Nuclear Power 2008

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Bulletin of the Atomic Scientists

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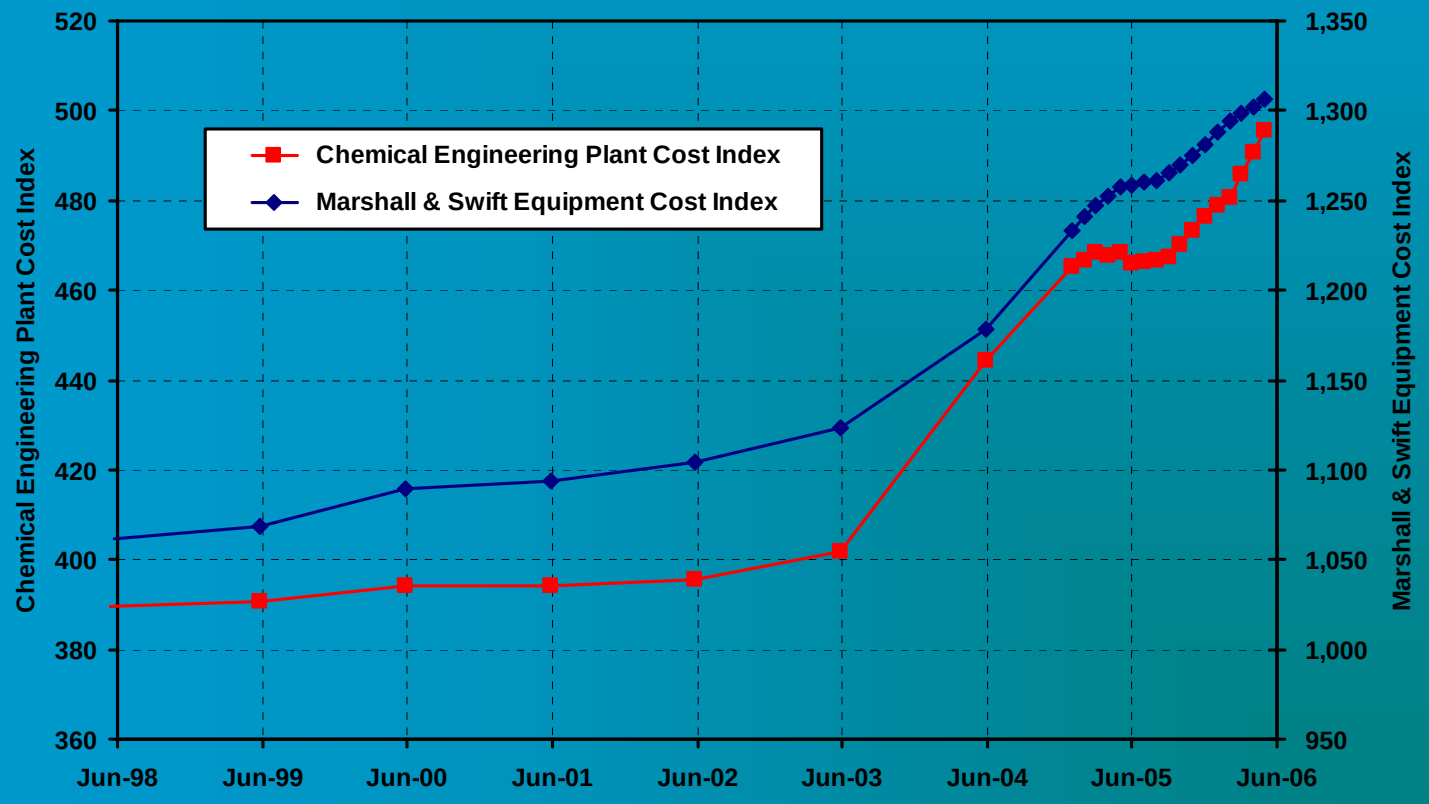
Estimated Life Cycle Costs for Major Supply Options (2007$s)

	Pulverized Coal	**Gas (CCCT)**	**Eastern IGCC**	**Wind**	**Nuclear**
Capital Cost ($/kW)	3000-4000	1000	???	1700-2500	5000
Capital charges (cents/kWh)	6.3	2.1	9.0	7.1-13	10.4
Delivered Fuel (cents/kW)	4.0	8.8	4.0	0	1.7
O&M (cents/kWh)	2.2	1.1	2.2	1	2.9
Cents/kWh	***12.5***	***12.2***	***15.2***	***8-14***	***15.0***

Transmission not included; life cycle costs assume private ownership. Essentially all the bottom line numbers have doubled in three years!

How Did We Double in Three Years?



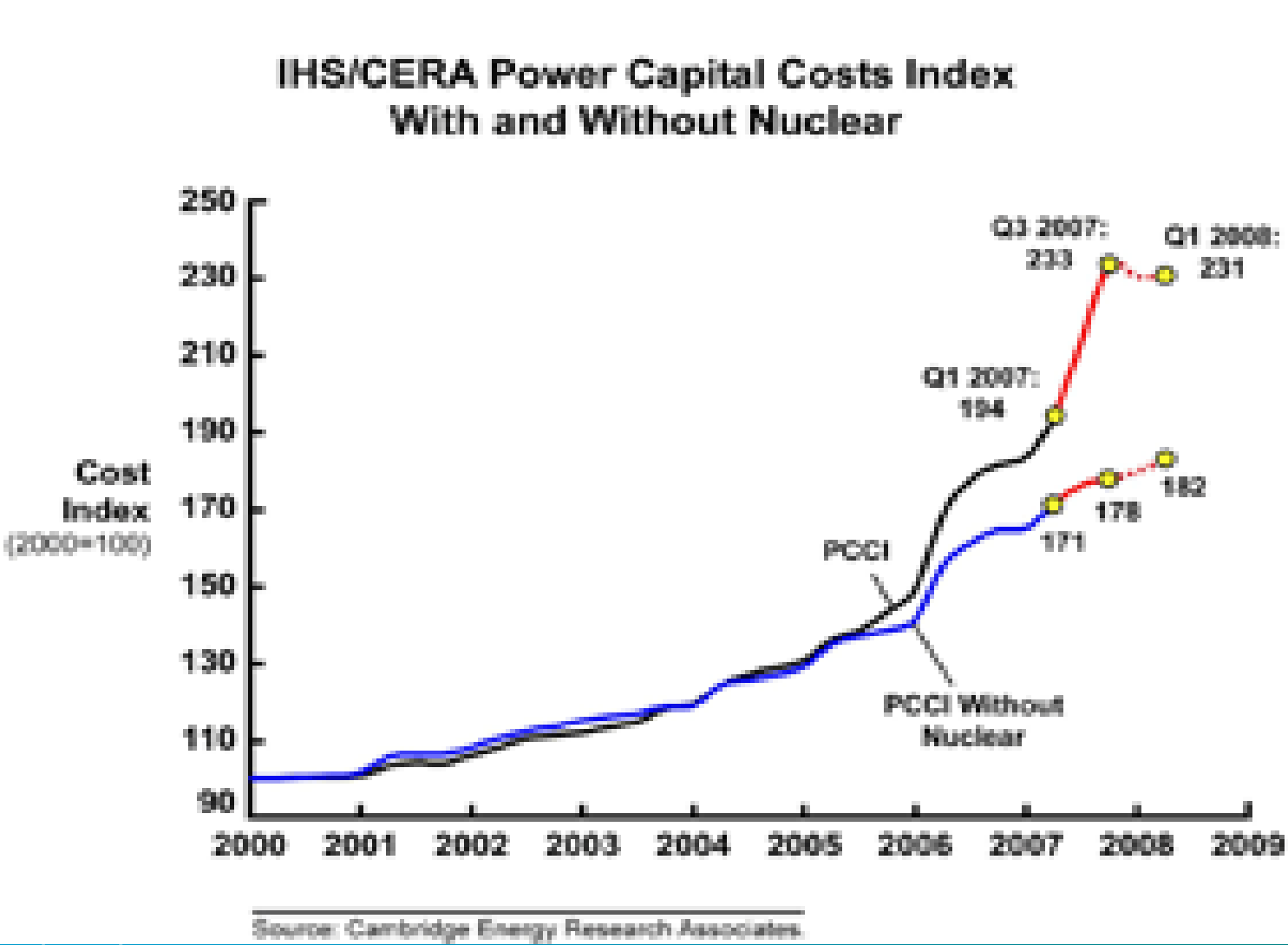
Provided to Keystone panel by EPRI

Why? Commodities Are One Reason

Commodity	Esc 86-03	Esc 03-07	Ratio vs. History
Nickel	3.8%/yr	60.3%/yr	15.9x
Copper	3.3%/yr	69.2%/yr	21x
Cement	2.7%/yr	11.6%/yr	4.3x
Iron/Steel	1.2%/yr	19.6%/yr	16.3x
Heavy construction	**2.2%/yr**	**10.5%/yr**	4.8x

Source: American Electric Power

It Is More Than Commodities – at least for nuclear - ~ 14 Percent Real Per Year



Where to Next? The Risk is Worst for Long Lead Time Technologies

	0% Real	4% Real	8% Real	14% Real
Med overnight	$4050/kW	$5400/kW	$7100/kW	$9050/kW
High overnight	$4540/kW	$6050/kW	$8000/kW	$10150/kW
Med overnight	10.7 c/kWh	13.4 c/kWh	16.9 c/kWh	20.7 c/kWh
High overnight	11.7 c/kWh	14.7 c/kWh	18.6 c/kWh	23.0 c/kWh

Future overnight cost estimates are in 2007 dollars, and are based on FP&L's recent Turkey Point 6/7 estimate. Electricity costs are levelized lifecycle costs, with interest and operating costs.

