Energy-Technology Innovation for Sustainable Prosperity

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Outline of the presentation

- The meaning of sustainable prosperity
- The energy-environment-prosperity nexus
- The roles of technological & institutional innovation
- The energy-technology innovation system and indices of its performance
- Insights and recommendations from the past decade’s work
- What we still don’t know

Abbreviations used in this presentation

E = energy

ER&D = E research and development

ERD&D = E research, development, & demonstration

ERD^3 = E research, development, demonstration, & deployment

GDP = gross domestic product

GWP = gross world product

ppp = purchasing-power parities

The meaning of “sustainable prosperity”

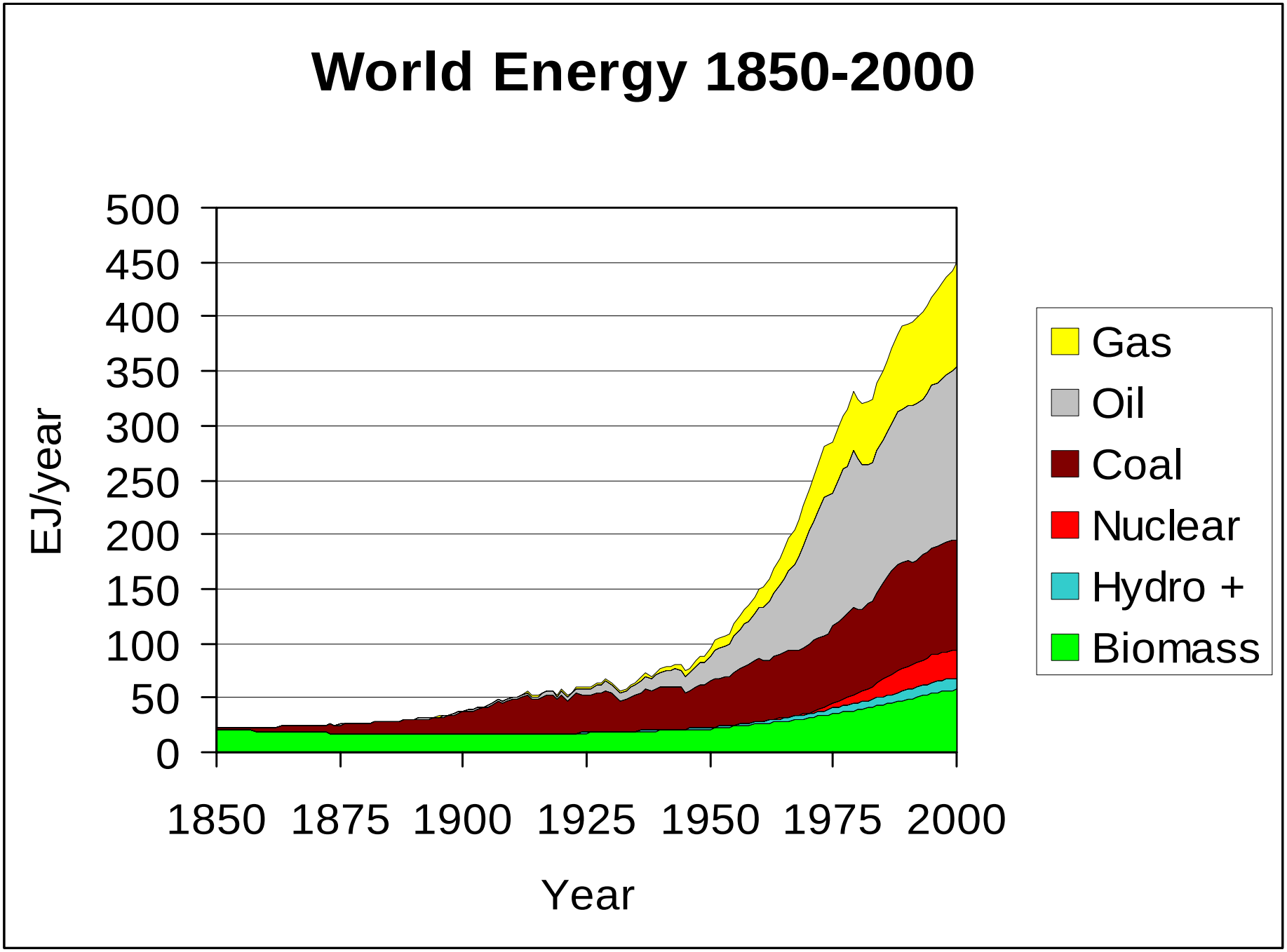
- Development should be thought of as the process of improving the human condition in all its aspects, not only economic but also environmental, political, social, cultural...

