The Economic, Environmental, & National Security Challenges of Energy Supply and the Role of Science & Technology in Addressing Them

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Topics to be covered

- The challenges of energy policy
- The role of improved technology in addressing them
- The two most demanding drivers of energy-technology innovation: oil dependence & climate change
- The character of energy-technology innovation
- Input, output, & outcome measures of innovation performance
- Conclusions about adequacy
- Recommendations from some major studies
- The international-cooperation dimension

THE MULTIPLE AIMS OF ENERGY POLICY

ECONOMIC AIMS

- reliably meet fuel & electricity needs of a growing economy
- limit consumer costs of energy
- limit cost & vulnerability from imported oil
- help provide energy basis for economic growth elsewhere

THE MULTIPLE AIMS (continued)

ENVIRONMENTAL AIMS

- improve urban and regional air quality
- avoid nuclear-reactor accidents & waste-mgmt mishaps
- limit impacts of energy development on fragile ecosystems
- limit greenhouse-gas contribution to climate-change risks

THE MULTIPLE AIMS (concluded)

HOMELAND- & NATIONAL-SECURITY AIMS

- minimize dangers of conflict over oil & gas resources
- avoid spread of nuclear weapons from nuclear energy
- reduce vulnerability of energy systems to terrorist attack
- avoid energy blunders that perpetuate or create deprivation

The problem is NOT that the world is "running out" of energy

- It may be running out of cheaply and reliably deliverable conventional oil and natural gas, in that
  - these energy forms are getting more costly, less reliable;
  - it's not clear for how much longer the rate at which they're extracted can be increased to meet rising demand.
- But energy resources of other types are immensely larger, capable in principle of being expanded to multiples of today's use rates of oil & gas combined:
  - 5-10 times as much coal as conventional oil and gas;
  - 5-10 as much oil shale and unconventional gas as coal;
  - energy potential of U and Th is larger still;
  - harnessing the sunlight falling on 1% of Earth's land area at 10% conversion efficiency would yield 2X civilization's current rate of energy use.

So why is energy policy so difficult?

It’s hard in part because the various economic, environmental, & security aims are often in tension with one another, e.g.

- cost reduction versus modernization & increased reliability
- domestic fossil-fuel production versus environment
- nuclear energy production vs reducing risks of accidents & terrorism

It’s also hard because…

There is no "silver bullet": No known energy option is free of significant liabilities

• oil & gas…	not enough resources?
• coal, tar sands, oil shale…	not enough atmosphere?
• biomass…	not enough land?
• wind & hydro…	not enough sites?
• photovoltaics…	too expensive?
• nuclear fission…	too unforgiving?
• nuclear fusion…	too difficult?
• hydrogen…	an energy carrier, not a source
• end-use efficiency…	needs end-users who are paying attention

The challenges for energy policy are thus…

- to find and implement the best compromise among competing economic, environmental, & security objectives, given the resources & technologies available at the time;
- to promote technological advances over time that reduce limitations of existing energy options, open new options, and reduce the tensions among energy-policy objectives.

These ends cannot be achieved by markets alone, without supplementary policies, because...

- many of the goals relate to public goods (like national security) & externalities (like pollution) that are not priced in markets unless policies achieve this;
- markets often also need other kinds of help to avoid "market failures" from abuse of monopoly power, lack of information, perverse incentives, short time horizons, etc.

Whatever energy-policy objective one is interested in, technological improvements are crucial. They can…

- Reduce the costs of energy end-use forms to consumers
- Further reduce costs of energy services by increasing end-use efficiency
- Increase the productivity of manufacturing
- Reduce dependence on oil in the USA and elsewhere
- Increase the reliability & resilience of energy systems against disruptions
- Minimize the environmental impacts of energy-resource exploration, extraction, and transport
- Reduce the emissions of hazardous air pollutants
- Improve the safety and proliferation resistance of nuclear energy
- Slow the build-up of greenhouse gases
- Enhance the prospects for environmentally sustainable & politically stabilizing economic development

Also, the most difficult problems of <u>conflicting</u> objectives ALL require improved technologies to solve.

That is, only with better technologies can we…

1. reduce oil demand & limit imports without incurring excessive economic or environmental costs
2. improve urban air quality while meeting growing demand for automobiles
3. use abundant coal resources without intolerable impacts on regional air quality & acid rain
4. expand the use of nuclear energy while reducing accident & proliferation risks
5. achieve & sustain economic prosperity worldwide while controlling the risks from global climate change

The policy concomitants of energy innovation

Policy is needed to…

- provide the scale, continuity, & 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
- 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

The two most demanding drivers of energy-technology innovation

- How to reduce the macroeconomic vulnerability arising from our oil dependence overall, and the balance-of-payments & foreign-policy liabilities associated with the part that is imported, despite huge & growing liquid-fuel demands from the transport sector.

- How to providing the affordable energy needed to sustain prosperity where it now exists, and to create and sustain it where it now doesn't, without entraining intolerable disruption of global climate by the emissions from fossil-fuel use.

These would be difficult even if only industrialized countries were involved. But the stakes and difficulties are larger still for developing countries. And the solutions require that we all get it right, because both the oil market and the climate are global.

Magnitude of the challenges: oil

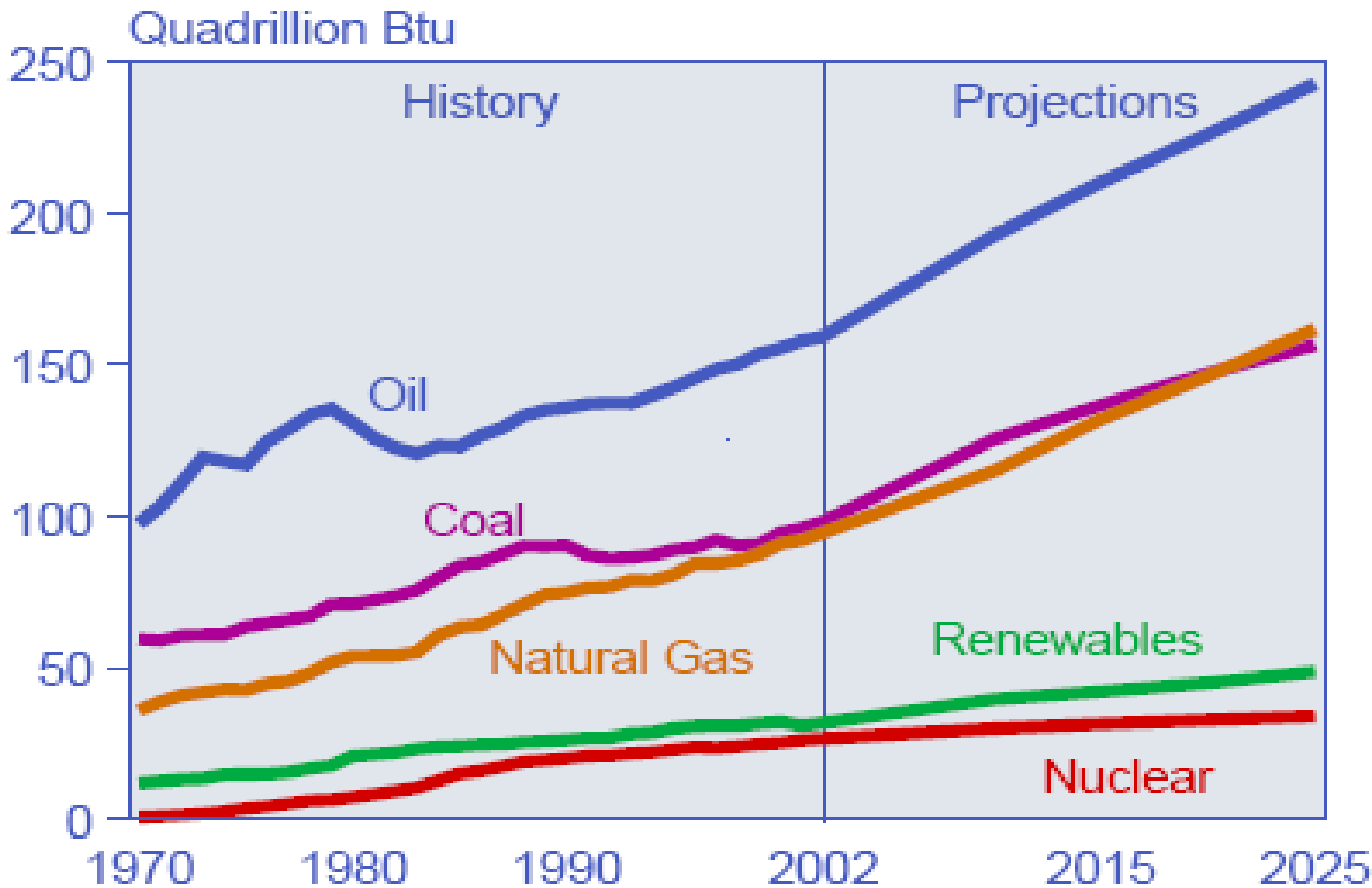
The economic dimension & the national- and international-security dimensions of oil are complicated & connected.

- Economic vulnerability to oil-price shocks depends on *total* oil dependence, not just import dependence.

