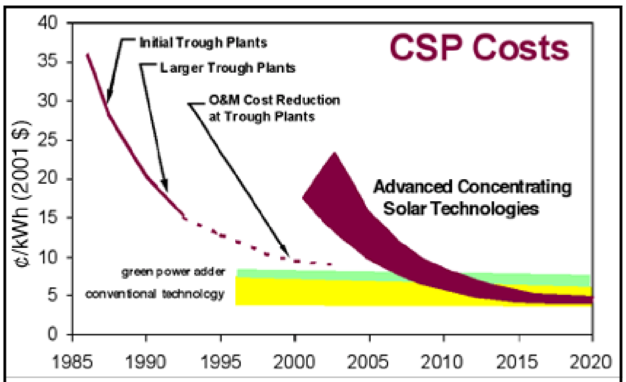
http://www.energylan.sandia.gov/sunlab/PDFs/solar_overview.pdf



http://www.energylan.sandia.gov/sunlab/overview.htm

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Solar Power Costs

Resource Zone	Zonal Cost Multiplier	Capital Cost ($/kW)	Fixed O&M ($/kW-yr)	Fuel Cost ($/MMBTU)	Capacity Factor Range	Busbar LCOE Range ($/MWH)	Net Resource Potential (MW)
Base Value	**1.00**	**$3,389**	**$53**		**40%**		**447,319**
AB	1.00	n/a	n/a	$0.00	n/a	n/a	-
AZ-S. NV	1.00	$3,389	$53	$0.00	37% - 38%	$130 - $133	141,243
BC	1.00	n/a	n/a	$0.00	n/a	n/a	-
CA	1.20	$4,067	$64	$0.00	37% - 40%	$149 - $161	89,117
CFE	1.00	n/a	n/a	$0.00	n/a	n/a	-
CO	0.97	n/a	n/a	$0.00	n/a	n/a	-
MT	1.02	n/a	n/a	$0.00	n/a	n/a	-
NM	0.96	$3,254	$51	$0.00	39%	$123	66,897
N. NV	1.09	$3,694	$58	$0.00	37% - 40%	$137 - $146	150,062
NW	1.11	n/a	n/a	$0.00	n/a	n/a	-
UT-S. ID	1.00	n/a	n/a	$0.00	n/a	n/a	-
WY	0.92	n/a	n/a	$0.00	n/a	n/a	-

E3 report for California Public Utilities Commission Report (2007)
www.ethree.com/GHG/19%20Solar%20Thermal%20Assumptions%20v4.doc

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SES

Dish Stirling System

http://www.stirlingenergy.com/imagesdet.asp?type=allsolar&imageID=11

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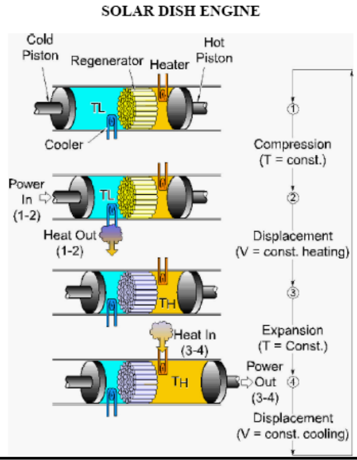

Stirling

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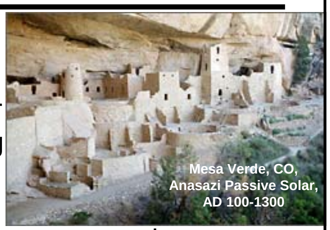
Passive Solar

- Design of buildings to make better use of solar energy for heating and cooling



- Variety of techniques to get solar heating in winter and lessen solar heat input during summer

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Passive Solar II

- All methods use south-facing windows
  - Direct gain uses floor and wall materials that absorb sunlight
  - Sunspaces (like greenhouses) heat air that is then circulated through house
  - Trombe walls are thick, south-facing walls designed to absorb and hold sunlight during day to provide heating during night
  - Clerestory windows in inside walls allow light into north-facing rooms

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NREL Building Energy Study

- Home with no increase in peak energy
  - http://www.nrel.gov/docs/fy06osti/39821.pdf
  - Increase cost of new 2,592 ft^2 house in Sacramento, CA by about $10,000
  - Reduces sum of mortgage payments and energy costs
  - Reduces heating load by 70%, cooling load by 60%, primary energy use by 60%
  - Passive solar plus solar water heating
  - Photovoltaic electricity not cost effective

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NIST Photovoltaics

- National Institute of Standards and Technology, Building and Fire Research Laboratory (BFRL) Presentation
- NIST BRFL Role: development of
  - measurement methods
  - standards
  - prediction tools
  - measurement facilities

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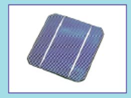
Photovoltaics