- Sustainable development should mean doing so by means and to end points that are consistent with maintaining the improved conditions indefinitely.

- Sustainable prosperity means sustainable development where prosperity does not yet exist and maintaining and expanding prosperity sustainably where it already does.

The energy-environment-prosperity nexus

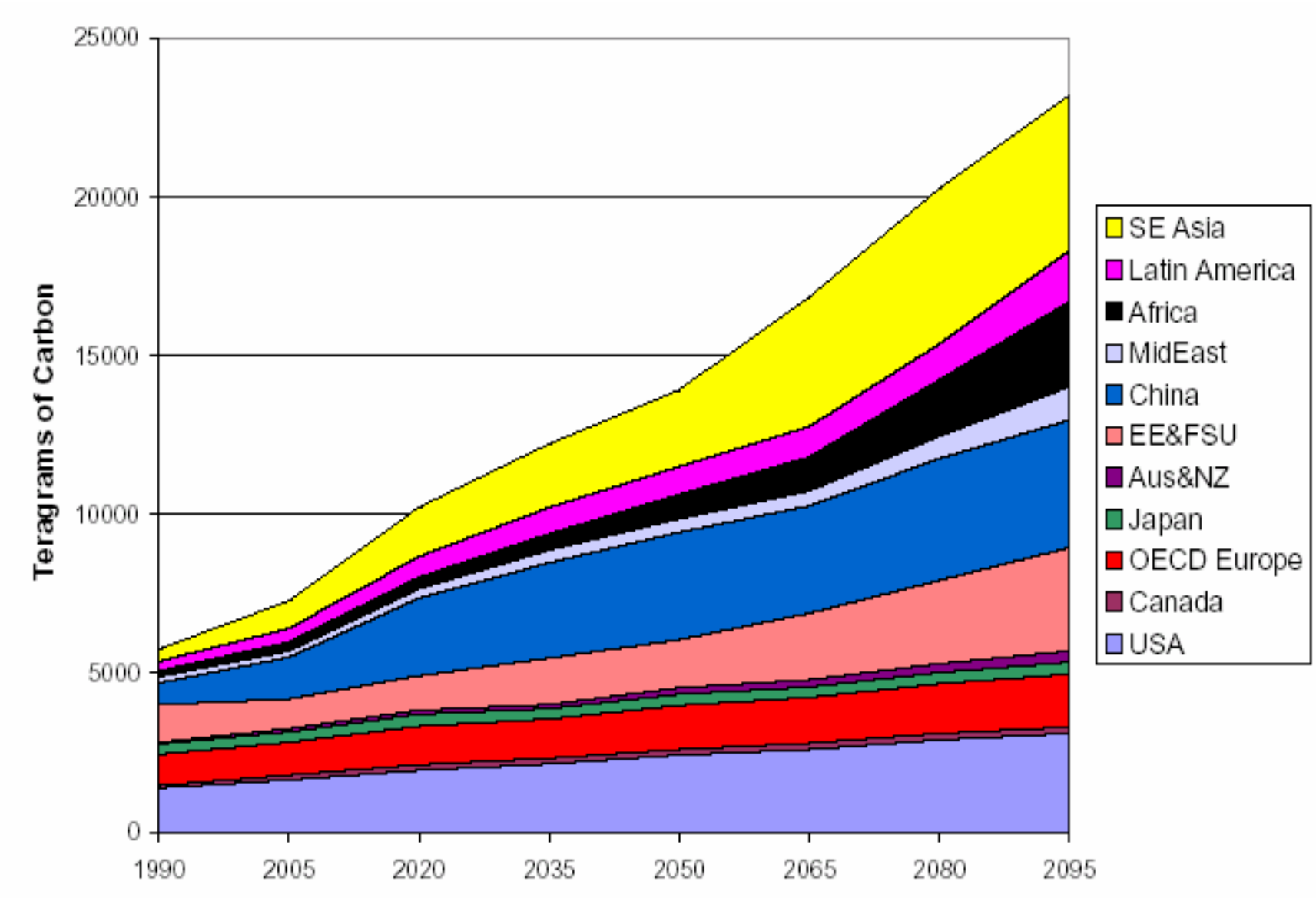
- Energy in convenient and affordable forms is essential to meeting basic human needs (heating, cooking, purifying water, lighting…) and an indispensable ingredient of economic progress (through energy for agriculture, manufacturing, transport…).
- Today's industrialized nations fueled their rise to prosperity with cheap and convenient coal, oil, and natural gas;
  - but their having done so has used up much of the cheap oil and gas, leading to rising prices and conflicts over access to what remains;
  - and the emissions from the oil, gas, and coal combined that were burned on the road to prosperity that these nations traveled have made energy supply the world's worst source of pollution, even before the majority of the world's population have had a chance to travel this path.


