Biomass Power Potential

Global: Top Down

- Requires Large Areas Because Inefficient (0.3%)
- 3 TW requires ≈ 600 million hectares = $6x10^{12}$ m^2
- 20 TW requires ≈ $4x10^{13}$ m^2
- Total land area of earth: $1.3x10^{14}$ m^2
- Hence requires 4/13 = 31% of total land area

N. S. Lewis: „Global Energy Perspective“, http://nsl.caltech.edu/energy.html

Biomass Power Potential

Global: Bottom Up

- Land with Crop Production Potential, 1990: 2.45×10^{13} m^2
- Cultivated Land, 1990: 0.897×10^{13} m^2
- Additional Land needed to support 9 billion people in 2050: 0.416×10^{13} m^2
- Remaining land available for biomass energy: 1.28×10^{13} m^2
- At 8.5-15 oven dry tonnes/hectare/year and 20 GJ higher heating value per dry tonne, energy potential is **7-12 TW**
- Perhaps 5-7 TW by 2050 through biomass (recall: $1.5-4/GJ)
- Possible/likely that this is **water** resource limited
- Challenges for chemists: cellulose to ethanol; ethanol fuel cells

N. S. Lewis: „Global Energy Perspective“, http://nsl.caltech.edu/energy.html

Solar Power Potential

- **Theoretical:** **120,000 TW solar energy potential**

  (176,000 TW striking Earth; 0.30 Global mean albedo)

  - **Energy in 1 hr of sunlight ↔ 14 TW for a year**

- **Practical:** **≈ 600 TW solar energy potential**

  (50 - 1500 TW depending on land fraction etc.; WEA 2000)

  Onshore electricity generation potential of ≈ 60 TW (10% conversion efficiency):

- ***Photosynthesis*: 90 TW**

N. S. Lewis: „Global Energy Perspective“, http://nsl.caltech.edu/energy.html

Solar Thermal Power

- **Roughly equal global energy use in each major sector: transportation, residential, transformation, industrial**
- **World market: 1.6 TW space heating; 0.3 TW hot water; 1.3 TW process heat (solar crop drying: ≈ 0.05 TW)**
- **Temporal mismatch between source and demand requires storage**
- **(ΔS) yields high heat production costs: ($0.03-$0.20)/kW-hr**
- **<u>High-T solar thermal</u>: currently lowest cost solar electric source ($0.12-0.18/kW-hr); potential to be competitive with fossil energy in long term, but needs large areas in sunbelt**
- **Solar-to-electric efficiency 18-20% (research in thermochemical fuels: hydrogen, syn gas, metals)**

N. S. Lewis: „Global Energy Perspective“, http://nsl.caltech.edu/energy.html

Solar Land Area Requirements

- **120,000 TW of solar energy potential globally**

- **Generating 20 TW with 10% efficient solar farms requires 200 / 120,000 = 0.16 % of Globe = 8 x 10^{11} m^2 = 800,000 km^2 (i.e., 8.8 % of U.S.A)**

- **Generating 12 TW (1998 Global Primary Power) requires 120 / 120,000 = 0.1 % of Globe = 5x10^{11} m^2 = 500,000 km^2 (i.e., 5.5% of U.S.A.)**

N. S. Lewis: „Global Energy Perspective“, http://nsl.caltech.edu/energy.html

The Energy Solution

UC SANTA CRUZ
A. Shakouri 11/25/2008

Solar
1.2×10^5 TW at Earth surface
600 TW practical

The need:
~ 20 TW by 2050

Wind
2-4 TW extractable

Biomass
5-7 TW gross
all cultivatable
land not used
for food

Tide/Ocean Currents
2 TW gross

Geothermal
12 TW gross over land
small fraction recoverable

Hydroelectric
4.6 TW gross
1.6 TW technically feasible
0.9 TW economically feasible
0.6 TW installed capacity

Mean terrestrial geothermal flux at earth's surface **0.057 W/m²**

Nate Lewis,

A. Shakouri, UCSB: „Overview of Renewable Energy Sources“, Talk, Philips Res. Lab., March 25, 2009, http://users.soe.ucsc.edu/~mona/Shakouri_Philips.ppt.

