Solar Energy

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Let's Remind Ourselves that Solar Already Exists at the Multi-TWh (multi-billion kWh) Level

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Solar Electricity

PV

- Converts light directly to DC electricity
- Simple, can be done without moving parts
- Lasts indefinitely (over 40 years, maybe 100 if designed for it)
- Can be any size – milliwatts to gigawatts
  - Some economies of scale
- Output proportional to local sunlight
- May need transmission for best sunlight and cheapest systems
- Very low costs after first-costs paid

Solar Thermal Electric

- Concentrated light makes heat then steam
- Operates like conventional steam generator
- Can easily use natural gas when sun doesn't shine
- Can be fitted for thermal storage
  - Among the most economical methods of storage
- Has to be big (over 100 MW?) for economies of scale
- Output requires excellent direct sunlight (limited to deserts and high plateaus)
- Usually needs transmission

Applications

- Residential Roofs (PV)
- Commercial roofs (PV)
- Large arrays (PV and Solar Thermal Electric)

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Two Paths in Parallel

Subtract Fuel and CO2

- Add solar and wind, and subtract the avoided fossil fuels
- Use the existing fossil fuel generators to fill in the gaps
- Potential about 1000 TWh/yr* of electricity in US with minimal storage costs

Provide New Electricity

- Add solar and wind to charge plug-in hybrids and electric vehicles
- Use the smart-grid customer connection to handle intermittent charging
- *Not add a single new fossil fuel electron to power all new vehicles, thus eliminating all CO2 from displaced gasoline*
- Another 1000 TWh/yr* potential

*US now uses 4000 TWh/yr electricity

So, What Happens on a Rainy Day?

Nothing (like now); or we get it from somewhere else.
But we still save fuel and avoid CO2

Current Capacity – Many TWh

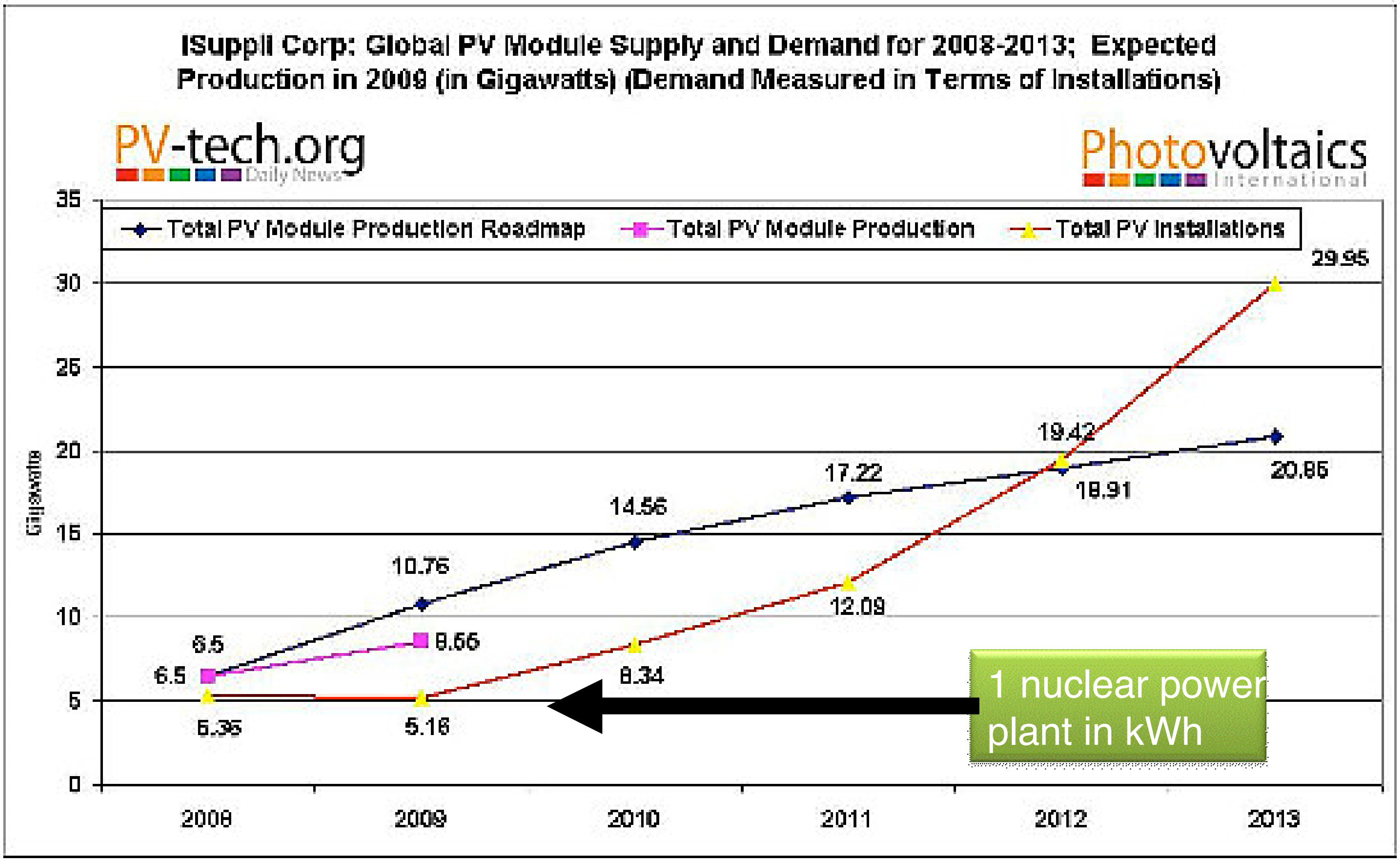
PV

- 5 GW installed in 2008 (a GW is about 1.5 TWh/yr)
- 4-7 GW expected 2009
- Capacity outstripped demand 2008 – now over 10 GW, and still growing
- Leadership driven by "PV module" leadership (hi tech)
  - Chinese capacity in conventional silicon technologies
  - US lead in one new thin film technology (First Solar, CdTe)
  - Europe under pressure from low-cost (China) and technology (US)