World Energy 1850-2000
500
450
400
350
300
250
200
150
100
50
0
EJ/year
1850
1875
1900
1925
1950
1975
2000
Year
Gas
Oil
Coal
Nuclear
Hydro +
Biomass

The nexus (continued)

- In the world of 2005, 80 percent of civilization's energy continues to come from fossil fuels.
- But conventional oil and natural gas are too scarce and will be too costly to fuel the 21st century economic growth that achieving prosperity for the whole world will require.
- And the far more abundant solid fossil fuels – coal, tar sands, oil shale – are so much dirtier, if current technologies are used to harvest and burn them, that relying on these fuels & technologies to power this growth risks environmental catastrophe.

Projected carbon emissions by world region



The nexus (continued)

- The greatest technological challenge of the 21st century will be figuring out how to provide the affordable energy needed to sustain prosperity where it already exists -- and to create and sustain it where it doesn't – without wrecking the regional and global environmental conditions and processes that, equally with economic conditions and processes, underpin human well-being.

- Vicki Norberg-Bohm understood this with great clarity, and it motivated and shaped her exceptionally productive and insightful work on energy-technology innovation.

ROLE OF TECHNOLOGICAL INNOVATION

ONLY WITH IMPROVED TECHNOLOGIES CAN WE

- efficiently, cleanly, & cost-effectively use local renewable energy resources to meet basic needs & fuel sustainable employment in the rural sectors of developing countries
- limit oil imports without incurring excessive economic or environmental costs
- improve urban air quality while meeting growing demand for automobiles
- expand the use of nuclear energy while reducing accident and proliferation risks
- use the world's abundant coal resources without intolerable impacts on regional air quality, acid rain, and global climate

ROLE OF INSTITUTIONAL INNOVATION

ONLY WITH IMPROVED INSTITUTIONS CAN WE

- provide the scale, continuity, and coordination of effort in energy research & development needed to realize in a timely way the required technological innovations
- gain the potential benefits of market competition in the electricity sector while protecting public goods (including provision of basic energy services to the poor, preservation of adequate system reliability, and protection of local and regional environmental quality)
- ensure the rapid diffusion of cleaner and more efficient energy technologies across the least developed countries and sectors
- devise and implement an equitable, adequate, and achievable cooperative framework for limiting global emissions of greenhouse gases

Elements of the E-innovation system

LINKS IN THE "CHAIN"

- basic research
- applied research
- development
- demonstration
- diffusion / deployment

PERFORMERS

- governments & their labs
- firms & consortia of these
- universities
- NGOs
- partnerships among these

