CORNING

Photovoltaic
Glass Technologies

Photovoltaics potential for reducing U.S. and global CO_2 emissions

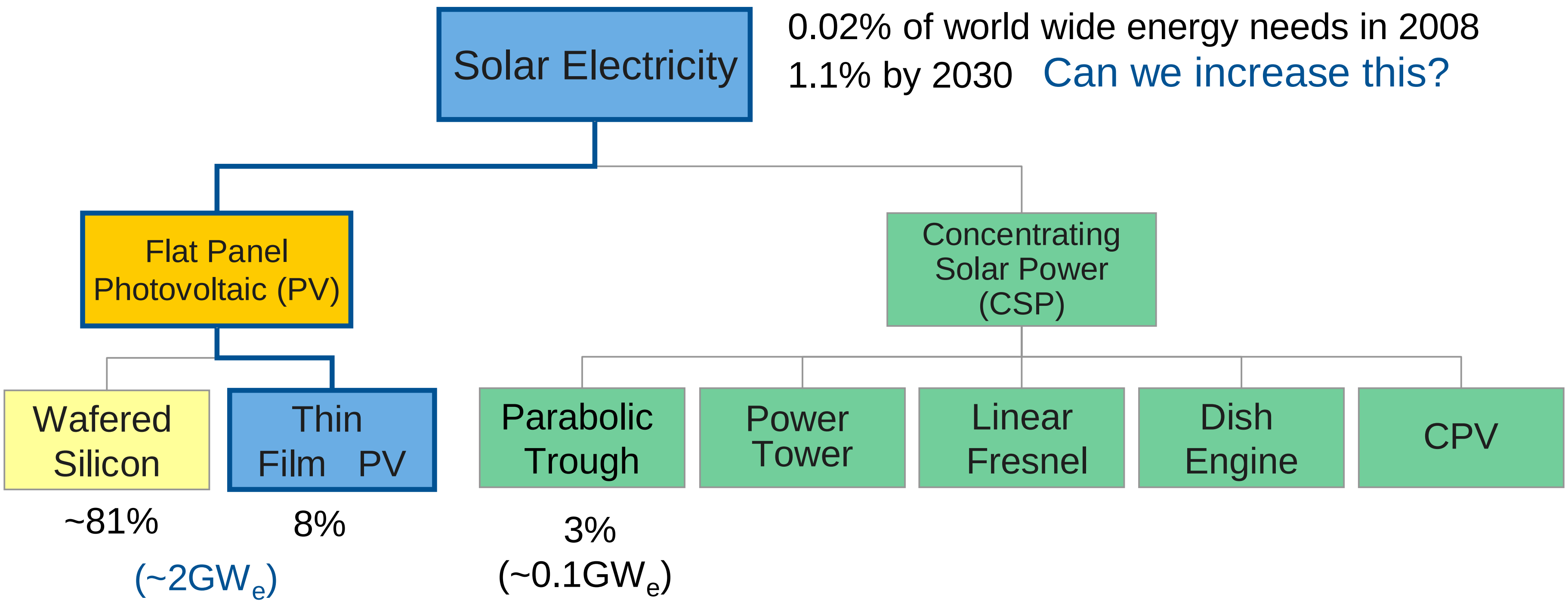
Energy & Climate mini-workshop

Dr. Doug Hall
Director, Product Technology
Corning Photovoltaic Glass Technologies
November 3, 2008

Outline

- Solar Electricity
- What are Photovoltaics?
- Potential for energy production
- PV Technology Choices
- What needs to be done