Solar Land Area Requirements

Generating

3 TW requires

1.25×10^{11} m^2 =

125,000 km^2 =

(354 km)^2

N. S. Lewis: „Global Energy Perspective", http://nsl.caltech.edu/energy.html

Solar Land Area Requirements

6 Boxes at 3.3 TW $(354\ \text{km})^2$ Each

N. S. Lewis: „Global Energy Perspective“, http://nsl.caltech.edu/energy.html

Summary

10 to 30 TW of CO_2-free power needed

The options and their limits:

•Nuclear Power: not enough resources, not CO_2-free, terrible energy payback times

•Carbon Capture and Sequestration: no safe storage option

•Renewables

- **Hydropower: nearly no additional potential**
- **Geothermal Power: too small power density, too expensive, basically not renewable**
- **Ocean Power: too small potential**
- **Wind Power: only additional option since limited potential**
- **Biomass: only additional option since low (solar) efficiency**
- **Solar Electricity: perfect option for PV and Solar Thermal Power, needs price reduction and storage**

Growth Needed: 20 – 30 %/a for 40 years!

Summary

What global PV production rate will be required?

(based on a back of the envelope calculation by Sean Shaheen, Univ. Denver, at I-CAMP 2012, Boulder, Colorado, 23 July 2012☺

Total future power need: 10 – 30 TW

Required capacity = 10 TW / capacity factor
= 10 - 30 TW / 0.21 = **48 – 144 TW_p**

PV module lifetime = 30 yr

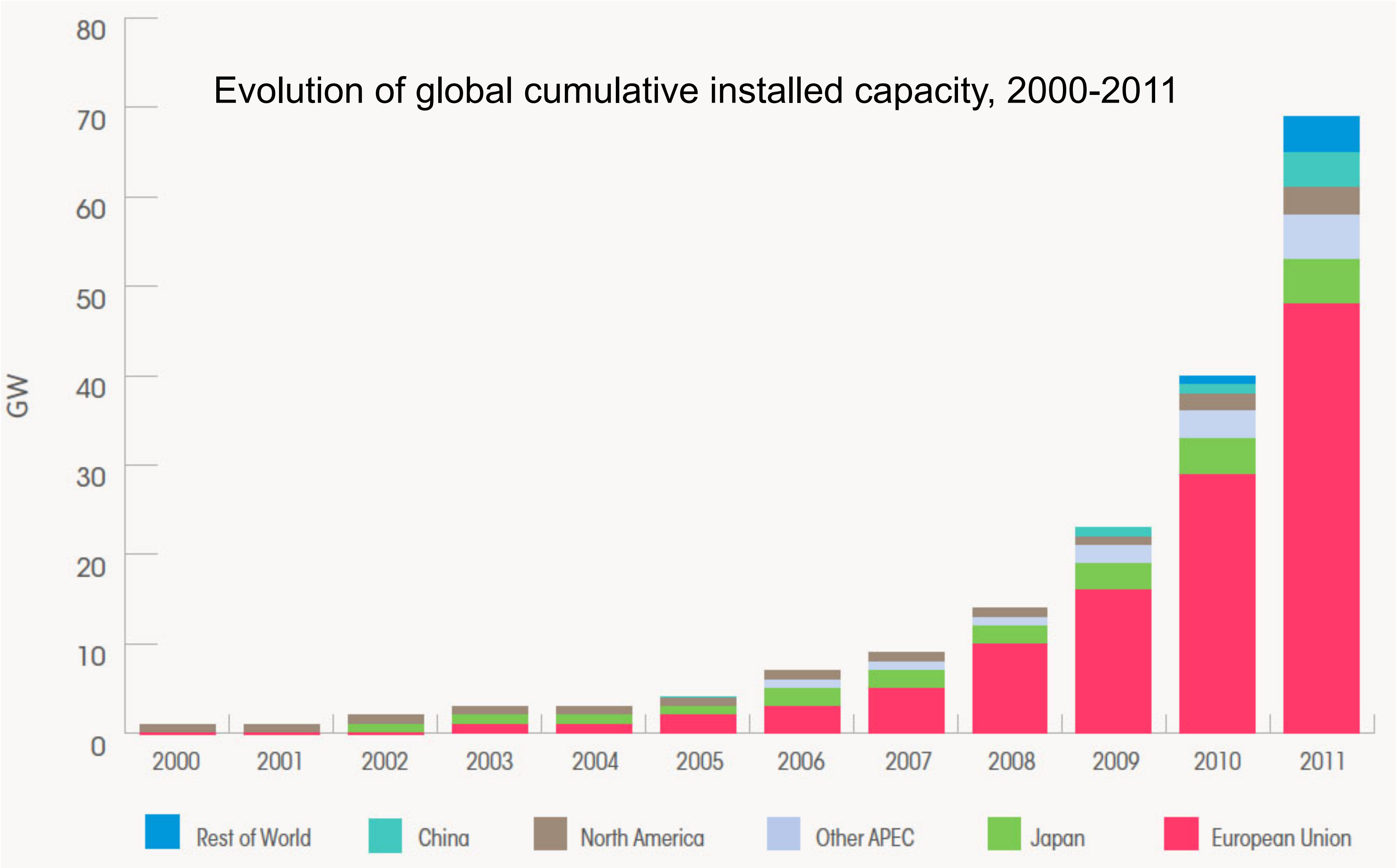
Annual production rate = 48 - 144 TW / 30 yr = **1.6 – 4.8 TW_p / yr**