Solar Thermal Electric

- 400 MW installed 1980s-1990s
- 100 MW installed recently in US and Spain
- Thousands of MW under new contract but with barriers (some cancellations)
- Hardware can be made many places, but few US leaders (yet)

PV Market Predictions



Future Capacity

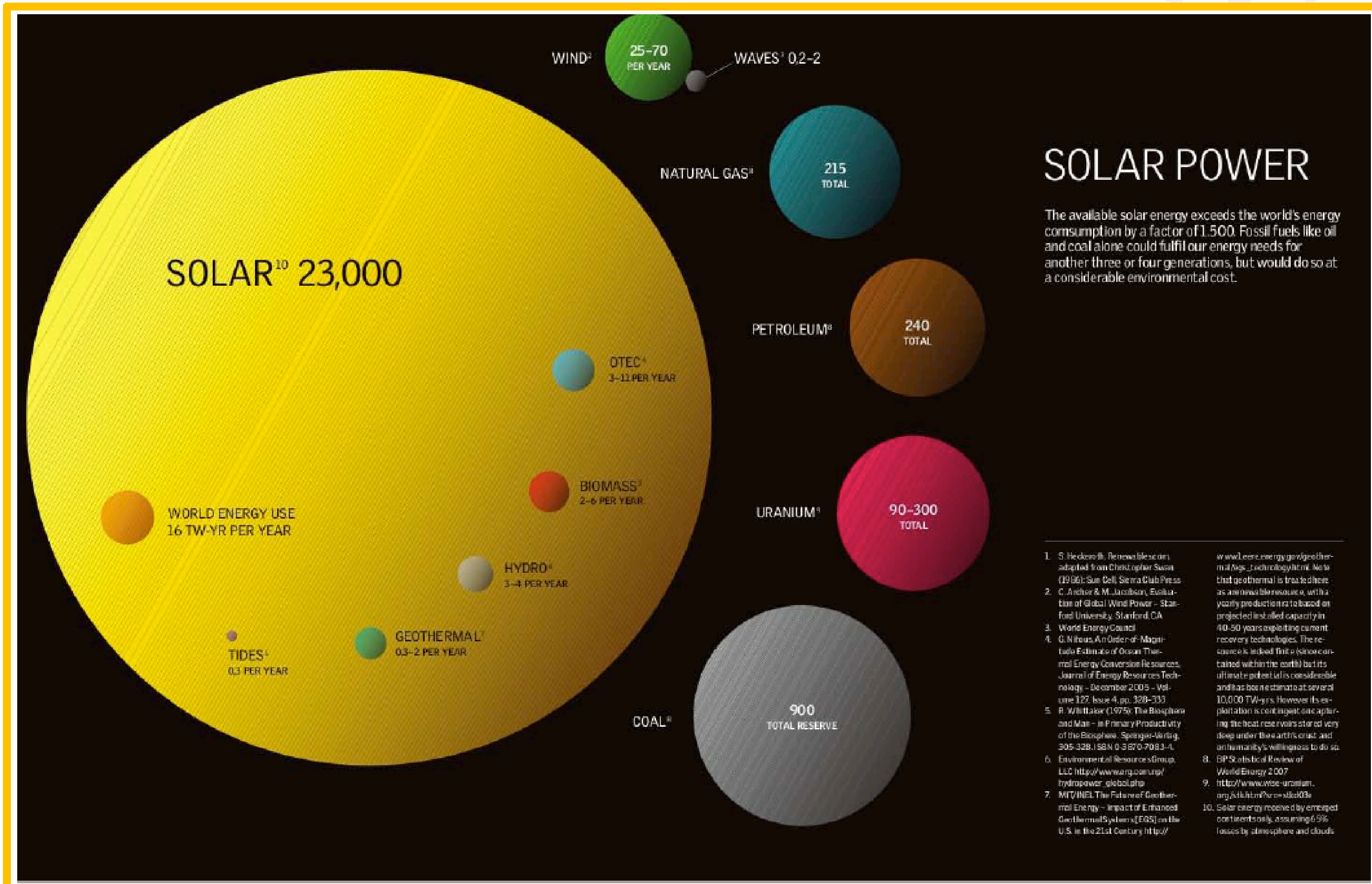
PV

- "Unlimited" – 10,000 times current annual demand falls on Earth
- Can be widely available, with proportional cost penalty for less sunlight

Solar Thermal Electric

- Many times existing national and global demand from sunniest regions (deserts, high plateaus)

Solar Power is Our Most Abundant Resource



Issues

PV

- High first costs (2009)
  - $3-$5/W large ground systems (15-25 c/kWh)
  - $4-$6/W commercial systems on flat roofs
  - $5-$7/W residential
- Intermittency
- Seasonal and diurnal nature
  - Less in winter
  - None at night
- High cost of storage