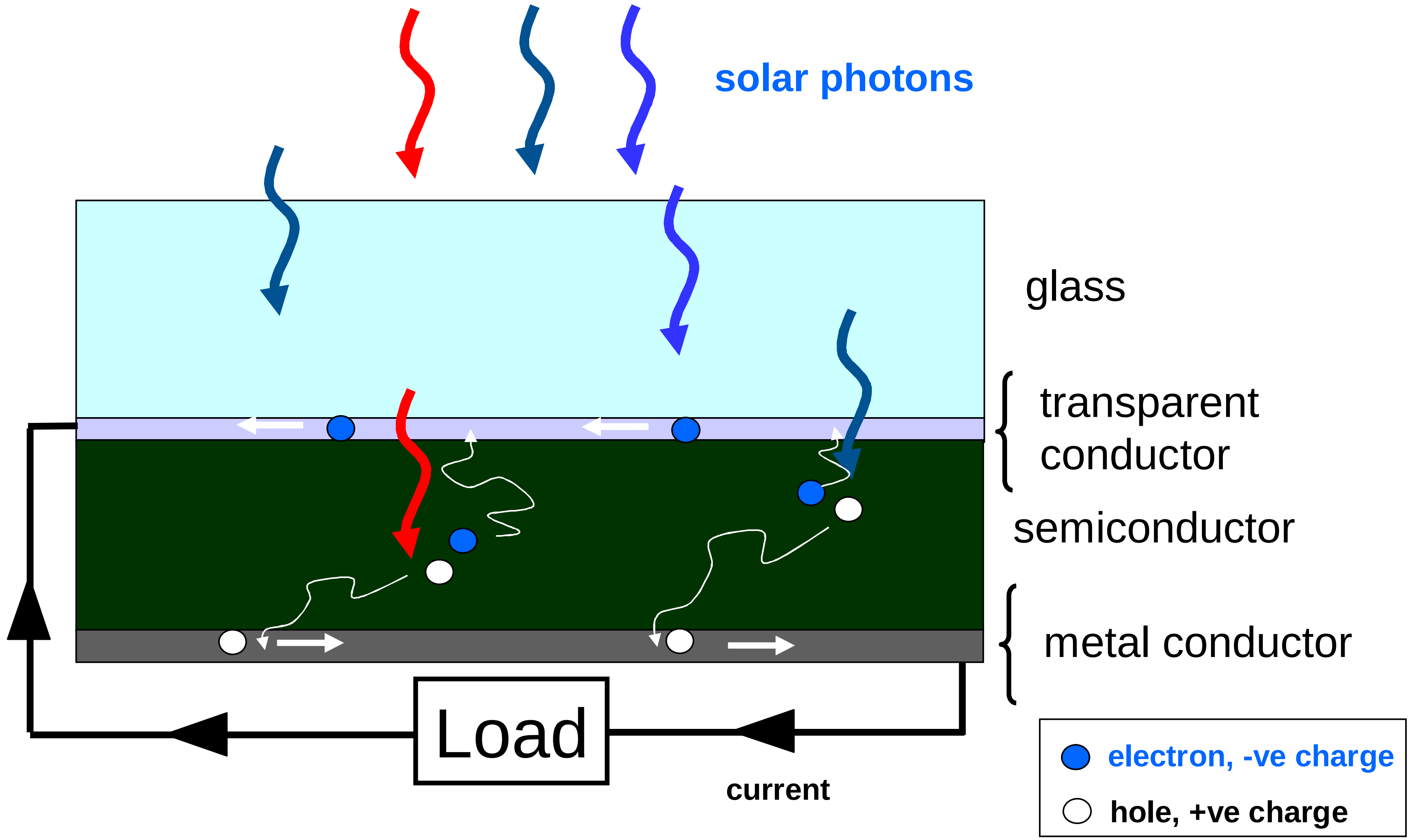
Solar Electricity Technology Landscape



Sources: IEA 2007 World Energy outlook, Alternative Scenario , Navigant (Dec 07),
Emerging Energy Research for Global CSP (nov 07)

Photovoltaic Cell

Electric current from photons



PV Modules are in use today

Rooftop near Boston

Installation in Spain

Large area deployments will be necessary to impact global warming

Modules: First Solar

Size: 40 MW
Installer: juwi solar GmbH
Waldpolenz Energy Park (townships of Brandis and Bennewitz)
Saxony (Germany)

Outline

- Solar Electricity
- What are Photovoltaics?
- Potential for energy production
- PV Technology Choices
- What needs to be done

PV and the Solar Resource
”back of the envelope”

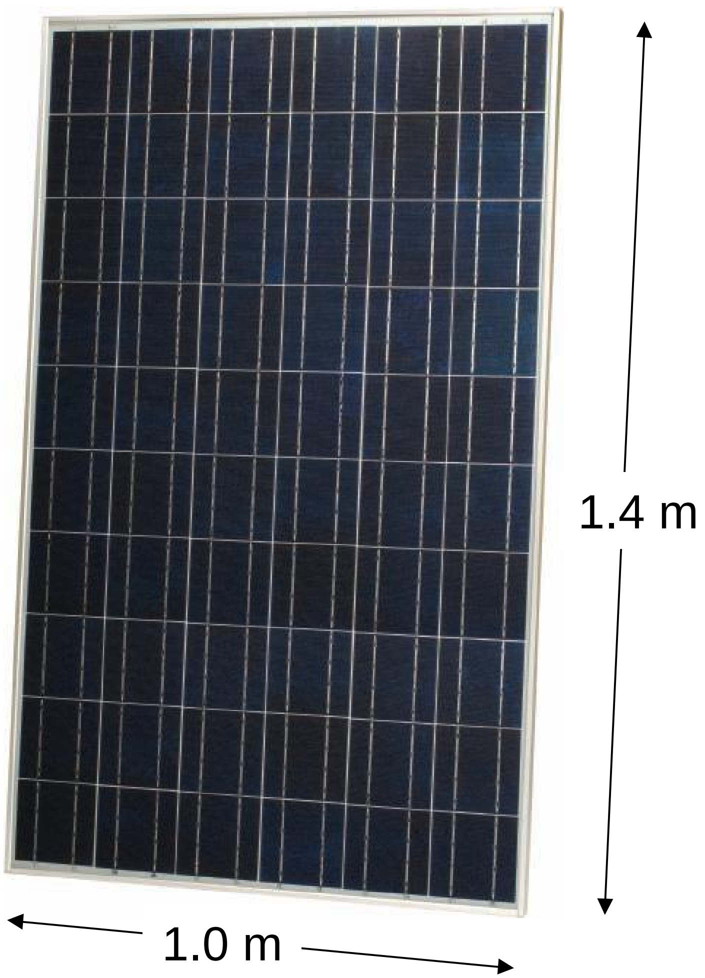
Parameter	value	units
Solar Irradiance	1.0E+03	W/m^2
Earth Radius	6.4E+06	m
Earth X-Sectional Area	1.3E+14	m^2
Solar Power on Earth	1.3E+17	W
Land Fraction of Surface Area	30%	-
Solar Power on Land	3.8E+16	W
Module Efficiency	15%	-
Solar Capacity Factor	20%	-
Array Shading	50%	-
Electrical Power Possible	5.8E+14	W_e
US Land Fraction for 1 TW_e (peak US summer load)	0.2%	-