PV module peak power (20% efficiency) = 200 W_p/m^2

Required production per year ≈ 8 - 24 billion m^2 / yr

Required production per hour ≈ 1 - 3 million m^2 / hr
≈ **1 – 3 km^2 / hr**

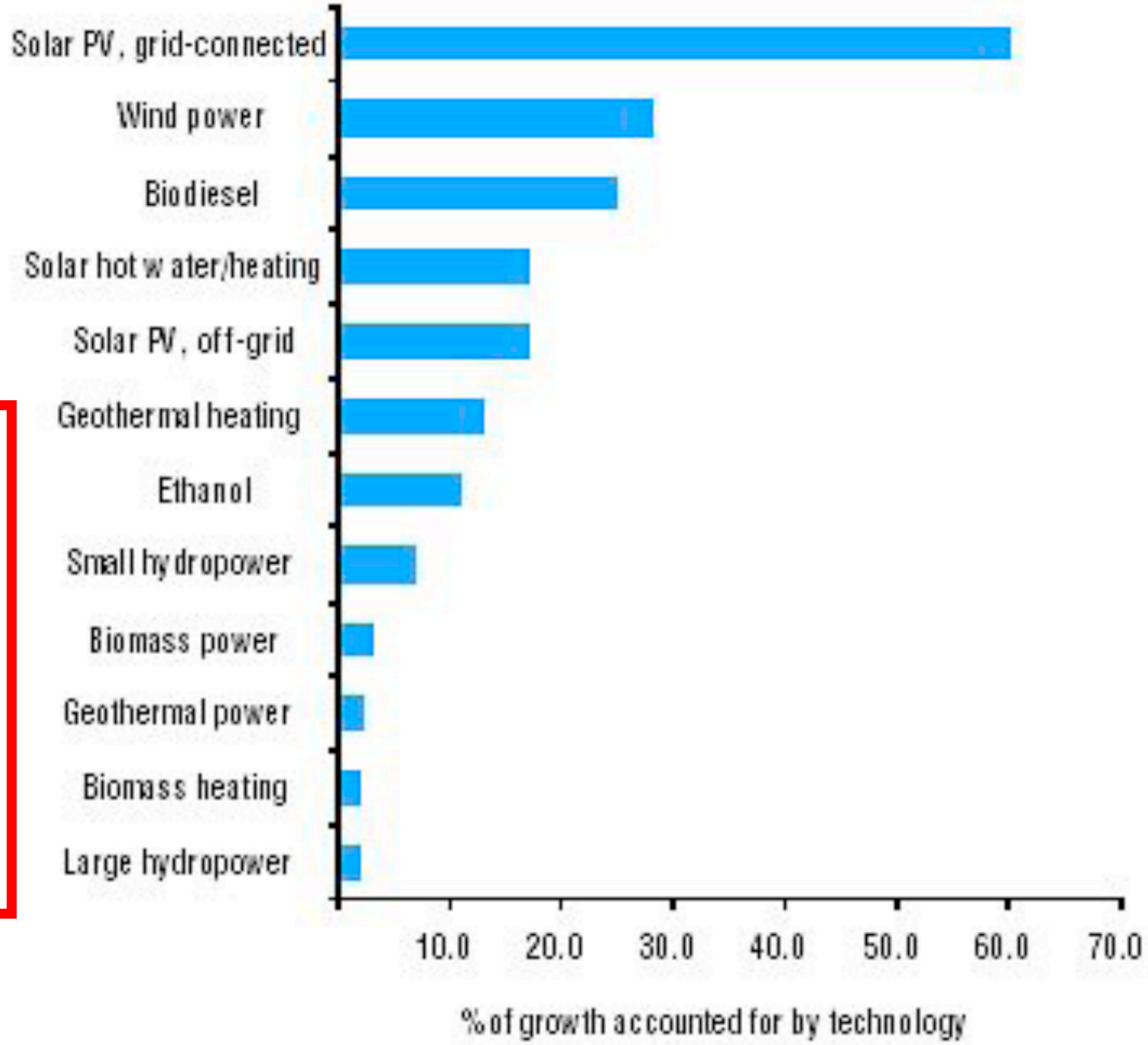
Installation of PV (June 2012)



Ref.IRENA: RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES, Volume 1: Power Sector Issue 4/5, Solar Photovoltaics, June 2012, Online: http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf (11.9.2012)

Renewables Growth

Average annual growth rates of renewable energy capacity, 2000 – 2004.