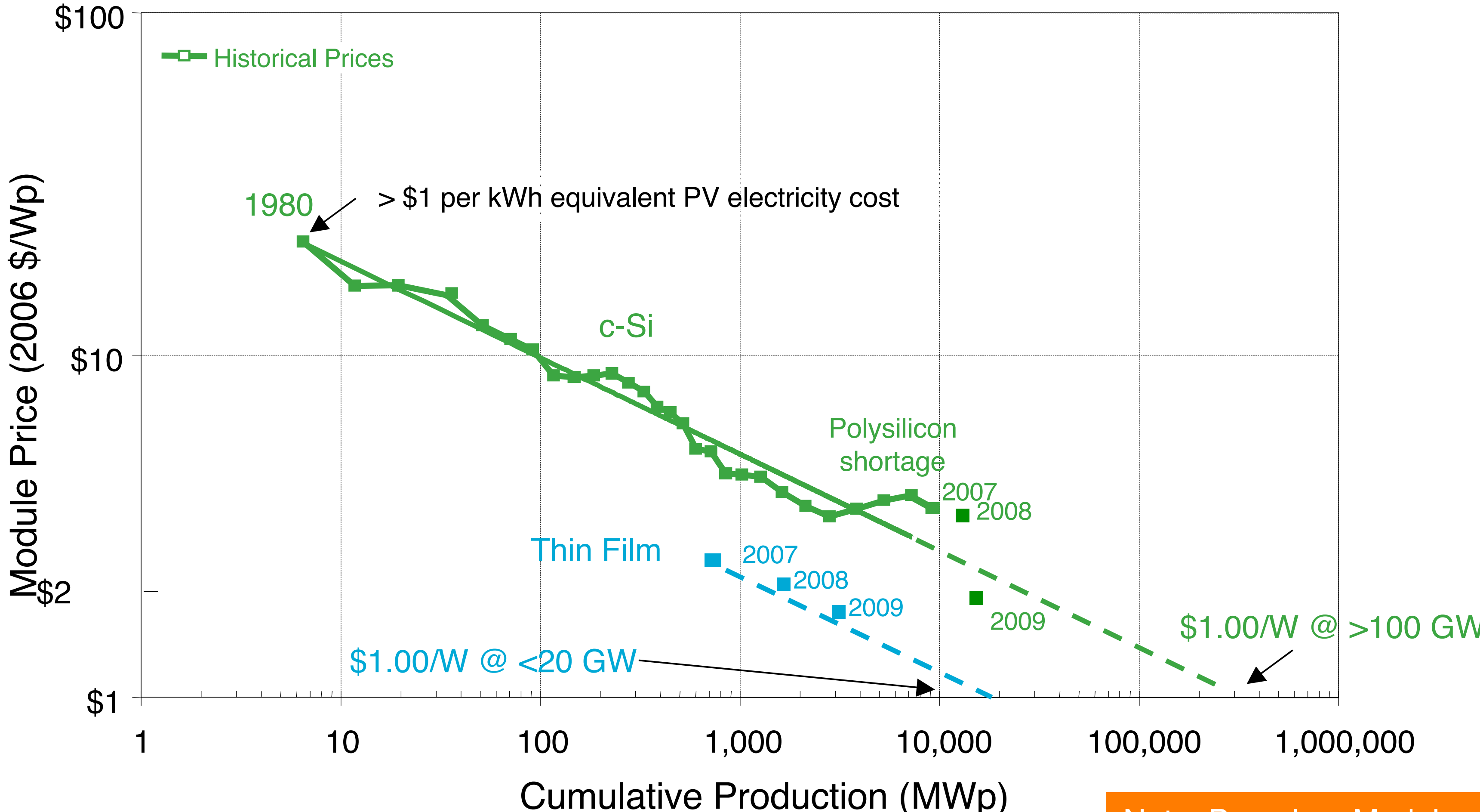
Solar Thermal Electric

- High capital cost
  - $5/W without storage (20 c/kWh)
  - $7/W with 6 hours storage
  - Threatened by rising commodity prices of steel and glass
- Considerable O&M, including natural gas back-up
- Smoother output with natural gas (and thermal storage)
- Seasonal and diurnal solar portion
- Preference for water cooling (can use air, but higher cost)
- Complex systems add risk

Meeting PV-Specific Issues

- First costs dropping rapidly
  - For modules, 20% per doubling of installation
  - Market maturation allows vertical integration and margin reduction (commoditization)
    - Half of current costs (or more) are not hardware or installation labor (worse for smaller systems)
  - Long life (over 50 years) eliminates these costs after they are paid (20 years)
- Cannot firm power “per plant” like with solar thermal electric (without further expense)
  - More like wind, where *firming is done system-wide*

