NAE Convocation of the Professional Engineering Societies

The Promises and Challenges Facing Renewable Electric Power Generation

April 20, 2009

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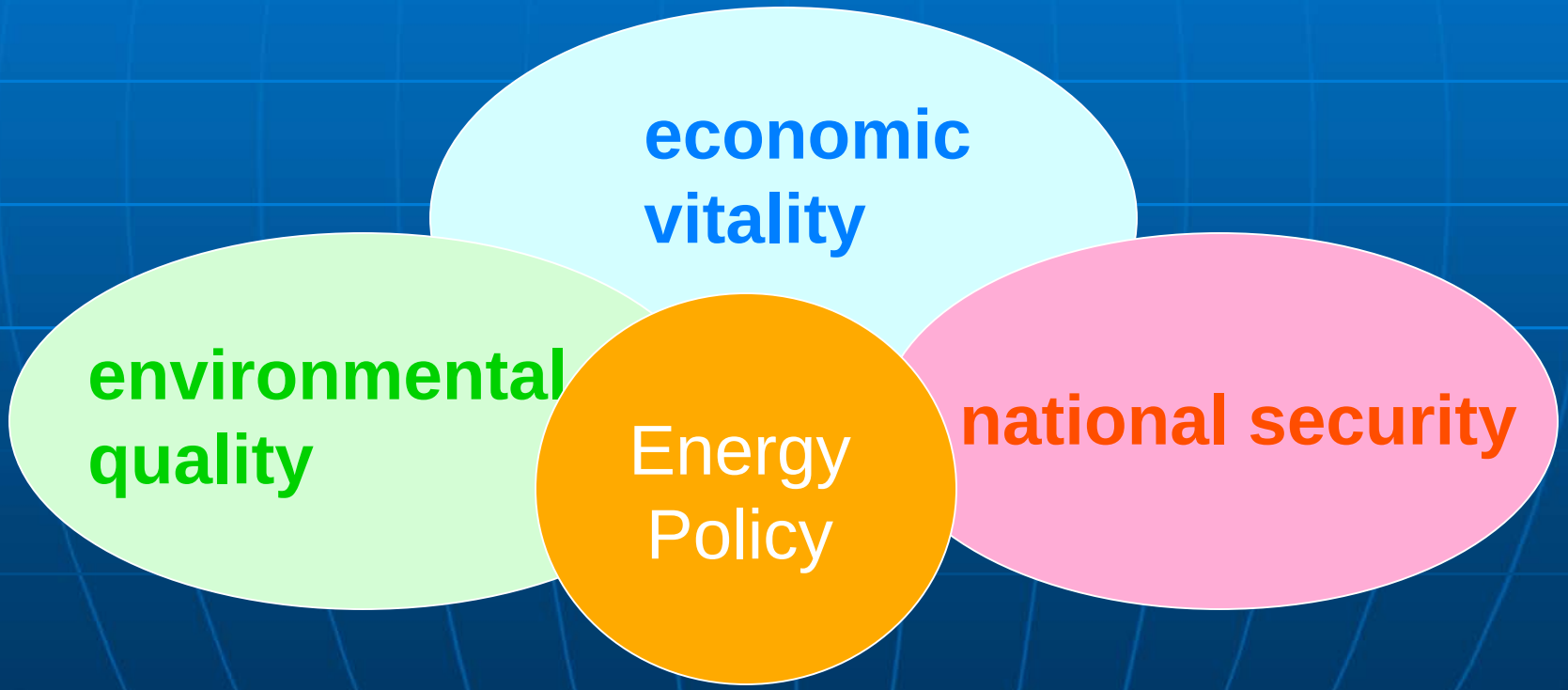
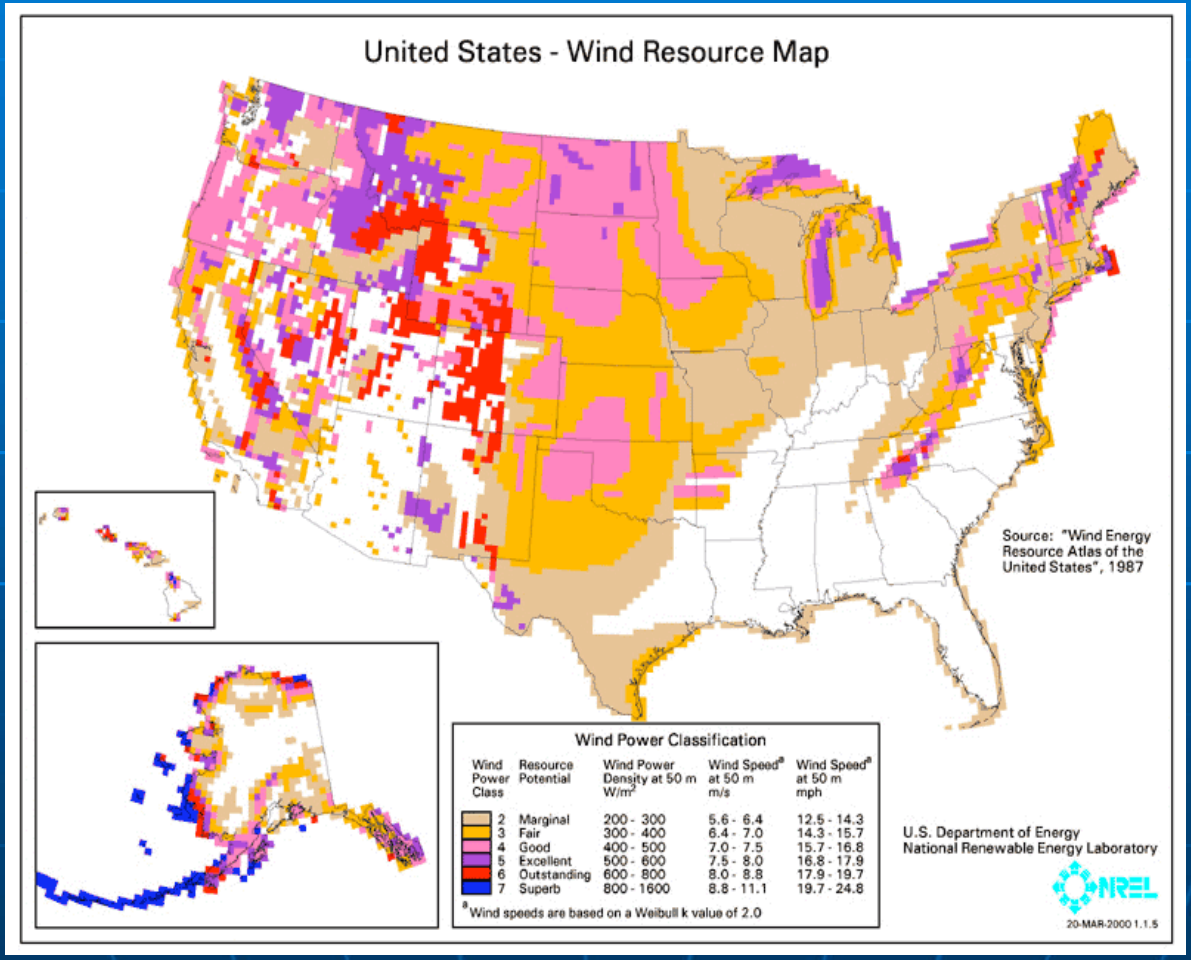
America‘s Energy Future
Changing Focus of Energy Policy

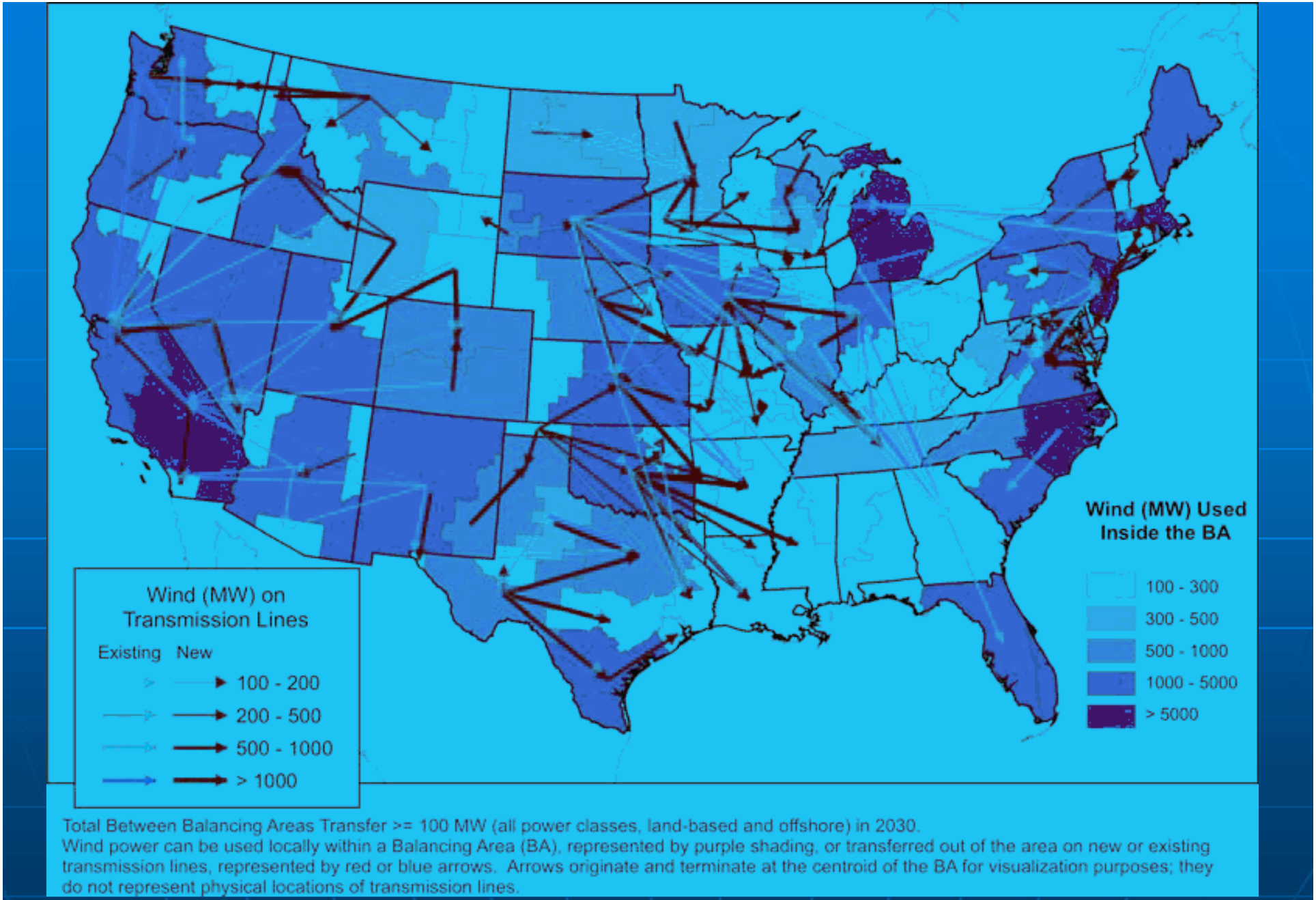


Status of Renewable Power in the U.S.

- Renewables are a modest 10% of all generated power
  - Over 7 % is hydroelectricity
  - Biomass (~2%) and wind (~1%) make up most of the rest
- But growth rates for renewables are impressive
  - Wind: 23% compounded growth (1997-2006)
  - Solar PV: over 40% compounded growth (2000-2005), but from a very low base
- What, then, might the future have in store?