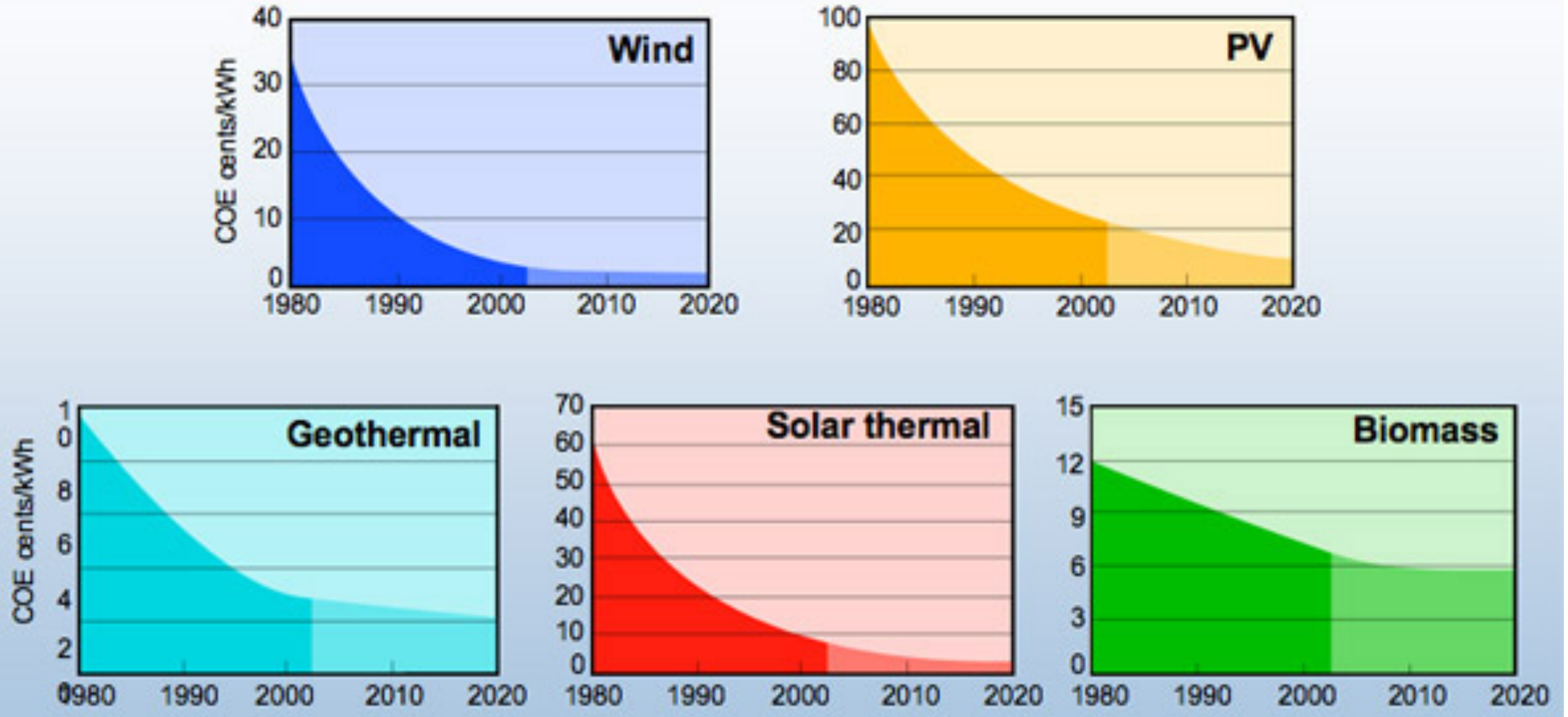
An annual growth of 25 to 30 %/a for PV

must

continue the next 40 years to go from 2 GW_e in 2007 to 10 - 30 TW in 2050 !