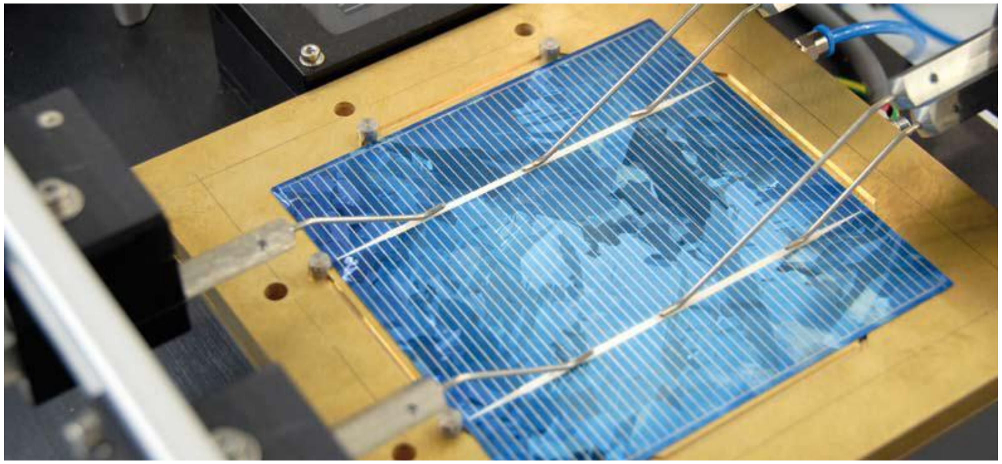
In US –
Roads occupy about 0.4% of land area
Military bases and reservations occupy 1.1%

Outline

- Solar Electricity
- What are Photovoltaics?
- Potential for energy production
- PV Technology Choices
- What needs to be done

Wafered Silicon

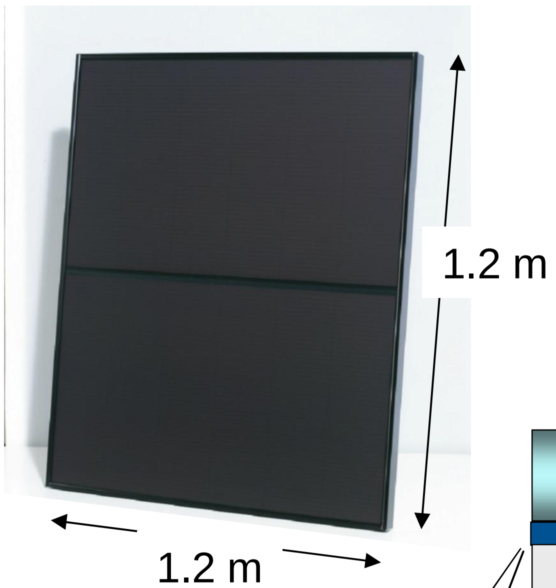




- Conversion Efficiency (W_p/m^2)
  - Improved material growth
  - Silicon coatings
  - Cover glass transmission
- Manufacturing Cost ($\$/m^2$)
  - Thinner wafers
  - Use of lower purity silicon

