# The Global Energy Innovation System


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**In Energy Technologies**

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# Outline of the presentation

- Why is the global E innovation system important?
- What do we know about its operation?
- Measures of performance: Spending
- Measures of performance: Learning
- Closing the rich-poor gap: Cooperation
- What more do we need to know?
- What more do we need to do?

# 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

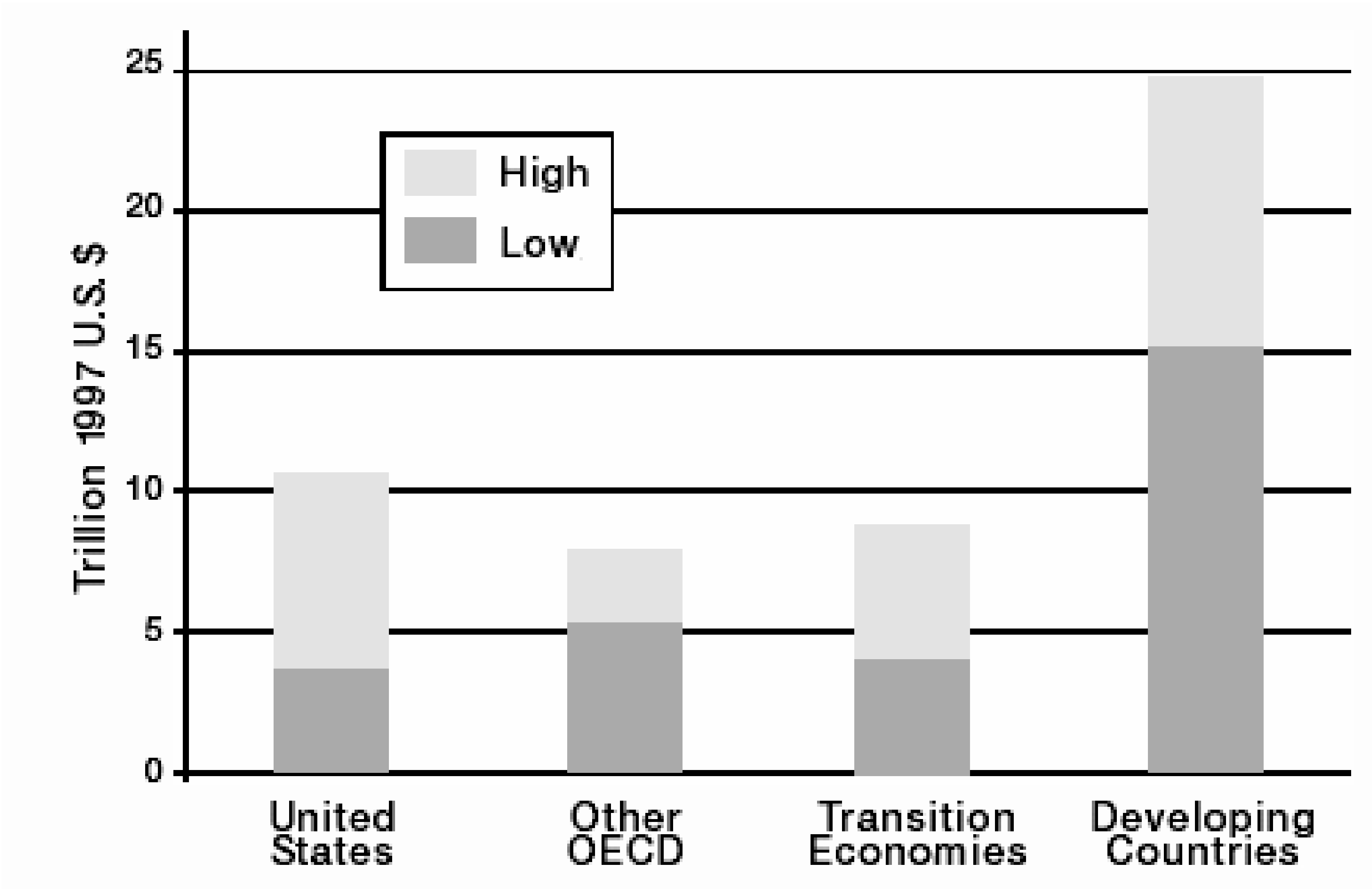
# Why is the global energy-innovation system important?

WHY UNDERSTANDING ENERGY-TECHNOLOGY INNOVATION IS IMPORTANT: Whatever you think “the energy problem” is, advances in technology are an important part of the solution. They can…