Renewable Energy Cost Trends

Levelized cents/kWh in constant $2000[1]



Source: NREL Energy Analysis Office (www.nrel.gov/analysis/docs/cost_curves_2002.ppt)
[1]These graphs are reflections of historical cost trends NOT precise annual historical data.
Updated: October 2002

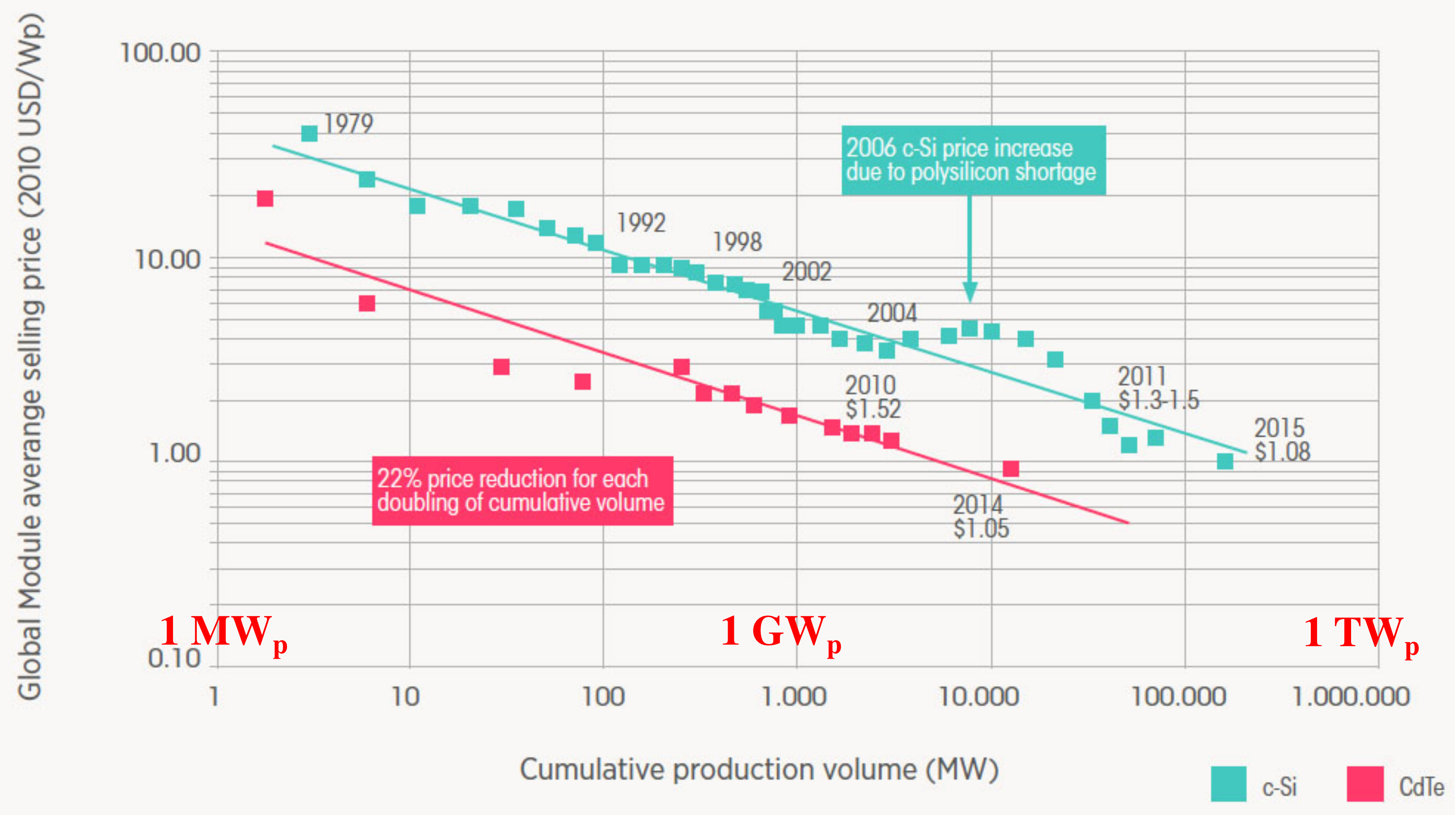
EAO Energy Analysis Office Understanding Energy Issues

http://resultsofglobalwarming.org/?p=377

NREL National Renewable Energy Laboratory

Module Prices of PV (June 2012)