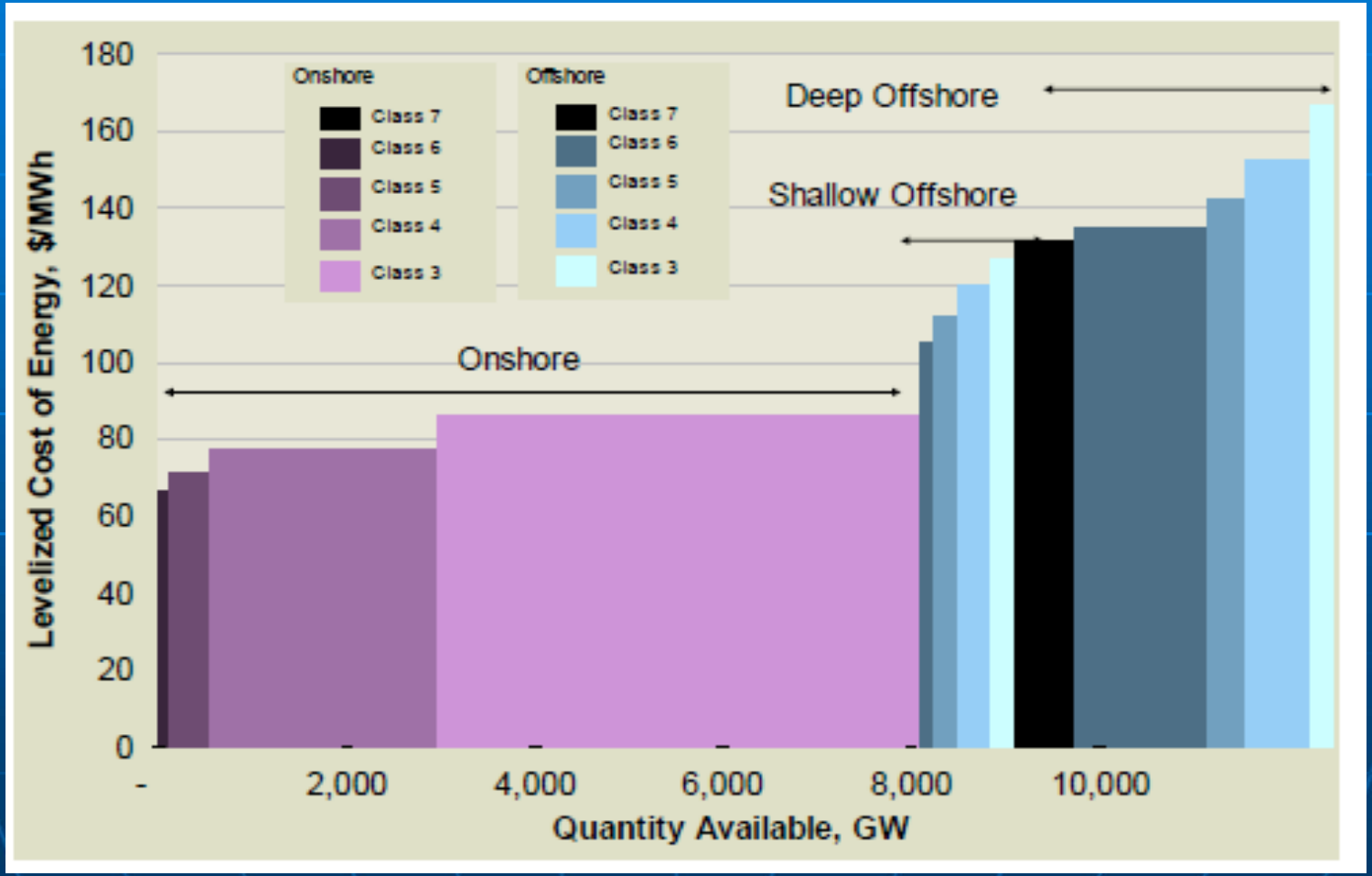
US Wind Resource Map of Various Wind Power Classes



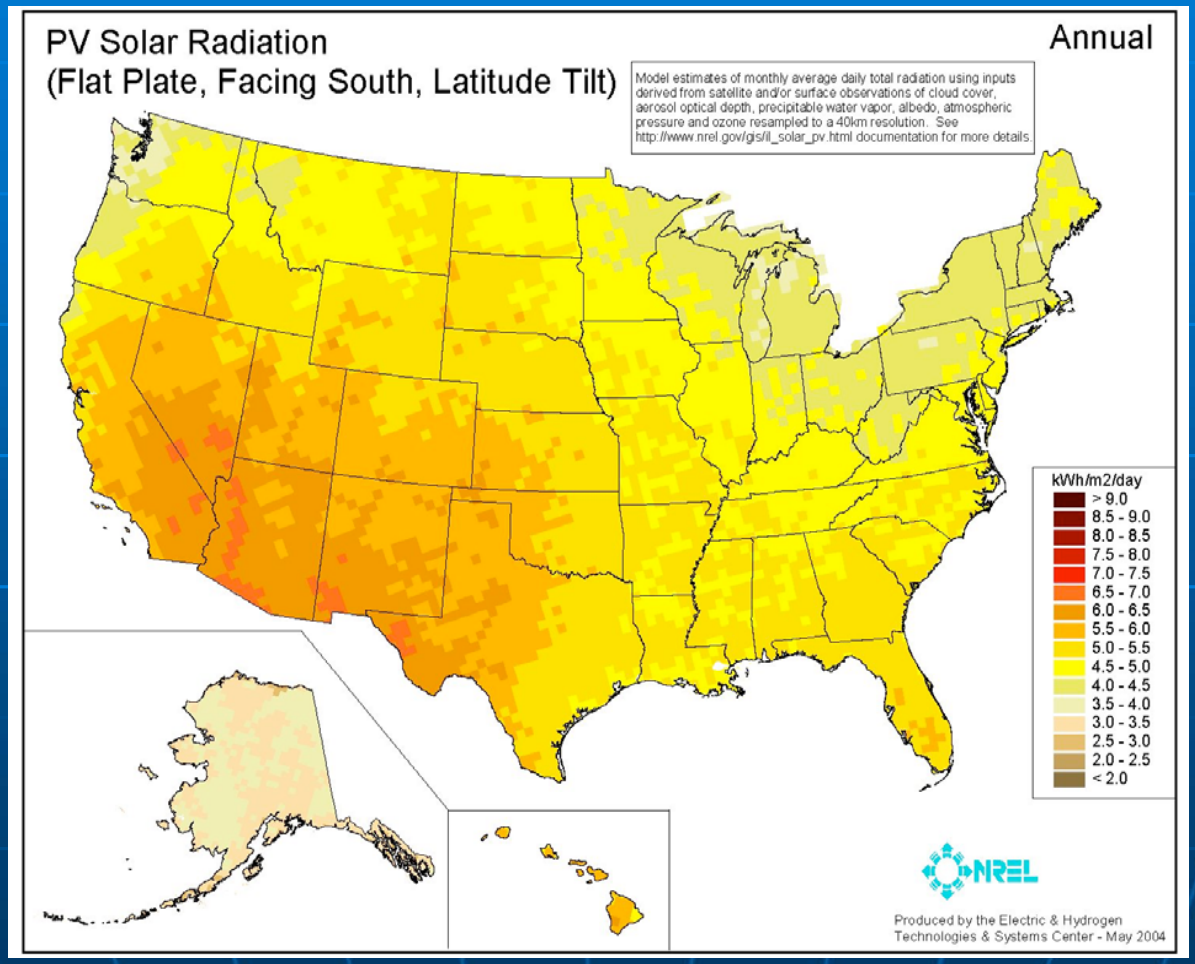


Map indicating potential new transmission corridors for integrating 300 GW of wind

Supply Curve for Wind without Accounting for PTC, Transmission, and Integration Cost

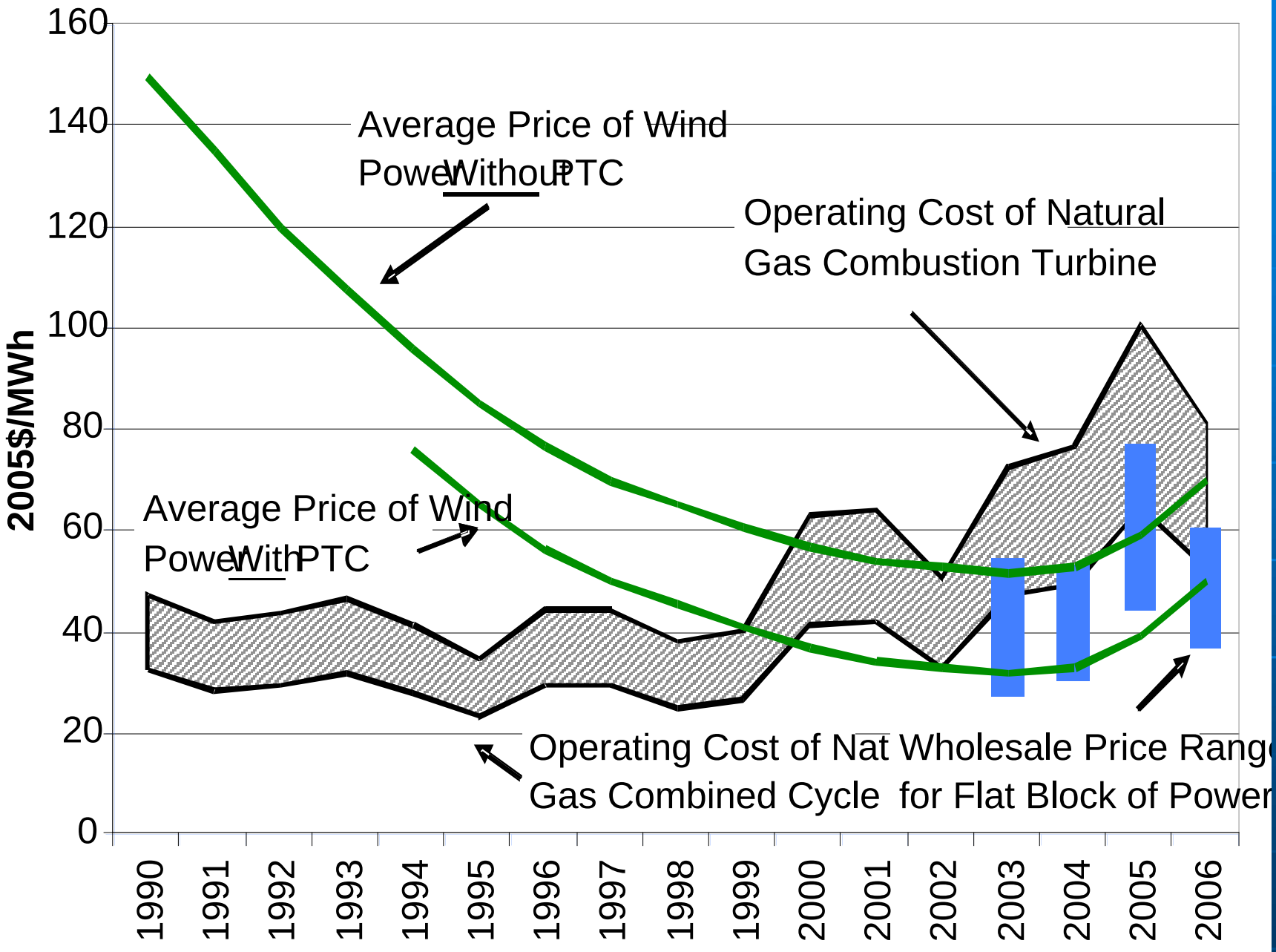


Solar energy resources in the United States

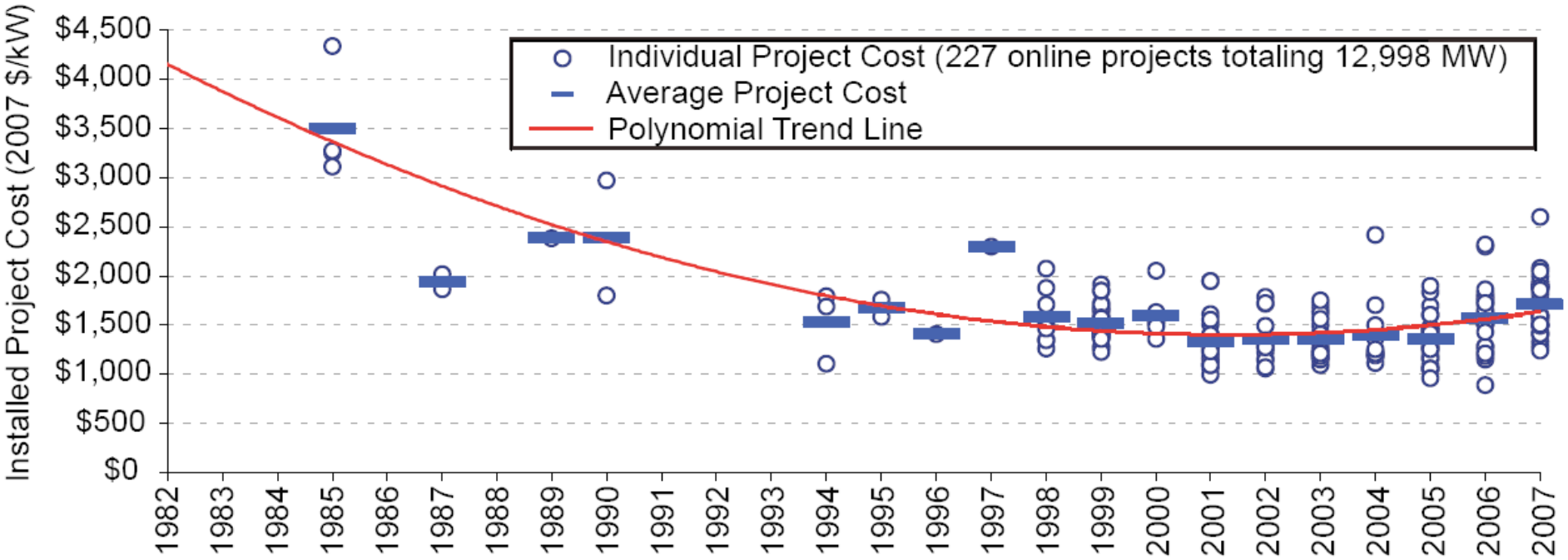


Resource Finding

- There is clearly a great deal of wind and solar resources and lesser amounts of geothermal, biomass, and hydropower to develop
- However, it is also clear that these resources are distributed unevenly around the country