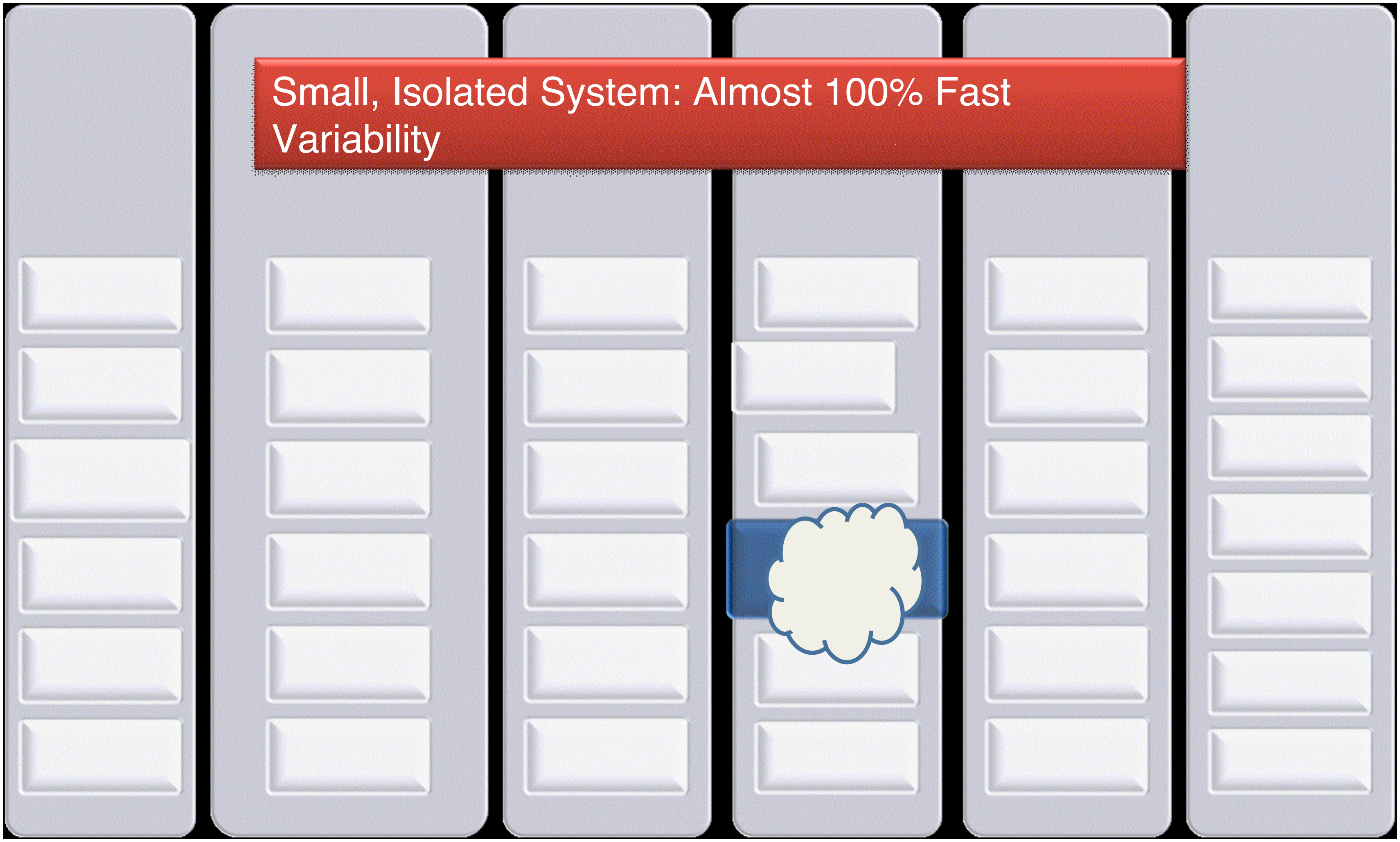
Crystalline Si and Thin Film Module Learning Curves



Note: Based on Module Purchase *Price* Not Manufactured Cost

Source: Adapted by First Solar and Applied Materials from National Renewable Energy Laboratory