Nuclear, Coal, and Gas All Vulnerable Going Forward

- Nuclear
  - Industry moribund in Western Europe, US, and Russia since TMI and Chernobyl
  - Twenty years ago (US): 400 suppliers, 900 N-Stamp holders; today 80 and 200
  - Only one forge for large parts – Japan Steel Works
  - Uranium production well below global consumption
- Coal
  - Imminent carbon controls, rail constraints
  - Rapidly rising international coal prices
- Gas
  - High price and volatility; hedges and other protections thin
  - At $13/million BTU, “only” $75.40/bbl of oil equivalent

What's Wrong Here?

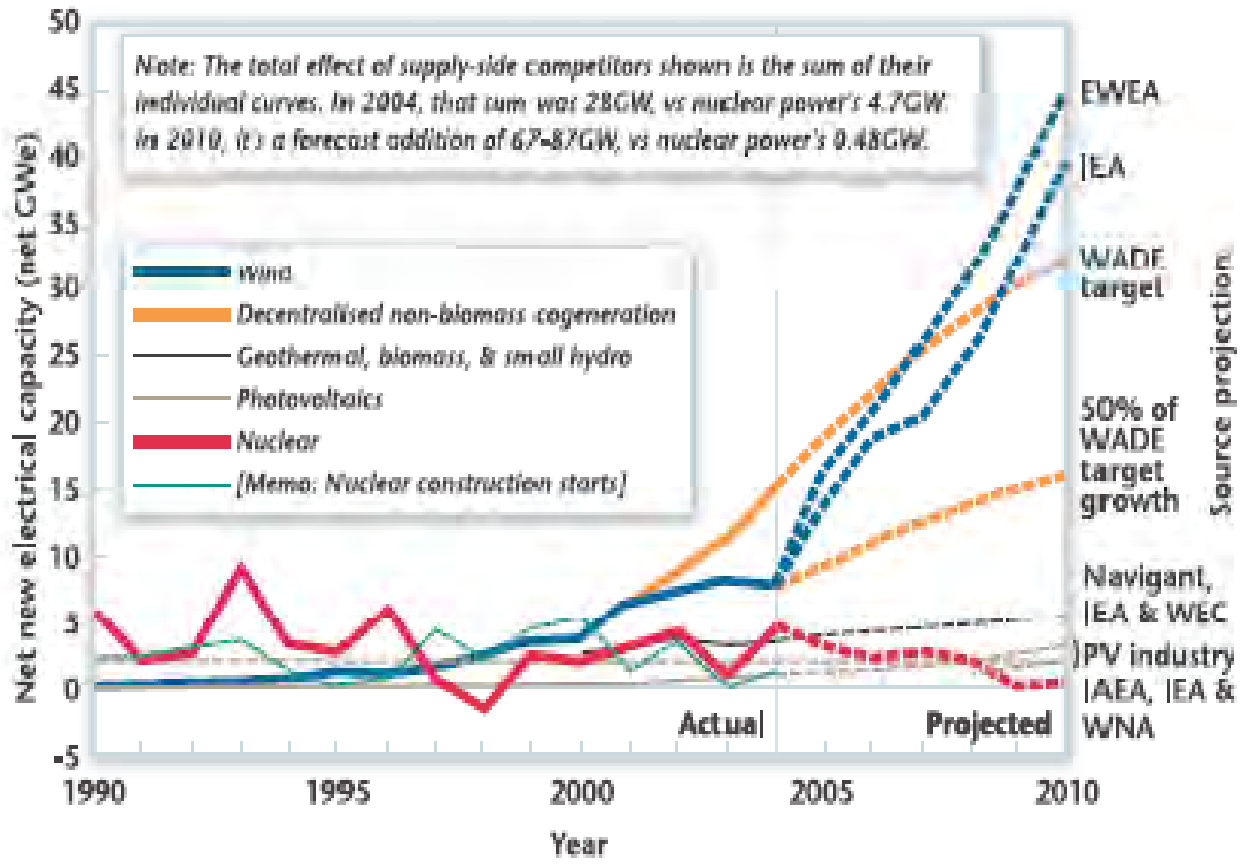
- Finance – capital cost for 2 coal or nuclear units may be larger than the utility's book value. Bet the company…
- Rate shock and physical bypass – first year cost is 1.6x levelized cost, or not appreciably better than today's photovoltaics. Bet the company and consumer…
- Delays and further cost escalation. Bet the company…
- Huge capital flows diverted from more promising options. Bet the consumer…

So What Happened to Solar Over this Period?

- It went down in cost, despite rising materials costs and supply-chain imbalances. Roughly 30 percent – 9 percent eaten away by materials cost escalation
- Now perceived as a disruptive technology (i.e., potentially cheaper than marginal operating and fuel costs of the existing system) in many parts of the world
  - How many new phone lines did MaBell build after the cell phone?
- Disruptive energy technologies have essentially unlimited growth potential – they can cannibalize the existing system and grow quickly enough to address climate problems
- Efficiency resources meet that definition – cost less than gas or coal. 3x more carbon savings per dollar than new supplies. Unfortunately, you can't buy them by the gigawatt
- Photovoltaics are now disruptive in high cost regions – grid parity may be a few years away for most of the world

Rapid Renewable Growth Worldwide

Figure 2: Global additions of electrical generating capacity by year and technology



Recent worldwide annual growth in PV production capacity is +50% per year. Note that PV industry projections for 2005-2010 were nearly flat.

The Vendors Underestimated

	2001	2002	2003	2004	2005	2006	2007	*06 to 07 Growth*	Capacity YE07	Capacity YE08
US	100.3	120.6	103.0	138.7	153.1	179.6	266.1	*17.3%*	318.0	616.0
Japan	172.4	252.6	365.4	604.0	833.0	926.9	920.0	*11.3%*	1,482.5	1,707.5
Europe	73.9	122.1	200.2	311.8	472.6	680.3	1,062.8	*43.9%*	1,742.4	2,916.0
ROW	25.9	43.5	75.4	141.5	312.5	687.0	1,484.1	*119.8%*	2,633.0	5,009.5
	372.5	538.7	743.9	1,196.0	1,771.2	2,473.7	3,733.0	*50.9%*	6,175.9	10,249.0
% Thin Film	4.8%	3.2%	5.1%	5.1%	5.4%	6.9%	10.0%			

- Not flat through 2010, but 50% annual global growth
  - More poly-silicon available than commonly thought.
  - Increasing production of thin film
- Much growth has shifted to China, Taiwan, Malaysia
- US expansion is mainly thin film; also growing rapidly

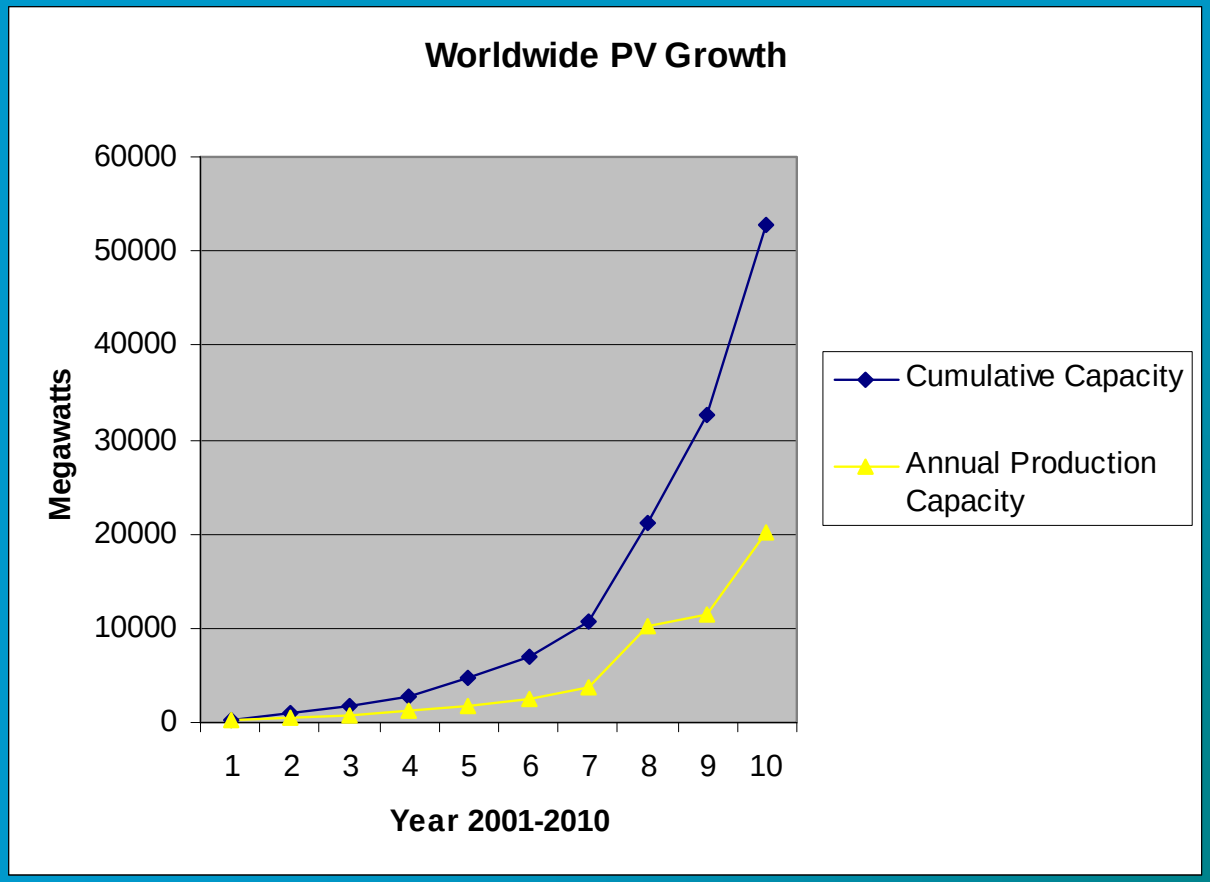
Source: Travis Bradford, Solar Energy Market Update, April 2008. Units are MW of annual production capacity.