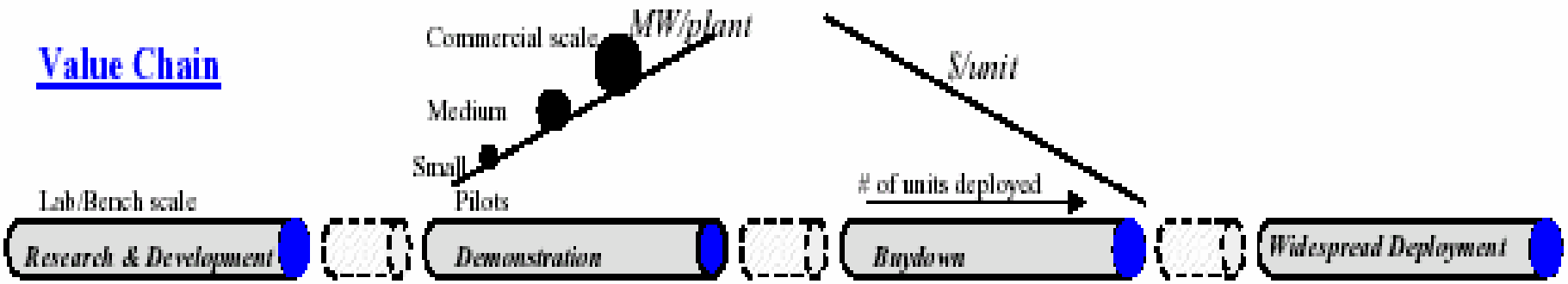
FUNDERS

- national gov'ts, consortia
- state, local gov'ts, consortia
- firms & consortia of these
- private foundations
- universities
- partnerships
- individuals

MEASURES

- spending
- publications & patents
- technology performance (cost, efficiency, emissions)

“Value” chain for ERD3 (from PCAST 1999)



Barriers

- Difficulty of capturing benefits of R & D
- Long time horizons
- High risks

- Difficulty of capturing benefits of demonstration
- Long time horizons
- Risks
- Large capital costs

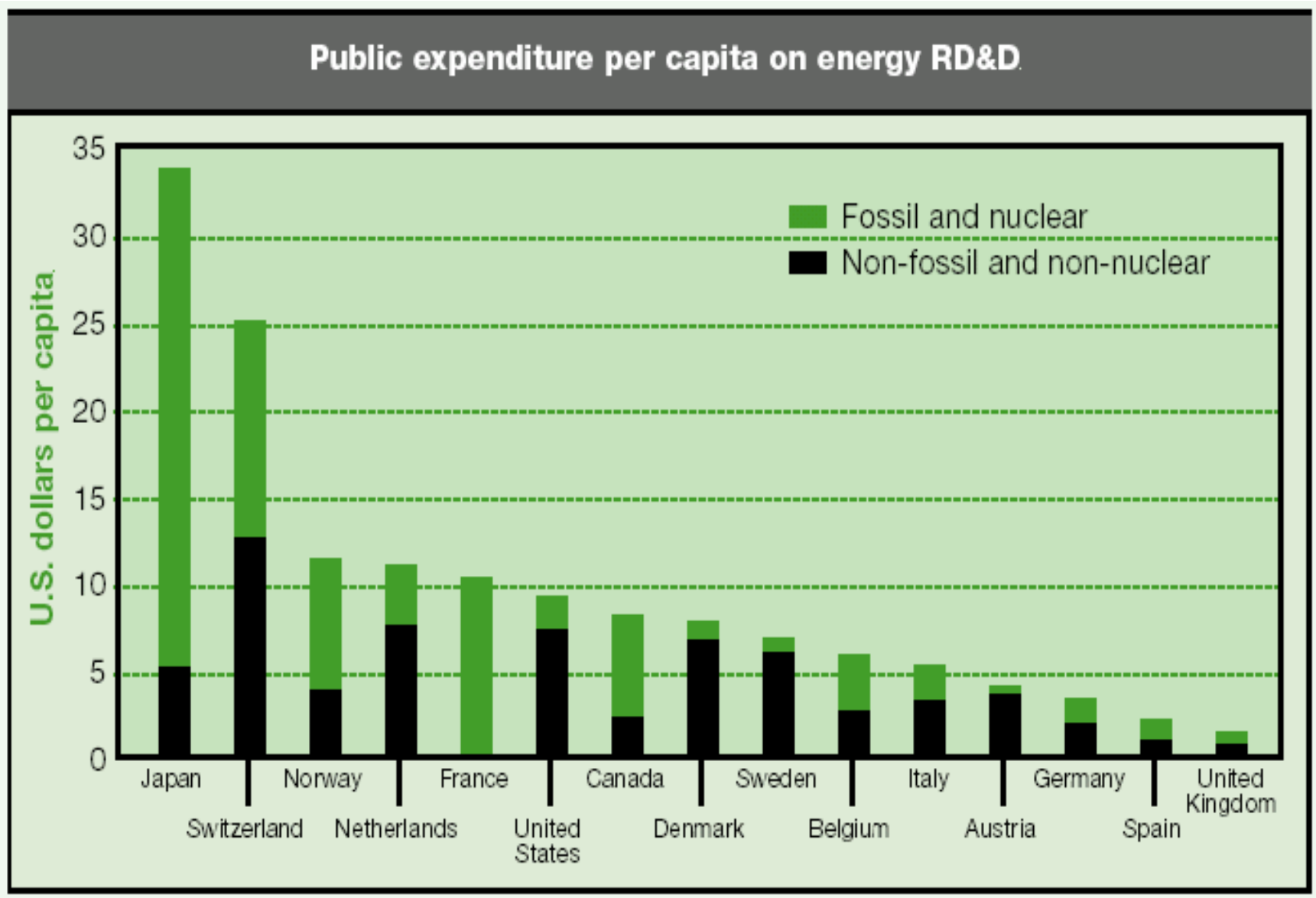
- Financing of incremental cost
- Cost uncertainty
- Technological and other risk