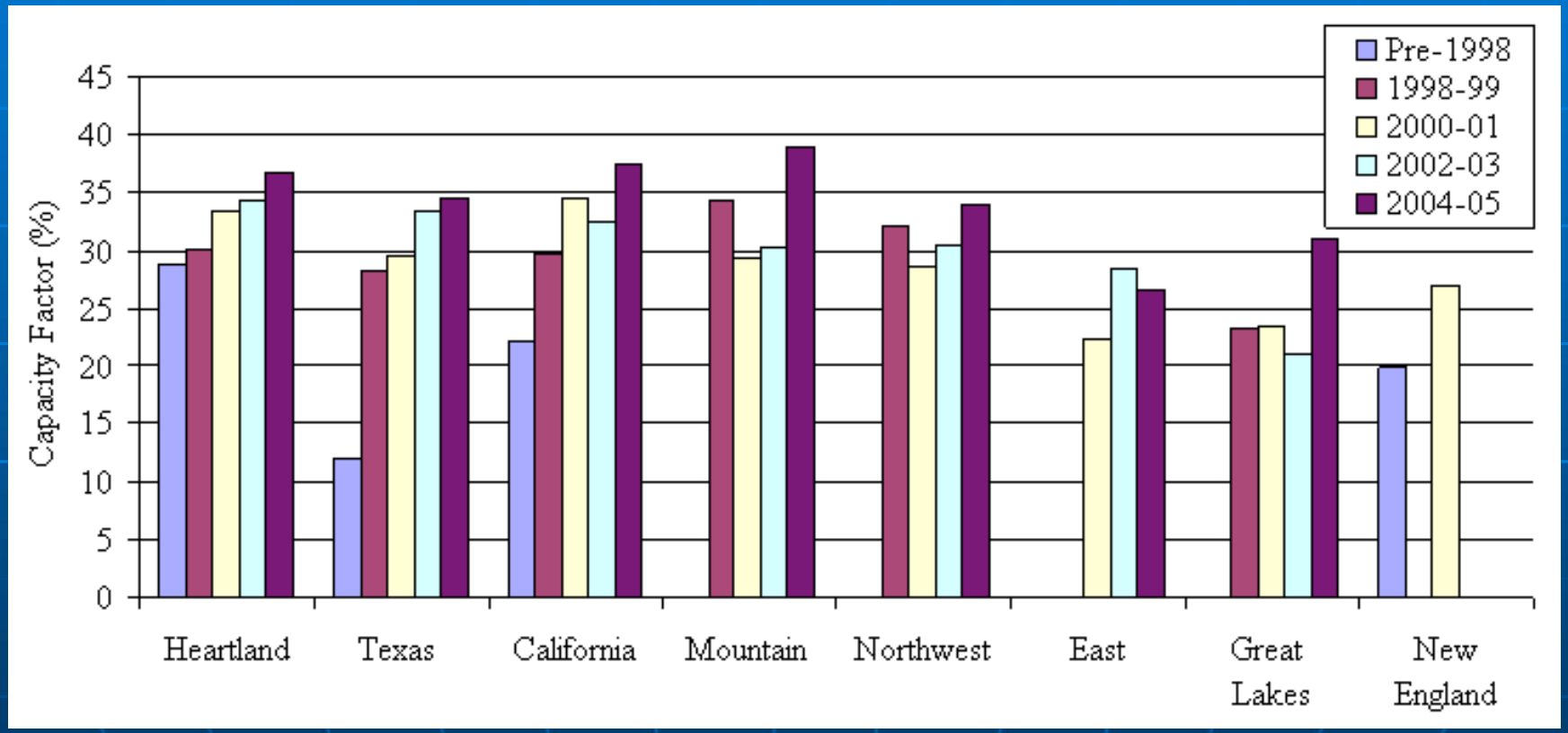
Impacts of the PTC on the price of wind power compare to costs for natural gas

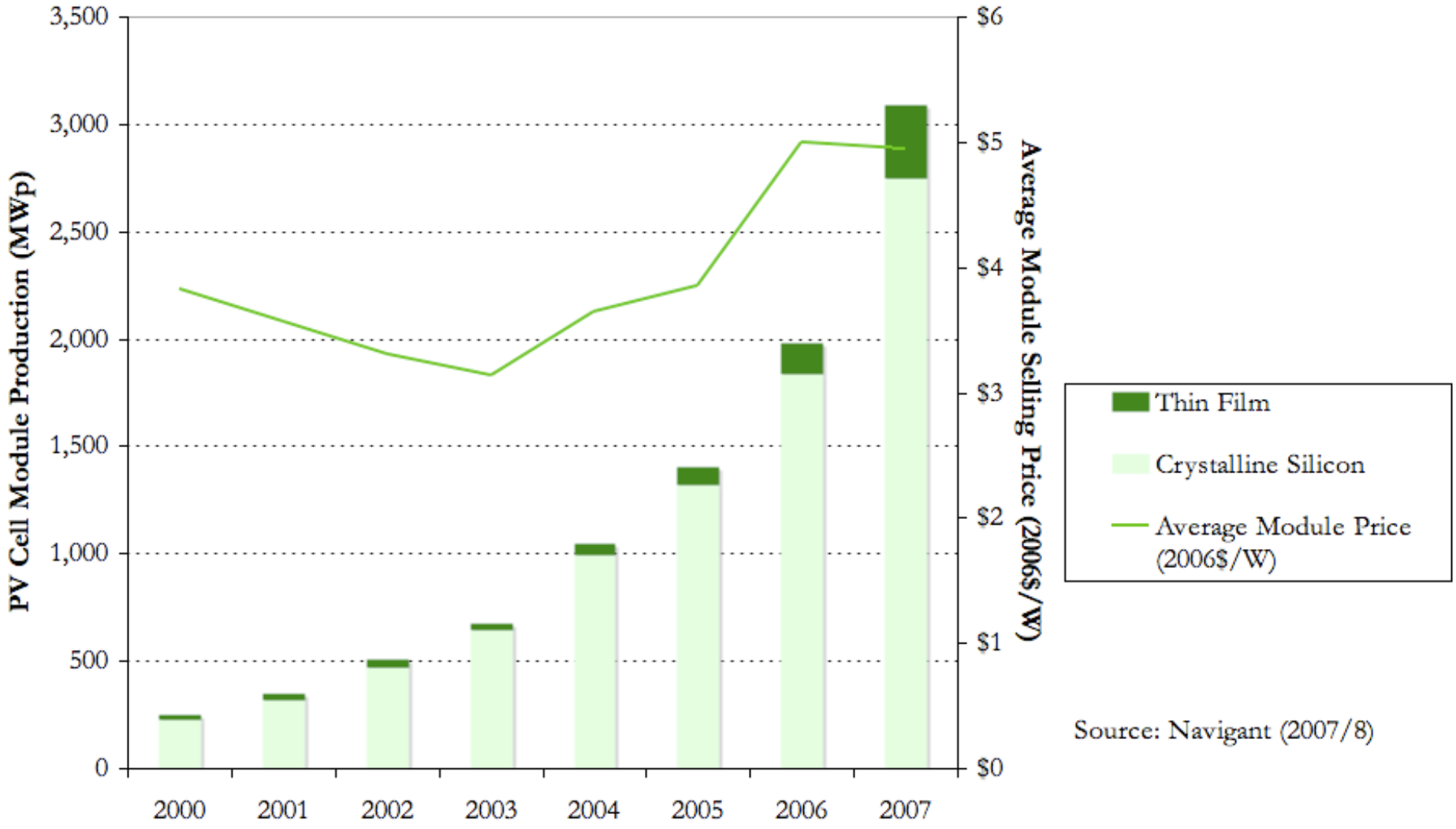


Source: Berkeley Lab database (some data points suppressed to protect confidentiality).

Installed Wind Project Costs over Time

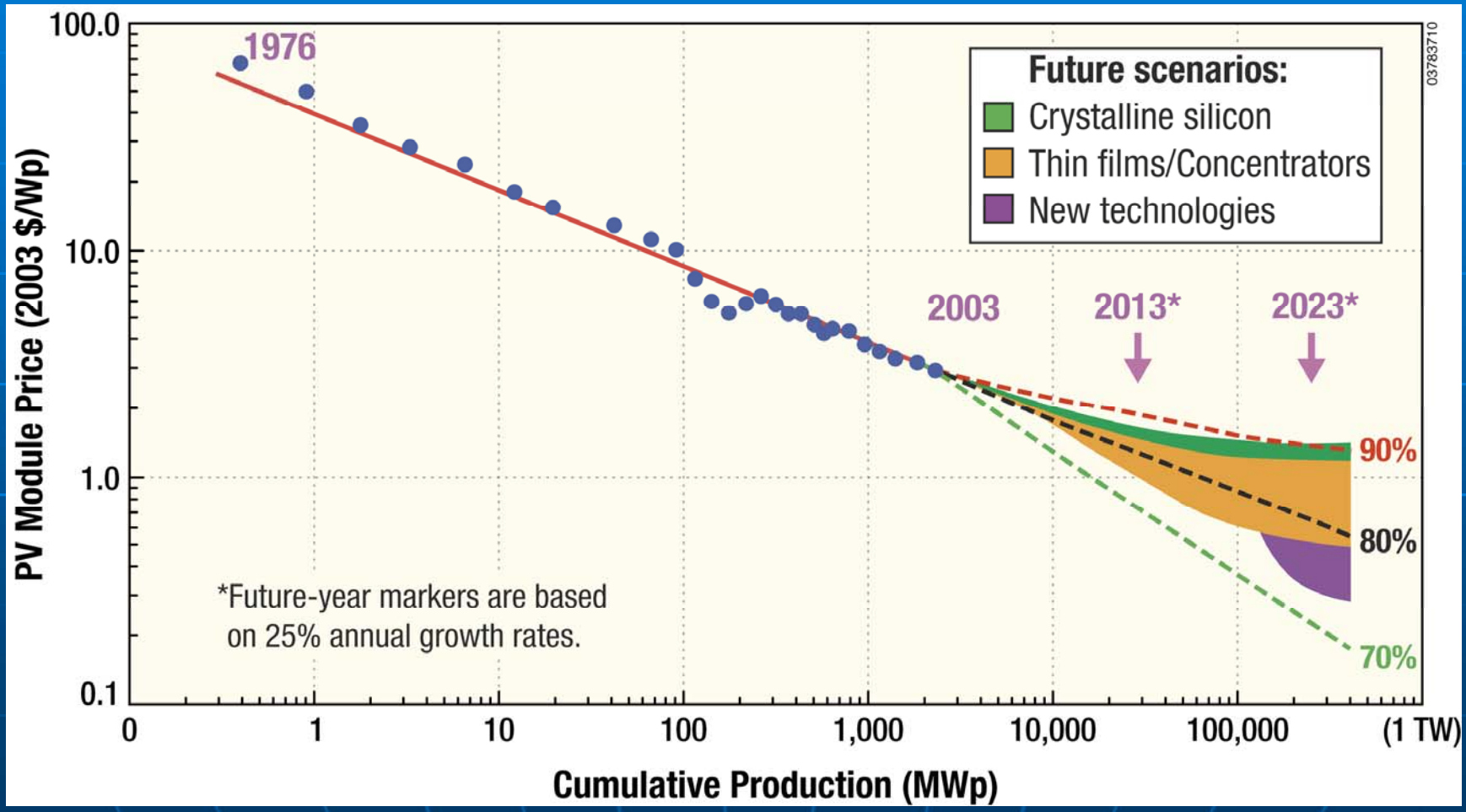
Wind Capacity Factors in 2006 by Region and Vintage of Wind Facility