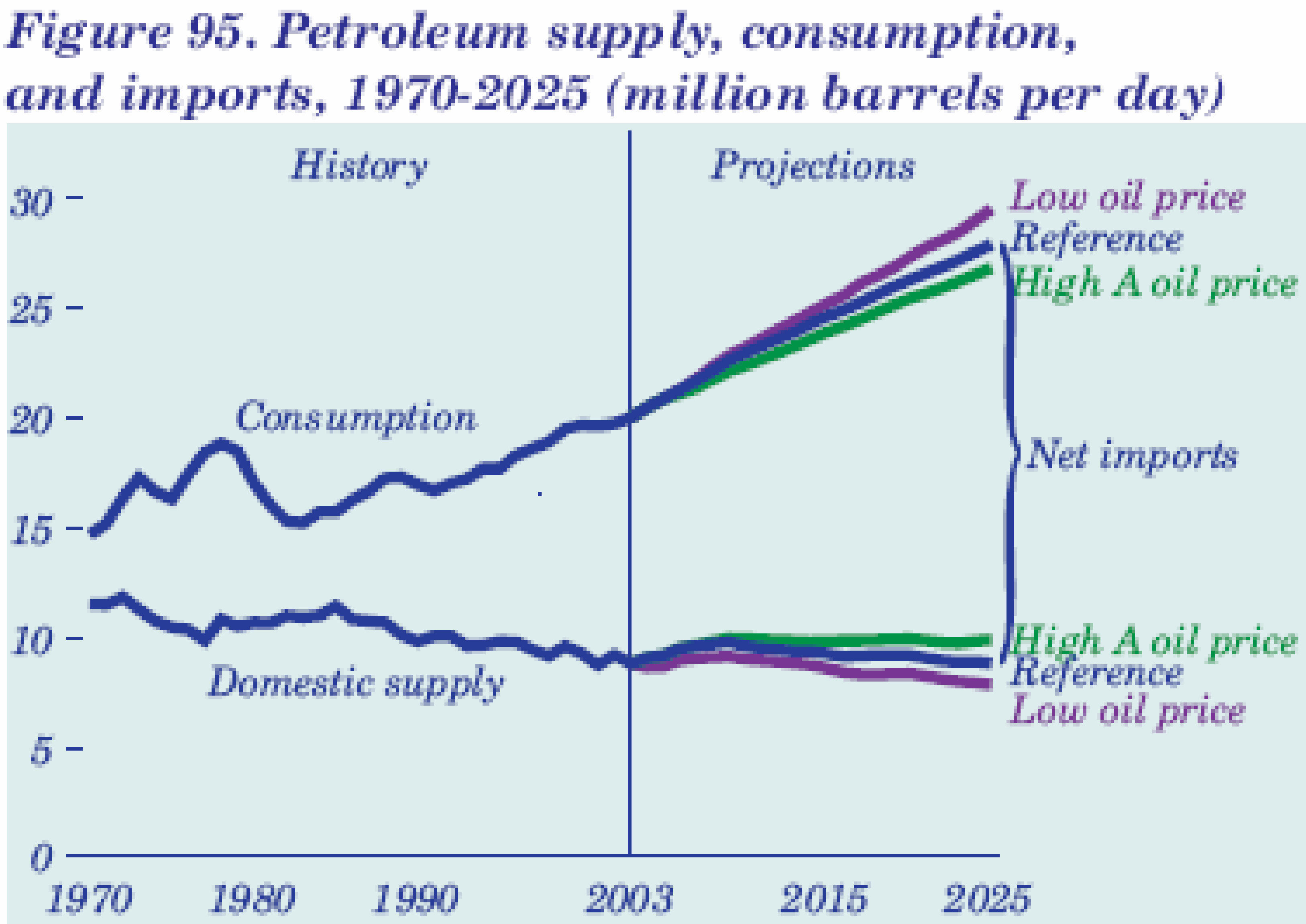
  In a world market, economies pay any increase in per-barrel price on every barrel used, not just on imports. (Import share does matter in terms of balance of payments.)

- Extent of our economic vulnerability affects…
  - likelihood we will resort to military action to try to prevent supply disruptions and the attendant price shocks;
  - our freedom of action in how we pursue a counter-terrorism / homeland-security agenda in our relations with oil-producing countries (some of which export terrorism as well as oil).

Figure 10. World Marketed Energy Use by Fuel Type, 1970-2025



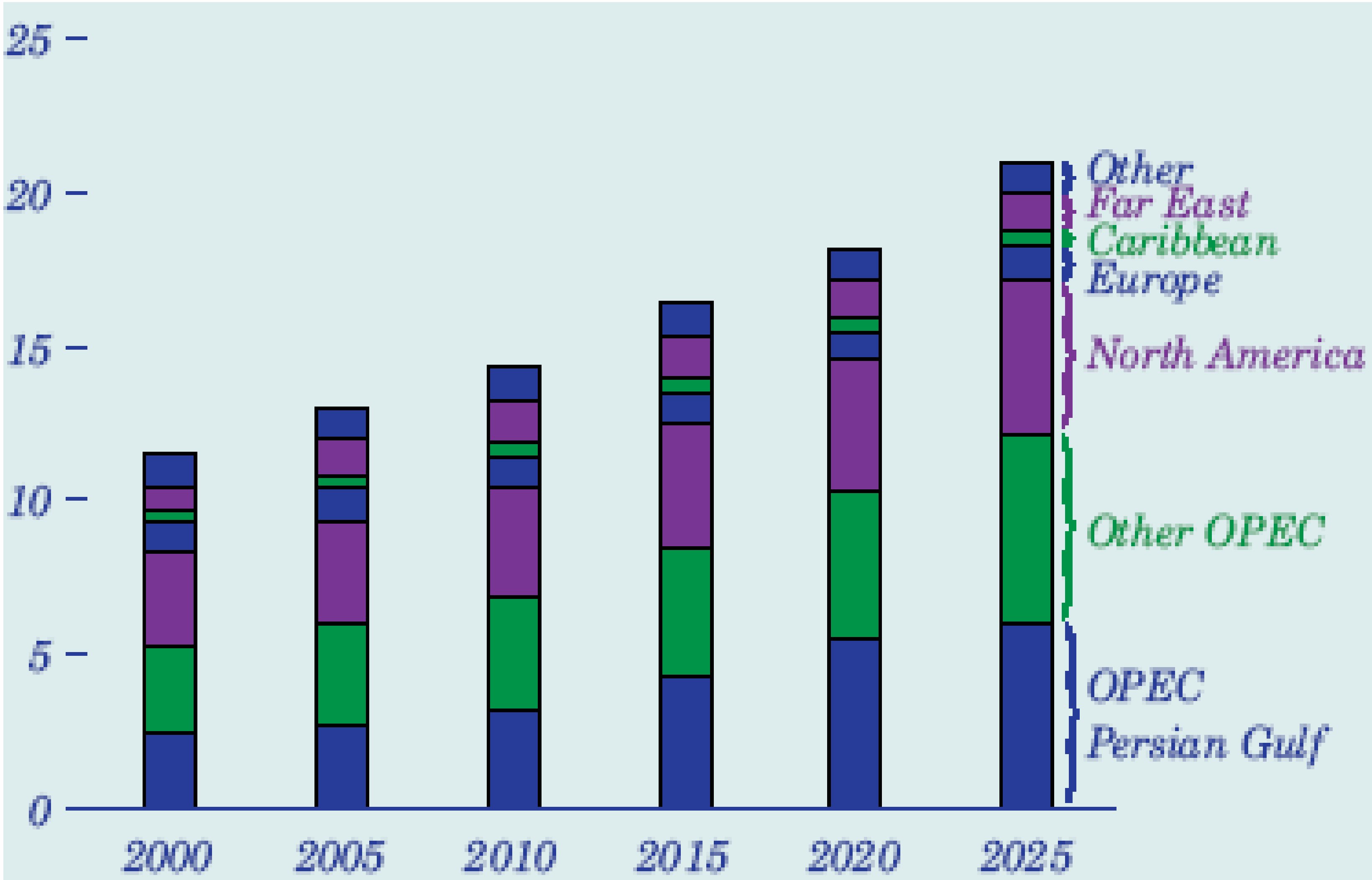
Source: EIA 2005 International Energy Outlook