- High transaction costs
- Price for competing technologies doesn’t include externalities;
- Lack of retail finance
- Lack of information

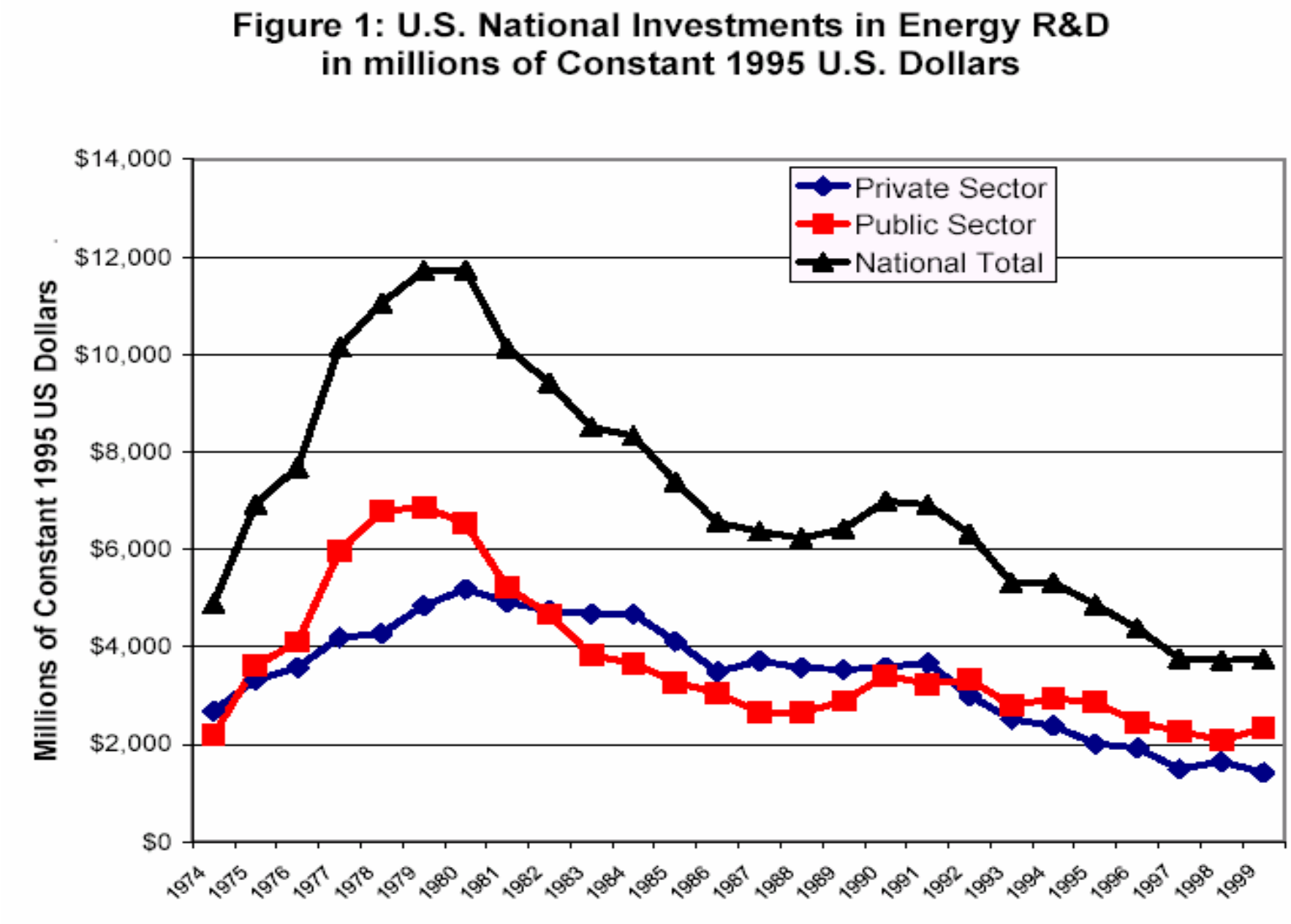
Spending for E and ER&D in perspective

(estimates for 2001 in millions of 2001 US$, converted at ppp)

World economic product	46,000,000
Value of E-system capital stock	12,000,000
Retail expenditures on energy	3,000,000
Annual investment in E-supply system	400,000
World expenditure on all R&D	740,000
US expenditure on all R&D	270,000
World expenditure on ER&D	15,000
US expenditure on ER&D	4,000



World Energy Assessment, 2000



From J. Dooley, US National Investment…, July 2001

Emerging insights of the 1990s about energy-technology innovation

- role of interactions among fundamental research, applied research, development, demonstration, and deployment
- importance of mechanisms for demonstrating advanced energy technologies & driving costs down to competitive levels
- appropriate roles of the public and the private sector in innovation processes…and the value of public-private partnerships
- need to develop a broad-based portfolio of energy RD3 balanced across technologies, sectors, time frames, risks
- leverage from technologies that address multiple goals (e.g., oil-import reduction, air-quality improvement, greenhouse gas abatement)
- necessity of addressing many of these issues in a global context.

The PCAST energy-technology innovation studies

(PCAST = President's Committee of Advisors on Science & Technology)

1997: Fed'l Energy R&D for the Challenges of the 21st Century

- 5 PCAST members & 16 other panelists from all energy sectors + non-energy "honest brokers"; conclusions unanimous;
- focused on applied-energy-technology R&D in USDOE.

1999: Powerful Partnerships

- 4 PCAST & 11 other panelists, similar composition to 1997 panel; conclusions again unanimous;