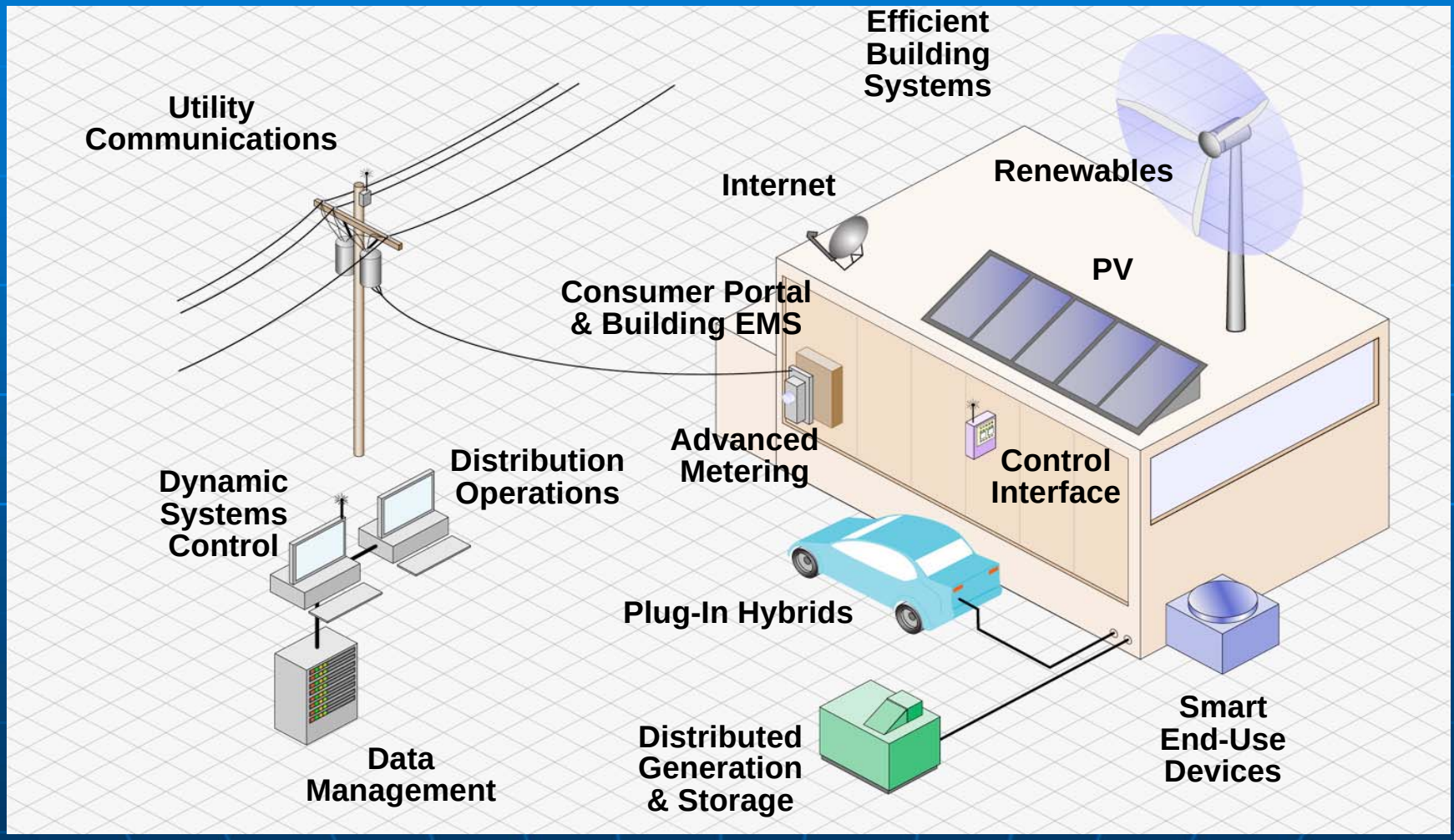


Global PV Module Production 2000 – 2007 and Average Module Price during the Same Timeframe

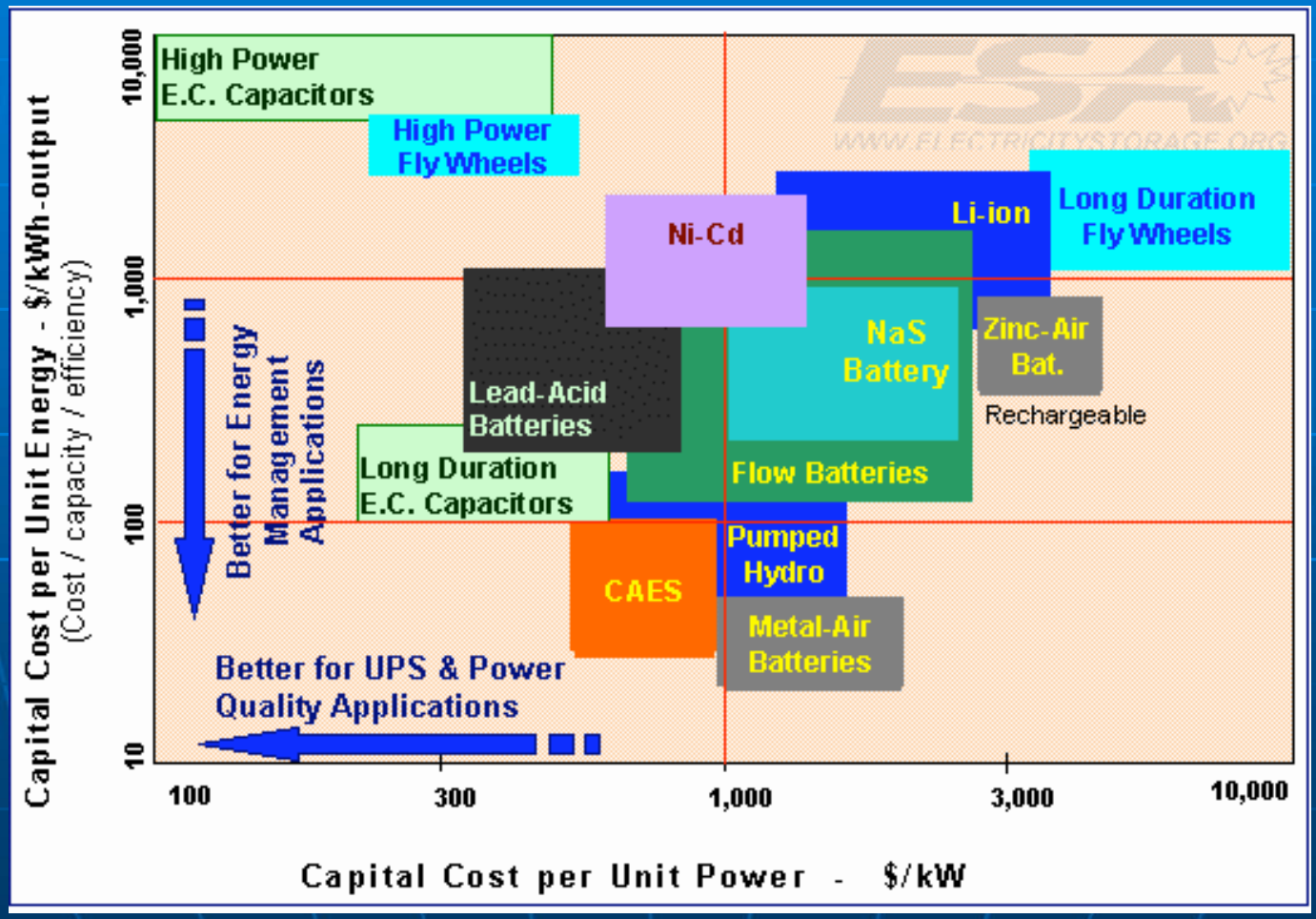
Learning Curve for PV Production



A Vision for the Distribution Grid of the Future



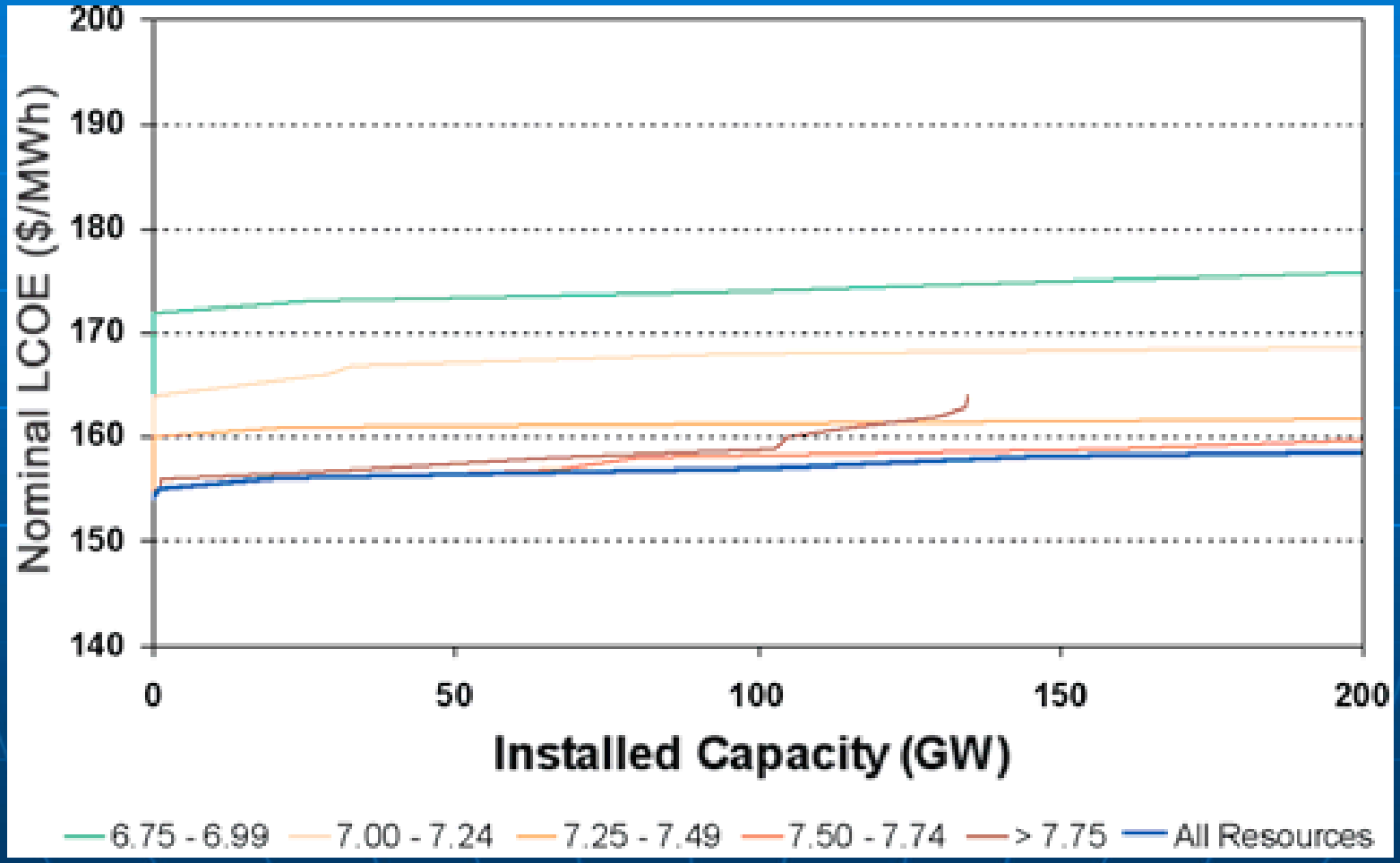
Storage Technolgies and Costs of Energy and Power



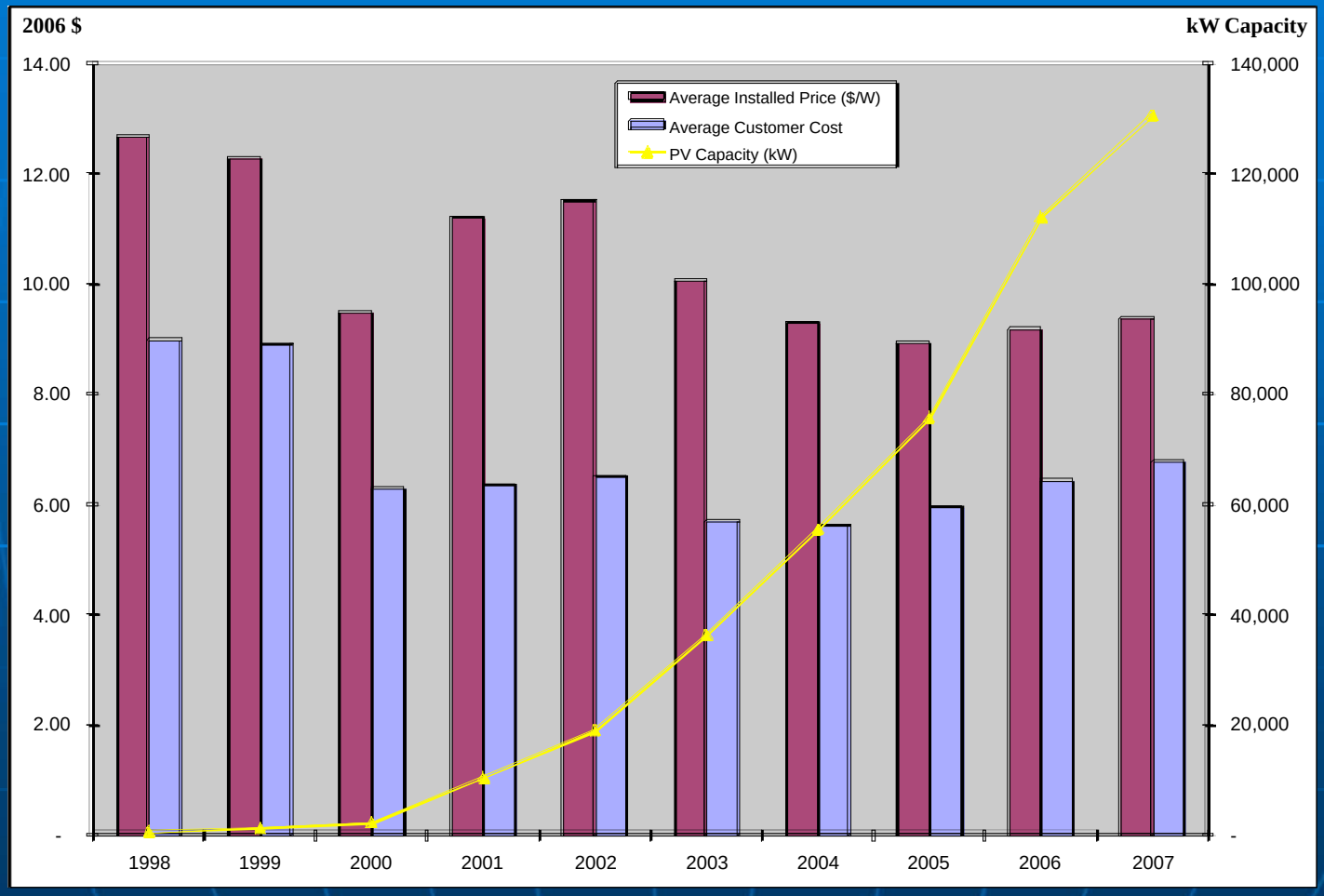
Technology Finding

- Clearly some technologies are sufficiently developed and are being deployed, such as wind turbines, solar PV and concentrating solar power, traditional geothermal, and biomass.
- There are other technologies that are further away, including enhanced geothermal, wave and tidal energy, and ocean thermal gradient technologies.