Source: EIA, Annual Energy Outlook 2005, p 101

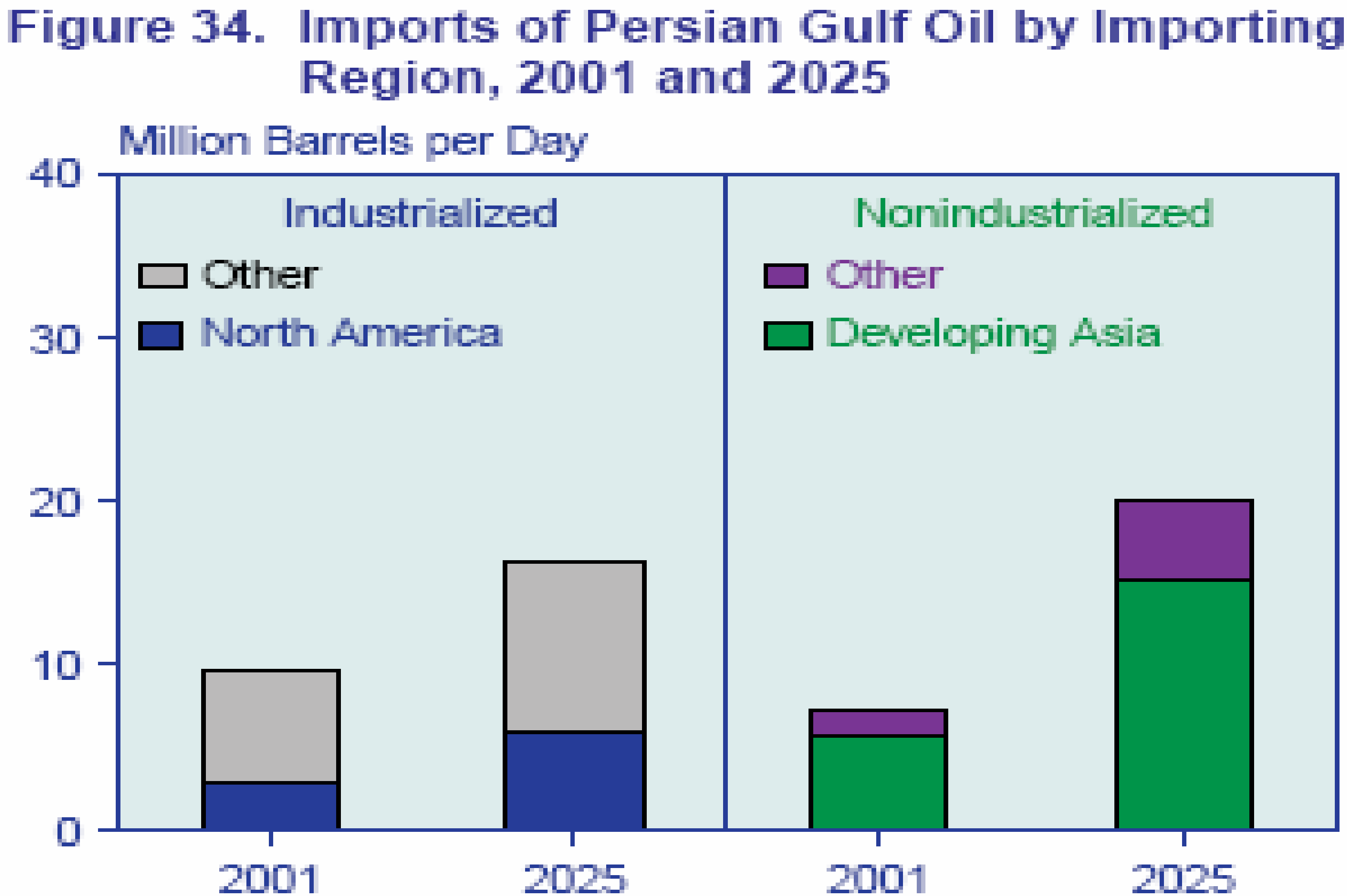
The United States faces growing oil imports in all EIA oil-price scenarios.

Figure 41. U.S. gross petroleum imports by source, 2000-2025 (million barrels per day)



Source: EIA Annual Energy Outlook 2005, p 74

U.S. oil imports are destined to come increasingly from the Persian Gulf



Source: EIA International Energy Outlook 2004, p 41

Developing Asia's dependence on the Persian Gulf is already bigger than North America's and is expected to grow much faster.

Magnitude of the Challenges: Climate change

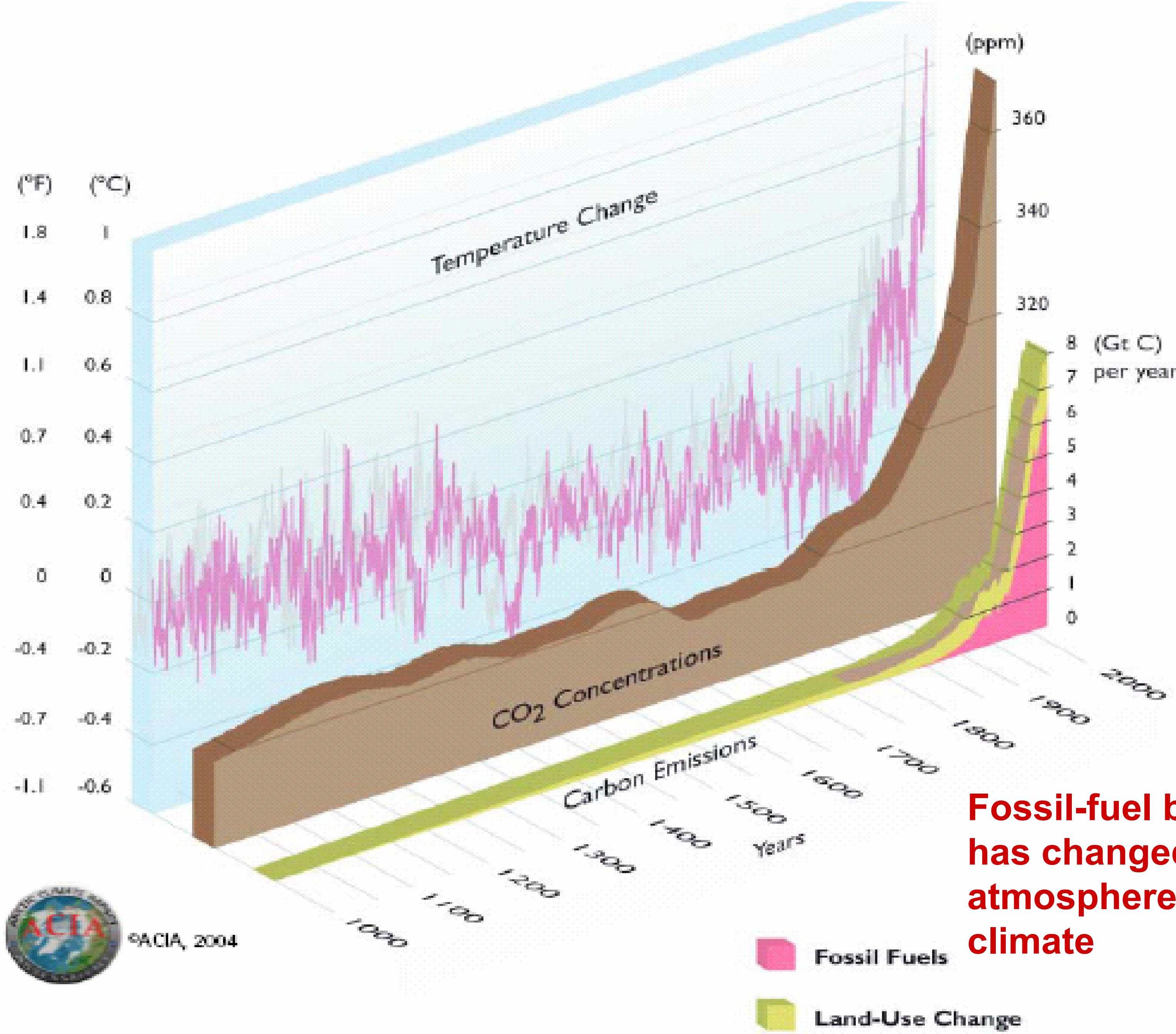
- Climate change is the most dangerous of all human impacts on the environment because climate is the “envelope” within which all other environmental conditions and processes operate.

  Distortions of this envelope of the magnitude that are in prospect are likely to so badly disrupt these conditions and processes as to impact adversely every dimension of human well-being that is tied to environment.

- It’s the most difficult of environmental problems because the main cause of the disruption – emission of CO_2 from fossil-fuel combustion – arises from the process that currently supplies nearly 80 percent of civilization’s energy