Generation Two PV

Thin-Film Photovoltaics

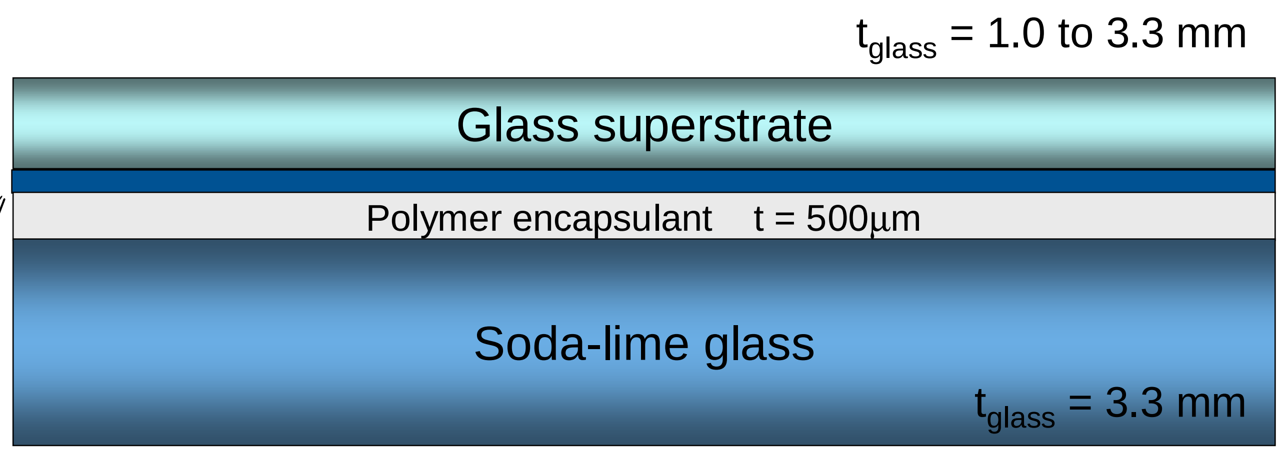


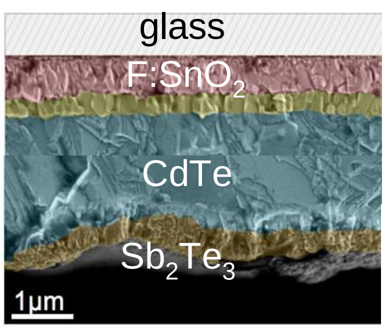
Thin-film materials

Cadmium Telluride (CdTe)

Copper-Indium di-Selenide (CIGS)

Thin-film Silicon





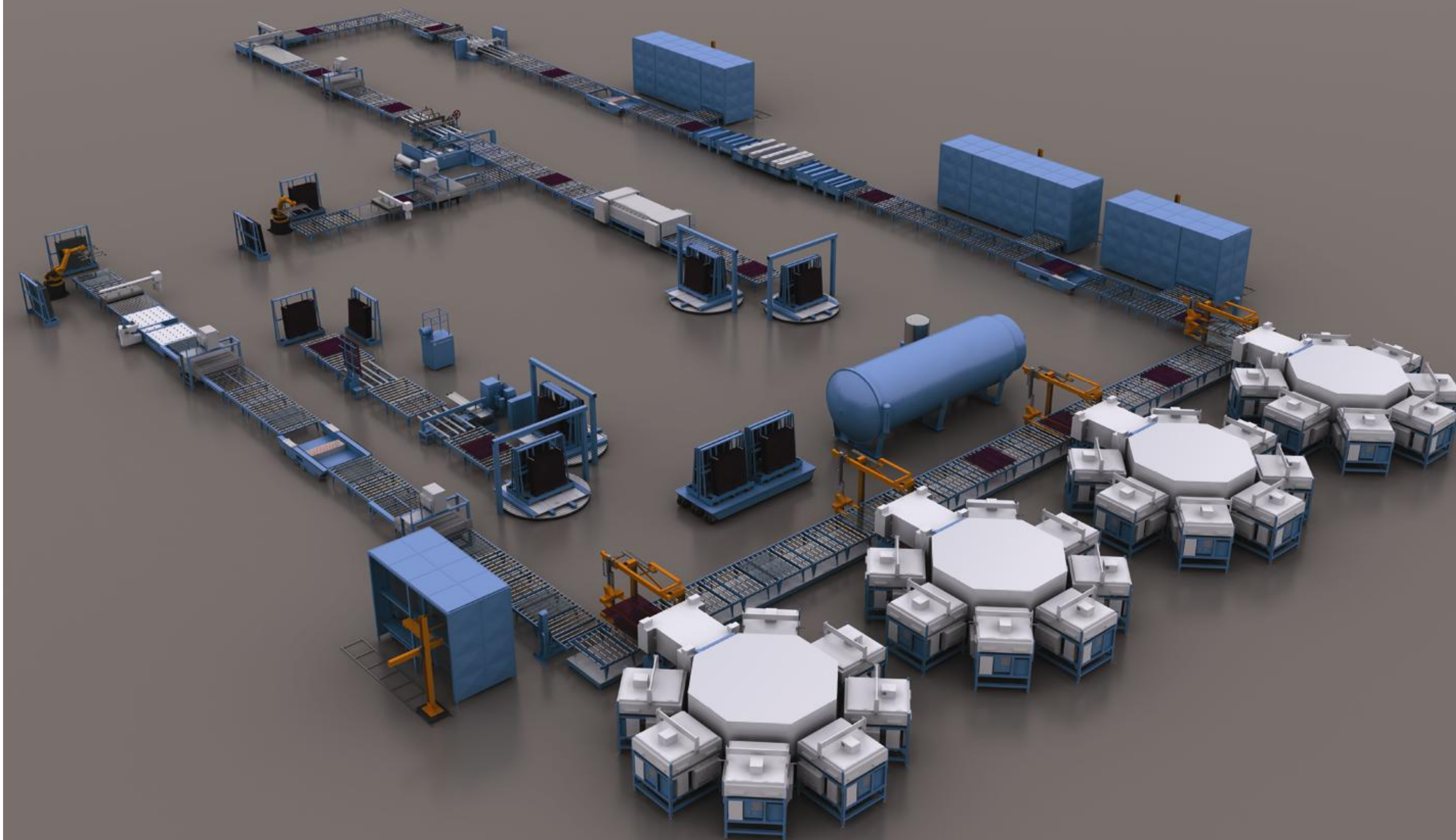
PV Figures of Merit (FOM)