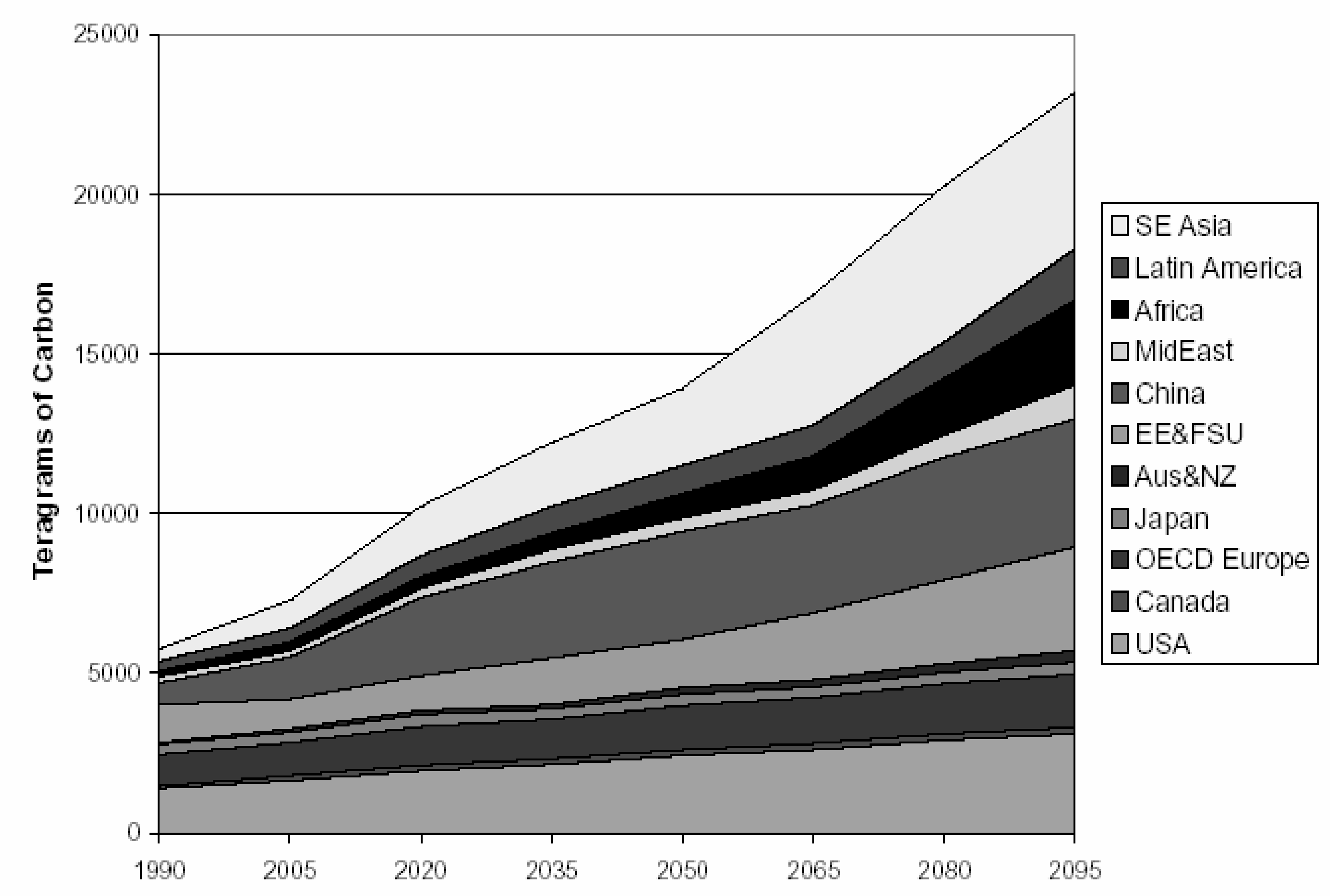
- Reduce the costs of energy end-use forms to consumers
- Further reduce costs of energy services by increasing end-use efficiency
- Increase the productivity of manufacturing
- Reduce dependence on oil in the USA and elsewhere
- Increase the reliability & resilience of energy systems against disruptions
- 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

## Projected investments in new energy supply to 2050

(adapted from WEC-IIASA 1998)



# Projected carbon emissions by world region



# How does the energy-innovation system work?

# 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

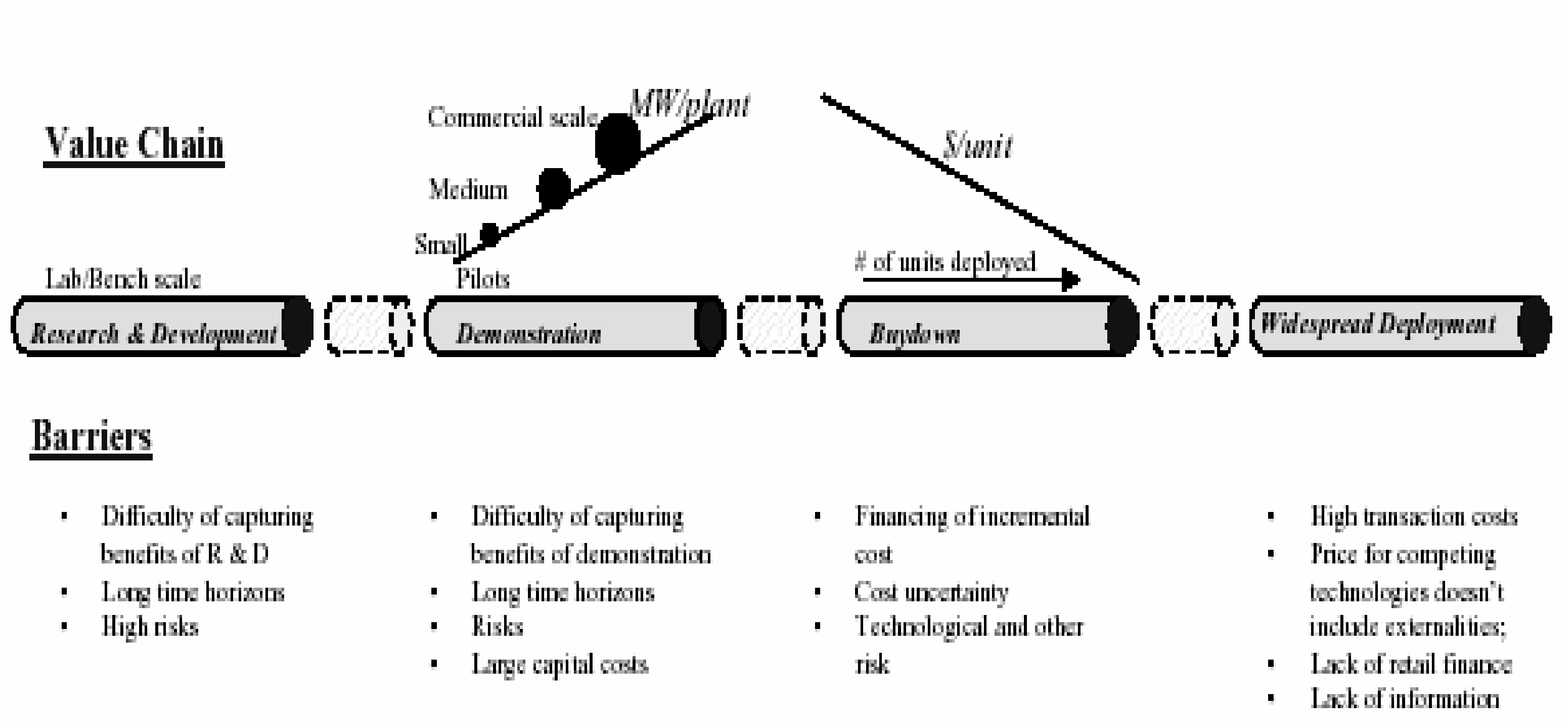
FUNDERS

- 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)



# The evolving ERD$^3$ environment

- Real energy prices continue to fluctuate but remain low in real terms on the average; for increases 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?