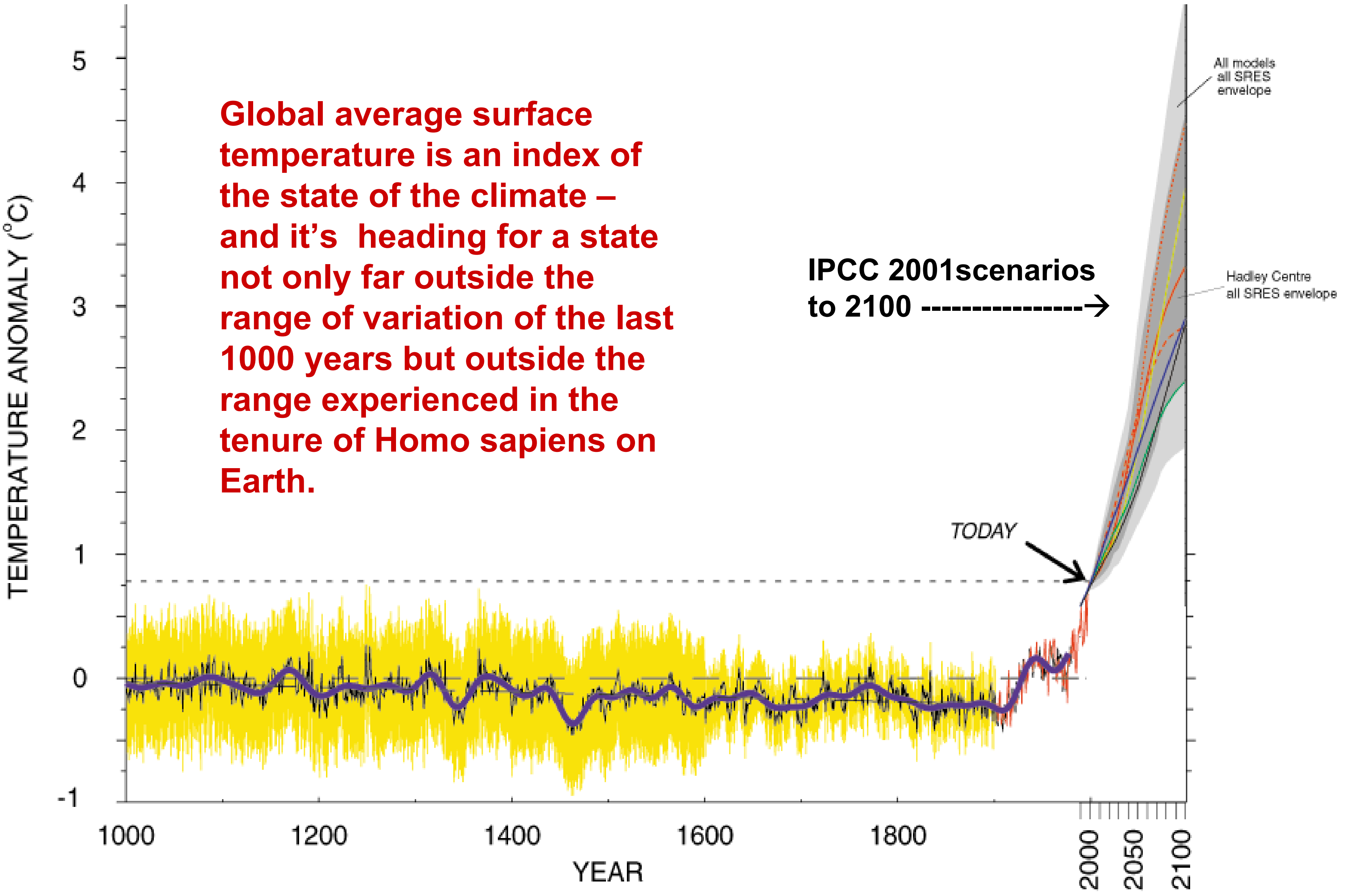
  and because the technologies currently used for this are not easily modified to limit those emissions, which amount to circa 25 billion tonnes of CO_2 per year.

1000 years of global C emissions, CO_2 concentrations, and temperature



Fossil-fuel burning has changed the atmosphere & the climate

1000 years of Earth temperature history…and 100 years of projection



Bad news — good news — bad news

- BAD: If the oil problem is a 600-pound gorilla who's already in the room, the climate problem is an 800-pound gorilla in the process of beating down the door.
  - Rapidly emerging science (current observations & improved understandings of climate history, not just models) says "dangerous anthropogenic interference" is already here and "tipping points" may be near.
- GOOD: There are some "win-win" approaches that reduce both oil & climate risks at modest cost.
  - Sharply increasing passenger-vehicle fuel economy offers large potential in this category, as do advanced biofuels.
- BAD: But some approaches to reducing oil dependence would make the climate problem worse.
  - Substitutes for conventional oil include tar sands, oil shales, and coal-to-liquid technologies, but without carbon capture & sequestration all these would greatly increase CO_2/gallon.

Which side is right about "peak oil" is <u>not</u> crucial to choices about what's to be done now

- U.S. domestic oil production peaked around 1970, as predicted 2 decades earlier by M. King Hubbert.
- Hubbert & others have used his approach to predict that world oil production would peak and start to decline between 2000 & 2010.
- But most oil-industry analysts don't believe "peak oil" will occur before 2030 & maybe not until 2050 or later.
- Whether occurrence of "peak oil" would precipitate an economic crisis or a reasonably smooth transition to alternatives is separately controversial.
- But the economic & security perils of current & growing oil dependence and the looming danger of unmanageable climate change tell us what's needed now <u>irrespective</u> of whether "peak oil" is near or far, dangerous or innocuous.

How does energy-technology innovation work?

- Research & development entail relatively modest investments in finding out what improvements are possible.
- Demonstrations entail somewhat larger investments in finding out how the most promising possibilities work out at near-commercial to commercial scale.
- Pre-commercial deployment (subsidized) and niche deployment can help "buy down" the unit costs of demonstrated technologies through learning, greasing the path to commercial competitiveness.
- Widespread deployment appropriately is determined in the marketplace, based on characteristics & information arising from R&D, demonstration, & initially subsidized & niche deployment, and on cost & price signals adjusted to account for important externalities and public goods.

The extent of private-sector engagement increases from a little at the top to the dominant role at the bottom.

Roles of the private & public sectors

- Firms engage in R&D because the technical advances made possible by innovation allow them to improve productivity, succeed in competitive markets, and meet environmental and regulatory requirements.
- The government's interest in energy innovation arises from the externality and public-goods dimensions of how energy is supplied and used, which mean that the societal benefits of energy innovation are greater than the private benefits and also that the directions of innovation are a legitimate focus of government concern.
- As the 1997 PCAST study of "Federal Energy R&D for the Challenges of the 21st Century" concluded, there is a case for government involvement not just in R&D but also, in a selective & limited way emphasizing partnerships with the private sector, in the demonstration & pre-commercial deployment phases of energy-technology innovations with large public benefits.

The evolving ERD^3 environment

- Real energy prices continue to fluctuate; recent increases have been impressive, but to stimulate much innovation they must be believed to be enduring.
- Deregulation and restructuring of energy markets in industrialized nations create some incentives for innovation but also create uncertainty about recovery of costs invested to secure public benefits.
- Increased pressures on short-term bottom line from deregulation & the merger/acquisition environment tend to inhibit investment in long-term R&D.
- Privatization of energy sectors in developing countries means increased private capital for conventional energy-supply technologies. Should public funds then focus on demonstration, buy-down, and financing of advanced technologies with higher public benefits?

Measures of adequacy & performance

A portfolio of energy-technology-innovation activities should be judged by "internal" and "external" criteria. The "internal" criteria have to do with whether…

- the goals of the program are reasonable;
- the program elements necessary to achieve the goals are all present, including redundancy appropriate to the level of uncertainty about the outcomes of particular elements and to the urgency of the goal;
- the individual elements are suitably designed for their purposes;
- they are suitably linked and phased;
- they are being funded at levels commensurate with the tasks involved, the opportunities available, the other (competing or cooperating) entities pursuing or likely to pursue the same goal, and the timing desired; and
- observed rates of progress are consistent with the goals.

After PCAST 1995

Adequacy & performance (continued)

- The "external" criteria have to do with whether the funding allocated to the program can be justified in relation to the total resources available in the agency, or in the society, for similar activities, e.g.,
  - for all energy R&D, or
  - for all R&D in general, or
  - for non-R&D activities supporting societal goals
- Judgments in this category entail reaching conclusions about the importance and prospects of attainment of a program's goals in relation to
  - its cost, and
  - the importance / prospects / cost combinations of other R&D programs and non-R&D programs.