FOM	unit	wafered crystalline	thin-film	controlling factors
Conversion Efficiency (ave mfg distribution)	%	15	10	materials science manufacturing science
Module Mfg Cost	$\$/m^2$	315	117	automation materials usage
DC Power Module Cost	$\$/W_p$	2.10	1.17	

$$\frac{\$}{W_p} = \frac{\frac{\frac{\$}{m^2}}{W_p}}{m^2}$$

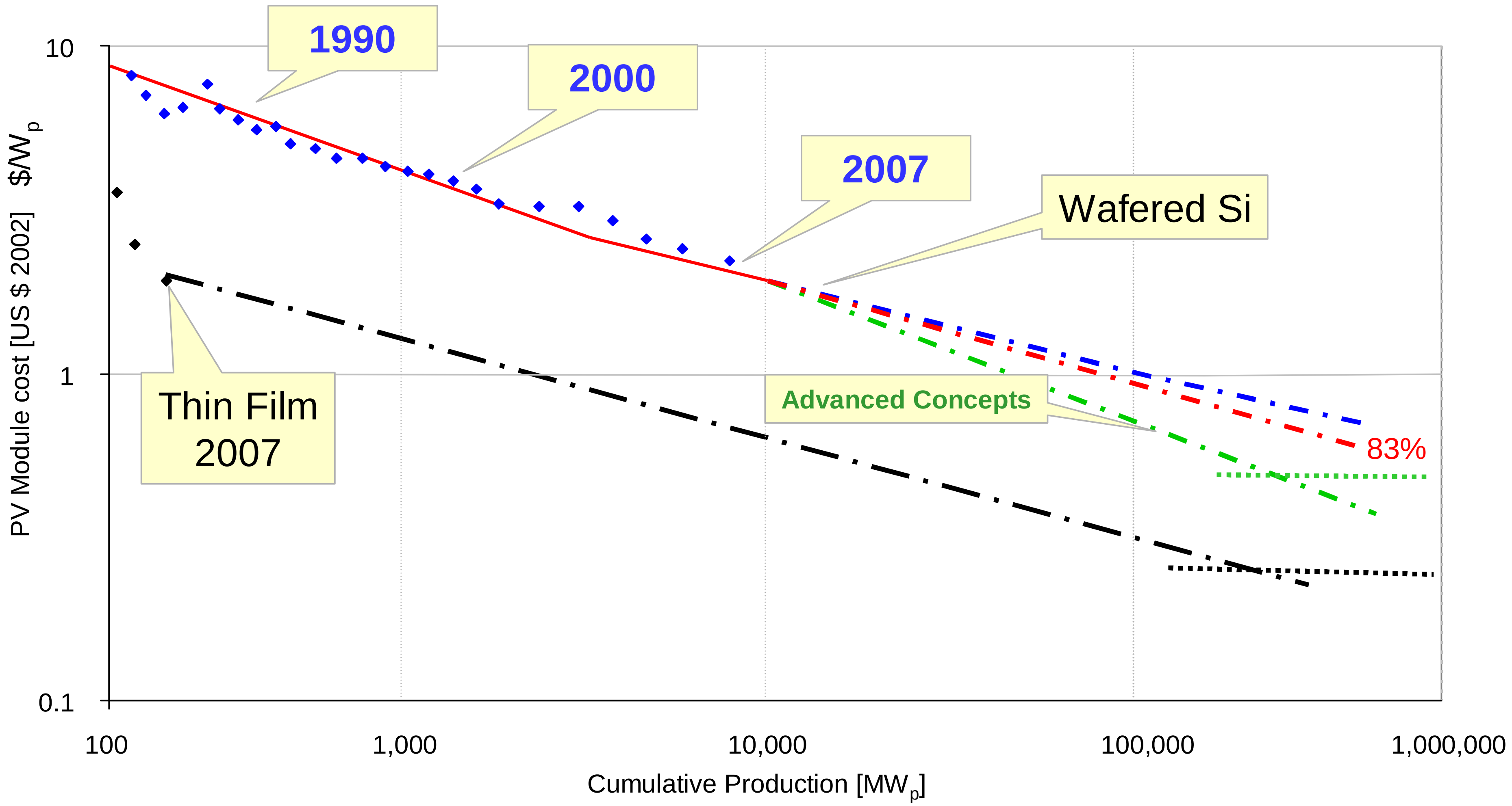
$$= \frac{\frac{\$}{m^2}}{CE \times P_{solar,STC}}$$