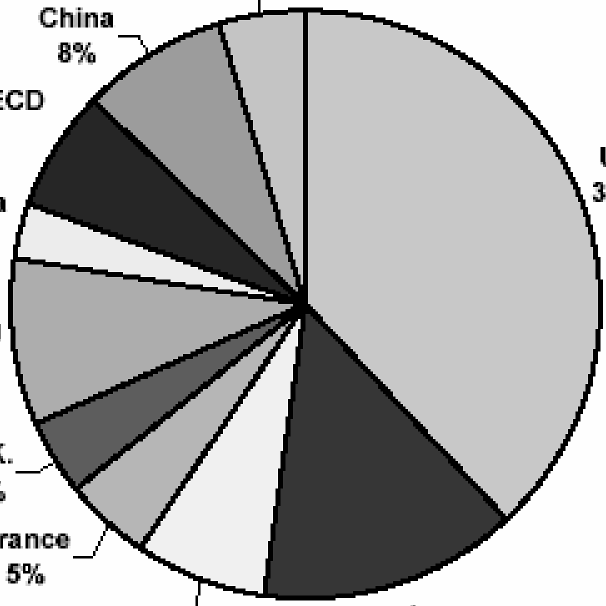
# Measures of performance: Spending

## Spending for E and 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 |
| 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 |

# Shares of Total World* R&D, 2001




Total World* R&D = U.S. $739.2 billion**

* World = OECD members plus Argentina, China, Romania, Israel, Russian Federation, Singapore, Slovenia, Taiwan

Source: OECD, Main Science and Technology Indicators, 2003.

* *- calculated using purchasing power parities.



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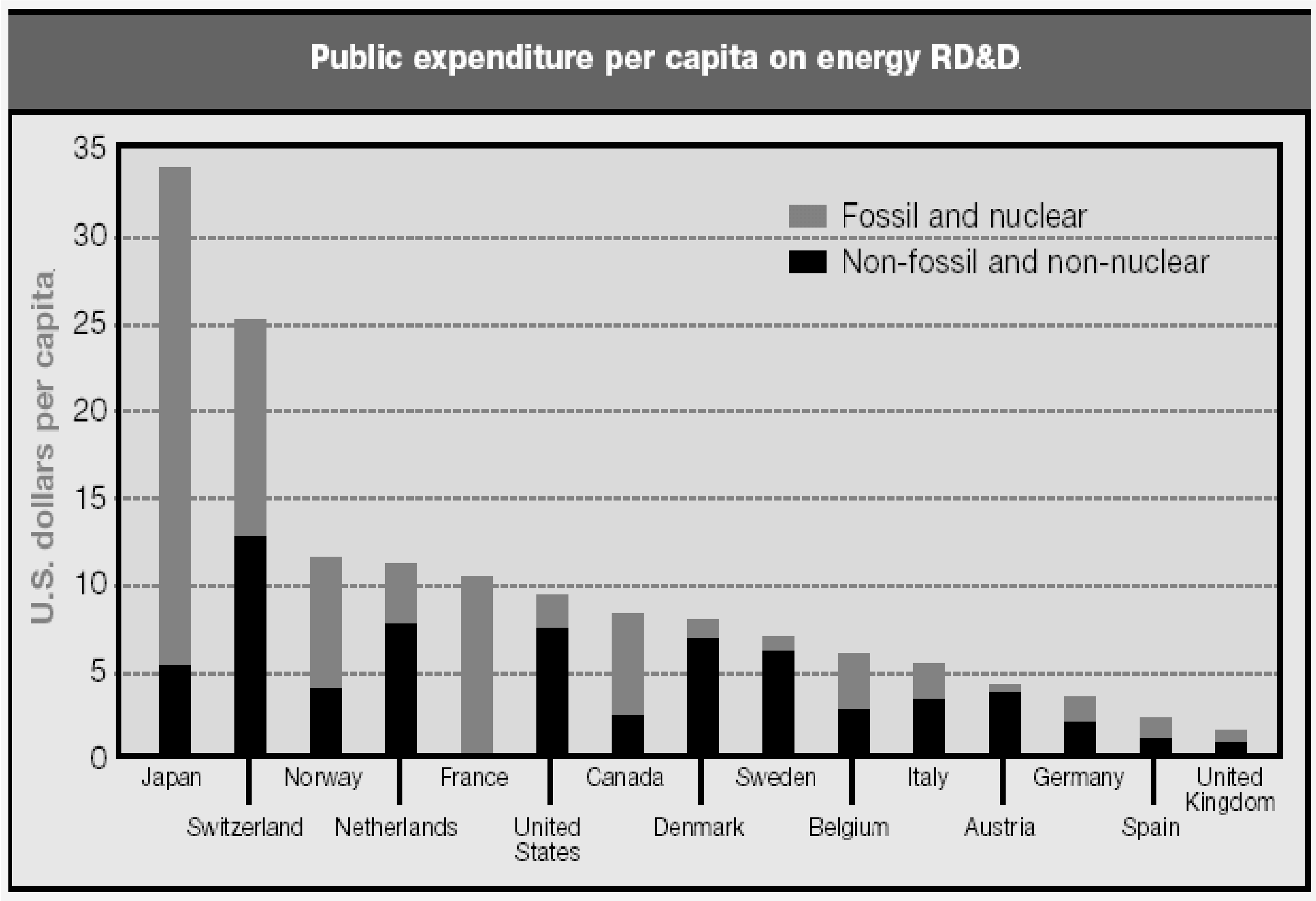
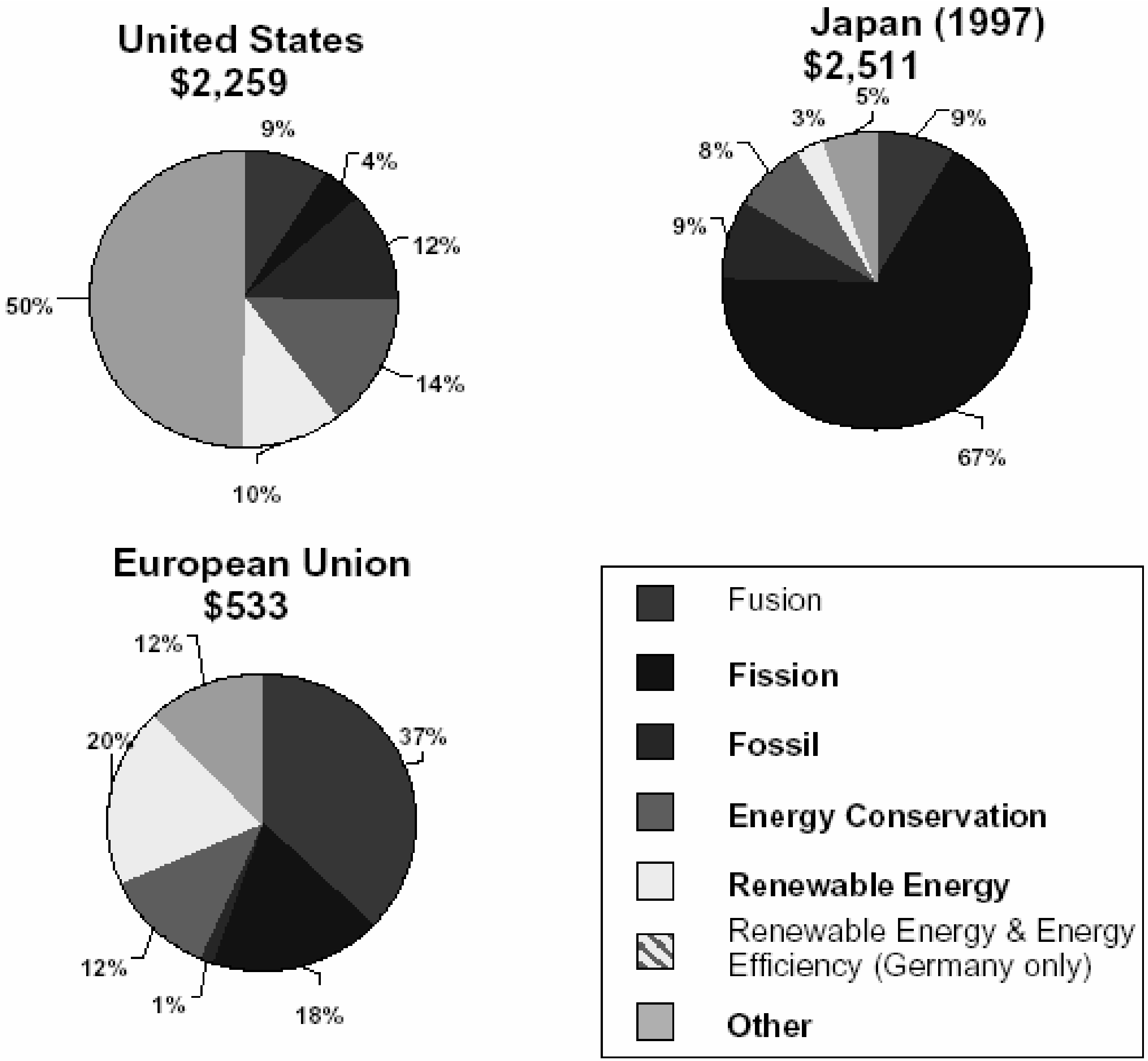