Fast Growing Production Capacity

- **Massive Plants expected through 2010:**
  - Sharp – 2 GW (2010)
  - Kyocera – 500 MW (2009)
  - Sanyo – 350 MW (2008)
  - First Solar – 450 MW (2009)
  - United Solar – 300 MW (2010)
  - SunPower – 500 MW + (2010)
  - Suntech – 1 GW + (2010)
  - Q-Cells – 1 GW? (2010)
  - Conergy – 250 MW (2008)
  - Ever-Q – 300 MW (2010)
  - Solland – 500 MW (2010)
  - Schott – 480 MW (2010)
  - SolarWorld – 1 GW (2010)
  - Yingli – 600 MW (2010)
  - Motech – 450 MW (2010)
  - Trina – 660 MW (2010)
  - E-Ton – 300 MW (2009)
  - JA Solar – 275 MW (2008)

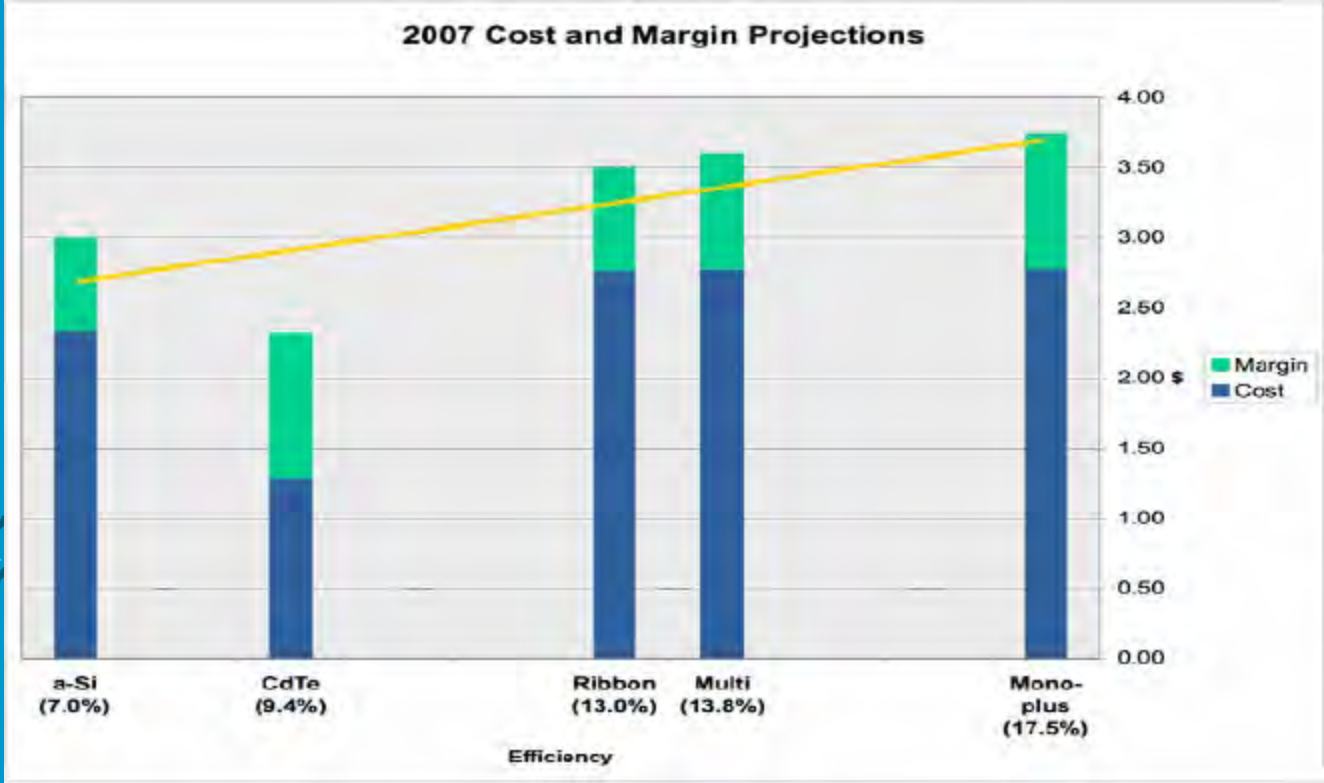
Source: Bradford, ibid. April 2008

PV Production and Installed Capacity Are Taking Off



Source: Prometheus Institute numbers for worldwide capacity and projects underway. Let's go back to slide 11 – off the chart! These estimates are well below those of Photon Consulting

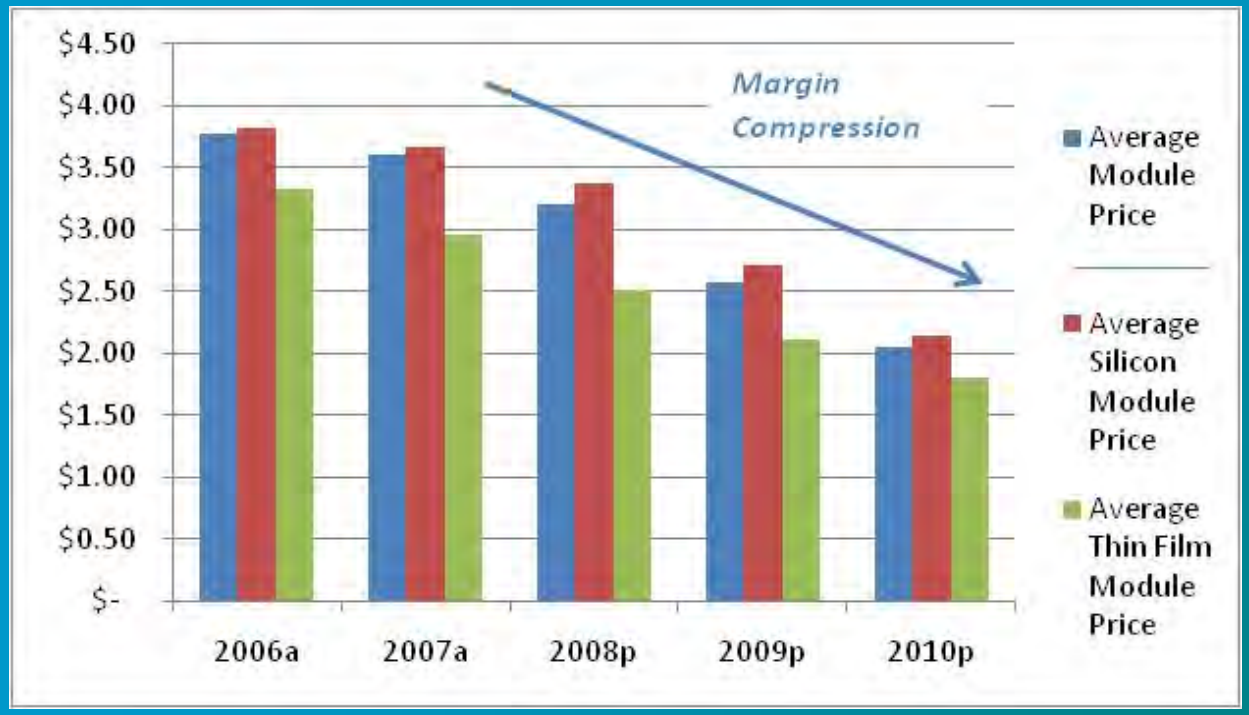
Current Market Dynamics – Crystalline vs. Thin Film



- Current market dynamics suggest prices and costs not correlated

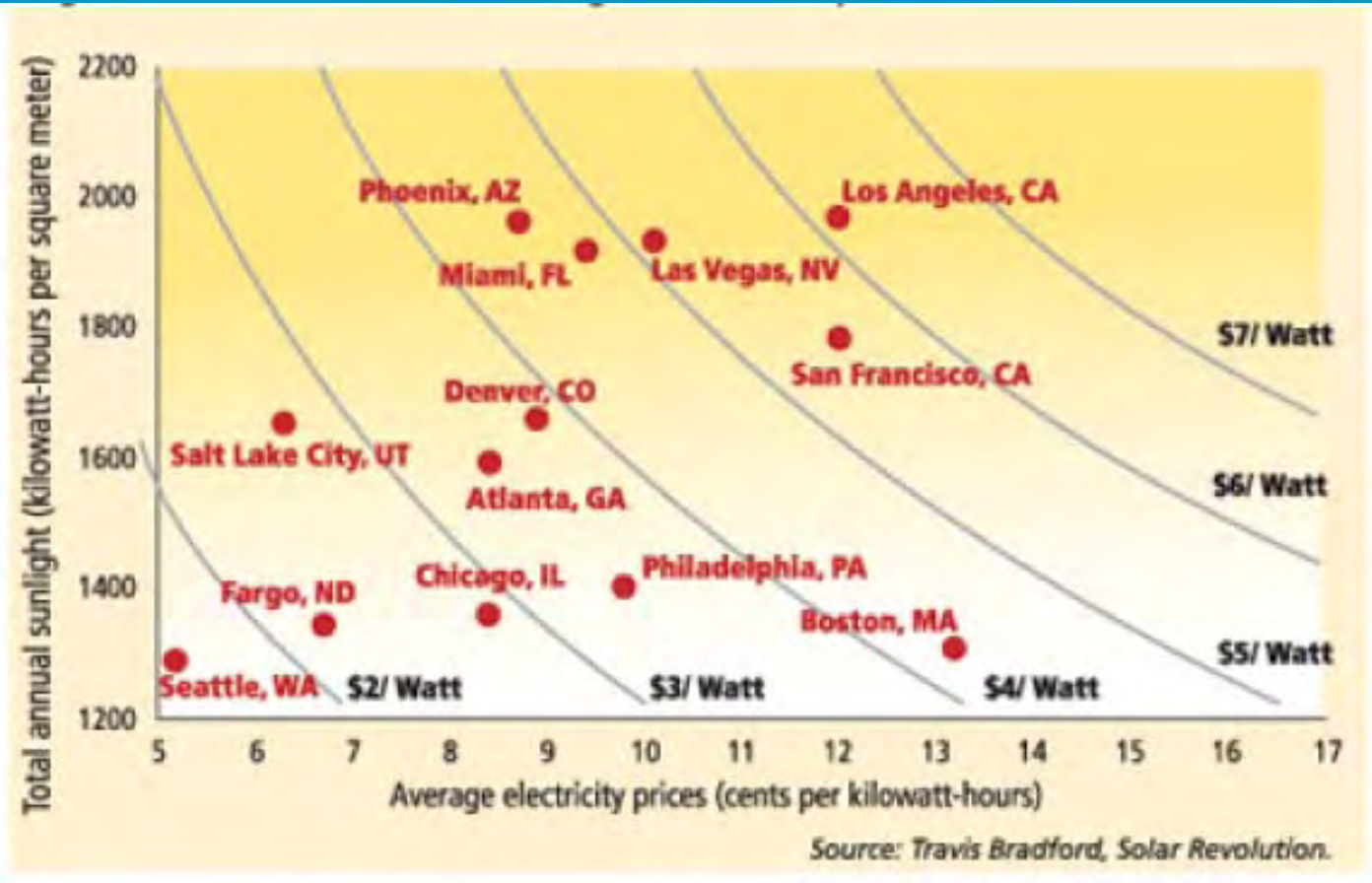
Source: Bradford, ibid.