Thin-film: Automation is key to lower cost



production layout
courtesy of Applied Materials
Illustration only. Actual design varies

We believe thin films will win the cost game

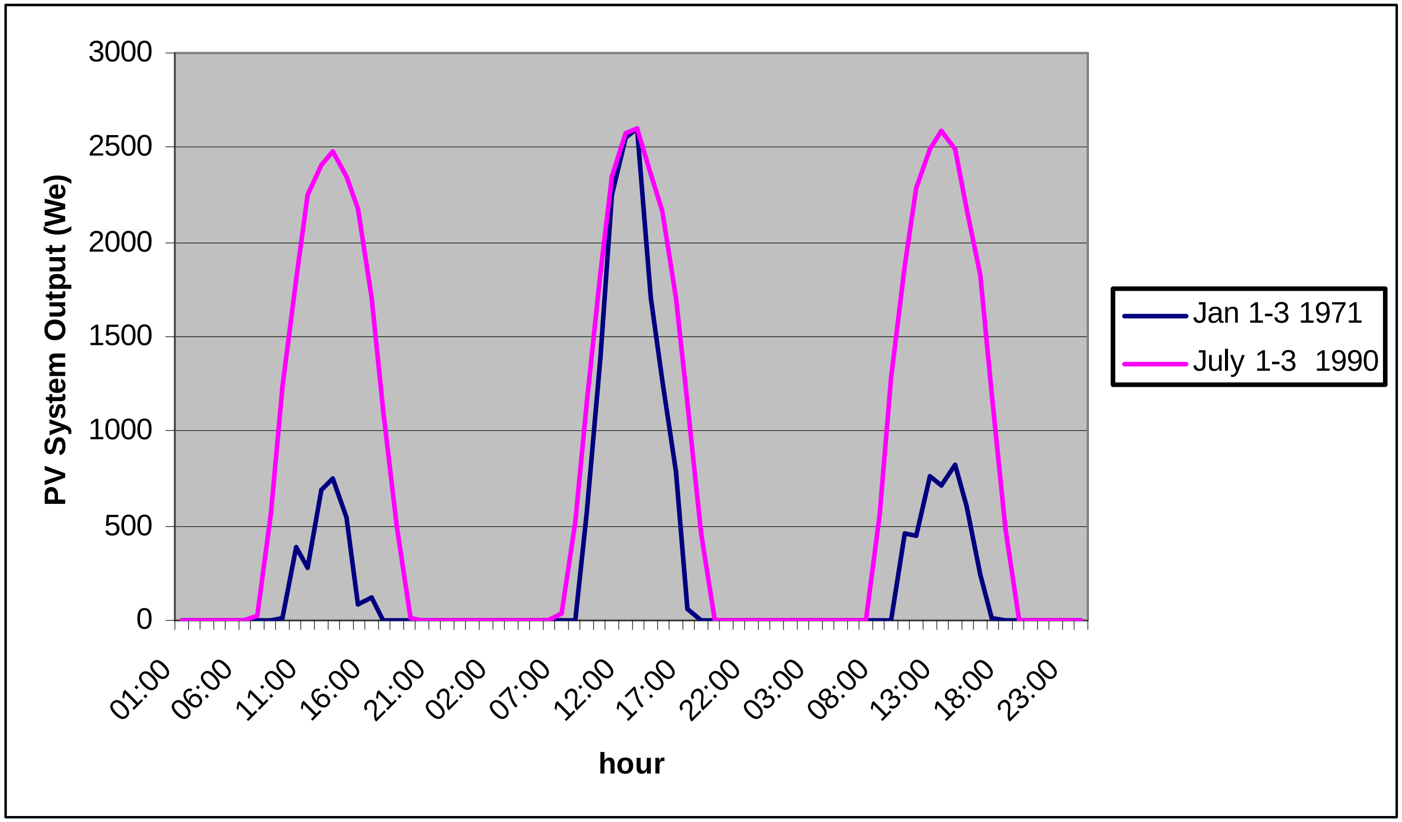


Source: Arnulf Jaeger-Waldau, European Commission, DG JRC, Ispra, Institute for Energy, Renewable Energies
Presented at European PVSEC in Valencia on 9-3-2008

PV Figures of Merit (FOM)