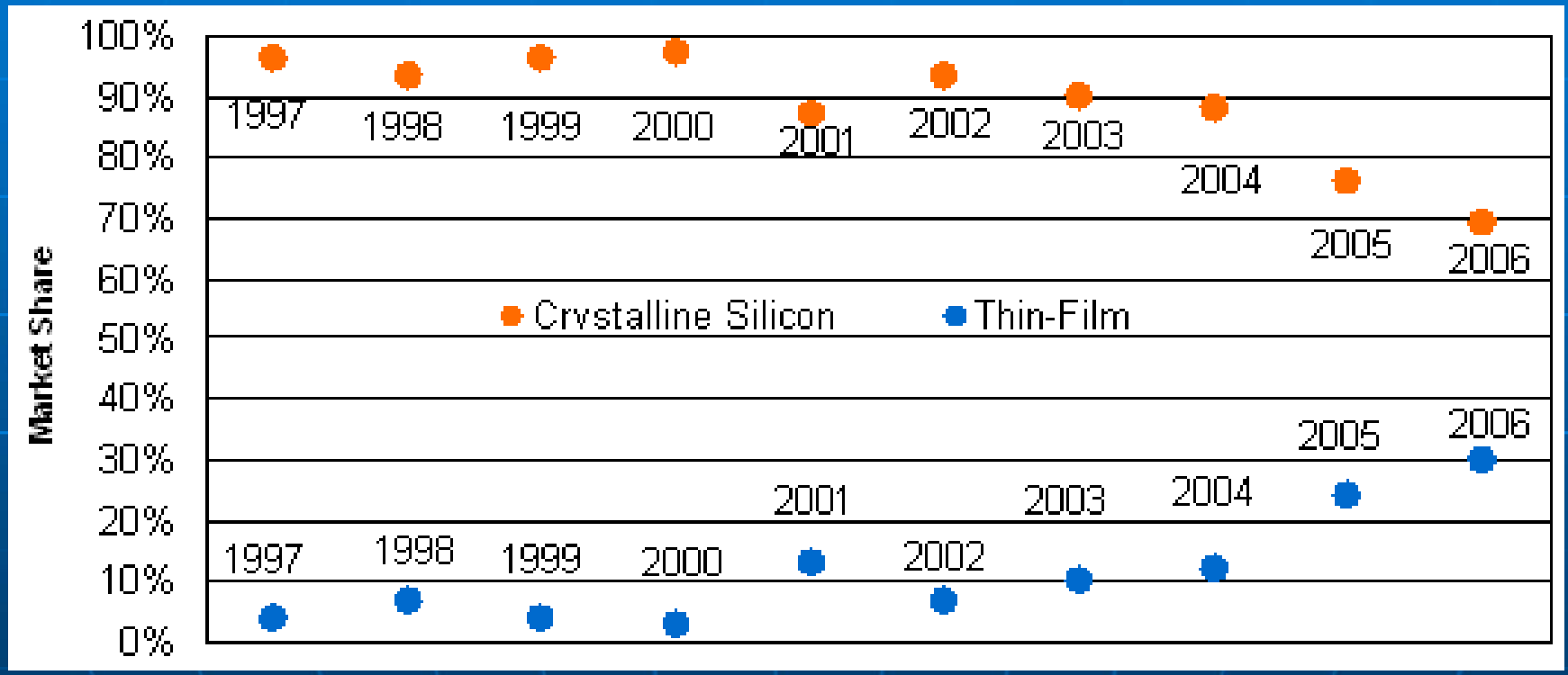
Potential Capacity and Current Busbar Costs in Terms of Nominal LCOE of Concentrating Solar Power



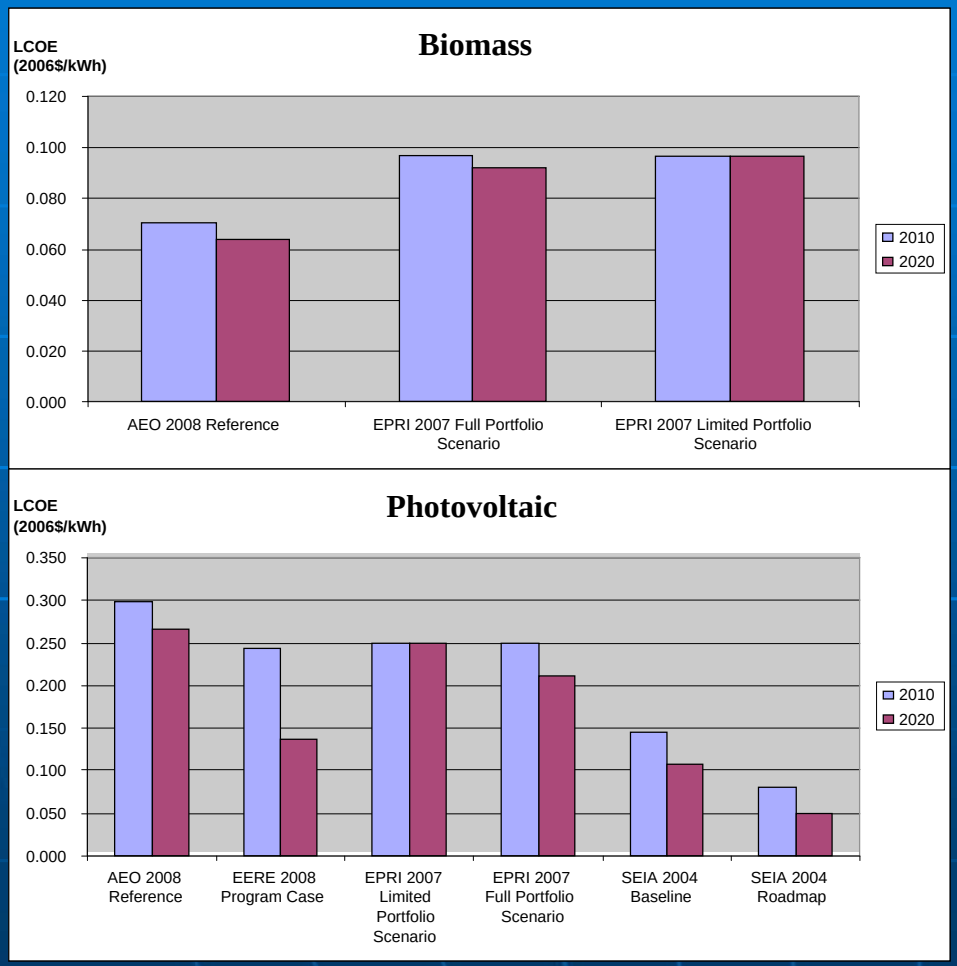
Price, Customer Cost after Subsidy, and Number of PV Installations per year in California under CEC Incentive Programs

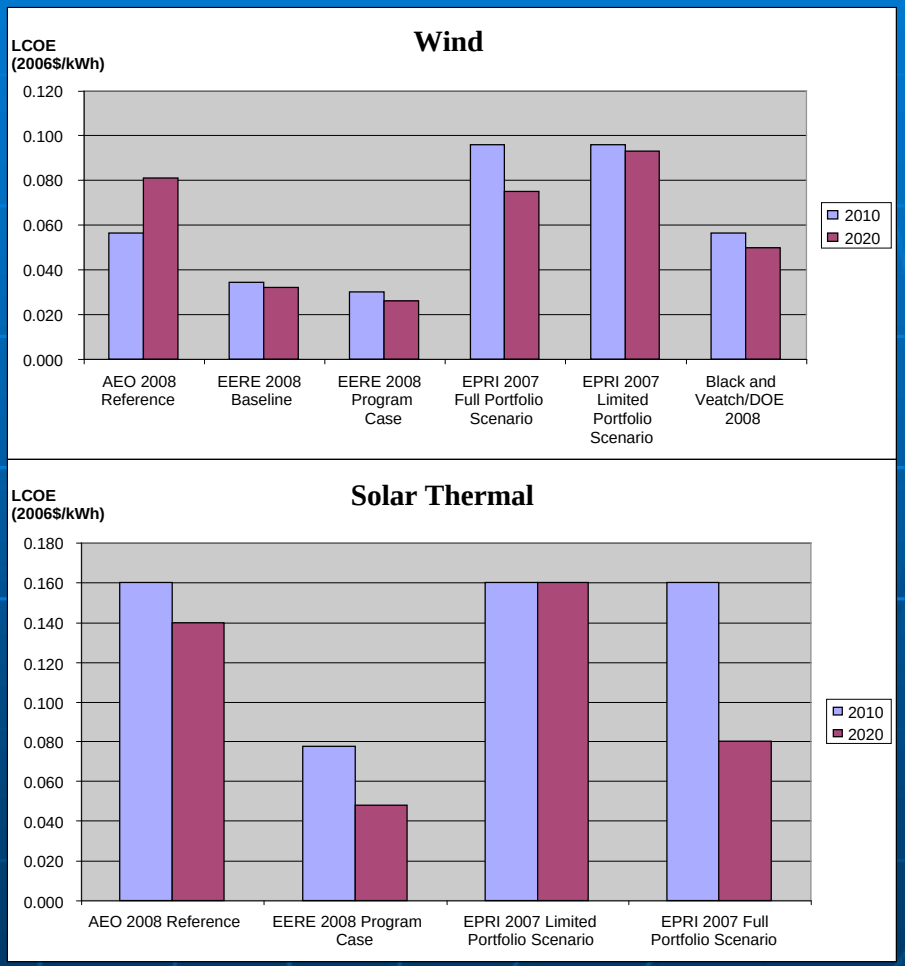


Crystalline Silicon and Thin-Film Shipment Market Shares in the US, 1997-2006



Levelized Cost of Energy for Selected Renewable Technologies in 2010 and 2020 from various studies (note EIA 2010 numbers are for 2011)