Module Price Forecasts



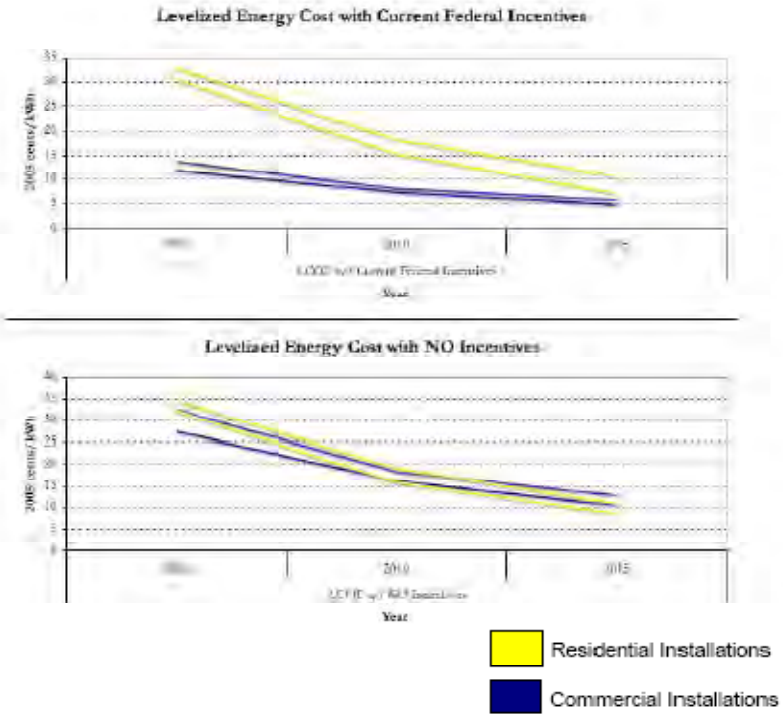
Source: Bradford, ibid, April 2008.

Grid Parity Accelerates at $4/Watt



Note: if new resource options – like nuclear – cost 12-16+ cents/kWh, then Seattle and Fargo look like Boston!

Installed system cost ranges have implications for levelized cost of energy



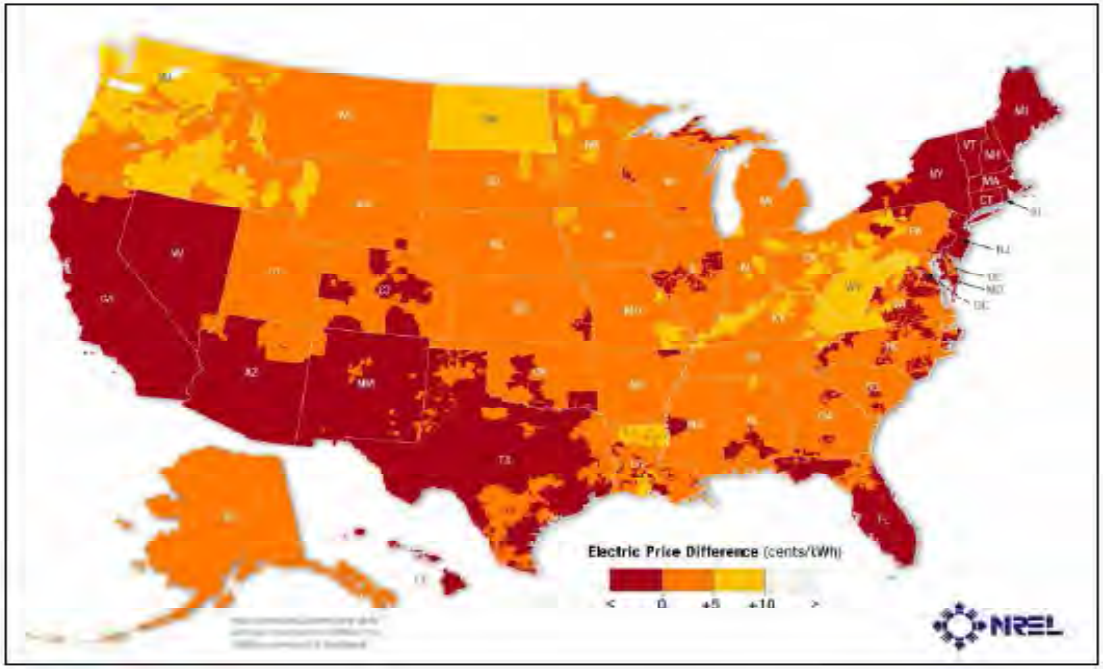
- Commercial / utility scale PV systems are currently economically competitive with grid electricity prices in many areas
- Both residential and commercial systems will be less expensive that grid electricity by 2010, assuming that the 4.7% annual growth rate continues

Solar market penetration is created by the levelized cost of energy (LCOE) over the lifetime of the solar system vs. grid electricity prices and government/utility incentives

US DOE, Solar Energy Industry Forecast: Perspective on US Solar Market Trajectory, May 2008.

Solar acceleration in a conservative forecast - 2015 residential without incentives and moderate increase in electricity prices

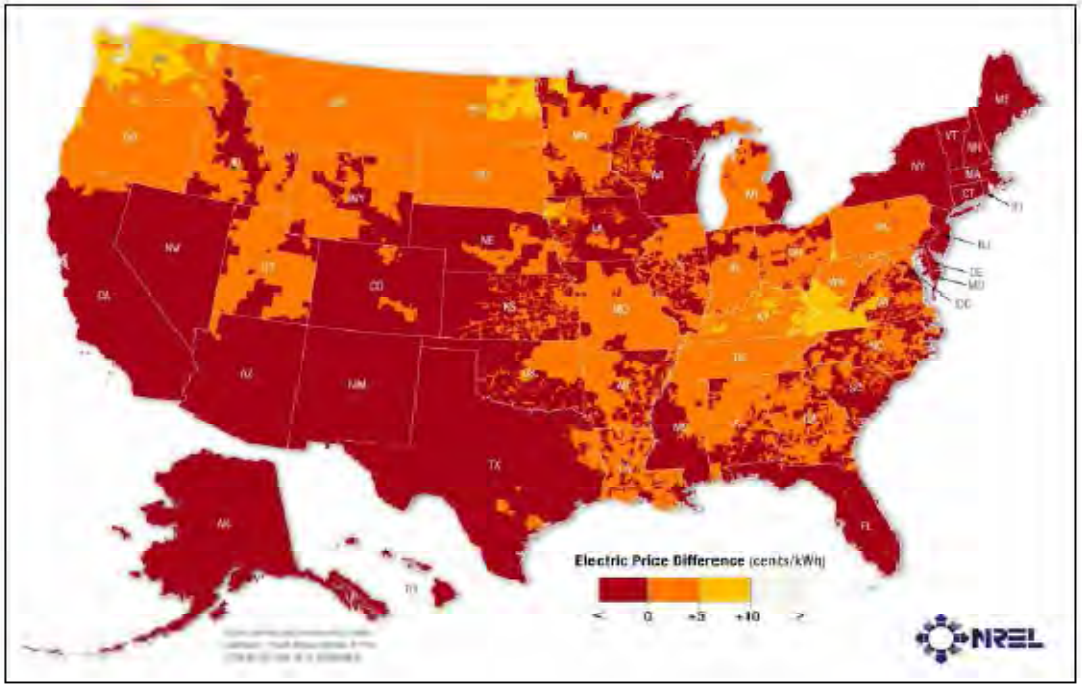
- Attractive in about 250 of 1,000 largest utilities, which provide ~37% of U.S. residential electricity sales.
- 85% of sales (in nearly 870 utilities) are projected to have a price difference of less than 5 ¢/kWh between PV and grid electricity.
- In large areas, PV is cheaper than grid electricity



US DOE, Solar Energy Industry Forecast: Perspective on US Solar Market Trajectory, May 2008.

2015 residential installations without incentives and aggressive increase in electricity prices

- Attractive in about 450 of 1,000 largest utilities, which provide ~50% of U.S. residential electricity sales.
- 91% of sales (in nearly 950 utilities) have a price difference of less than 5 ¢/kWh between PV and grid electricity.
- Across most of the highest U.S. population areas, PV is cheaper than grid electricity.



Ibid.