A. Hunter Fanney
Heat Transfer & Alternative Energy Systems Group
National Institute of Standards and Technology

January 26, 2007

NIST National Institute of Standards and Technology

Photovoltaic Terminology

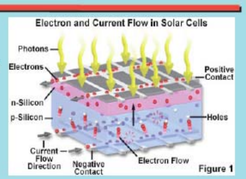


- CELL - basic building block in factory
- MODULE - smallest unit that can do real-world work; building block in the field
- ARRAY - electrically interconnected modules
  - Series Wired to Increase Voltage
  - Parallel Wired to Increase Current

NIST National Institute of Standards and Technology

PV Cells – How They Work

- Silicon absorbs photons from solar radiation
- If photon energy is great enough, an electron from the outer electron shell is freed
- Results in -
  - Hole – lack of an electron
  - Excess electron in crystal structure
  - Without a barrier, the excess electron would rapidly fill the hole
- A barrier is introduced inhibiting the free migration of electrons resulting in n layers and p layers
  - Buildup of electrons in n-layer
  - Deficiency of electrons in p-layer
- By connecting n and p layers through electrical circuit, current will flow



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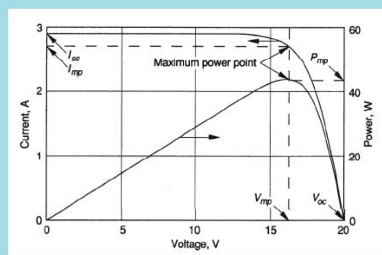
Photovoltaic Terminology



Typical *I-V* and *P-V* curves for a PV module

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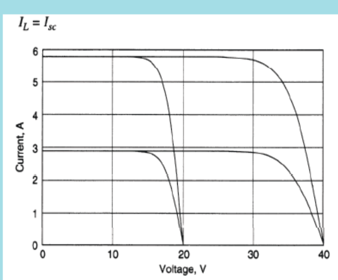
Series and Parallel Connections



IV curves for *PV* modules connected in various series and parallel arrangements.

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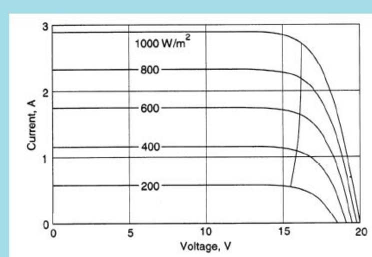
Solar Irradiance Level Versus Output



IV curves for a *PV* MODULE at several radiation levels. The locus of maximum power points is shown.

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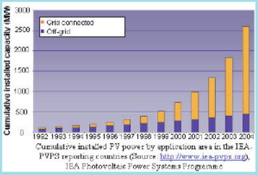
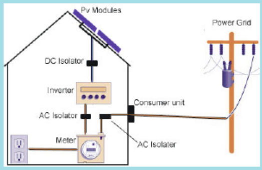
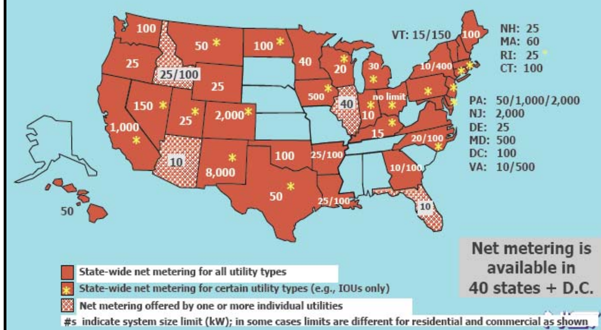
Grid Interconnected Systems





Net Metering State by State

www.dsireusa.org January 2007



Conversion Efficiency

$$\eta_c = \frac{\int_o^{\tau} P_o \, d\tau}{A \int_o^{\tau} H_T \, d\tau}$$

where

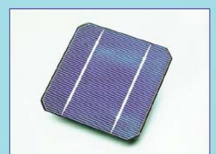
A is a representative area, m^2,

H_T is the incident solar radiation, W/m^2,

P_o is the panels electrical power output, W

and τ is the time interval selected for monitoring, h.