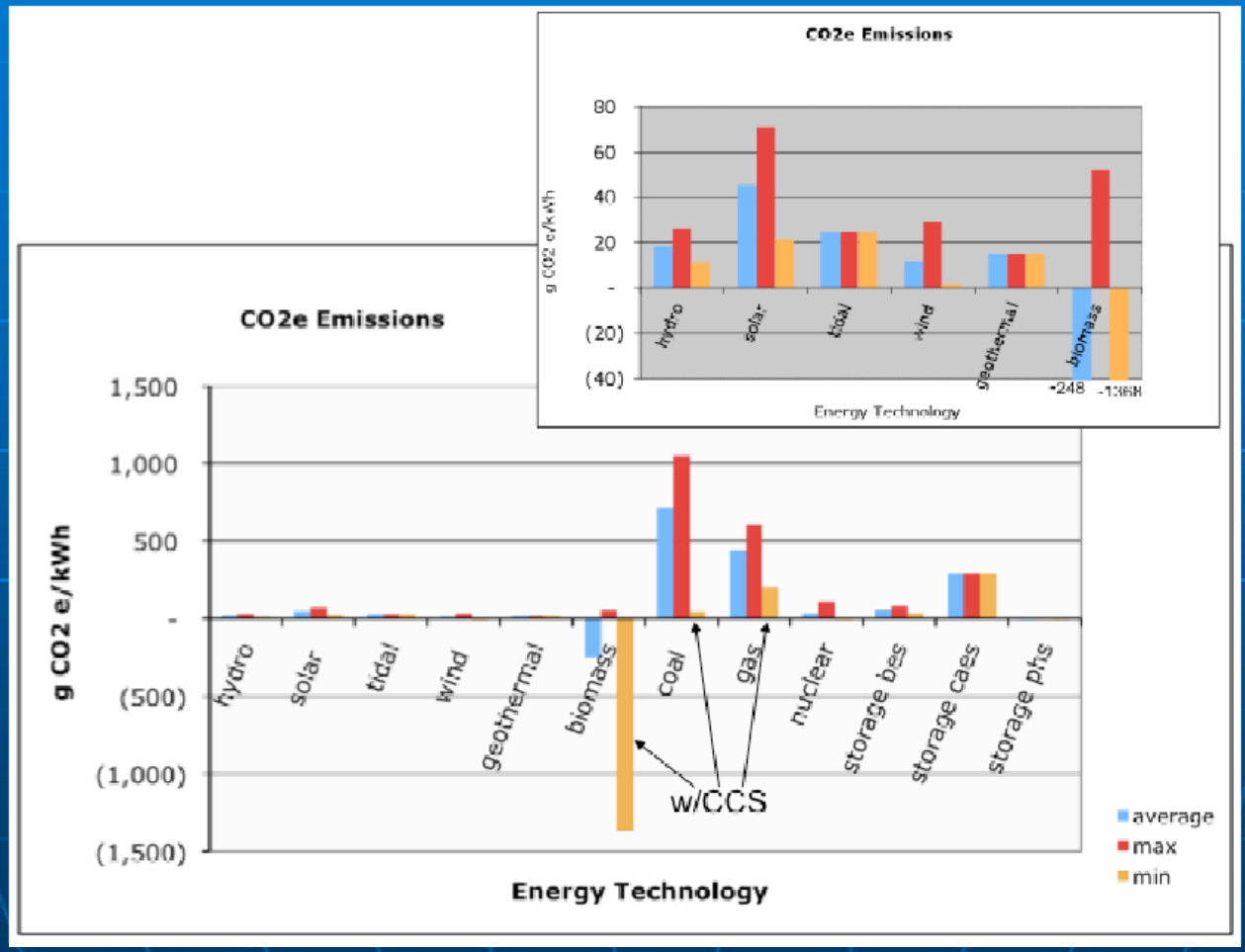




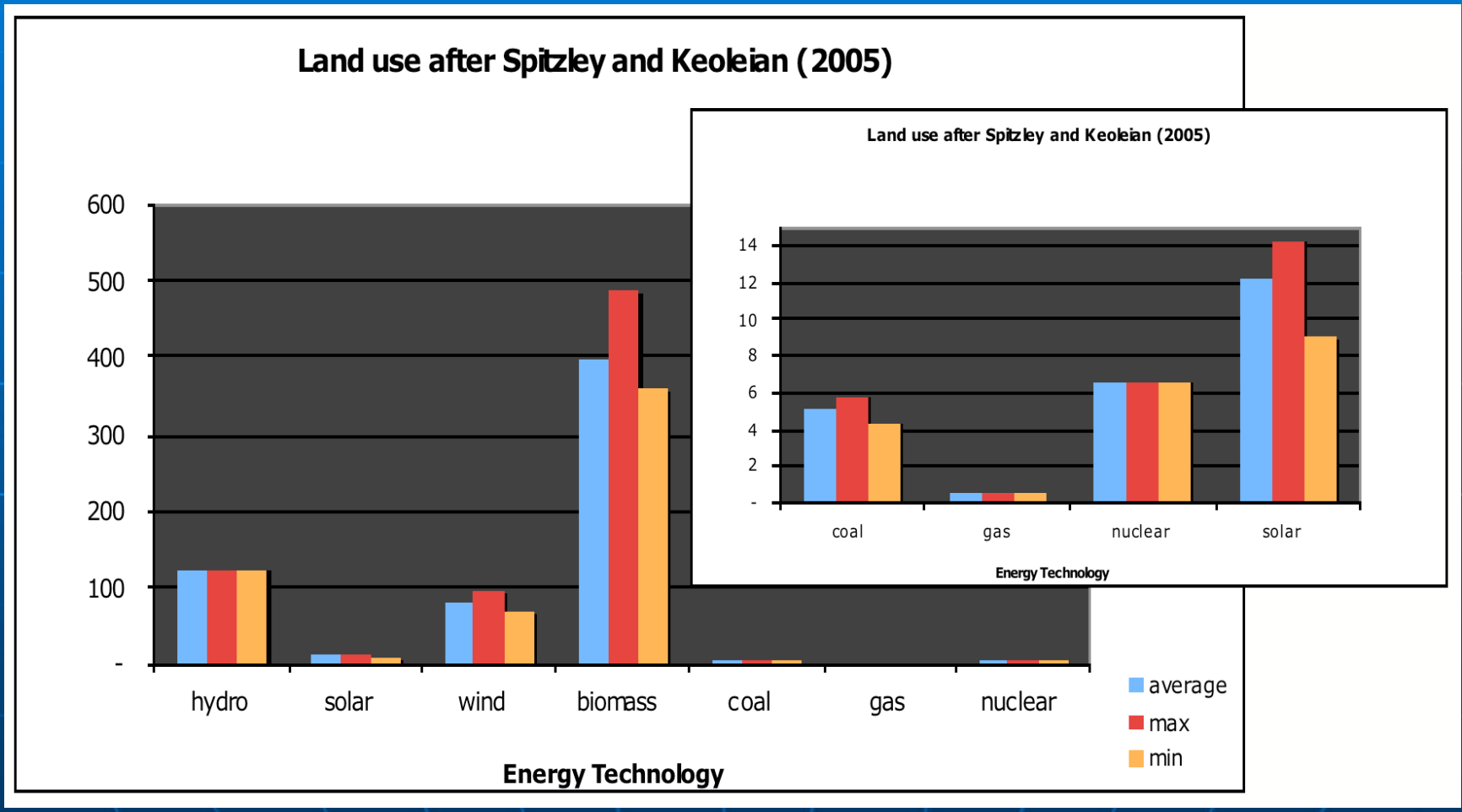
Economics Finding

- For renewable technologies to improve their cost competitive position will require improvements in technology and stable and clear public policies that should result in greater penetration and accelerate production and deployment at meaningful rates
- Clearly wind (and regionally hydrothermal geothermal) enjoys the best cost competitive position of all (non-hydroelectric) renewable technologies

Life-cycle Emissions of Greenhouse Gases (in CO_2 Equivalents) for Various Sources of Electricity



LCA of Land Use for Various Renewable and Non-renewable Technologies in Square Meters per MWh/yr



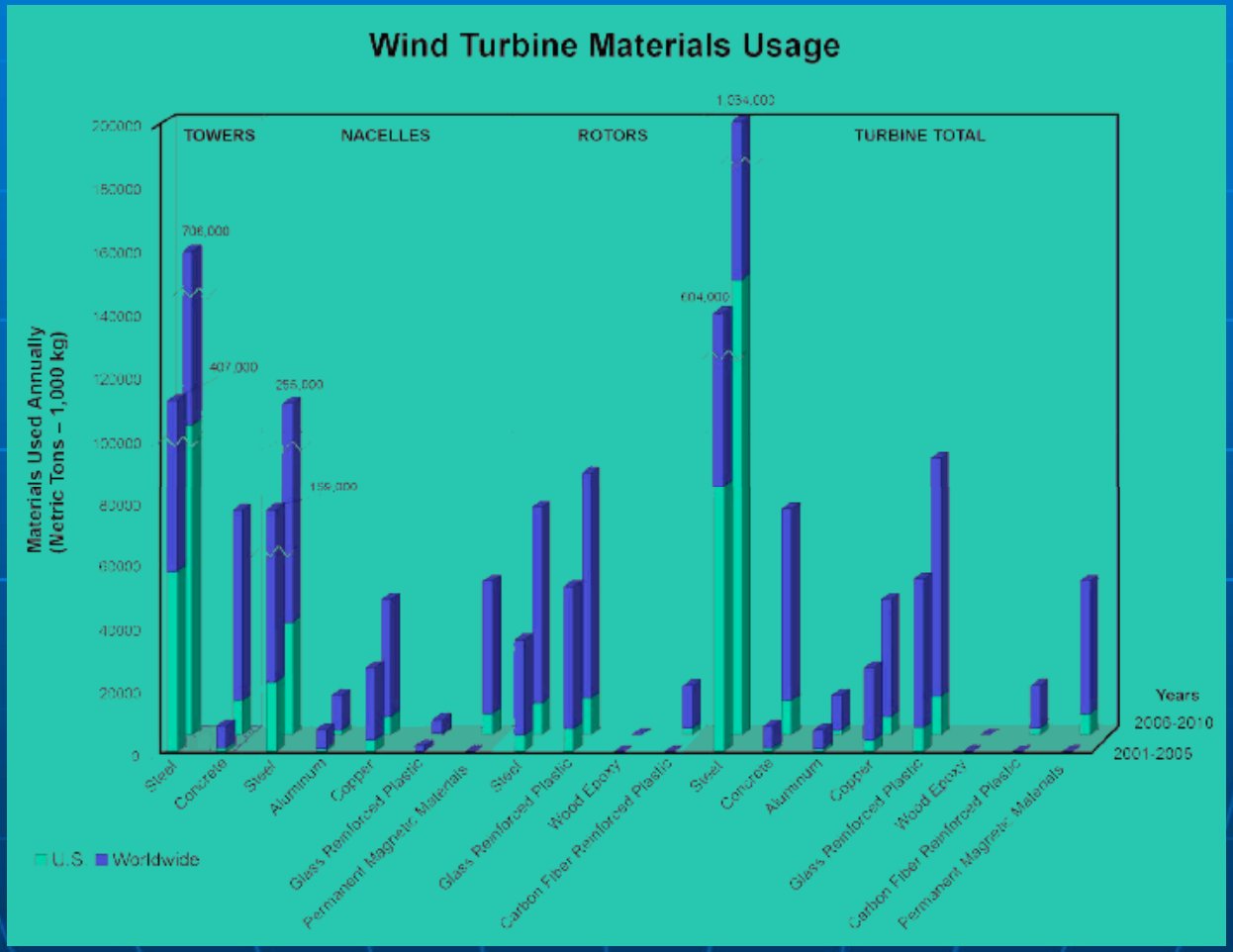
Impacts Finding

- Renewable electricity technologies are attractive since they generally have inherently low life-cycle carbon dioxide emissions, other atmospheric emissions and and water use
- Because of the diffuse nature of the resources, they need to be spread over large collection areas but this mitigated by the facts that the land may be used for multiple use and impacts tend to remain localized and not spread beyond the land areas directly in use

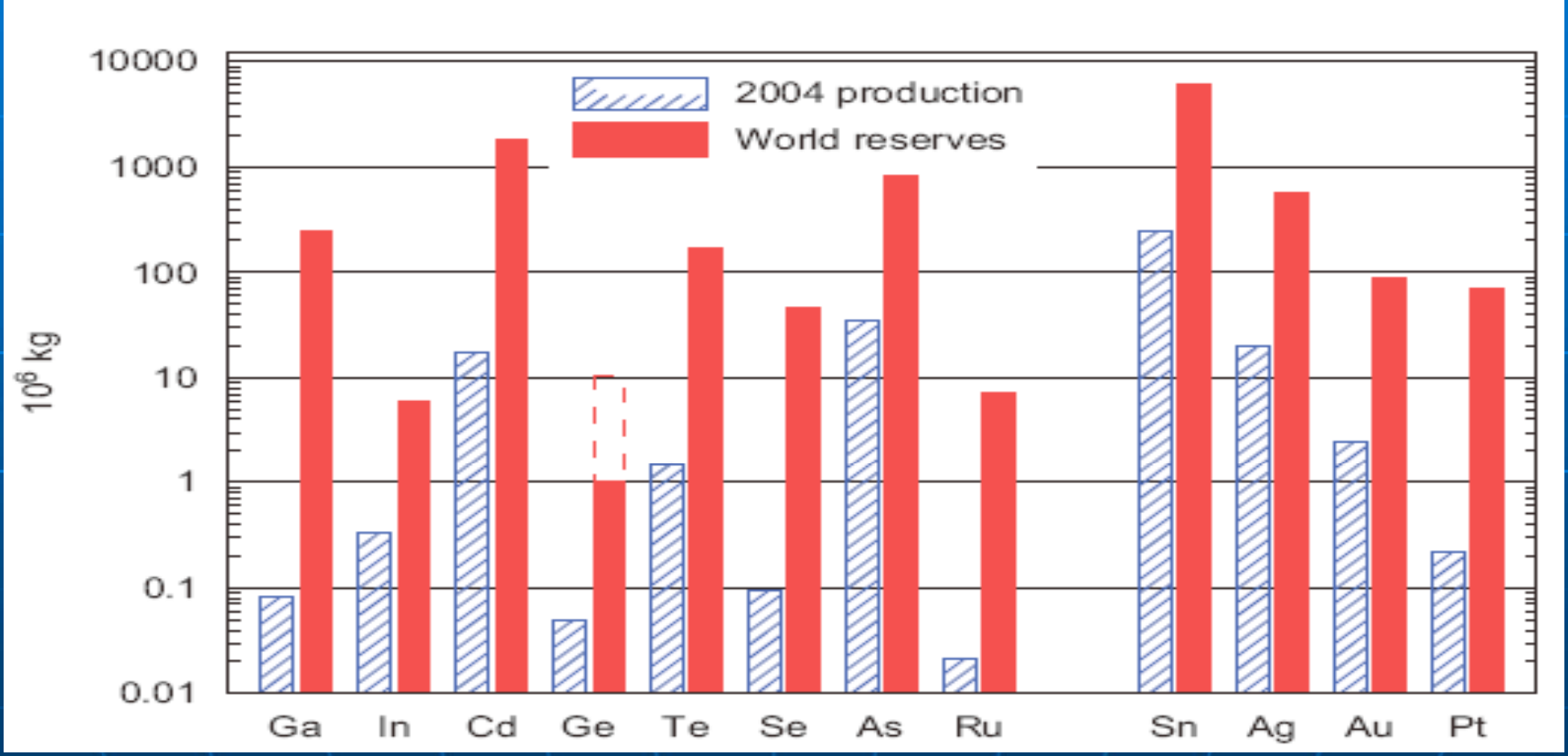
Key barriers impacting the wide-scale deployment and integration of renewable energy sources