In the last six months…

- Nearly all major PV manufacturers are sharing quantified plans for achieving grid parity ~ 2010
- Nanosolar announces 1 GW/yr CIGS production tool for $1.65 million (10-30 MW/yr is typical)
- Big utilities are jumping in
  - Iberdrola builds wind, PV, and solar thermal (Spain)
  - Eon/Schuco and Enel/Sharp building thin-film plants in Germany and Italy, respectively
  - Endesa building PV plant with Isofoton in Spain
  - Electricite de France takes major stake in Nanosolar
  - SCE rate-basing 50 MW/yr at $3.50/watt installed
  - Long Island Power Authority 50 MW solicitation
  - PSE&G announces major PV financing program

The Bottom Line

- Coal and nuclear power are expensive distractions
- Efficiency remains the cheapest supply option
- PV is at or near parity with new resources in most of the world, and is rapidly nearing grid parity
  - Every utility needs to stay on top of this technology
- How to you do that?
  - Communicate with peers in other utilities
  - Figure out your own business model, and understand the business models of the solar vendors (your counter-parties)
  - Subscribe to publications (e.g., Photon Magazine) that follow industry developments

Supplemental Slides

Start with the Nuclear Renaissance

- It isn't cheap - capital cost is growing rapidly
  - EIA - $2083/kW (2005)
  - Keystone - $3600-4000/kW (June 2007)
  - S&P - $4000/kW (May 2007)
  - Moody's - $5000-6000/kW (October 2007)
  - FP&L - $5700-8020/kW (Fall 2007)
  - Puget Sound Energy - $10,000/kW (January 2008)
- Operating costs less important but not insignificant
- Discounted life cycle cost estimates range from 6-18 cents/kWh.
- Inconsistent economic methodologies (e.g., mixed vs real current dollars at different completion dates)

Estimating Cost is Tough

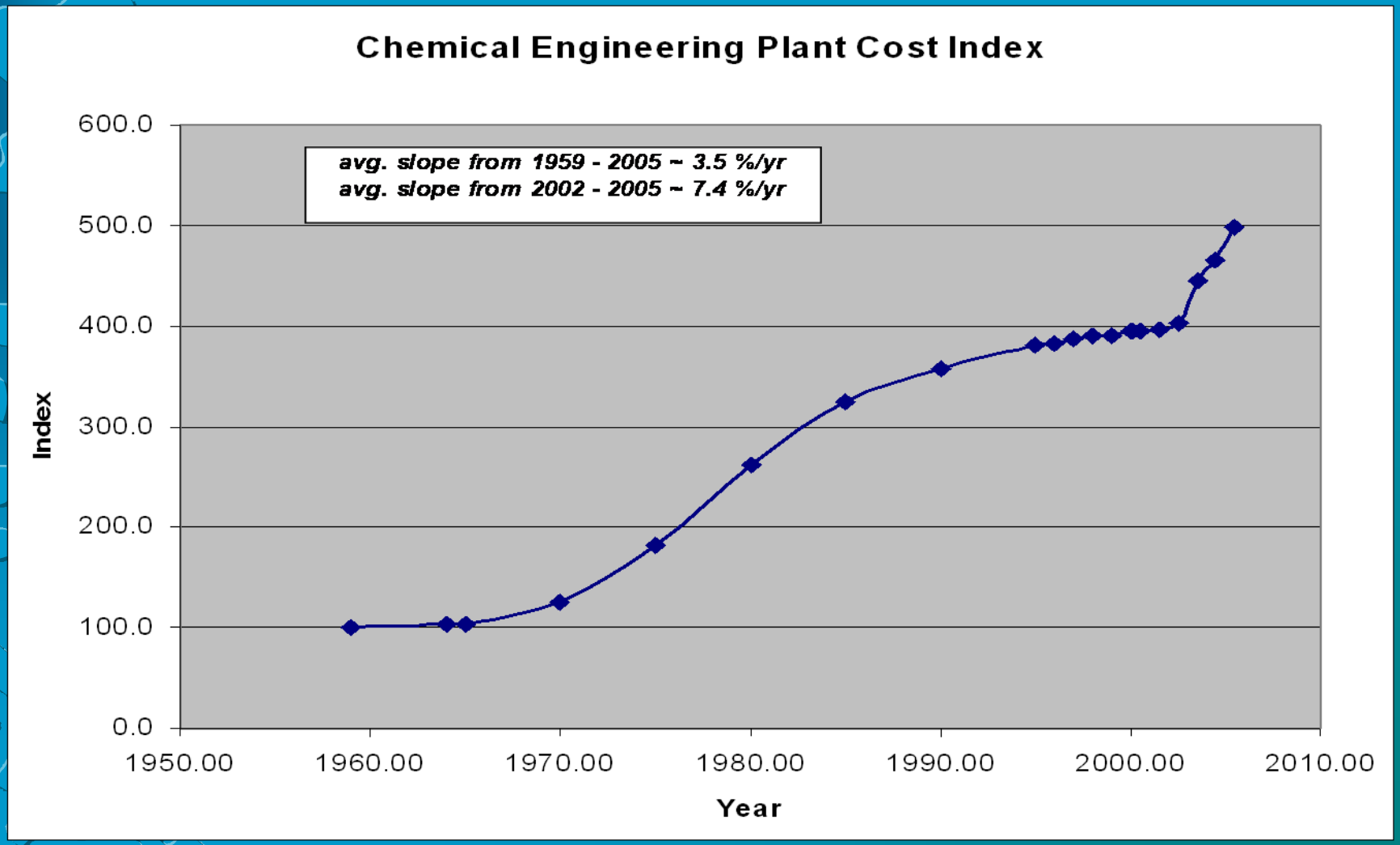
- No recent North American or European nuclear construction experience
- Historical estimates were “targets” more than estimates
  - Software assumes Asian construction practices, and excludes owner’s costs – contingency, escalation, interest during construction, land, transmission, and oversight. No delays
  - No incentive to be accurate; no real money being spent
- Often not considered:
  - Escalation during construction; first of a kind premiums and learning curves instead
  - Supply-chain problems (key parts, leadtimes, skilled labor, sub-suppliers, uranium)
  - Transmission costs and lead time
  - Finance and siting challenges

Keystone Basis -Asian Experience

Plant	MWe	COD	Yen@COD	2002$s/kW	2007$s/kW
Onagawa 3	825	Jan 2002	3.1 Billion	2409	3332
Genkai 3	1180	Feb 1994	4 Billion	2643	3656
Genkai 4	1180	Jul 1997	3.2 Billion	1960	2711
KK 3	1000	Jan 1993	3.2 Billion	2615	3617
KK 4	1000	Jan 1994	2.2 Billion	2609	3608
KK 6	1356	Jan 1996	4.2 Billion	2290	3167
KK 7	1356	Jan 1997	3.7 Billion	1957	2707
Y 5 (SK)	1000	Jan 2004		1700	2352
Y 6 (SK)	1000	Jan 2005		1656	2290
Average				2354	3257

Cost data from MIT 2003 Future of Nuclear Power study. Average does not include South Korean units, owing to labor rates. Real escalation from 2002-2007 at 4 percent/year.

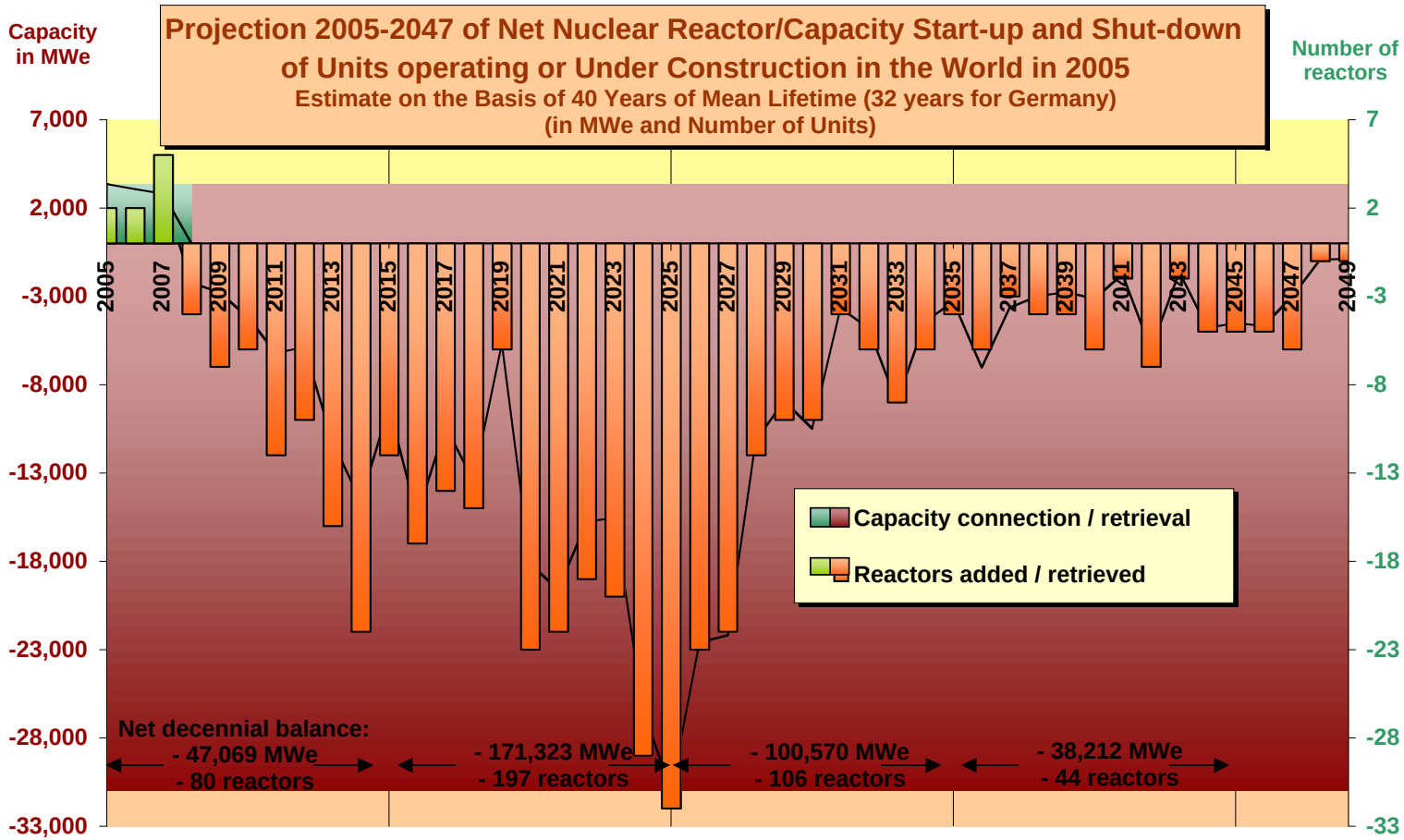
Steeper Curve Than in the Mid 80s



The International Challenge

- 370 GWe of existing nuclear capacity in 20+ nations
- All retired, with or without life extension, by 2030-2050
- Socolow/Pacala wedge – 1 GTe of carbon avoidance; 7 GTe are required
  - 700+370=1070 GWe of nuclear capacity required by 2050-2060
  - 21 GWe per year on average
  - 23 new enrichment plants
  - 10 Yucca Mountain repositories
  - 36 new reprocessing plants and 100+ MOX plants, if fuel is recycled
- Is it possible? Can it happen without weapons proliferation?