The Worst Case: System about the Size of a Fast Moving Cloud



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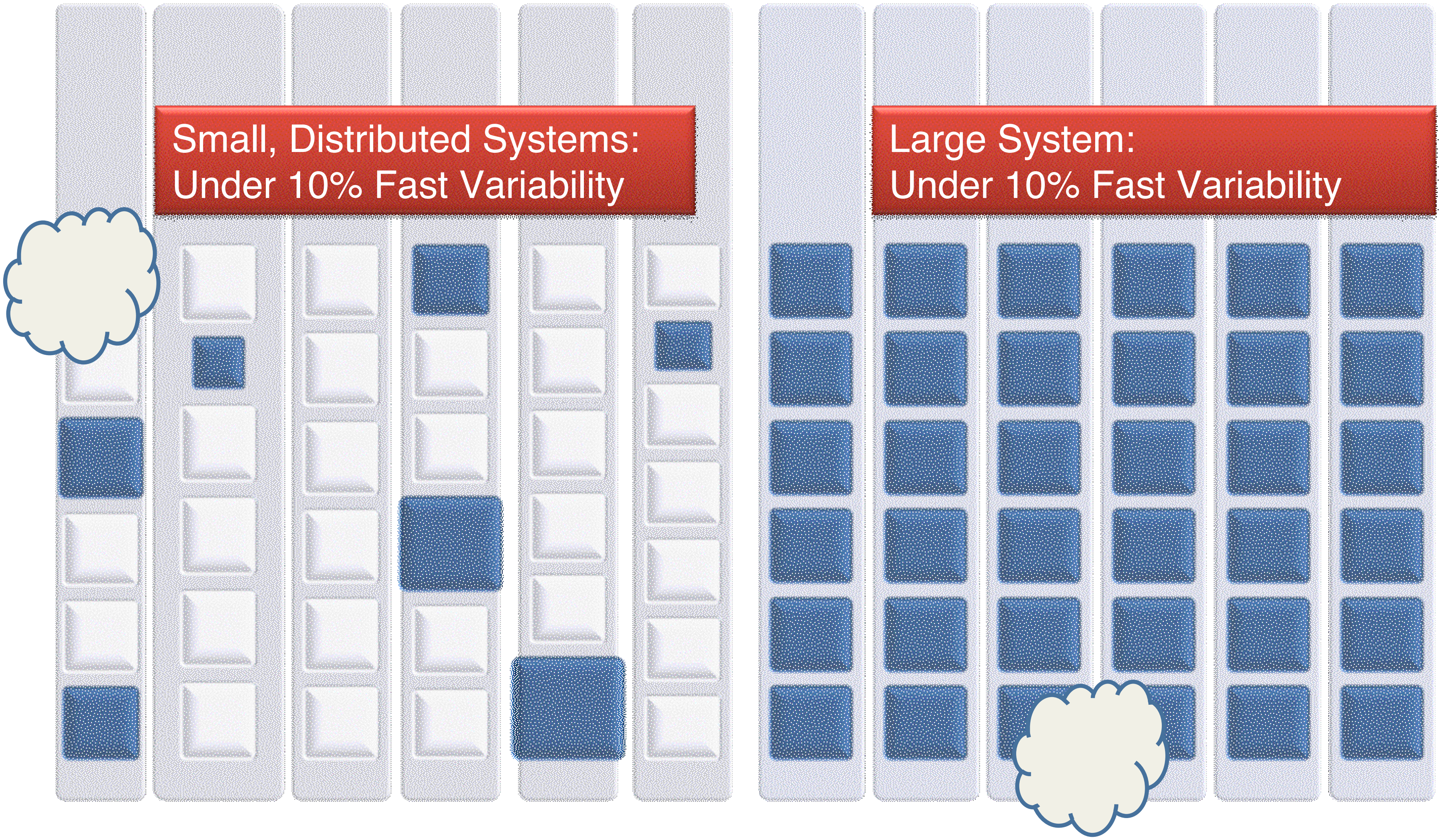
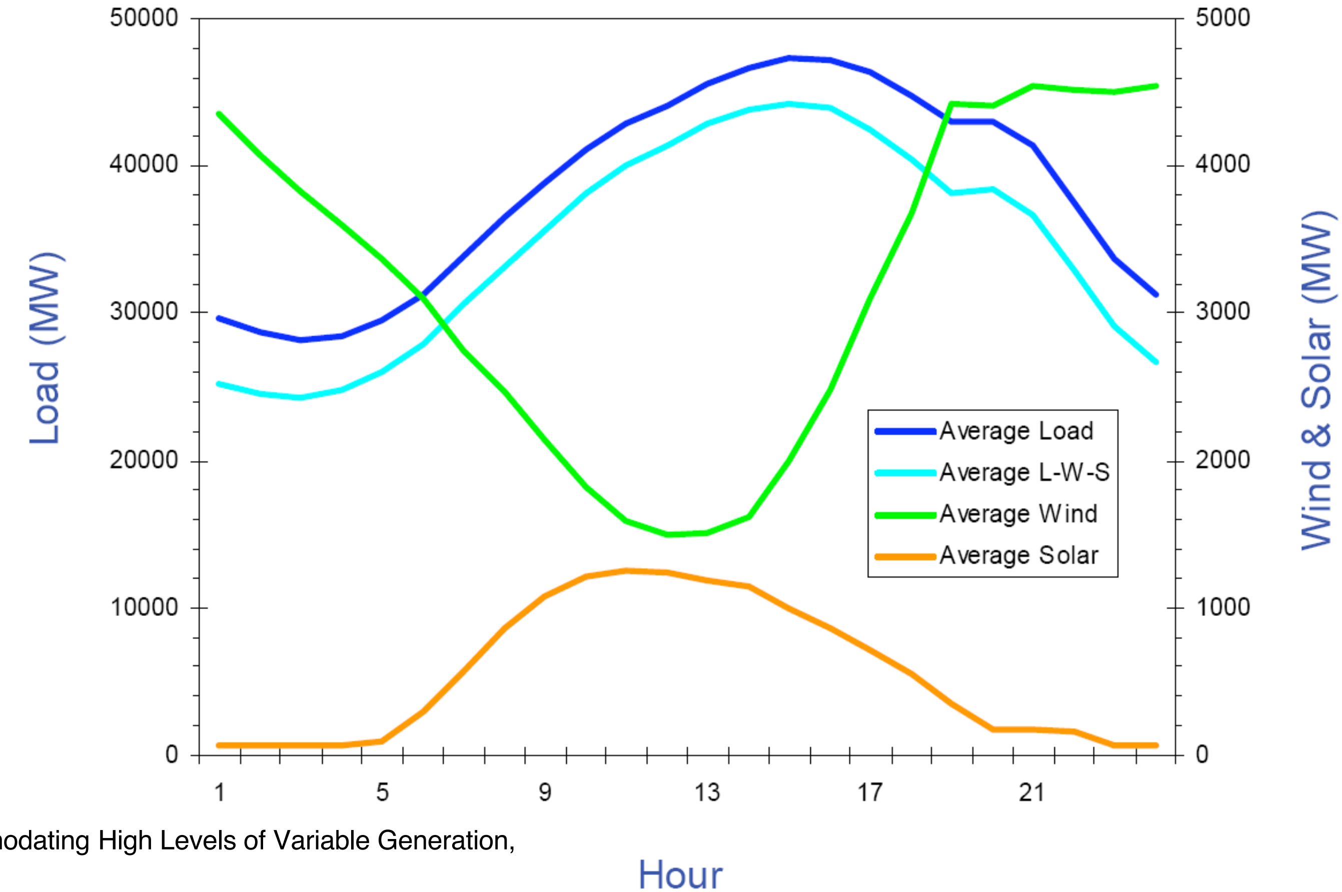
Different Arrays Cause Very Different Fast Variability Effects



Solar Thermal Electric-Specific Issues

- Costs can be reduced with innovative towers instead of troughs
- Water and natural gas pipeline to desert
  - Air cooling costs about 10% more
  - Natural gas can be replaced with thermal storage
- Risk for big systems
  - Less for proven troughs
  - More for others

Diurnal Variation in Solar and Wind Power in California



NERC, Accomodating High Levels of Variable Generation, April 2009

Post-20% Demand Matching

- More thermal storage for solar thermal electric
- Compressed air (large caverns, large capacities)
  - Compensating PV, CSP, and wind
  - Transmission from distant sunny regions
  - Some availability for evening peak on East Coast due to time zones
- Newer electric storage options

Societal Issues

- Land
- Water
- CO_2 and energy payback
- Plants, animals, birds
- Real-estate value

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Hydropower artificial lakes in 2004 > 100,000 km^2

Hydropower accounts for 7% of US electrical production

Land Use is a *Strength* for Solar

	Conventional	Solar
Hydro	Hydro lakes over 1% US land 7% electricity 300 TWh/yr	0.5% US land could make 4000 TWh/yr (100% US electricity) **30 times less land than hydro per kWh**
Coal	About the same as solar when strip mining is not "stripped away"*	With solar, the land is not destroyed
Biomass	Plant efficiency less than 0.1% after conversion to useful work	**Efficiency and land use about 40-100 times better than biomass (and no water or food**
Farm set-aside program	34 million acres	**Solar for all electricity – 20 million acres**