World Energy Assessment, 2000

# Portfolios of government ER&D (Dooley & Runci, 1999)



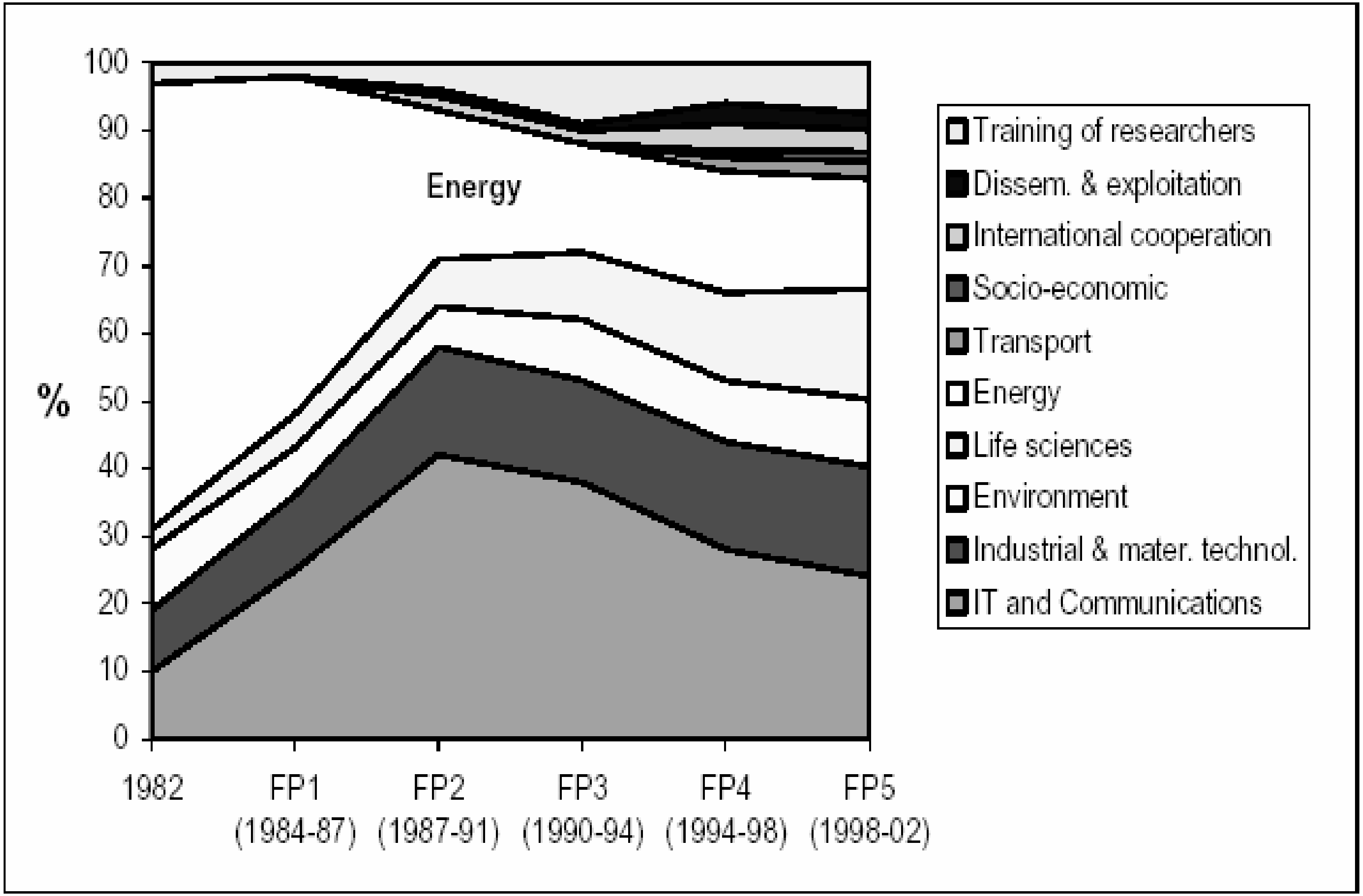
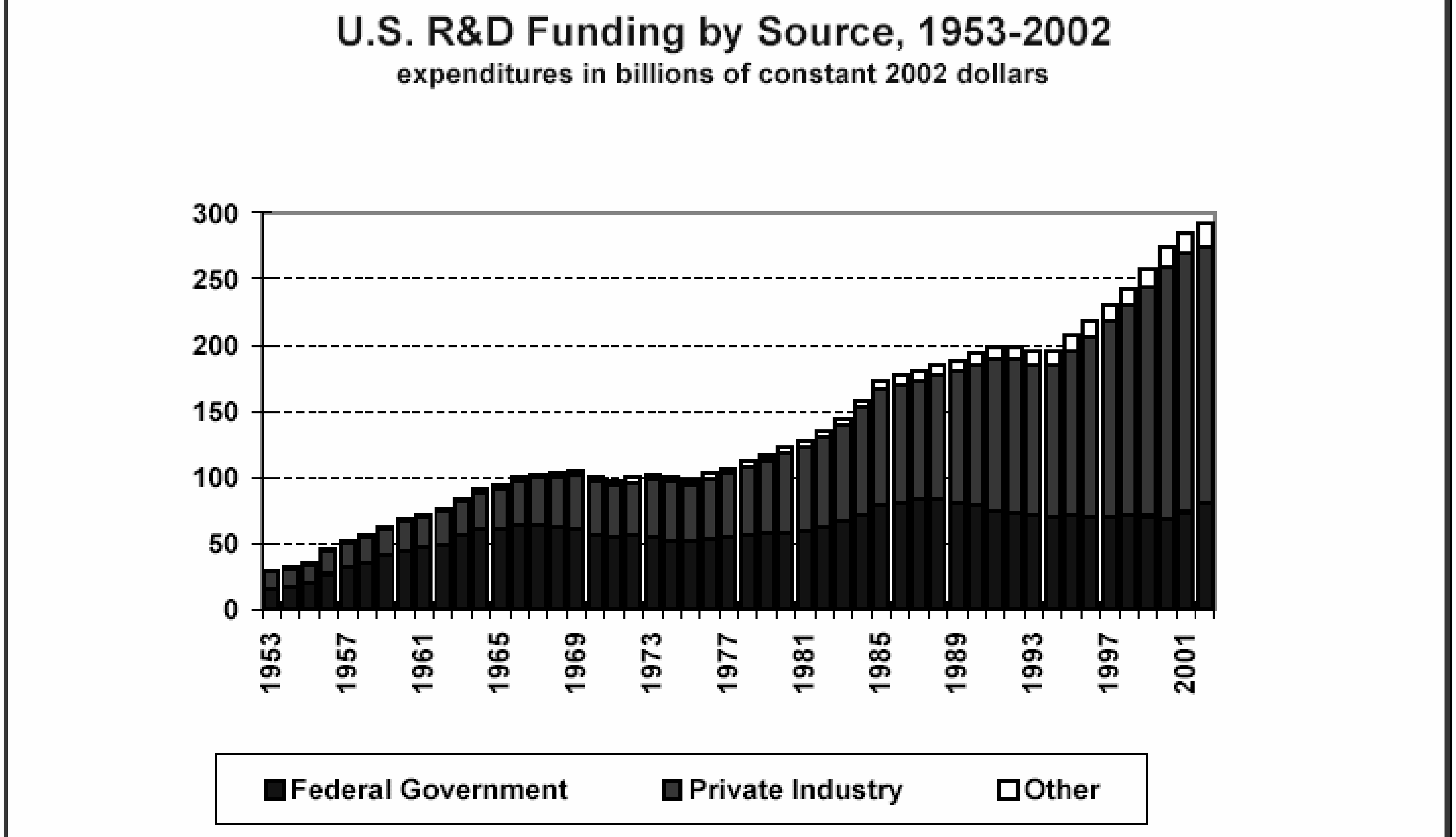



*Chart 9. European Union research & technology development: changing priorities within the five framework programmes.*




Source: NSF, Division of Science Resources Statistics. (Data for 2001 and 2002 are preliminary.)