Retirements Quicken by 2020



Source: IAEA PRIS

Forecasts of International Capacity by 2030

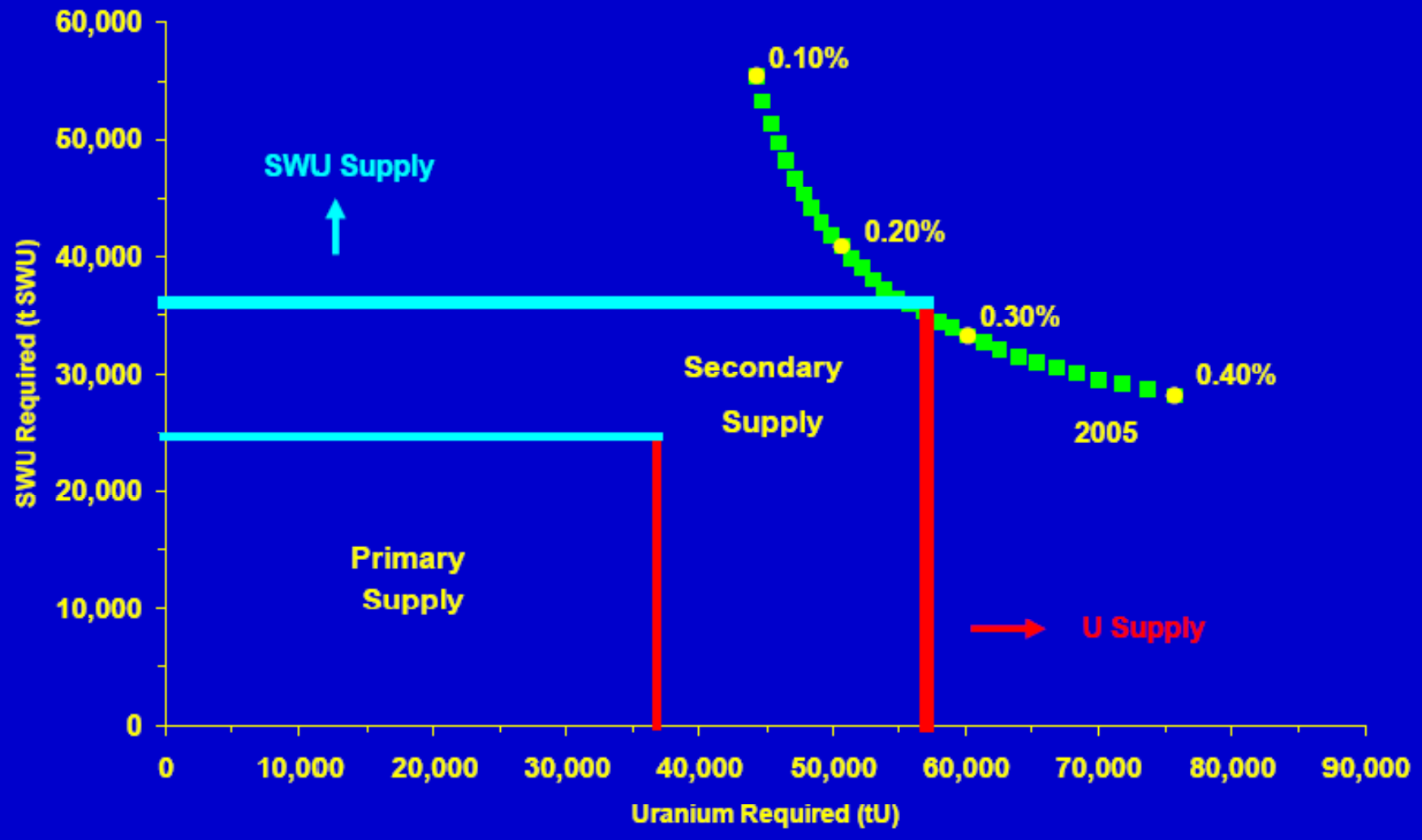
Source	GW 2030	GW/yr	% world electricity	Net additions	Outside OECD and Russia
IEA Reference (WEO)	415	2 GW	10%	45	100
IEA Advanced	519	6.5 GW	15%	149	50
US EIA	481	4.7 GW	12%	110	72
Institute for Energy Economics (Japan)	480	4.7 GW	NA	110	100

GW per year is calculated by assuming no existing worldwide capacity is retired before 2030

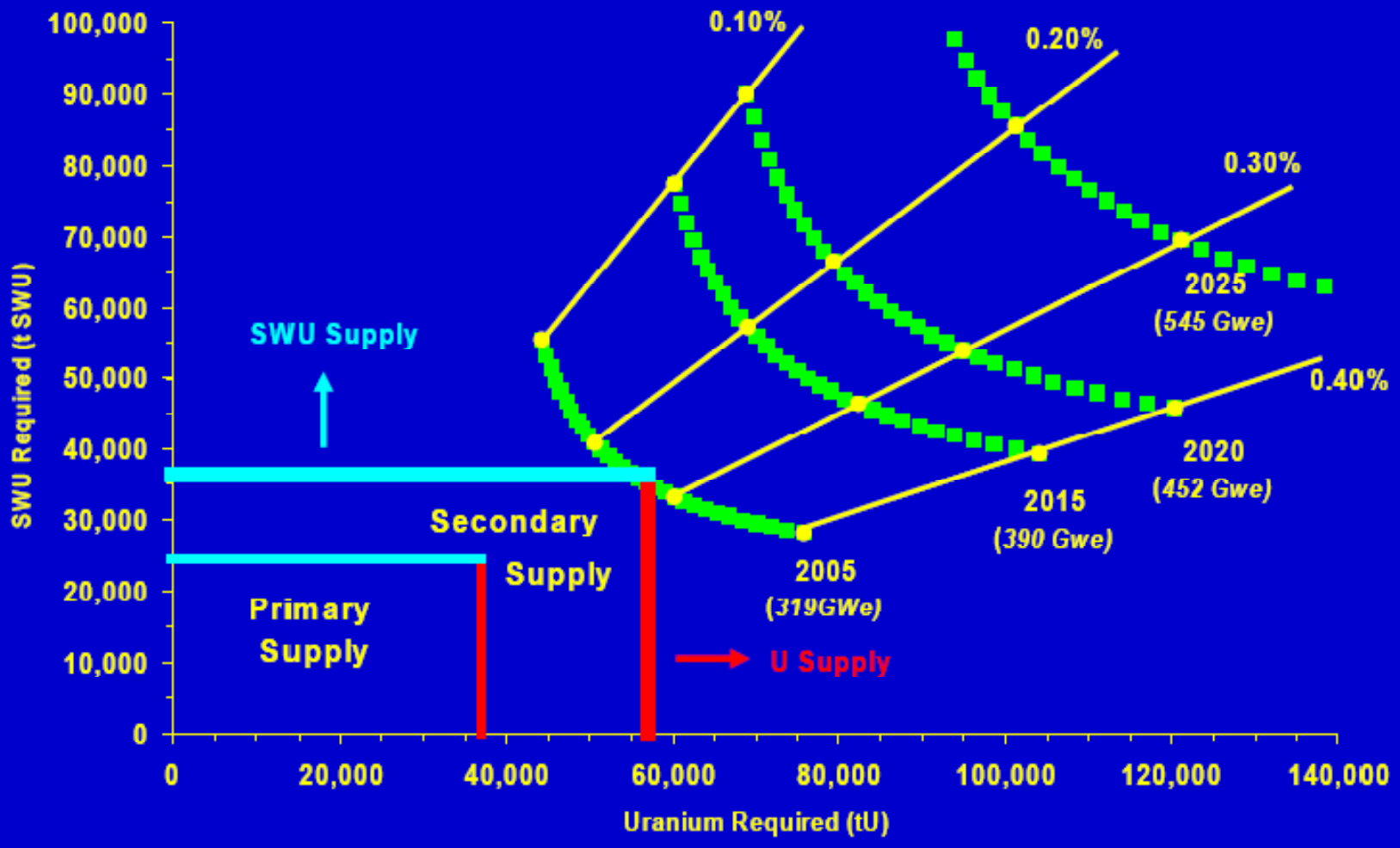
Proliferation is the Big Problem

- 700 GWe net additions make a wedge
- EIA and IEA forecasts show near zero net growth in non-Asia OECD through 2030
- Projected growth in India and China keeps nuclear at current fraction of supply (2-6%)
- Bulk handling facilities are the problem – reprocessing and enrichment