Land use and electricity generation: A life-cycle analysis

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ABSTRACT

Renewable-energy sources often are regarded as dispersed and difficult to collect, thus requiring substantial land resources in comparison to conventional energy sources. In this review, we present the normalized land requirements during the life cycles of conventional- and renewable-energy options, covering coal, natural gas, nuclear, hydroelectric, photovoltaics, wind, and biomass. We compared the land transformation and occupation matrices within a life-cycle framework across those fuel cycles. Although the estimates vary with regional and technological conditions, the photovoltaic (PV) cycle requires the least amount of land among renewable-energy options, while the biomass cycle requires the largest amount. Moreover, we determined that, in most cases, ground-mount PV systems in areas of high insolation transform less land than the coal-fuel cycle coupled with surface mining. In terms of land occupation, the biomass-fuel cycle requires the greatest amount, followed by the nuclear-fuel cycle. Although not detailed in this review, conventional electricity-generation technologies also pose secondary effects on land use, including contamination and disruptions of the ecosystems of adjacent lands, and land disruptions by fuel-cycle-related accidents.

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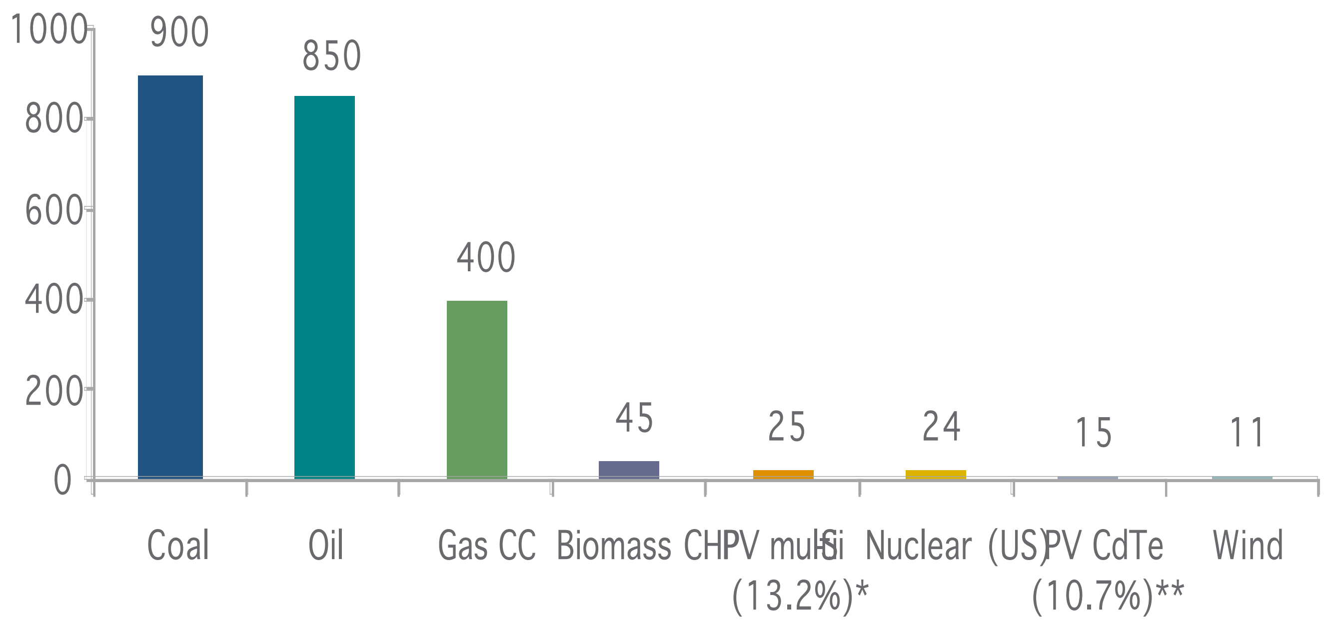
Mountain Top Removal