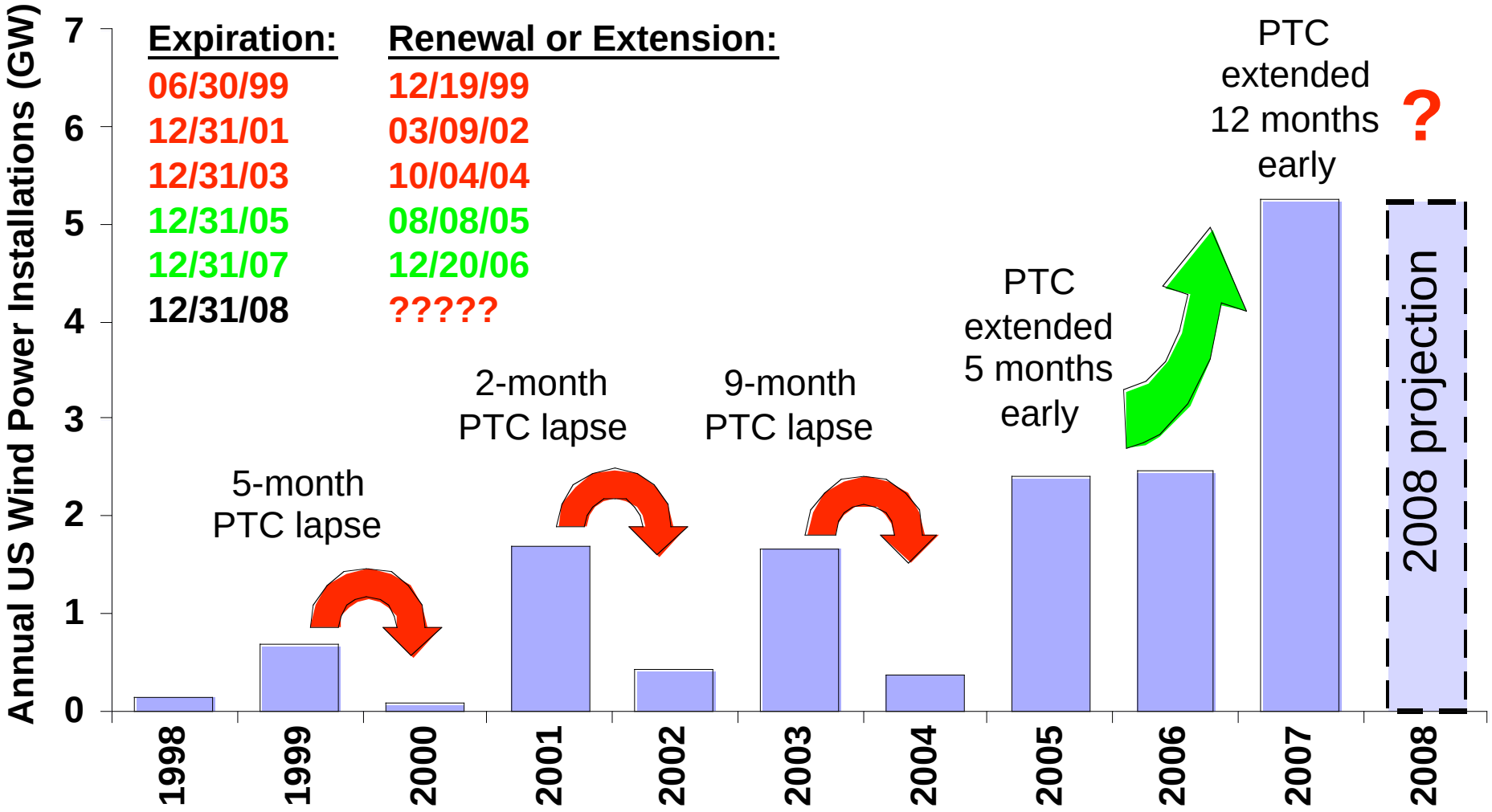
- Relatively high costs
- Performance uncertainty
- Supply of materials
- Inertia
- Perception of risk
- Inadequate workforce
- Complex decision making
- Infrastructure limitations

US and World Wide Wind Turbine Material Usage



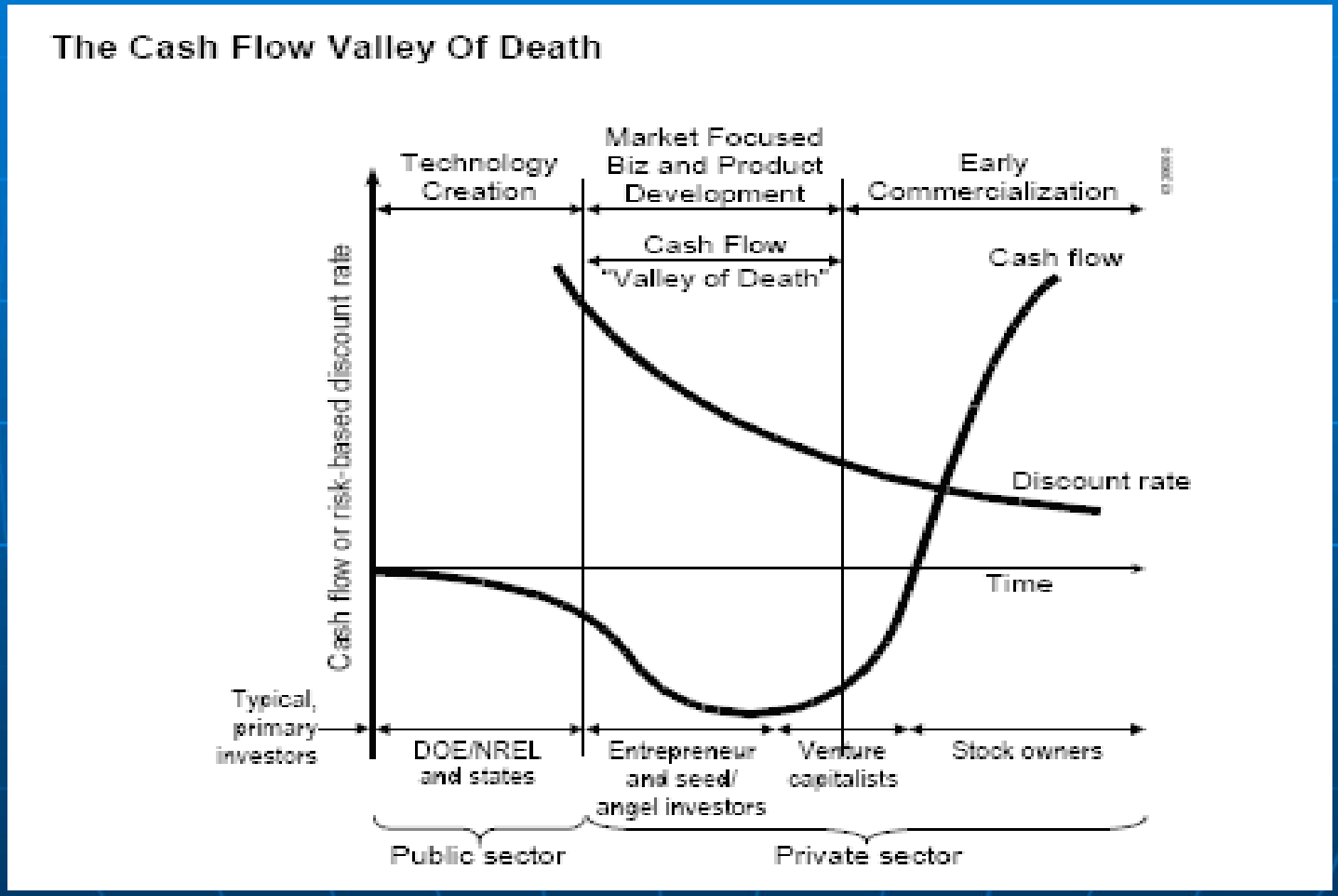
Estimated (2004) Annual Production Levels and World Material Reserves of Raw Materials Used in PV Cell Manufacturing. (Note, non U.S. Reserves of Ge are a Best Guess)