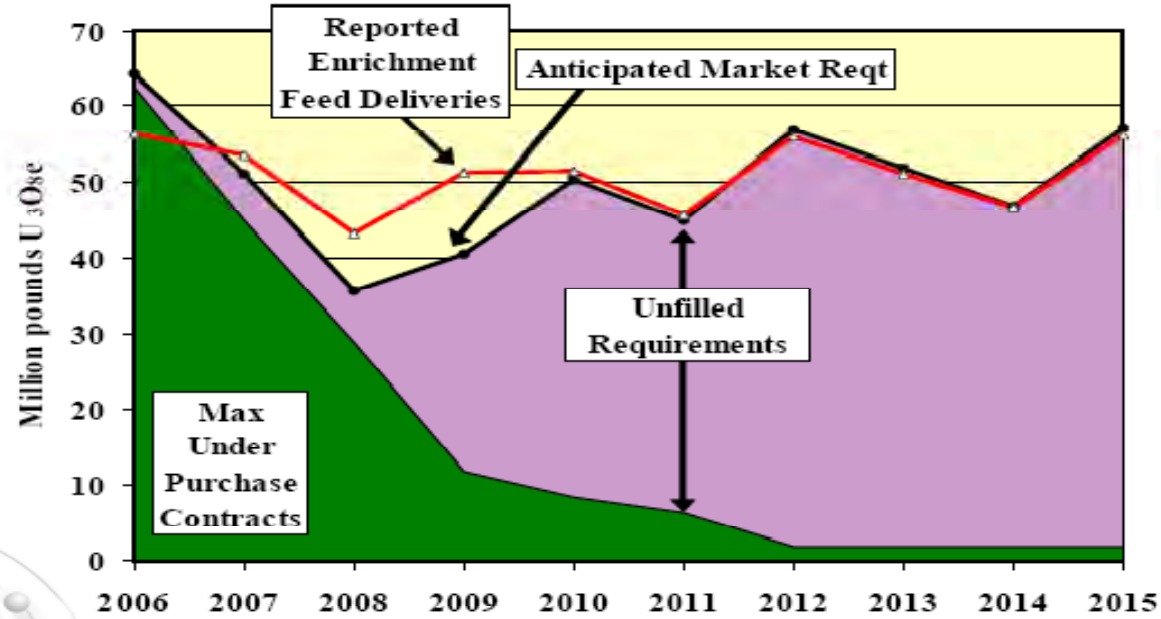
2005 SUPPLY VS REQUIREMENTS



THE SUPPLY CHALLENGE



EIA Anticipated U.S. Uranium Market Requirements



Source: EIA *Uranium Marketing Annual Report*, May 2006

Jeff Combs, President, Ux Consulting Company, Price Expectations and Price Formation, presentation to Nuclear Energy Institute International Uranium Fuel Seminar 2006

Reprocessing Is Still Expensive

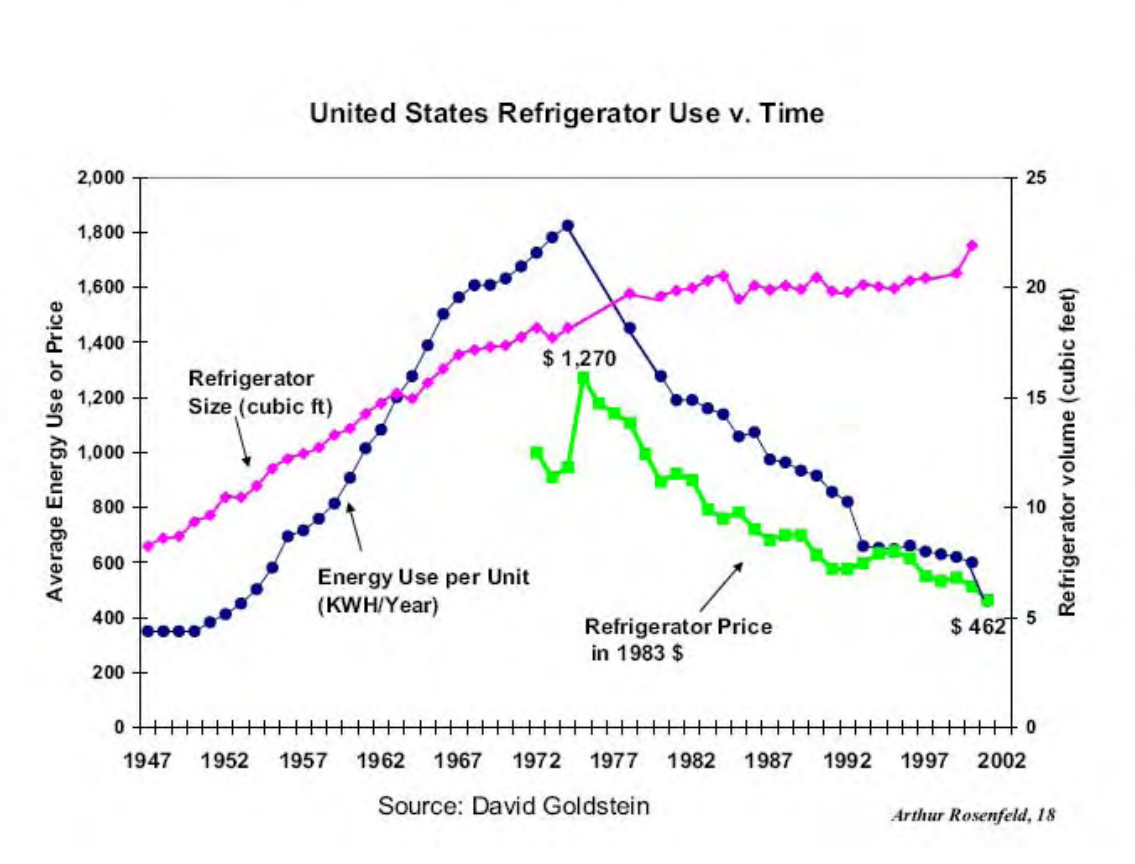
Fuel cycle steps	MIT	This analysis
Uranium	$30/kg	$300/kg
Enrichment	$100/SWU	$140-340/SWU
Fabrication	$275/kg	$275/kg
Disposal	$400/kg	$400/kg
Reprocessing	$1000/kg	$1500-2000/kg
Fuel cycle cost		
Open	0.5 cents/kWh	1.6-2 cents/kWh
Closed	2 cents/kWh	3.4-4.3 cents/kWh
Differential	4x	2-3.5x

Approximately 5.25 kgs of spent fuel must be reprocessed to obtain 1 kg of MOX.

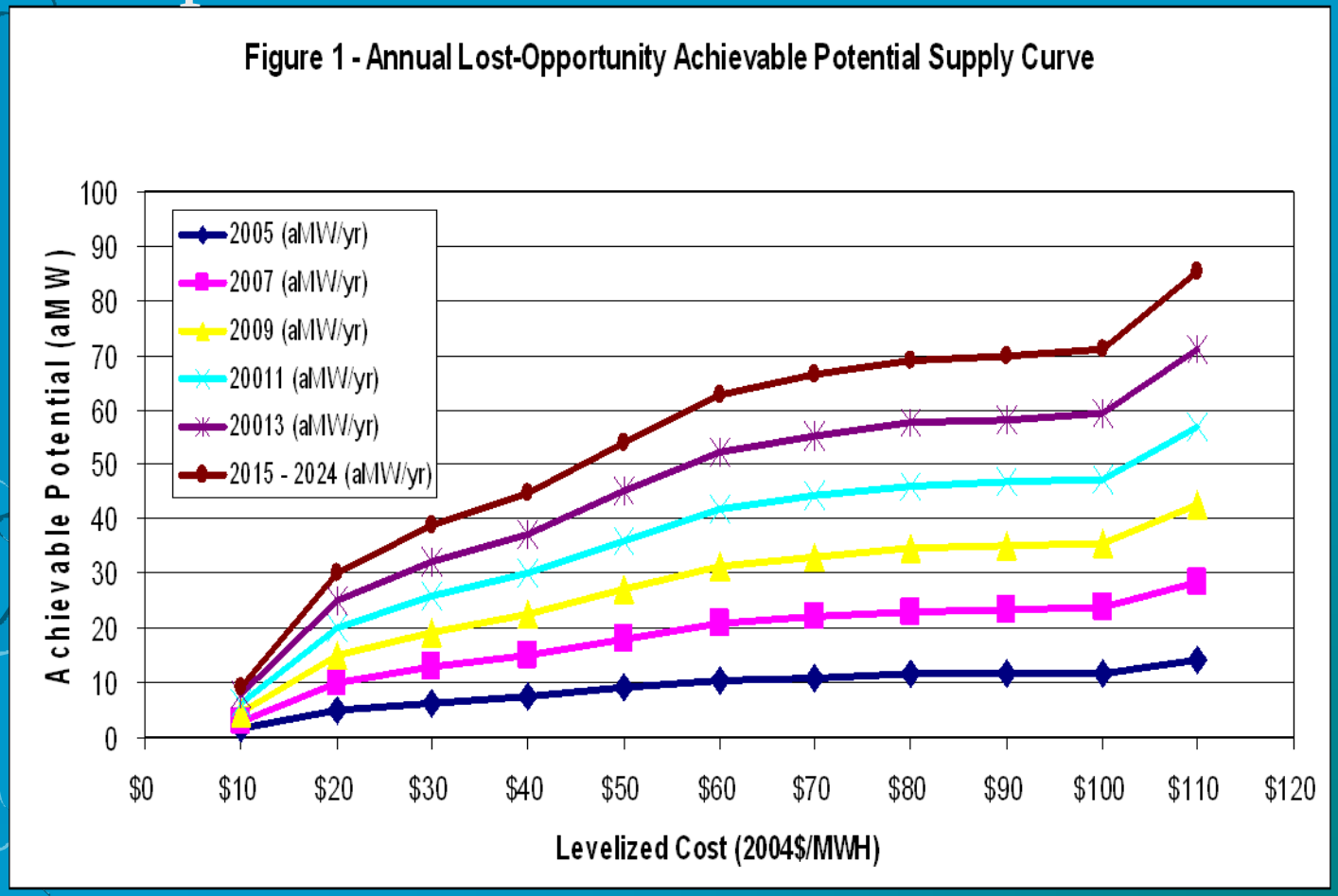
Recent Estimates

- Keystone - $3600-4000/kW; 8-11 cents/kWh
  - Real 2007 dollars, 5-6 years of construction, for operation in 2012/2013. Would be $5600/kW (16-17 cents/kWh) at AEP escalation rate to 2013.
- Standard & Poor's - $4000/kW; 9-10 cents/kWh
  - Basis not stated; levelized fixed charge rate
  - Life cycle costs reflect Keystone O&M and fuel costs
- Moody's - $5000-6000/kW
  - Basis not stated; operating and fuel costs not estimated
- Florida Power & Light - $4200-6100/kW
  - Current dollars at COD converted to real 2007 dollars
- Puget Sound Energy - $10,000/kW
  - Basis not stated, but consistent with FP&L plus AEP escalation rate through completion.