Photovoltaic Technologies



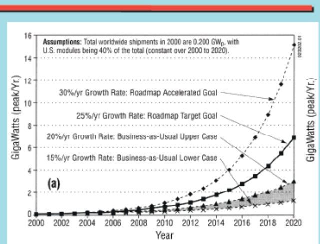
Conventional - 94% of Market

Thin Film – 6% of Market

Material	Laboratory Cell Efficiency	Laboratory Module Efficiency
Crystalline Silicon	24.7%	23%
Multi Crystalline Silicon	20.3%	15.3%
CIGS	18.8%	13.4%
CdTe	16.5%	10.7%

The Photovoltaic Industry

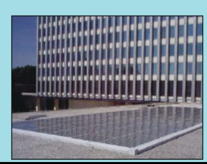
- Worldwide PV Shipments
  - 1998 - $1.5 billion
  - 2020 - $27 billion
- Price History
  - 1959 - $1000 per Watt
  - 1973 - $100 per Watt
  - 1980 - $10 per Watt
  - 12/06 - $5.47 per Watt



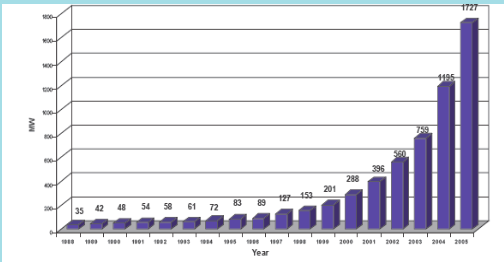
PV Growth Strategy 2000-2020
PV Technology Roadmap Workshop, 6/99

Photovoltaic Industry

- PV Manufacturers and Technologies
  - Single-Crystalline – SolarWorld, Sun Power (Back Contact)
  - Polycrystalline – BP Solar, Sharp, Kyocera Solar, Mitsubishi, GE
  - Polycrystalline String Ribbon – ASE Americas, Evergreen Solar
  - Silicon Film – General Electric
  - Amorphous Silicon – United Solar Ovonic Corporation
  - Cadmium Telluride – First Solar
  - Copper Indium Diselenide/Copper Indium Gallium Diselenide – Wurth Solar, Global Solar, Shell Solar



Worldwide PV Module Manufacturing Activity



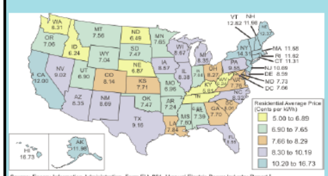
Sources - Photovoltaic News, March 2006

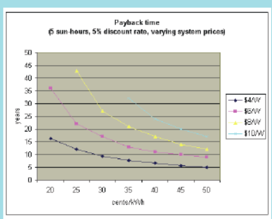
DOE's Solar America Initiative Program Goals

Market Sector	Current Market Price	PV Generated 2005	PV Generated 2010	PV Generated 2015
Residential	5.8 -16.7	23-32	13-18	8-10
Commercial	5.4 – 15.0	16-22	9-12	6-8

Prices are cents per kWh
Current prices based on electric generation with conventional sources
Market goals based on grid-tied sources

Photovoltaic Economics



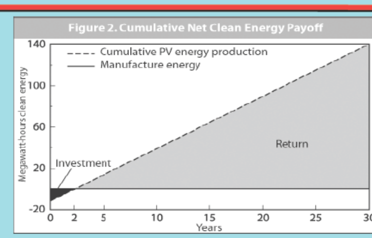


PV Incentives
30%Federal Tax Credit

- Maryland – Lesser of 20% or $3K Grant
- Germany –Rebate of $0.54 per kWh declining at 5% per year

Example
2000 Watt System in Maryland
2000 watt @ $9/watt = $18,000
Less $5,000 Tax Credit, Less $3,000
Net Cost 10K or $5/watt

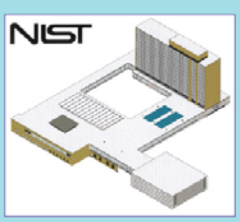
Photovoltaic Energy Payback and Avoided Emissions



- A PV system that meets 50% of average household use would:
  - Eliminate 0.5 tons of SO_2 and 0.3 tons of NO_x
  - CO_2 emissions avoided would offset the operation of two cars for 28 years

Source- What is the Energy Payback for PV? DOE's National Center for Photovoltaics

NIST Administration Building's PV System



NIST Administration Building's PV System

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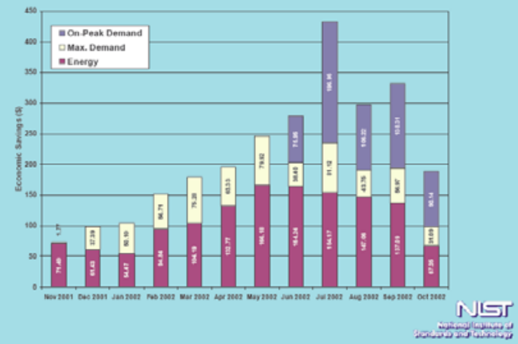

Solar Conclusions

- Promise of large amounts of pollution-free energy with significant limitations
  - Low energy flux requires large area
  - Costs for current solar materials are not justified by cost savings
  - Solar peak matches electricity demand and thermal storage extends generation time
  - Science of solar energy well understood, but problems with pervious commercial
  - Still need significant cost reductions to make solar PV cost effective

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