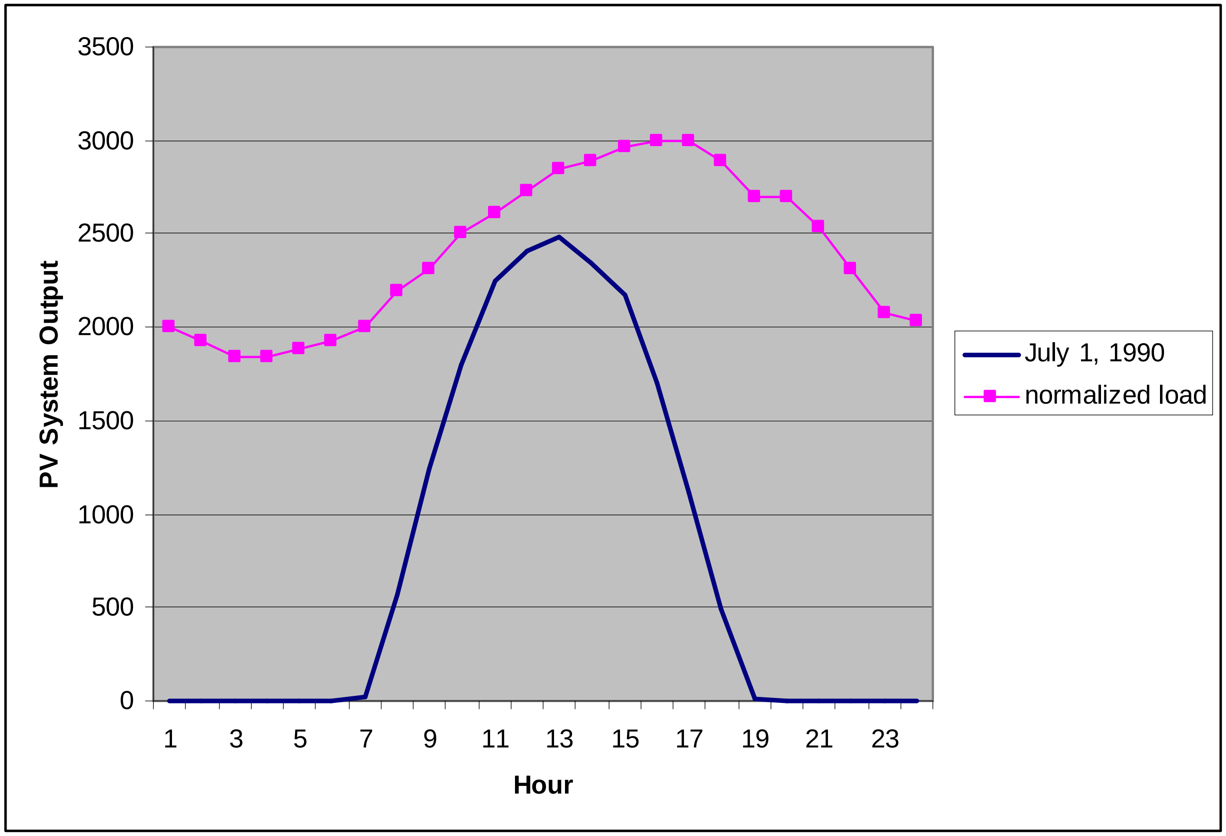
FOM	unit	wafered crystalline	thin-film	controlling factors
Conversion Efficiency (ave mfg distribution)	%	15	10	materials science manufacturing science
Module Mfg Cost	$\$/m^2$	315	117	automation materials usage
DC Power Module Cost	$\$/W_p$	2.10	1.17	
Solar Utilization (average US location-1700 kw-hr/m^2-yr)	**%**	**19%**	**19%**	**light capture storage**

Summer and Winter PV Output - Topeka, Kansas



Lat (deg N):	39.07
Long (deg W):	95.63
Elev (m):	270
Array Type:	"Fixed Tilt"
Array Tilt (deg):	39.1
DC Rating (kW):	4

Daily PV Output vs. typical load – Topeka, Kansas



Lat (deg N):	39.07
Long (deg W):	95.63
Elev (m):	270
Array Type:	"Fixed Tilt"
Array Tilt (deg):	39.1
DC Rating (kW):	4