- focused on international ERD^3 cooperation – not just R&D but also demonstration & deployment – including efforts of EPA, USAID, Depts of Commerce and State, as well as DOE.

http://www.ostp.gov/PCAST/pcastdocs93_2000.html

Recommendations of the 1997 PCAST study

- Ramp up DOE's applied energy-technology R&D spending from $1.3 B in FY1997 and FY1998 to $2.4 B in FY2003 (as-spent dollars), with circa 80% of the increases in efficiency & renewables. Cut funding for short-term coal R&D better done by industry.
- Expand research in "basic energy sciences" & improve DOE internal communication among technology "stovepipes" and between stovepipes & BES. Undertake "portfolio" analysis.
- Develop a commercialization strategy complementing public investments in R&D, emphasizing public-private partnerships
- Increase US participation in international cooperation on ER&D & commercialization, esp with developing countries.

The case for ERD^3 cooperation (PCAST 1999)

BENEFITS FROM ENERGY-TECHNOLOGY IMPROVEMENTS IN ONE'S OWN COUNTRY

- lower cost & improved reliability of energy services
- reduced need for energy imports
- reduced local & regional environmental impacts of energy
- reduced risks from domestic nuclear-energy operations

BENEFITS FROM ENERGY-TECHNOLOGY IMPROVEMENTS IN ALL COUNTRIES

- reduced world oil prices and vulnerability
- reduced transboundary pollution & greenhouse gases
- reduced transboundary nuclear risks
- economic & security benefits of sustainable development

CORRESPONDING INCENTIVES FOR COOPERATION

- increase the pace & reduce the cost of energy-technology innovation for application in one's own country
- address the global dimensions of energy challenges by accelerated development & deployment of innovations worldwide

Recommendations of the 1999 PCAST study

Increase US federal funding for international cooperation on ERD^3 from $250M (1997) to $500M in FY2001, $750M in FY2005, to be spent on…