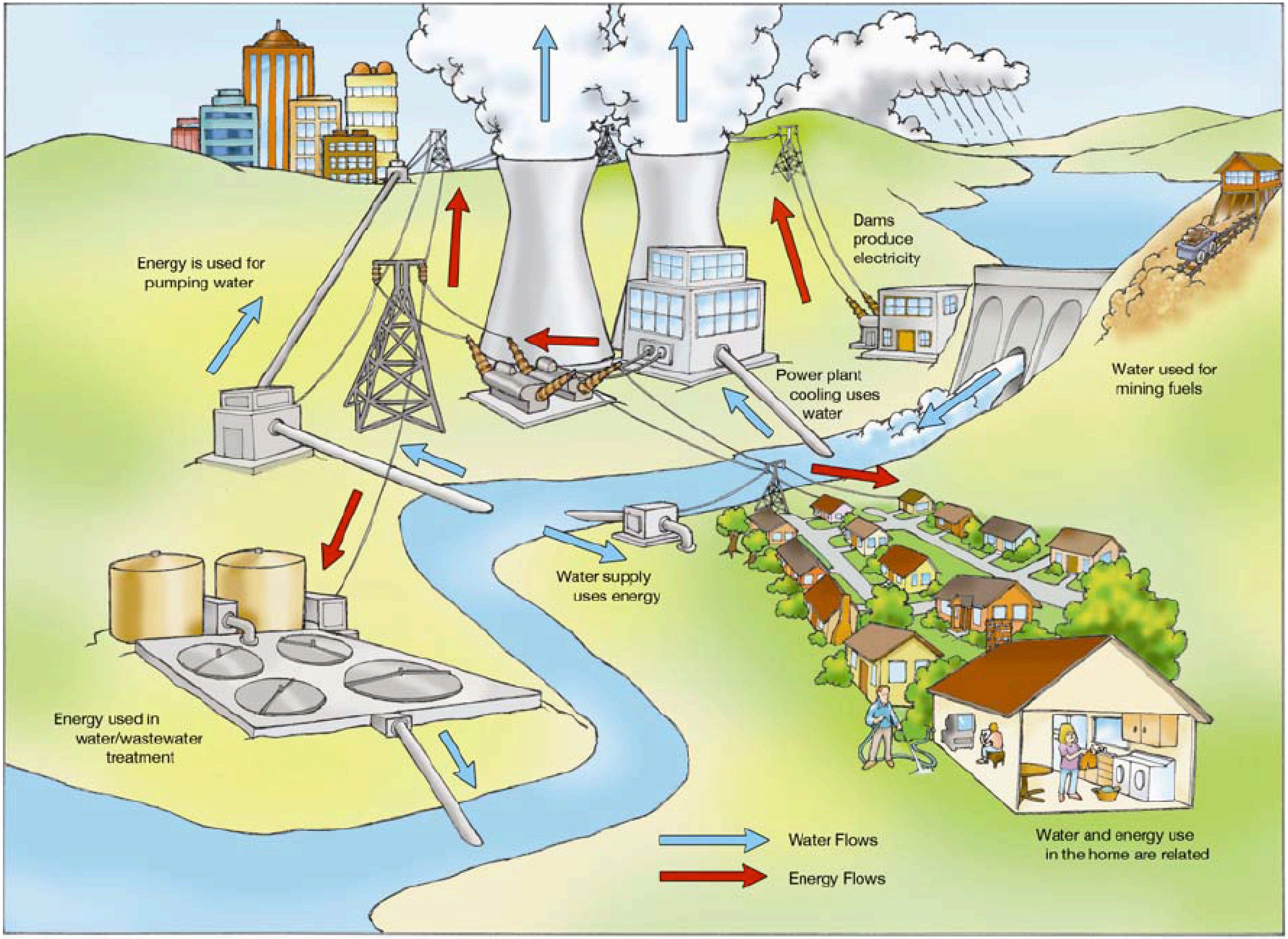
Energy Will Use Land

- That is why we must have clarity about *comparative* land use
- Shoving off energy production somewhere else does not help the planet or nation
- NIMBY has to be replaced by *Enlightened IMBY* for both energy security AND environmental reasons

Carbon Footprint - Comparison across Technologies



Sources: *de Wild-Scholten, M., presented at CrystalClear Final Event in Munich on May 26, 2009. **de Wild-Scholten, M., 'Solar as an environmental product: Thin-film modules – production processes and their environmental assessment,' presented at the Thin Film Industry Forum, Berlin, April, 2009. Both PV technologies use insolation of 1700 kWh/m^2. All other data from ExternE project, 2003; Kim and Dale, 2005; Fthenakis and Kim, 2006: Fthenakis and Alsema, 2006; Fthenakis and Kim, in press.



"Energy Use and Water Use," Report to Congress 2006

Water

- PV and wind use essentially zero water during operation and a small amount over their life cycle
- Most thermal plants use huge amounts of cooling water "once through" or can be adapted to recirculating water at about 1 gal/kWh (est.)
  - "Once through" cooling trails irrigation (40%) as the second largest use of water in the US (39%)
  - But actual consumption from water system is much smaller (but will rise as "once through" is phased out)
- CSP uses a lot but can be made "dry cooling" at a cost

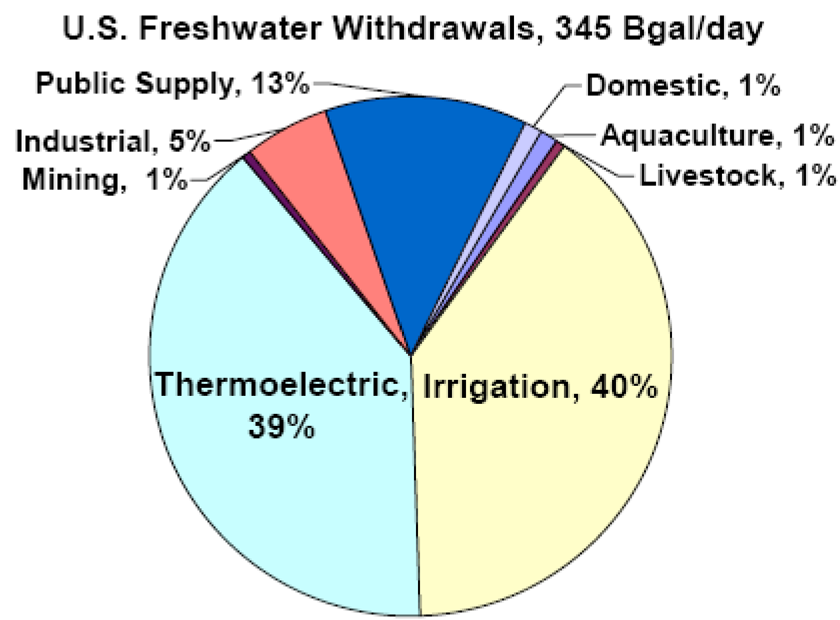


Figure II-1. Estimated Freshwater Withdrawals by Sector, 2000 (Hutson et al., 2004)

Some Good News on Affordability

Does anyone ever wonder how much the Hoover Dam cost?