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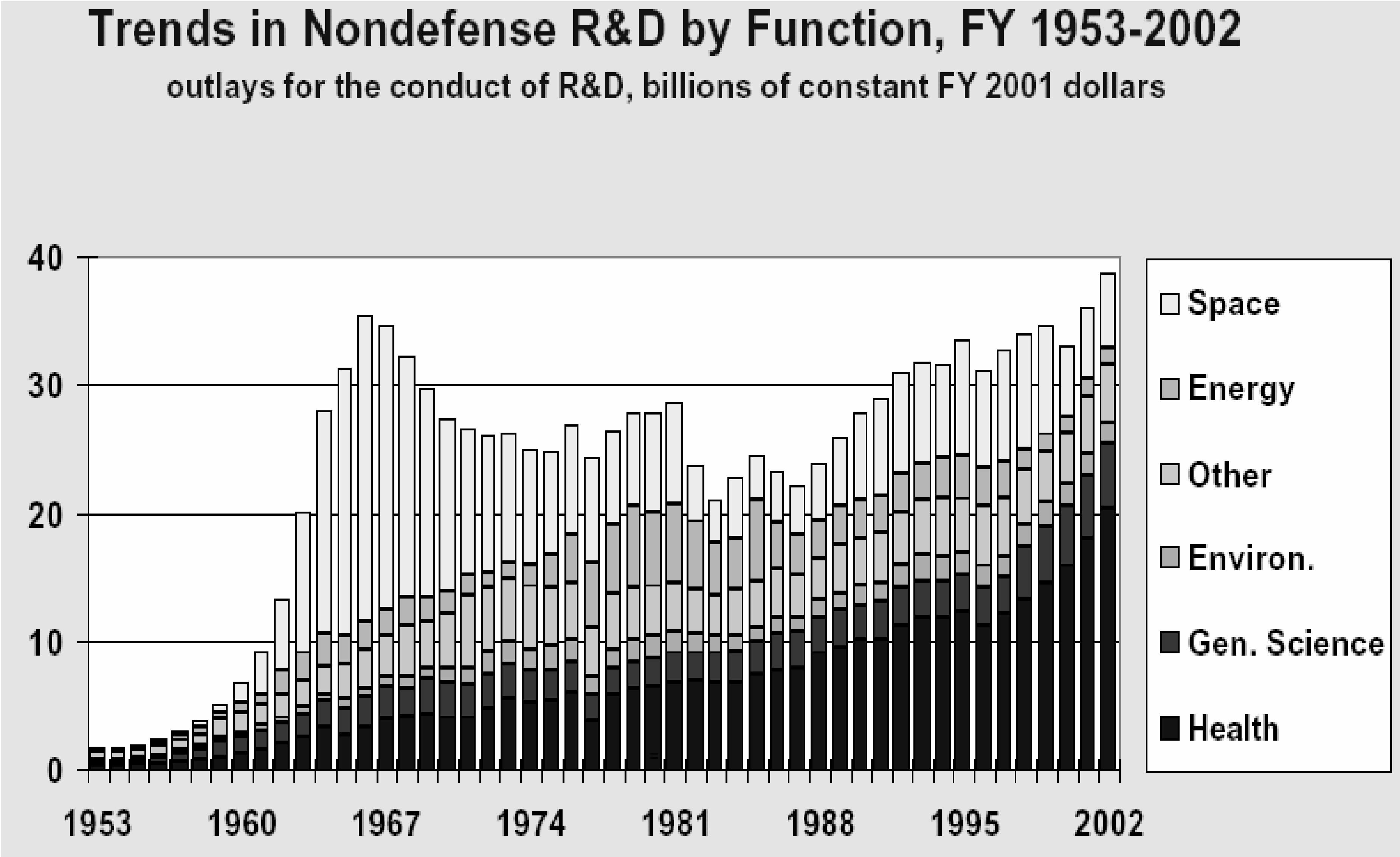