Technical Innovation Driven by Standards

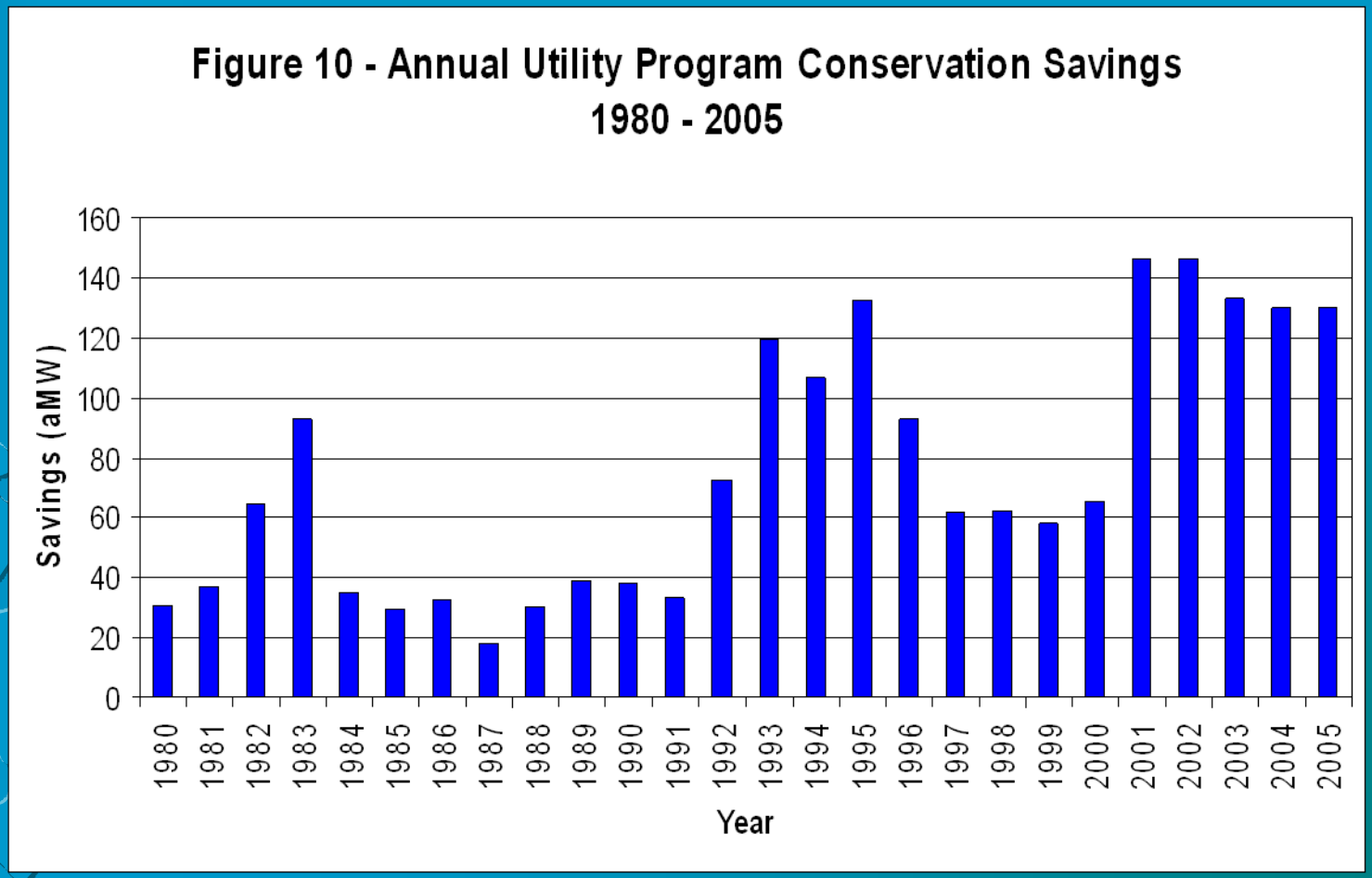


Utility Programs Are Also Important



Northwest Power Planning Council, Achievable Savings, August 2007

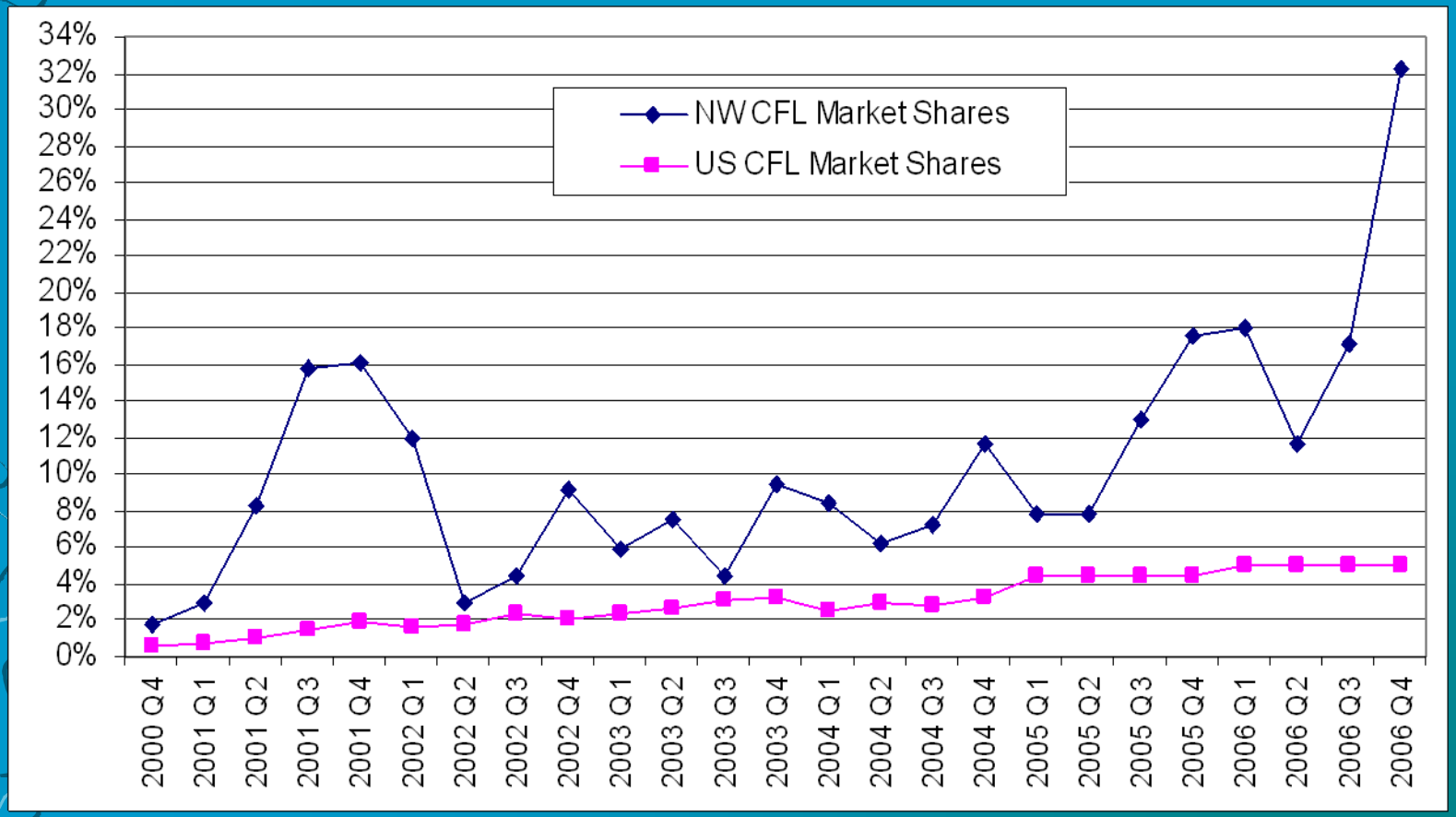
Historical Northwest Utility Programs



Northwest Power Planning Council, Achievable Savings, August 2007

Compact Fluorescent Market Penetration

Figure 8 -Estimated ENERGY STAR CFL Market Share for the Northwest and U.S., 2000-2006



Sources: NW CFL sales 2000-2006: PECI and Fluid Market Strategies sales data reports; and NEEA estimate of an additional 1.5 million WAL-MART CFLs sold region-wide in 2006 (See Appendix A [Section 9.1.1] of MPER3 for more detail); U.S. and NW population estimates 2000-2006: U.S. Census 2004; U.S. market shares and non-CFL sales 2000-2005: Itron California Lamp Report (2006); U.S. market share 2006: D&R International (personal communication).

“Updated” Lifecycle Costs

Cost Category	Low Case	High Case
Capital Costs	6.0	7.9-12.7
Fuel	1.6	2.0
Fixed O&M	1.3	2.5
Variable O&M	0.5	0.5
Total (Levelized Cents/kWh)	9.4	12.9-17.7

Low case is Keystone, without South Korean units. High cases cover Keystone through Puget capital cost estimates. First year 1.7 times higher.

Why Take Solar in Seattle Seriously?

- Rapidly rising costs and risks for all new conventional resources, including nuclear, coal, gas, and wind
- Rapidly falling cost, and increasing efficiency and production capacity for PV – at or approaching parity with all the above – in many parts of the world!
- Building integrated materials won’t stop at the border
- Imminent major investments by NW utilities
- Consistent with community values
- Digestible size, no transmission required
- Possibility of state or federal RPS carve-out for solar or feed-in tariffs