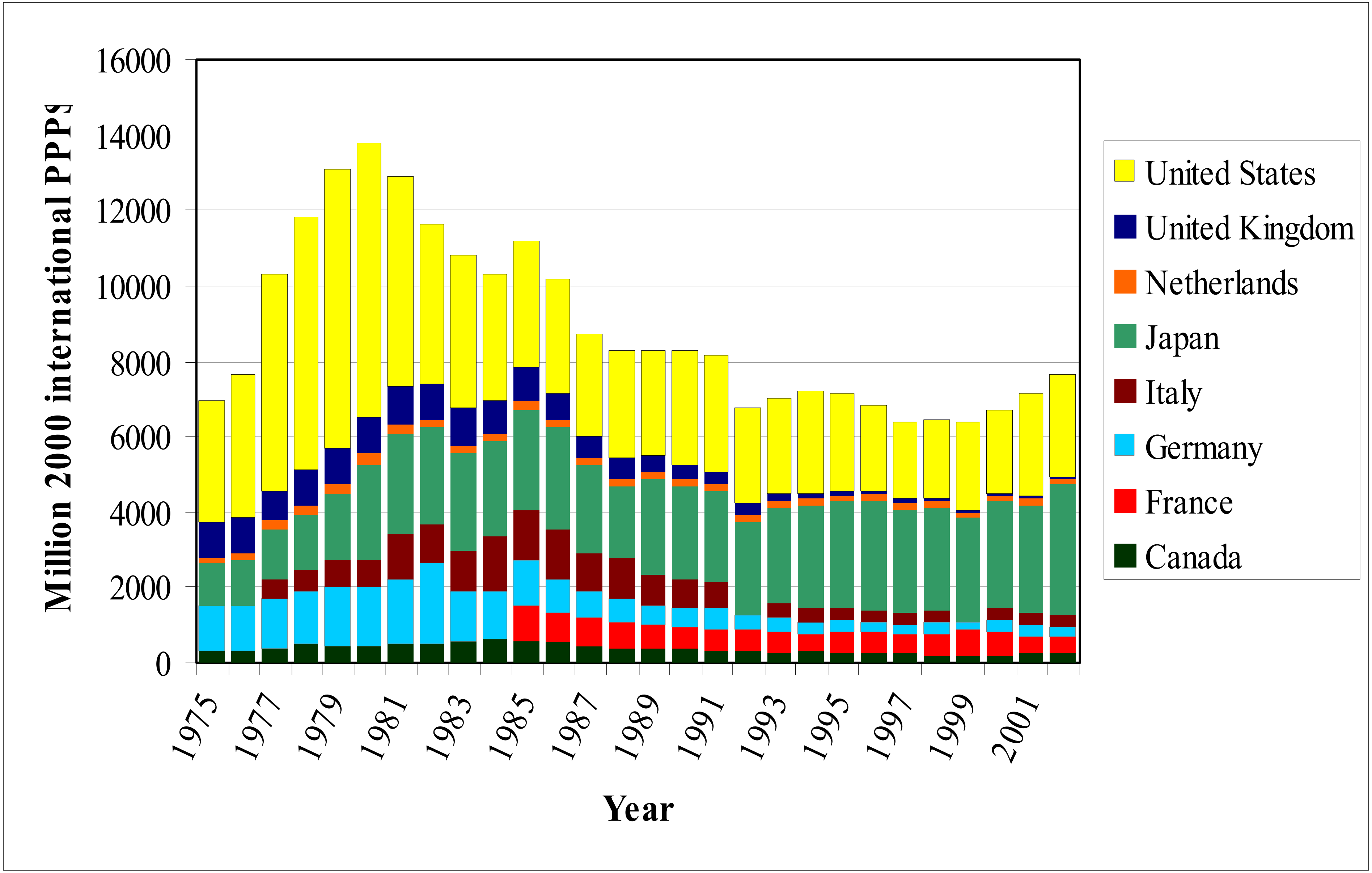
“Input” measures: R&D spending

Spending for energy & ER&D in perspective

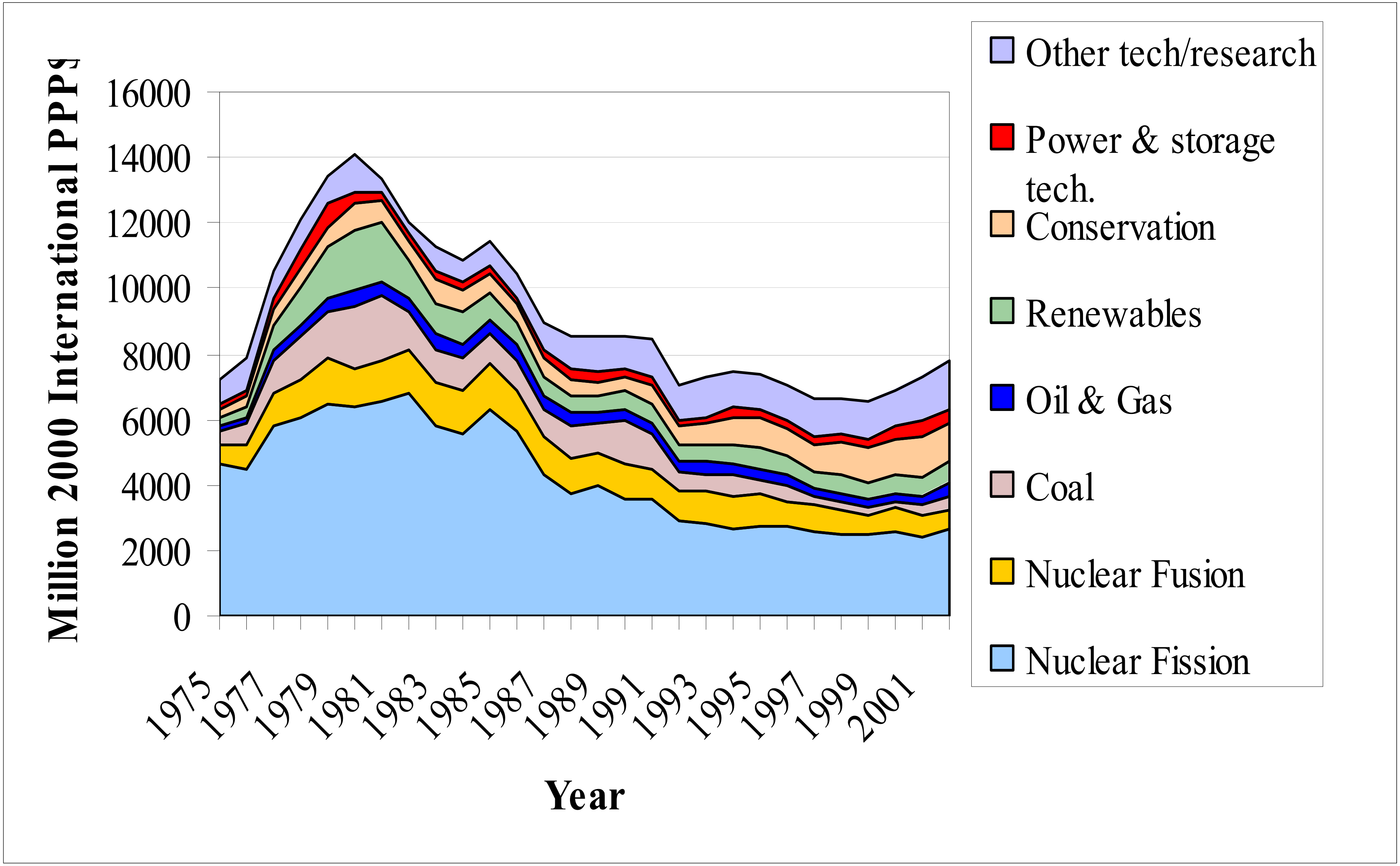
(estimates for 2001 in millions of 2001 US$, converted at ppp)

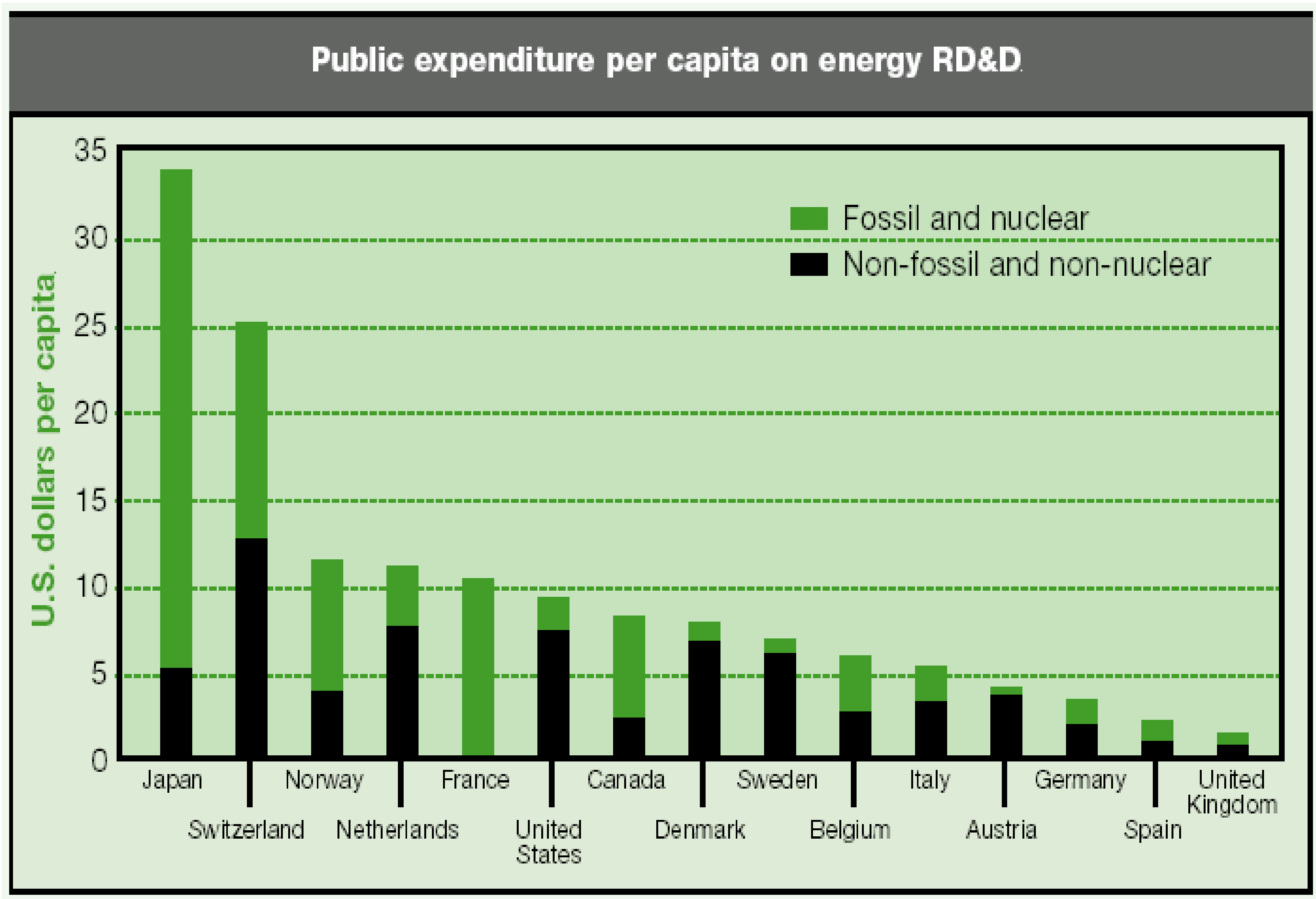
World economic product	45,000,000
…value of E-system capital stock	12,000,000
…retail expenditures on energy	3,000,000
…expenditure on all R&D	740,000
…investment/yr in E-supply system	400,000
…expenditure on energy R&D	15,000
US economic product	10,000,000
…expenditure on energy	600,000
…expenditure on all R&D	270,000
…expenditure on ER&D	4,000