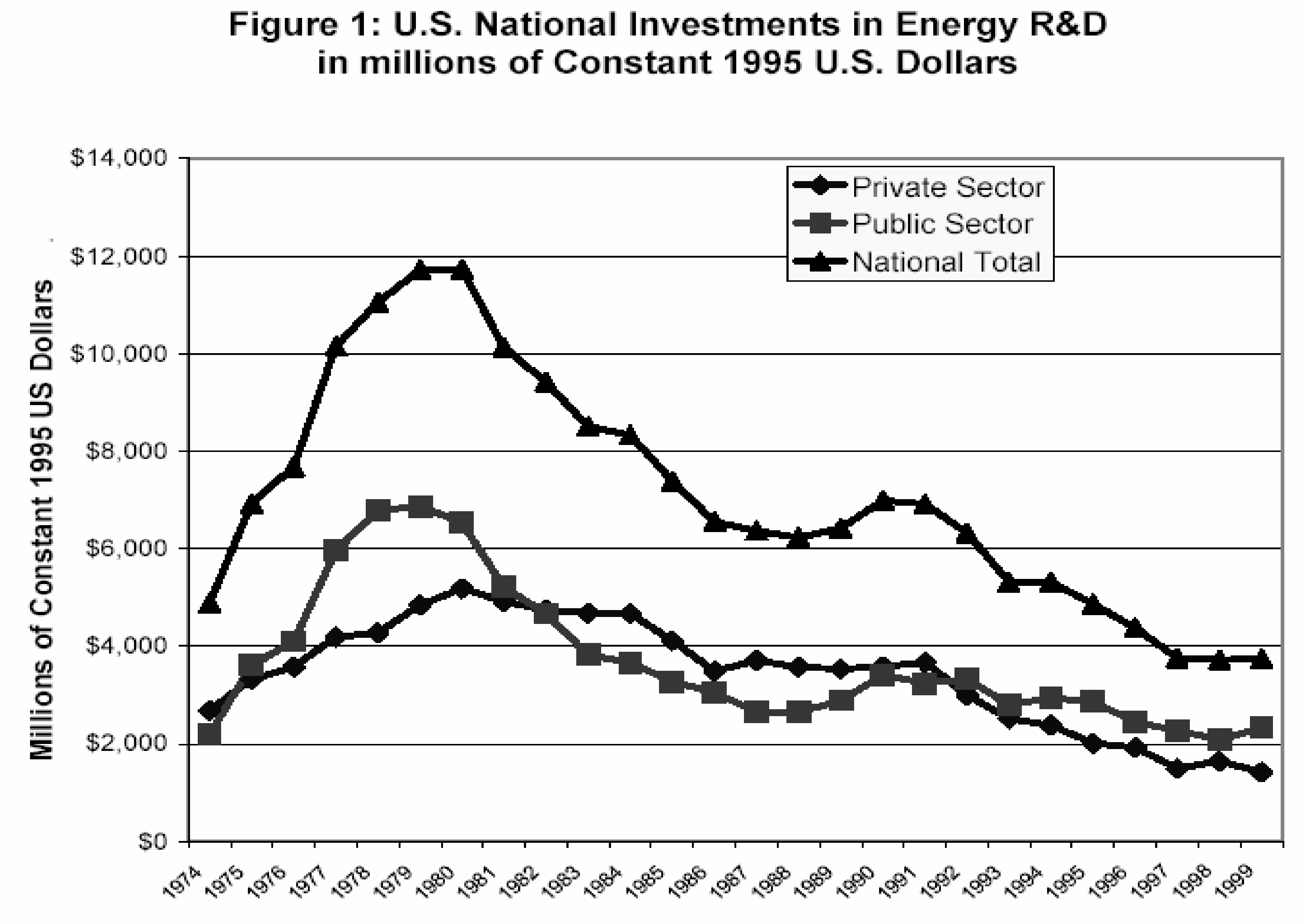
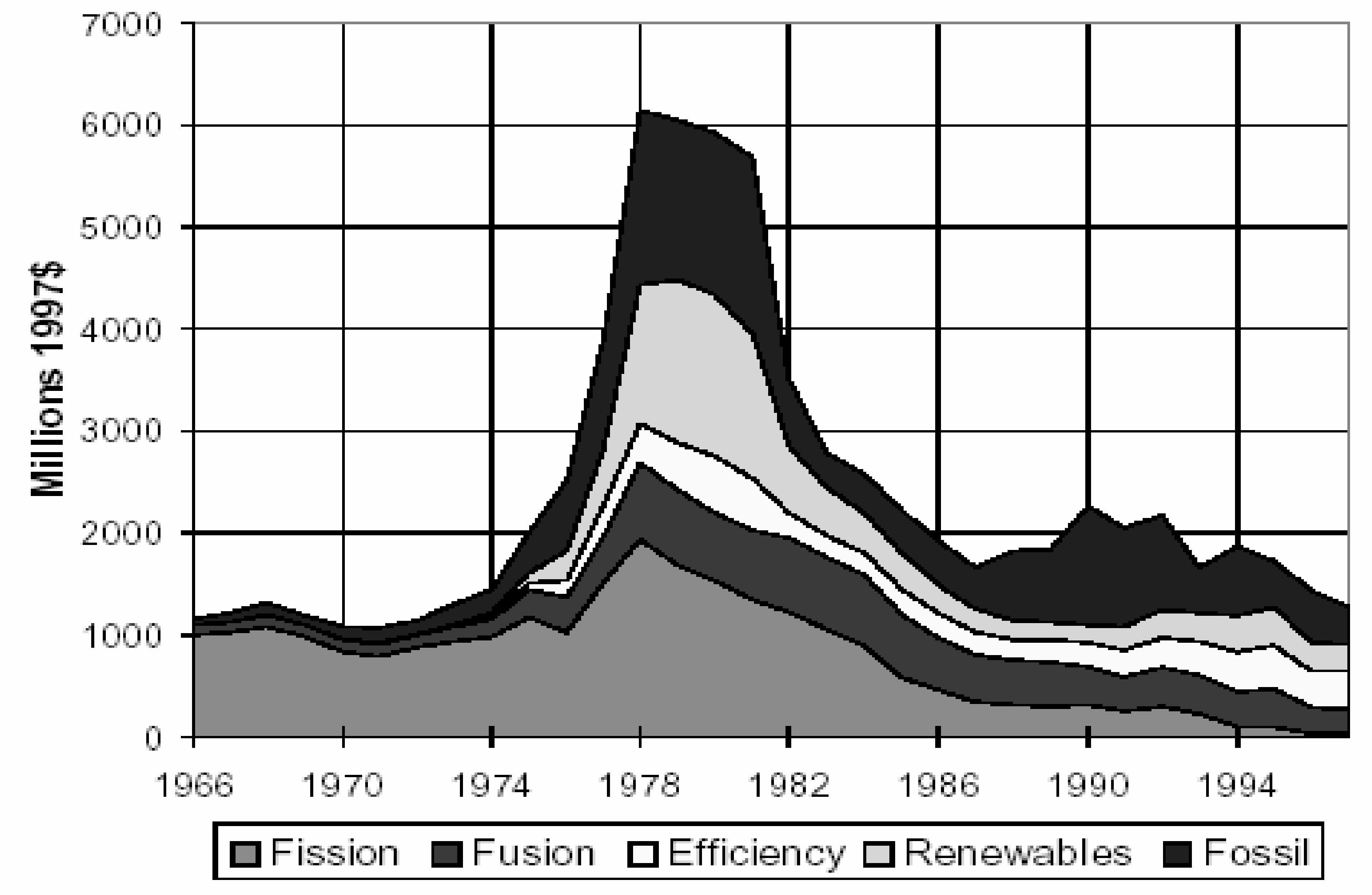