FOUNDATIONS OF INNOVATION & COOPERATION

capacity building, energy-sector reform, energy-technology demonstration and cost buy-down, financing for accelerated deployment

COOPERATION ON ERD^3 IN ENERGY END-USE EFFICIENCY

building-sector standards, design software, grant & lending programs; transport-sector emissions standards, vehicle testing, R&D on buses and 2-3 wheelers; industrial-sector roadmaps, training, joint ventures; combined heat and power education, training, barrier reduction

COOPERATION ON ERD^3 ON ADVANCED ENERGY SUPPLY

renewables, C capture & sequestration, nuclear fission & fusion

IMPROVEMENTS IN MANAGEMENT OF ERD^3 COOPERATION

interagency task force, improved accountability, multi-year funding

Recommendations of the 2001 WEC Study Group

- Energy RD&D spending and technology transfer need to be increased in almost every country, and internationally.
- Priorities within this effort should go to technologies that…
  - increase efficiency of conversion & end use
  - promote deployment of locally appropriate renewables
  - respond to public concerns about nuclear energy
  - allow carbon sequestration
- Regional collaboration on ERD&D should be encouraged.
- Governments should…
  - produce more detailed ERD&D data;
  - review balance of long-term E research vs short-term development;
  - require better ERD&D data from the private sector;
  - promote increased private-sector ERD&D;
  - use market-like mechanisms to encourage renewables (e.g., RPS).

Technology-innovation recommendations of the National Commission on Energy Policy (2004)

- Revise the US tax code to increase private-sector incentives to invest in energy research, development, demonstration, & early deployment.
- Roughly double annual real US federal expenditures for energy research, development, & demonstration (ERD&D) in next 5 years (reaching ~3.3 billion 2004$ per yr in 2010).

  Within this effort, triple the funding for international cooperation on ERD&D, to $750 million per year.
- Complement the increased RD&D activity with a tripling of federal expenditures supporting accelerated deployment of the most promising technologies that successfully pass the demonstration phase (reaching ~$2 billion/year in 2010).

Despite the importance of energy-technology innovation, our understanding of how it works is limited

- The simplest measure of “inputs” to the innovation process is outlays for energy R&D, but even these are poorly characterized – boundaries are fuzzy, private-sector data are incomplete.
- “Output” measures for R&D – publications, patents, performance measures for technologies, sales – are often difficult to correlate with specific inputs.
- The innovation “chain” – basic research, applied research, development, demonstration, diffusion – is more complex than once thought because of feedbacks and blurred boundaries.
- Progress from basic research to technology diffusion increasingly involves partnerships & interactions, within and among sectors (firms, governments, universities, NGOs) that have scarcely been mapped, not to say analyzed and understood.

“Learning by doing” is an important part of technology innovation, but how it works and how it can be predicted remain inadequately understood.

- The phenomena that can lead to declining unit cost for a given technology over time are diverse and interactive, including not only “learning by doing” in the strict sense of improving through practice in building and/or operating exactly the same devices, but also evolutionary or even radical improvements in design or manufacturing processes or the combination of these, resulting from interactions of learning by doing, learning by using, and R&D.
- It remains difficult to sort out these phenomena analytically, for a particular technology, in ways that permit identifying leverage points for improving progress ratios, or even predicting future progress ratios from past ones (hence predicting investments needed to reach a specified cost or performance target).