PV System the Size of Hoover Dam Going into China w/US Technology*

September 8, 2009, 12:26 PM ET

First Solar To Build 2-Gigawatt Solar Power Plant in China

over the next decade at an estimated cost of $2.5 - $3/W

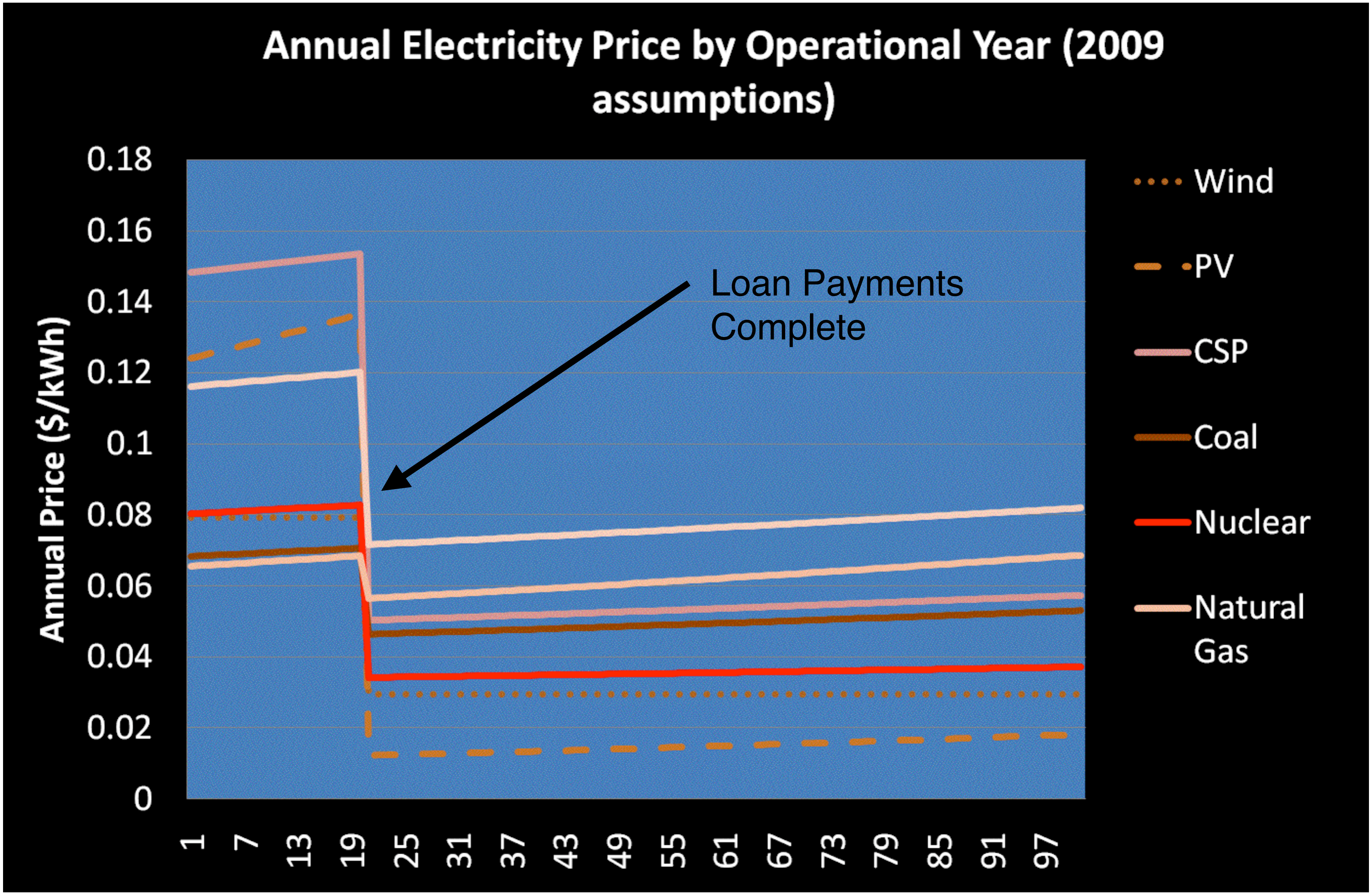
Hoover Dam – 2-4 billion kWh/yr – 250 square miles w/Lake Mead

2-GW PV in Mongolia - ~3 billion kWh/yr – 25 square miles

*Doesn't fit our picture of helpless US manufacturing

The Lowest Long-Term Cost

- No fuel
- Long-lived, simple, reliable
- Will last 30 years, may last 100 if designed for 100
- *Once they are paid for*, operate at about 1-2 c/kWh – cheaper than any other source of electricity *right now*
  - *Over time, there is some date at which even* current *PV systems become the cheapest source of energy, maybe even in Switzerland*


Annual Electricity Price by Operational Year (2009 assumptions)
Annual Price ($/kWh)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
7
13
19
25
31
37
43
49
55
61
67
73
79
85
91
97
Loan Payments Complete
Wind
PV
CSP
Coal
Nuclear
Natural Gas

Alvin Weinberg in Energy Policy*

- "If the [power] plants produce electricity from one of the inexhaustibles…then the cost of electricity can be expected to become very low, perhaps around 1 c/kWh. Ordinary economics discounts the future at a rate that reflects our uncertainty about the future, as well as the realities of today's money markets. Should we discover that these gadgets last "forever," **economic doctrine would still forbid our investing in them rather than in more immediate gadgets whose lifetime, and payoff, is much shorter**. Large, "immortal" energy systems might acquire much the same status as roads or bridges – part of society's infrastructure, for which society is willing to pay more than strict economic accounting would dictate. **Thus a political decision, one dictated by the broad concern for the future, may be the only way to switch to the low cost "immortal" energy system**."

*A. M. Weinberg, 1985, "Immortal energy systems and intergenerational justice." Energy Policy 13(1):51-59

Multi-Generational Value

- PV after 20 years – negligible cost
- Transmission after 20 years – negligible cost
- Firm power from low-cost PV, storage & transmission
  - East–West for day-night
  - North-South for winter-summer

Thanks

Alhama de Granada, Spain (1.88MW); Phoenix Solar AG