Energy RD&D expenditures by major IEA governments



IEA government expenditures on energy RD&D by category





World Energy Assessment, 2000

Output measures:

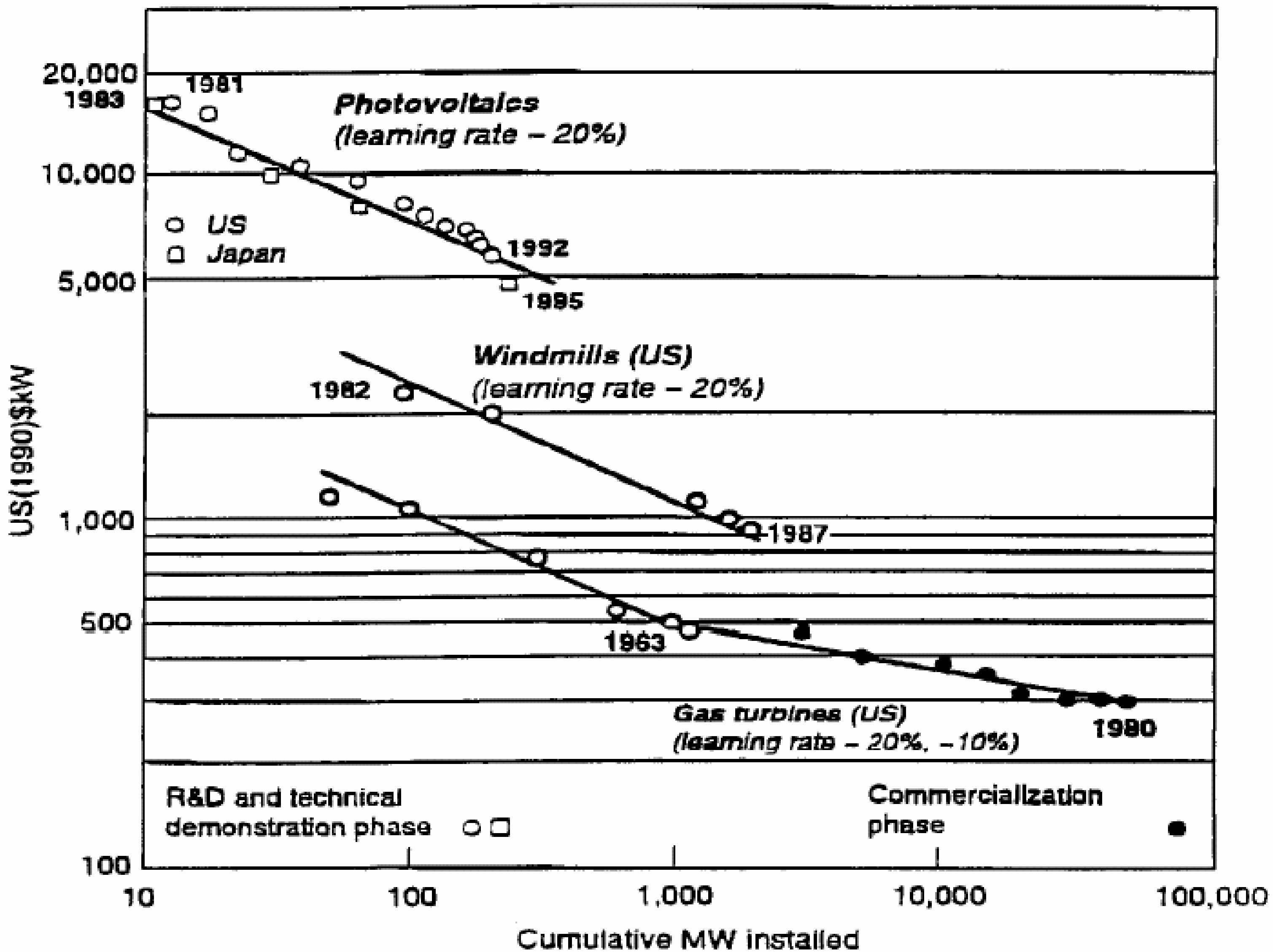
- Performance of individual technologies
  - capital cost
  - cost of energy
  - emissions per unit of energy

Outcome measures:

- Sector-wide & economy-wide intensities
  - energy intensity (E/GDP)
  - oil intensity (oil/GDP)
  - emissions intensity (carbon/kWh, carbon/GDP)

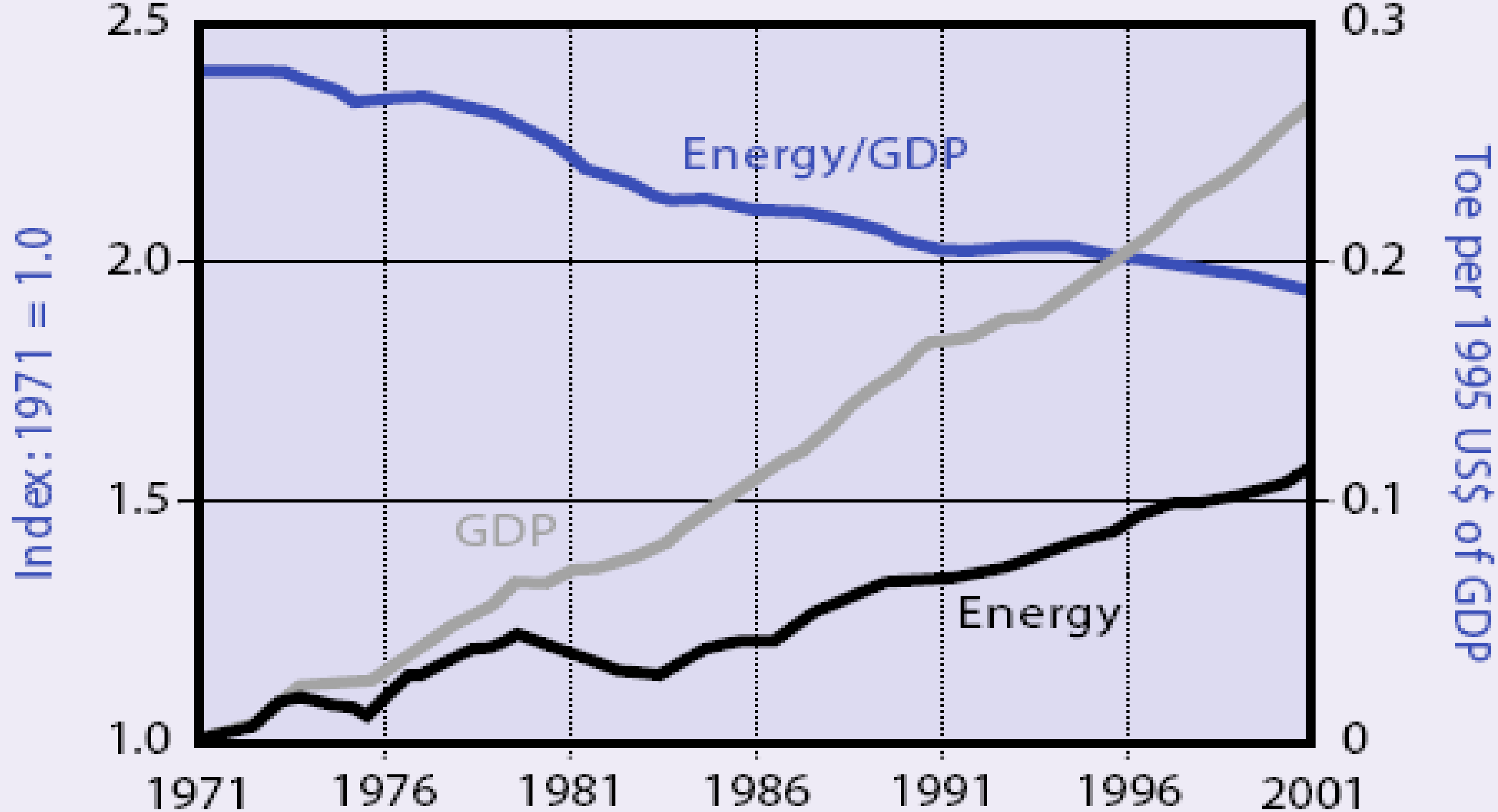
With respect to these:
How much are we getting?
How much do we need?