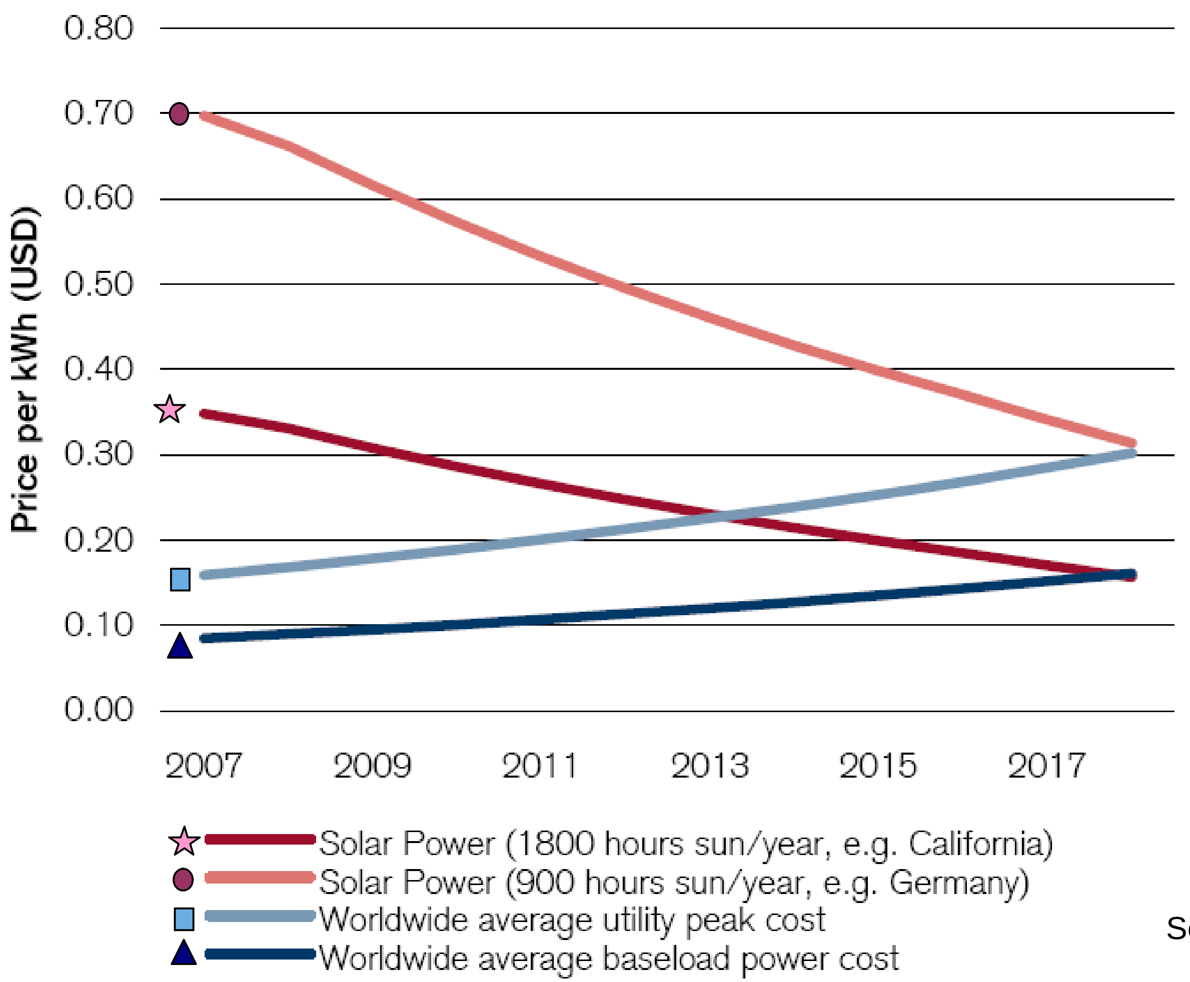
Model average load:
J. Bebic NRELsubcontract report
Feb 2008 SR-581-42297

PV Figures of Merit (FOM)

FOM	unit	wafered crystalline	thin-film	controlling factors
Conversion Efficiency (ave mfg distribution)	%	15	10	materials science manufacturing science
Module Mfg Cost	$\$/m^2$	315	117	automation materials usage
DC Power Module Cost	$\$/W_p$	2.10	1.17	
Solar Utilization (average US location- 1700 kw-hr/m^2-yr)	%	19%	19%	light capture storage
System AC Energy Cost	**$/kw-hr**	**0.35**	**0.28**	**location temp. coefficient system lifetime financing methods**

Thin-film lifetime assumption 25-30 years…….

Due To Rising Energy Costs, And Declining PV Prices, PV Could Reach Grid Parity by 2013



Source: EPIA, Credit Suisse

PV Figures of Merit (FOM)

FOM	unit	wafered crystalline	thin-film	controlling factors
Conversion Efficiency (ave mfg distribution)	%	15	10	materials science manufacturing science
Module Mfg Cost	$\$/m^2$	315	117	automation materials usage
DC Power Module Cost	$\$/W_p$	2.10	1.17	
Solar Utilization (average US location-1700 $kw\text{-}hr/m^2\text{-}yr$)	%	19%	19%	light capture storage
System AC Energy Cost	$/kw-hr	0.35	0.28	location temp. coefficient system lifetime financing methods
System Lifecycle Energy Payback Time	**years**	**1.7-2.7**	**0.9**	**materials fabrication**
System Lifecycle CO_2 emission	**g $CO_{2\text{-}eq}$ /kWh**	**33**	**20**	**materials fabrication**

Nuclear fuel cycle:
wide range of estimates
16-55 g $CO_{2\text{-}eq}$/kWh

V.M. Fthenakis, H.C. Kim
Energy Policy 35 (2007) 2549–2557

Agenda

- Solar Electricity
- What are Photovoltaics?
- Potential for energy production
- PV Technology Choices
- What needs to be done

Long-Range Technology Needs

- Efficiency and cost are today's battlefield

- Storage for PV
  - Compressed Air Energy Storage
  - Hydrogen electrolysis
  - Liquid fuel from electricity (via hydrogen?)
  - Other ideas…..

- PV System Reliability Science