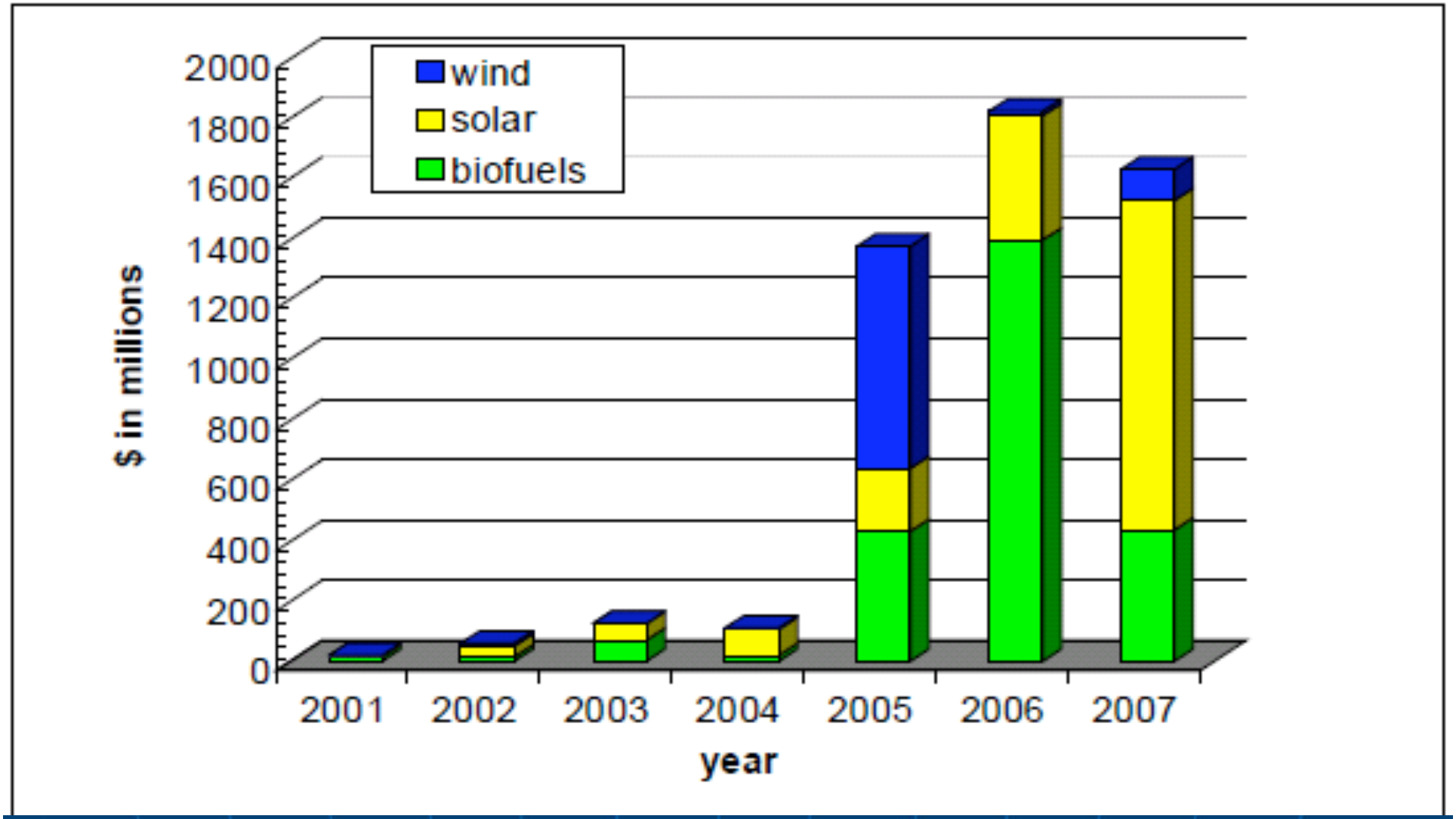




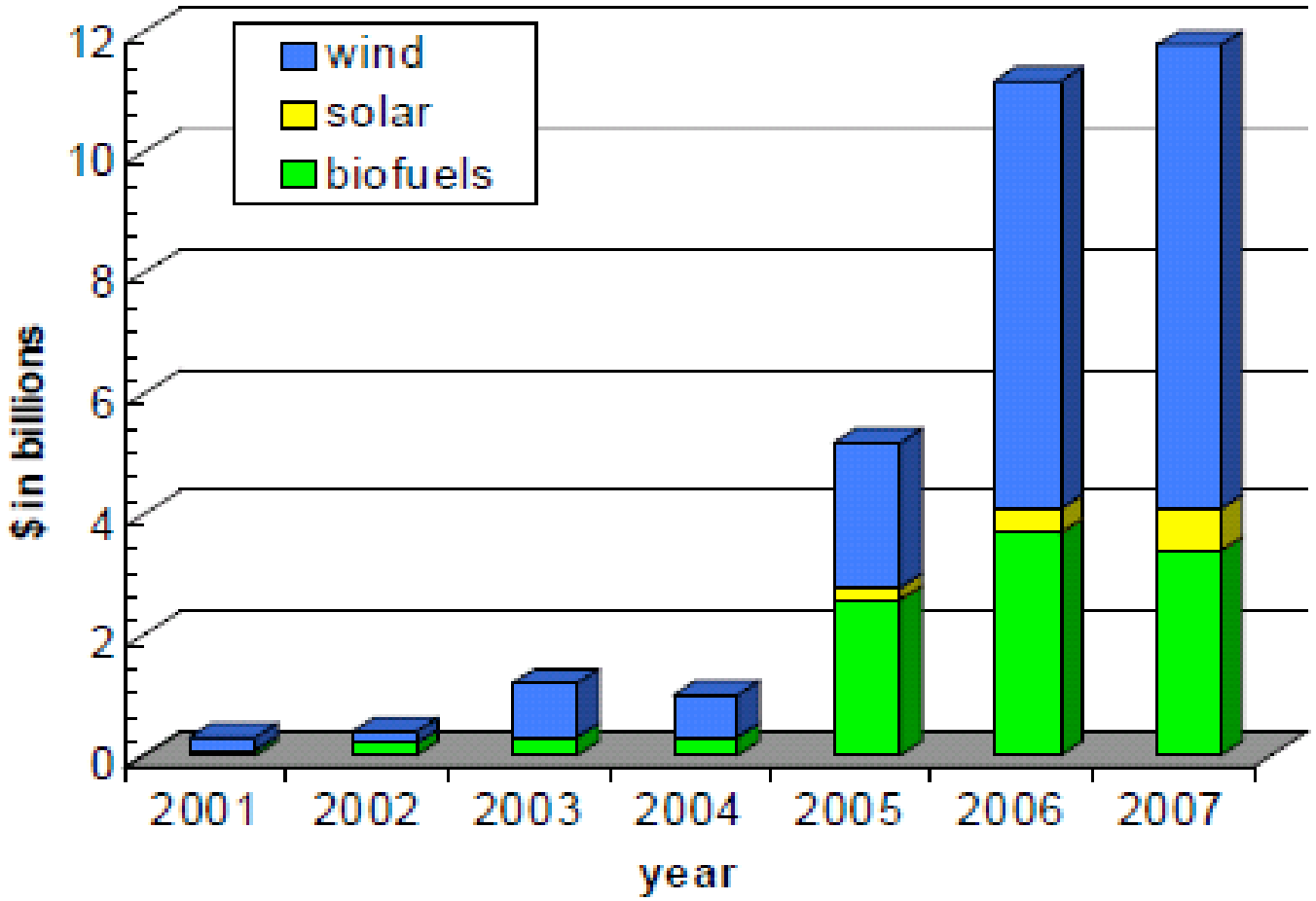
Effects of PTC Expiration and Extension on Wind Power Investment

The Cash Flow "Valley of Death" for the Process from Product Development to Commercialization





Annual Venture Capital Investment in Wind, Biofuels, and Solar

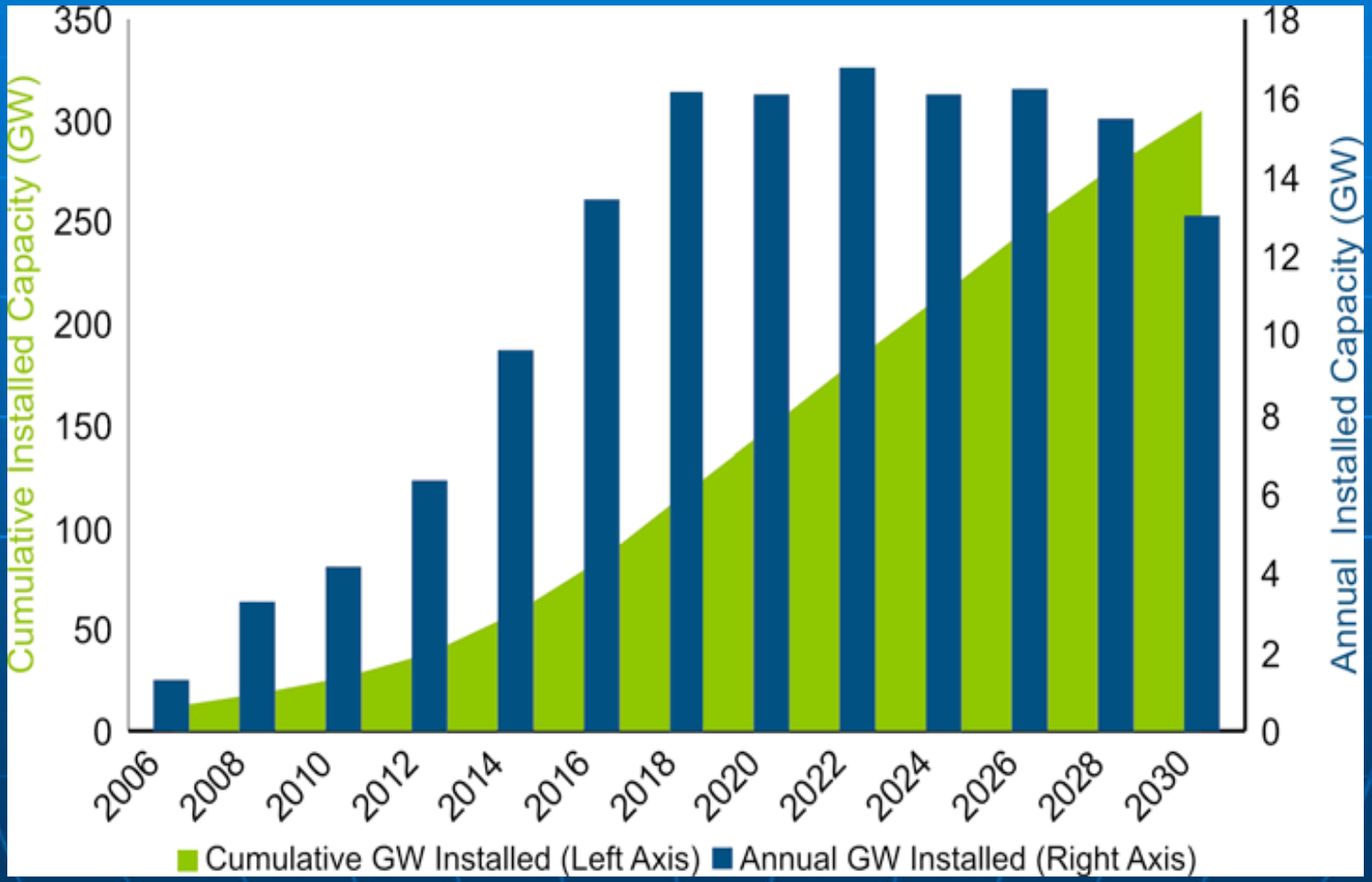


Annual Private Investments in Wind, Biofuels, and Solar

Deployment Finding

- The rate of deployment of renewable technologies will require consistent and long term, public policies and the public, as well as investment in business growth, market transformation
- Improvements in several areas, including labor and workforce enhancements, transmission and distribution grids, and the framework and regulations under which the systems are operated, also are required for widespread deployment

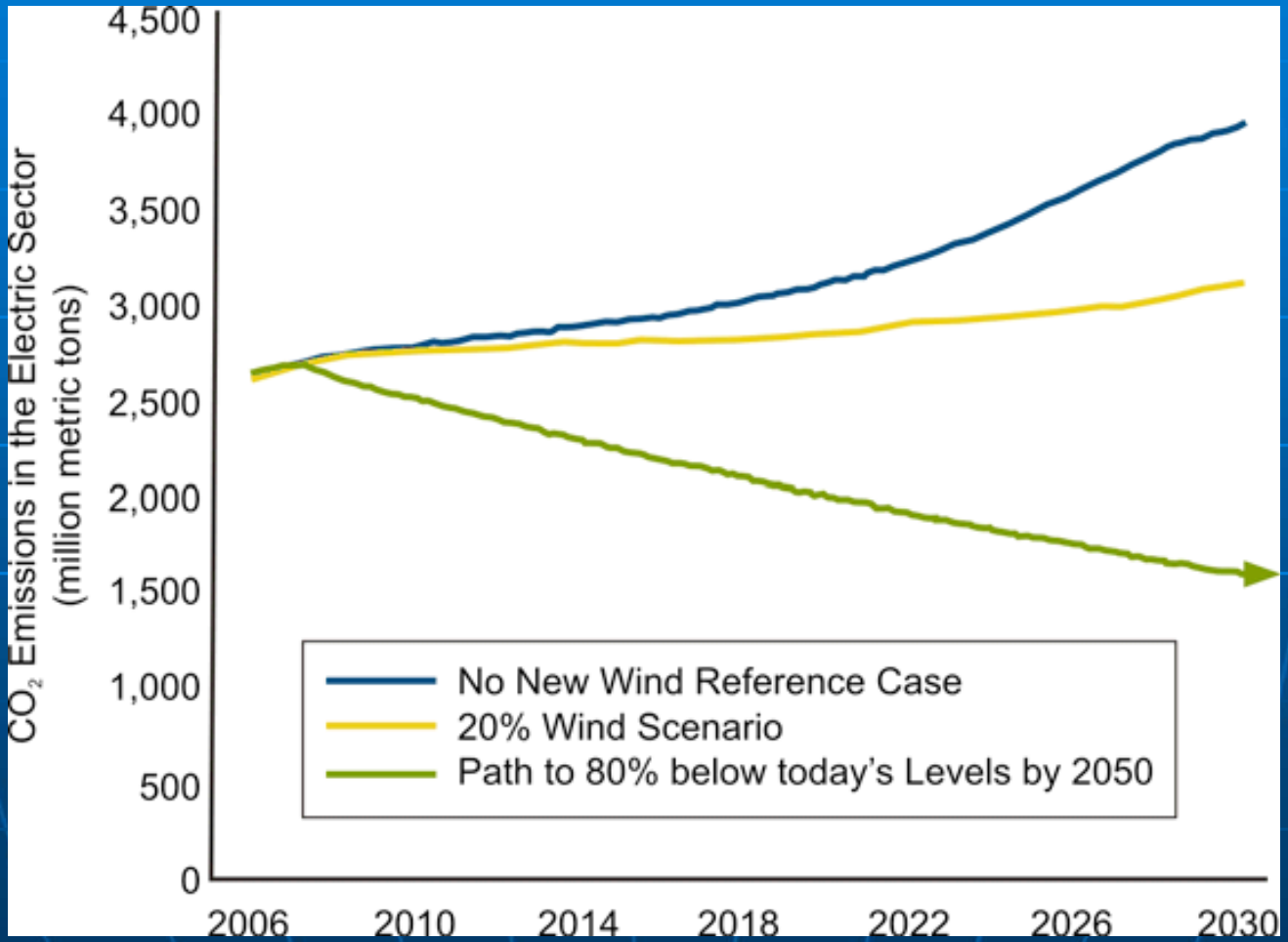
Annual and Cumulative Generation Needs to Achieve 20-percent Wind by 2030



Net Present Value (NPV) Direct Electricity Sector Costs for 20-percent Wind Scenario and No New Wind Scenario (US$2006)

	NPV direct costs for 20-percent wind scenario (billion US$2006)	NPV direct costs for no new wind after 2006 scenario (billion US$2006)
Wind Technology O&M Costs	$51	$3
Wind Technology Capital Costs	$236	$0
Transmission Costs	$23	$2
Fuel Costs	$813	$968
Conventional Generation O&M	$464	$488
Conventional Generation Capital Costs	$822	$905
Total	$2,409	$2,366

CO_2 Emissions Reductions Resulting from 20-percent Wind Scenario Compared to the No-New Wind Reference Case. Also shown is the Trajectory for Reducing CO_2 Emissions by 80%



Percent of the Total Electricity Generation from Renewable Sources from Analysis of CSA Scenarios

	2020			2030		
	Reference	Core Case	High Cost	Reference	Core Case	High cost
Hydropower	6.87	7.18	7.37	6.23	6.63	7.13
Geothermal	0.55	0.98	1.21	0.65	1.14	1.45
Municipal waste	0.44	0.56	0.65	0.44	0.54	0.89
Biomass	1.79	5.54	5.30	1.72	3.74	4.58
Solar	0.059	0.06	0.061	0.066	0.068	0.095
Wind	2.33	5.76	6.73	2.57	5.63	13.94
Total renewable	12.0	20.1	21.3	11.6	17.8	28.1
Total non-hydro renewable	5.13	12.92	13.93	5.37	11.17	20.97

Average Annual Growth Rate for Each Renewable Energy Source from 2005-2030 for Two CSA Scenarios and AEO2008 Reference Case in Percent

	Hydropower	Geothermal	Municipal waste	Biomass	Solar	Wind
Reference	0.49	3.05	1.88	9.45	18.51	8.78
Core Case	0.57	5.38	2.93	18.02	18.51	12.03
High Cost	0.71	6.34	5.08	21.94	19.4	15.85

Scenarios Finding

- The technological readiness of conventional hydropower, wind, solar photovoltaics and concentrating solar power, hydrothermal geothermal and biopower technologies are such that they could comprise up to 20 percent of all electricity generation by 2020, up from about 10 percent today
- By 2035, further accelerated deployment based on current and improved technologies, and supportive public policies, could result in non-hydro renewables could collectively provide 20 percent or more of domestic electricity generation

“A diamond with a flaw is better than a pebble without imperfection”

- *Chinese proverb*
- *Gov. Linda Lingle (Hawai’i) on the need to begin moving ahead with renewable energy*