Trends in Nondefense R&D by Function, FY 1953-2002
outlays for the conduct of R&D, billions of constant FY 2001 dollars
40
30
20
10
0
1953
1960
1967
1974
1981
1988
1995
2002
Space
Energy
Other
Environ.
Gen. Science
Health




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

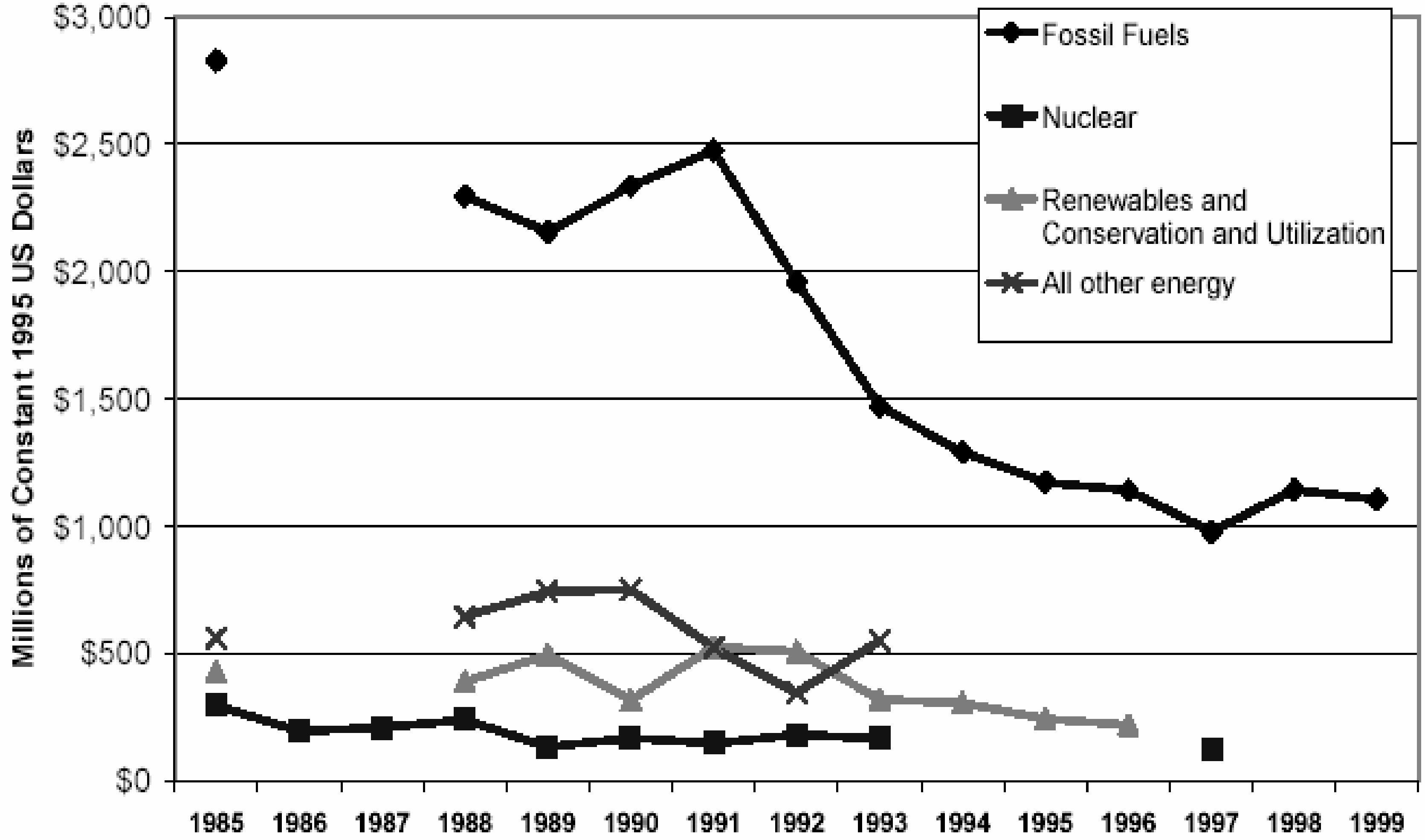
## **USDOE applied energy-technology RD&D** (from PCAST 1997)