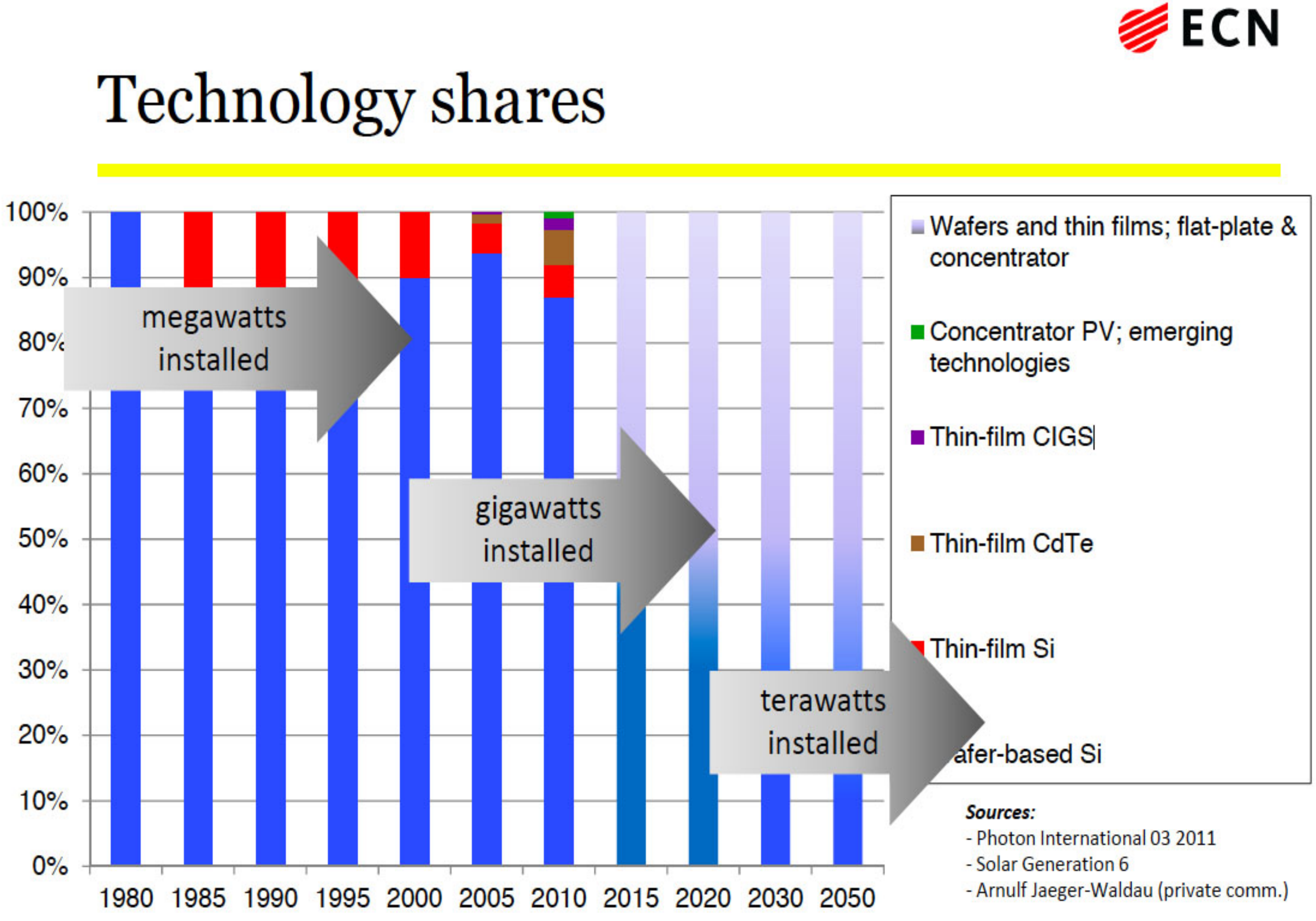
The global pv module price learning curve for c-si wafer-based and cdTe modules, 1979 to 2015



Sources: based on data from EPIA and Photovoltaic Technology Platform, 2010 and Liebreich, 2011

Ref.IRENA: RENEWABLE ENERGY TECHNOLOGIES: COST ANALYSIS SERIES, Volume 1: Power Sector Issue 4/5, Solar Photovoltaics, June 2012, Online: http://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-SOLAR_PV.pdf (11.9.2012)

PV Future



Ref.: W. Sinke,: "Prepare(d) for impact"; Quantsol Summerschool 2012, Hirschegg, Austria, Sept. 12, 2012