OUTPUTS: Some learning curves for electricity-generation technologies (from Gruebler, Nakicenovic, & Victor, "Modeling Technological Change", *Annual Review of Energy & Environment*, 1999, pp 545-69.



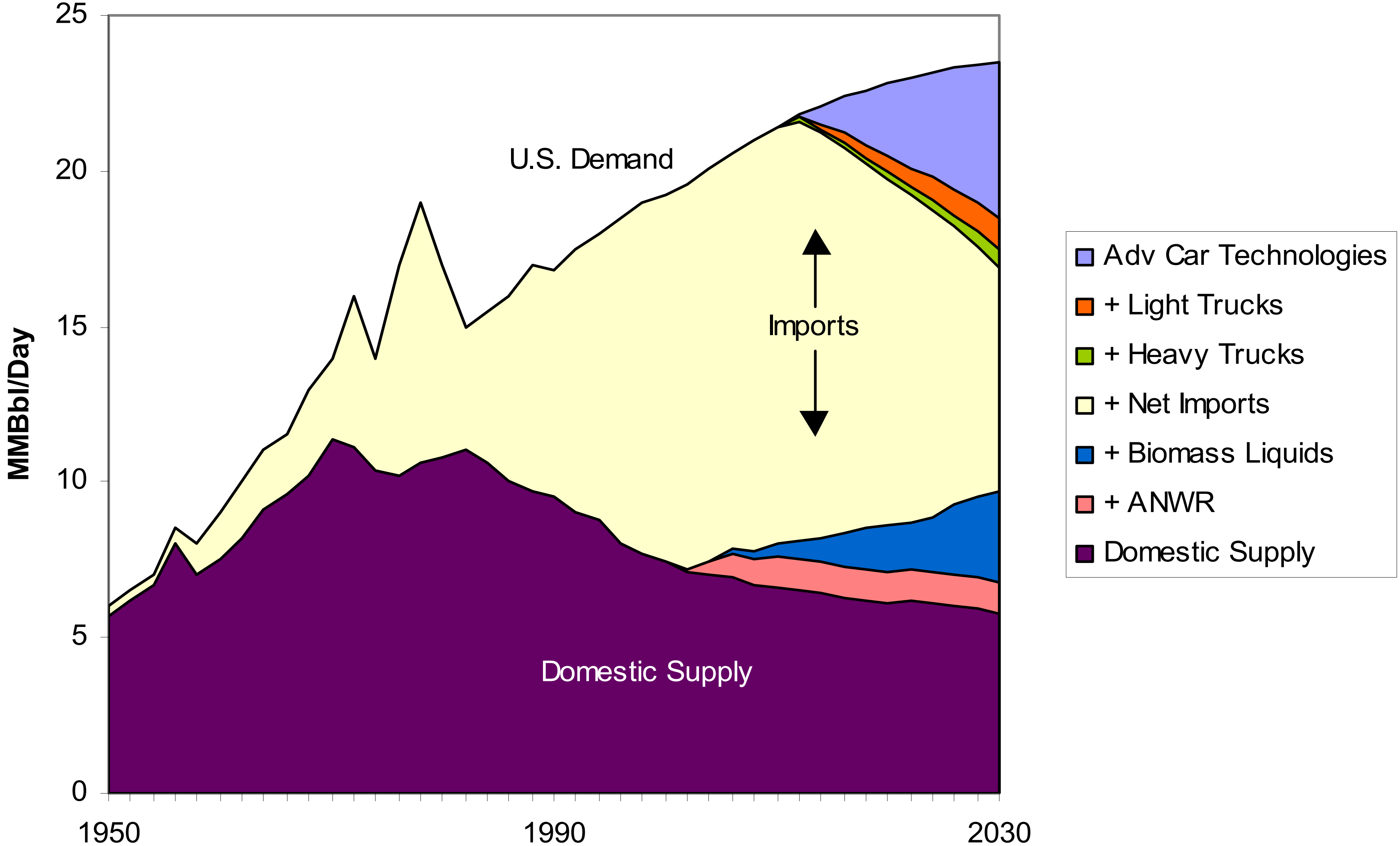
OUTCOMES:

GDP AND PRIMARY ENERGY USE IN OECD COUNTRIES, 1971-2001



Source: World Energy Assessment 2004

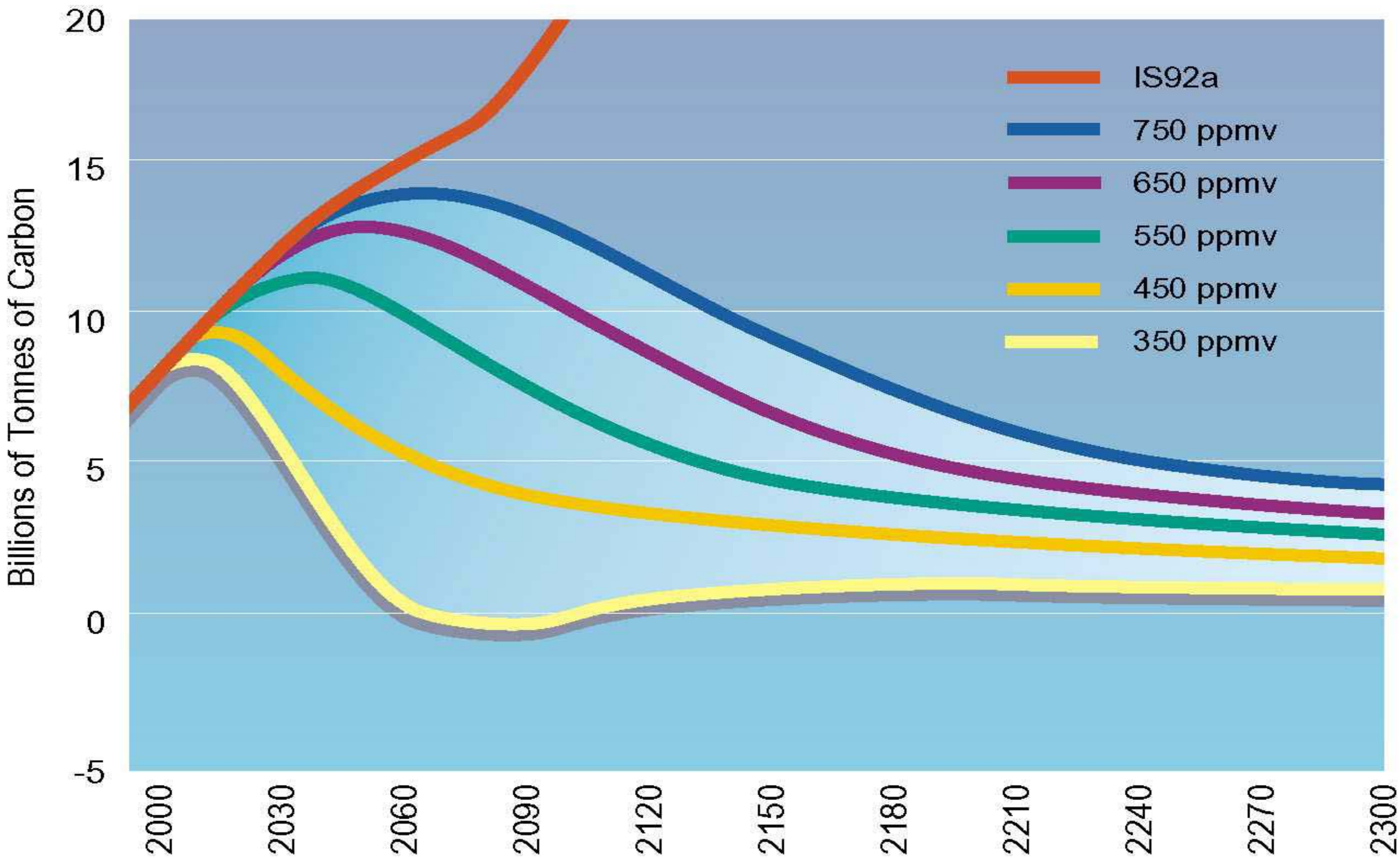
How much more do we need to do?
U.S. oil futures



PCAST 1997, DOE 2003

How much more do we need to do? Climate change

Emissions Trajectories Consistent With Various Atmospheric CO_2 Concentration Ceilings



Thought experiment: How much carbon-free energy needed to stabilize CO_2 at 550 ppm_v?

Carbon-free energy in 2000 (from renewables and nuclear energy) ≈ 100 exajoules/year. (Fossil fuels ≈ 350 EJ/yr)

With BAU economic growth, the future need for C-free energy (renewables, nuclear, & advanced fossil with CO2 sequestration) depends on rate of improvement of energy efficiency as follows:

C-free energy (exajoules) in	2050	2100
	------	-------
E/GDP falls 1%/yr (BAU)	600	1500
E/GDP falls 1.5%/yr	350	800
E/GCP falls 2.0%/yr	180	350

Assessments of adequacy

PCAST 1997

- "Current federal energy R&D programs are not commensurate in scope & scale with the energy challenges & opportunities the 21st century will present. (This judgment takes into account the likely R&D contributions of the private sector.)"
- "The inadequacy is particularly acute in relation to the challenge of responding prudently & cost-effectively to the risk of greenhouse-gas-induced global climate change. (That challenge is the most demanding of all the drivers of energy R&D.)"