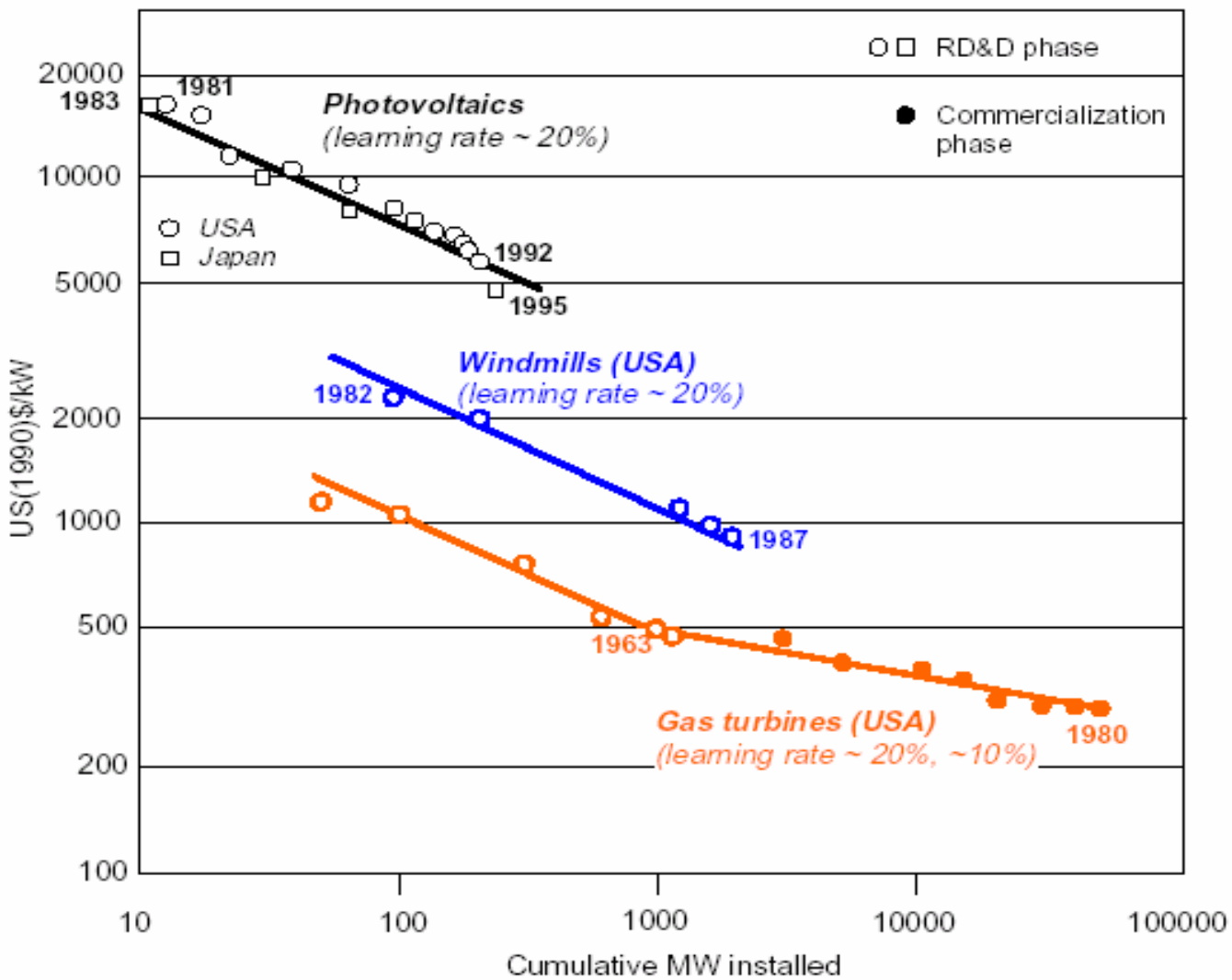


Figure 3.6: Learning Curve Relationships for Photovoltaics, Wind Generators, and Gas Turbines. All three have similar learning curves; however, after 1963 the gas turbine learning curve increased substantially, indicating attenuated experience effects. Note that gas turbines also have fuel costs and associated capital investment that are not shown here. Source: IIASA/WEC (1995).

These shortcomings in our understanding imperil effective policy-making.

- **The lack of detailed understanding of how incentives for and investments in energy-technology innovation translate into actual progress in the improvement of energy technologies and the deployment of the improved versions in the real world is a handicap to the formulation of effective energy-innovation strategies in the private sector & government alike.**
- **Among other difficulties, lack of knowledge of how energy-technology innovation actually works has led to inadequate representation of the innovation process in the energy-economic computer models used to forecast the results of different policy choices.**
- **Attempts to represent innovation processes more realistically indicate that conventional models systematically overestimate the economic cost of meeting ambitious targets for reducing greenhouse-gas emissions from the energy system. The effect is even larger when innovation is more realistically represented for demand-side technologies as well as for the supply side.**

A closing observation

- Vicki Norberg-Bohm was a key contributor to cutting-edge research on the mechanisms of innovation and learning aimed at closing these critical gaps in our understanding.
- This important field of study misses her badly, as do all who knew her.