World Energy Council 2001

- Meeting demands of sustainability – E services for poor, reduced environmental impacts – will require big improvements in end-use efficiency, use of renewables, clean-fossil.
- The 1997 PCAST conclusion for USA has wider validity: "Energy R&D programs are not commensurate in scope and scale with the energy challenges & opportunities the 21st century will present."

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.

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).

Some relevant recommendations from May 2001 “Cheney Report” on US energy policy

- National priority for improving energy efficiency.
- Permanent extension of existing R&D tax credits.
- Tax credits for fuel-cell vehicles & advanced bus propulsion.
- Tax credits & exemptions to support renewables.
- Commitment to advancing clean-coal technologies, next-generation nuclear fission, fusion, hydrogen.
- “Explore collaborative international basic research and development in energy alternatives and energy-efficient technologies; and explore innovative programs to support the global adoption of these technologies.”

The international-cooperation dimension

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

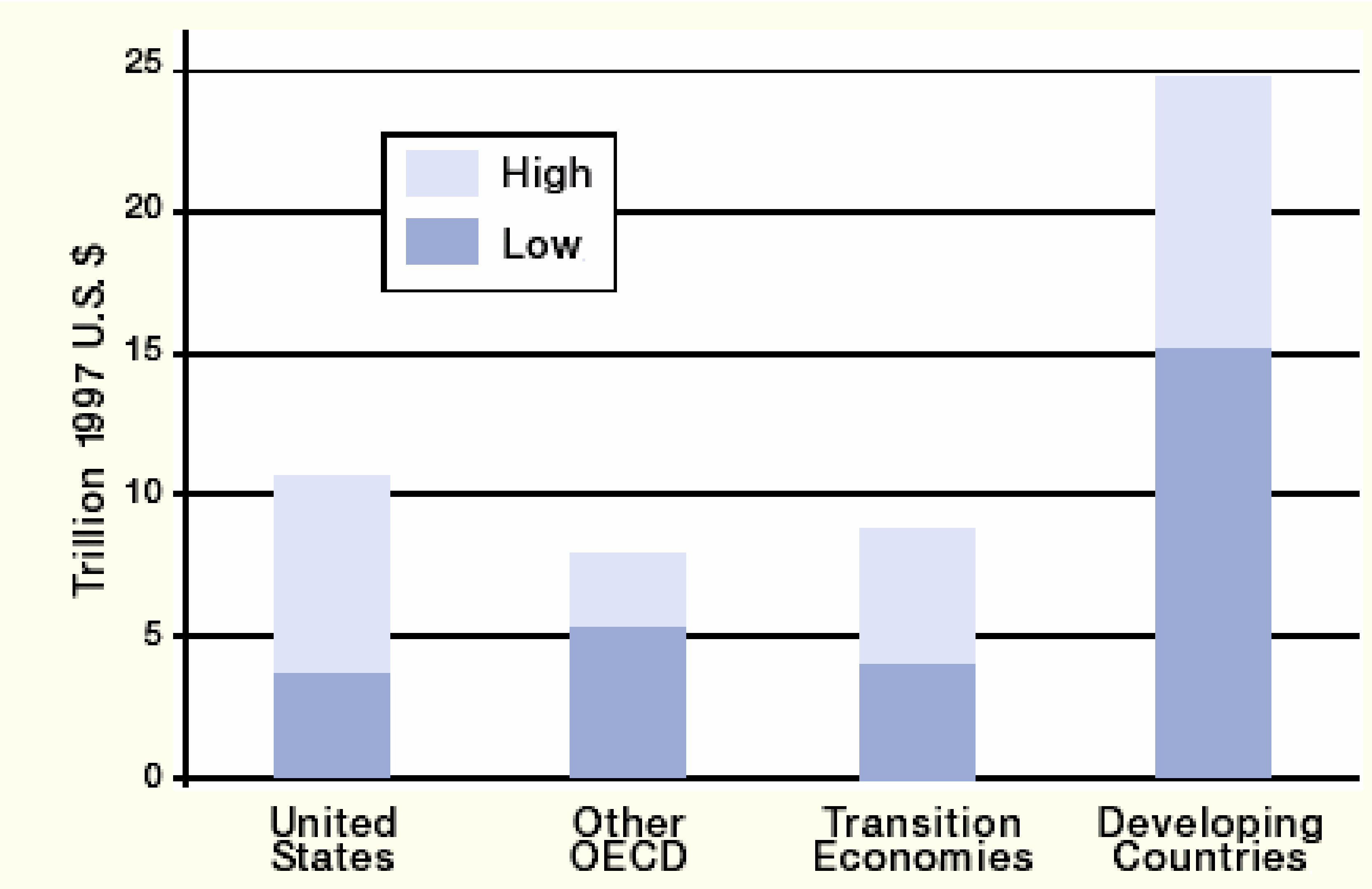
BENEFITS FROM ENERGY-TECHNOLOGY IMPROVEMENTS IN ALL COUNTRIES

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

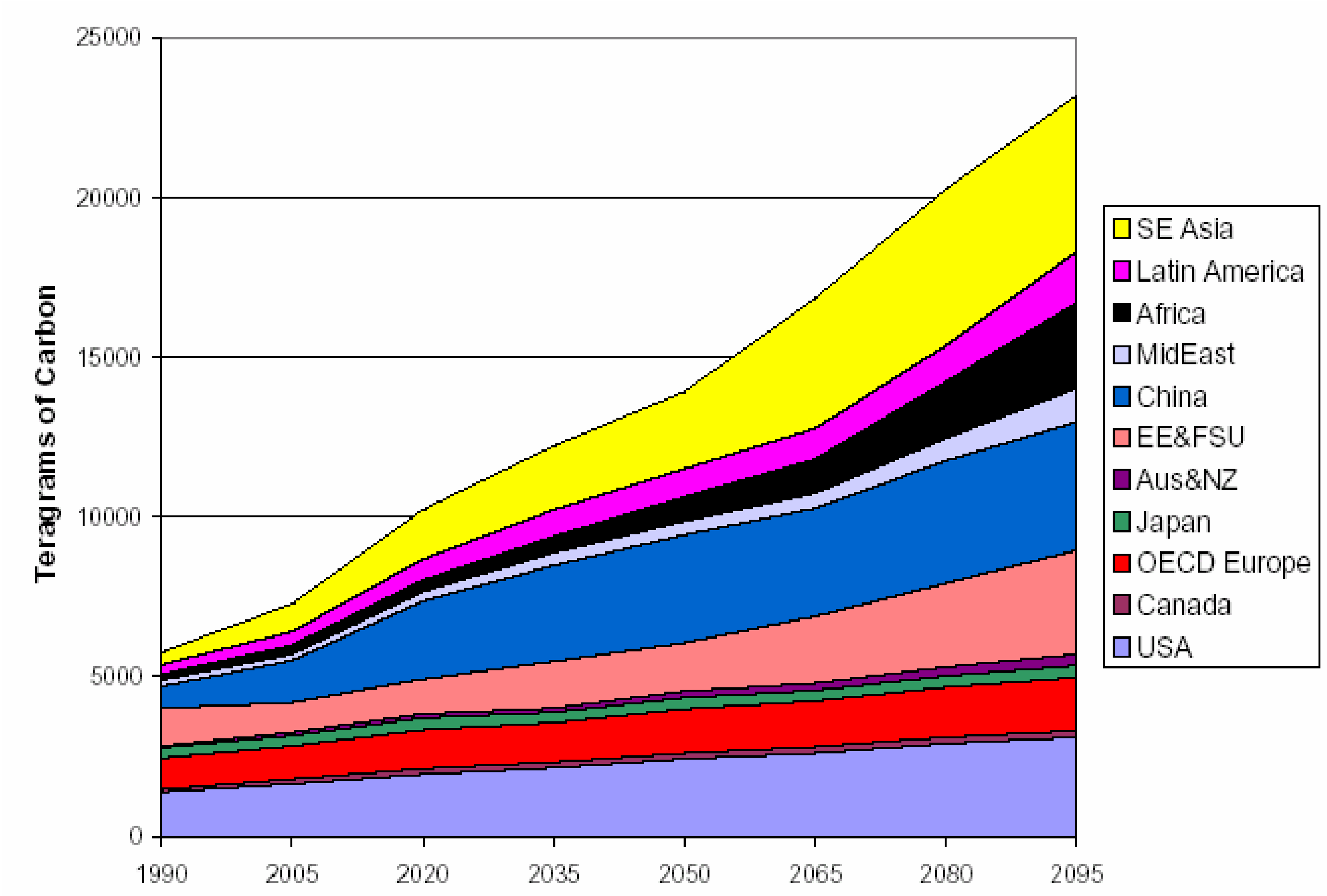
CORRESPONDING INCENTIVES FOR COOPERATION

- 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

Projected investments in new energy supply to 2050
(adapted from WEC-IIASA 1998)



Projected carbon emissions by world region



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

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

* Powerful Partnerships: The Federal Role in International Energy Cooperation