**Federal Energy Technology R&D: Congressional Appropriations, Administration Requests, PCAST Recommendations ($10^6$ as-spent-$)**

| | | effic | renew | foss | nucl fiss | nucl fusn | total |
|---|---|---|---|---|---|---|---|
| FY98 | appropriation | 437 | 272 | 356 | 7 | 223 | 1295 |
| FY99 | appropriation | 503 | 336 | 384 | 30 | 222 | 1475 |
| | Admin request | 594 | 372 | 383 | 44 | 228 | 1621 |
| | PCAST reccmdtn | 615 | 475 | 379 | 66 | 250 | 1785 |
| FY00 | appropriation | 552 | 310 | 404 | 40 | 250 | 1556 |
| | Admin request | 655 | 398 | 340 | 41 | 222 | 1656 |
| | PCAST reccmdtn | 690 | 585 | 406 | 86 | 270 | 2037 |
| FY01 | appropriation | 600 | 375 | 433 | 59 | 255 | 1722 |
| | Admin request | 630 | 410 | 385 | 52 | 247 | 1724 |
| | PCAST reccmdtn | 770 | 620 | 433 | 101 | 290 | 2214 |
| FY02 | appropriation | 617 | 386 | 446 | 68 | 248 | 1765 |
| | Admin request | 475 | 237 | 333 | 39 | 255 | 1339 |
| | PCAST reccmdtn | 820 | 636 | 437 | 116 | 320 | 2329 |
| FY03 | appropriation | 628 | 422 | 475 | 75 | 250 | 1850 |
| | Admin request | 561 | 408 | 483 | 89 | 257 | 1798 |
| | PCAST reccmdtn | 880 | 652 | 433 | 119 | 328 | 2412 |

## Figure 4: Estimated US Private Sector Energy R&D Investments By Fuel Type 1985-1999




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

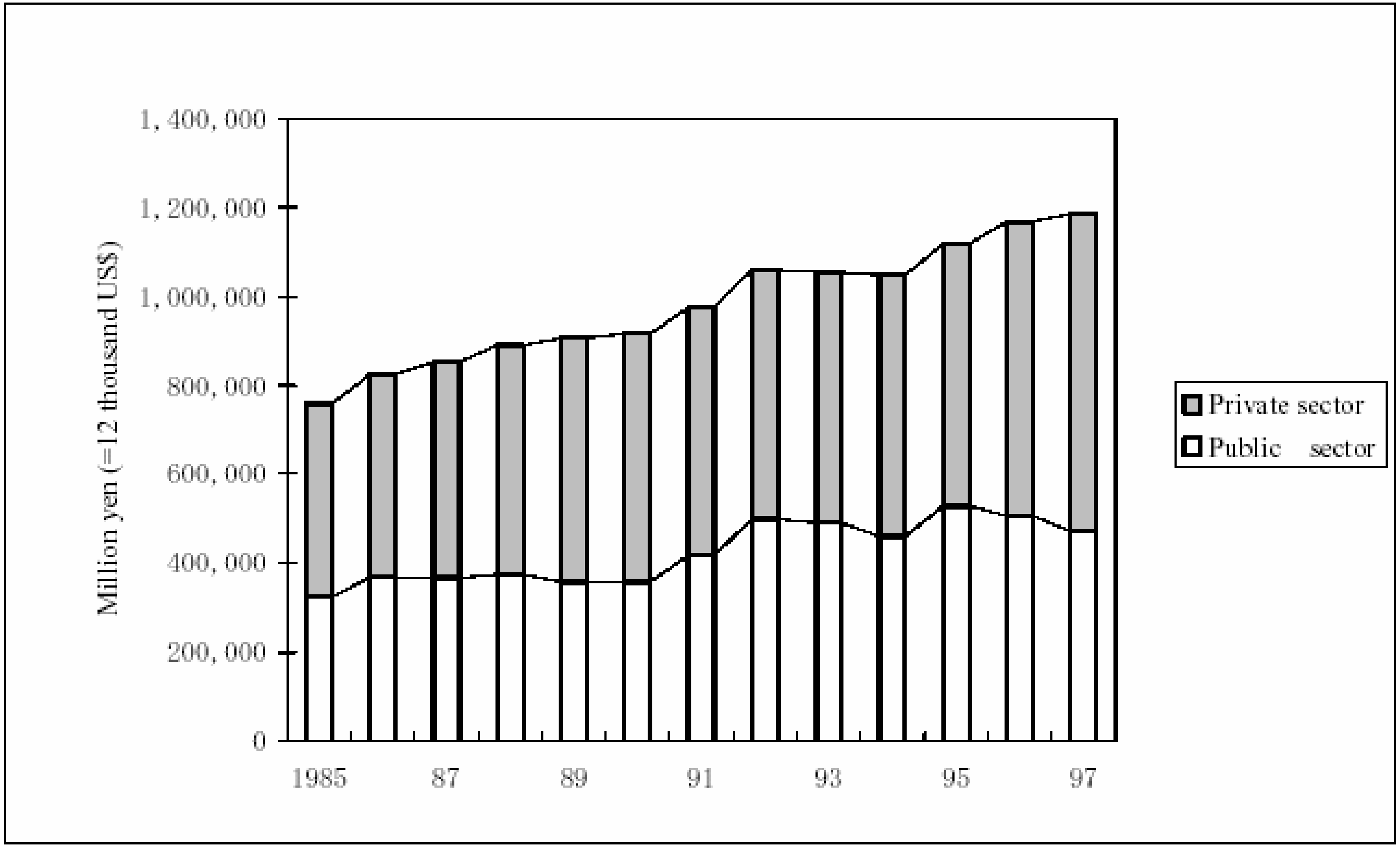



*Chart 2. Japan's total R&D on energy, public and private sectors, 1985-97. (Source: Statistics Bureau, Management and Coordination Agency, Government of Japan.)*

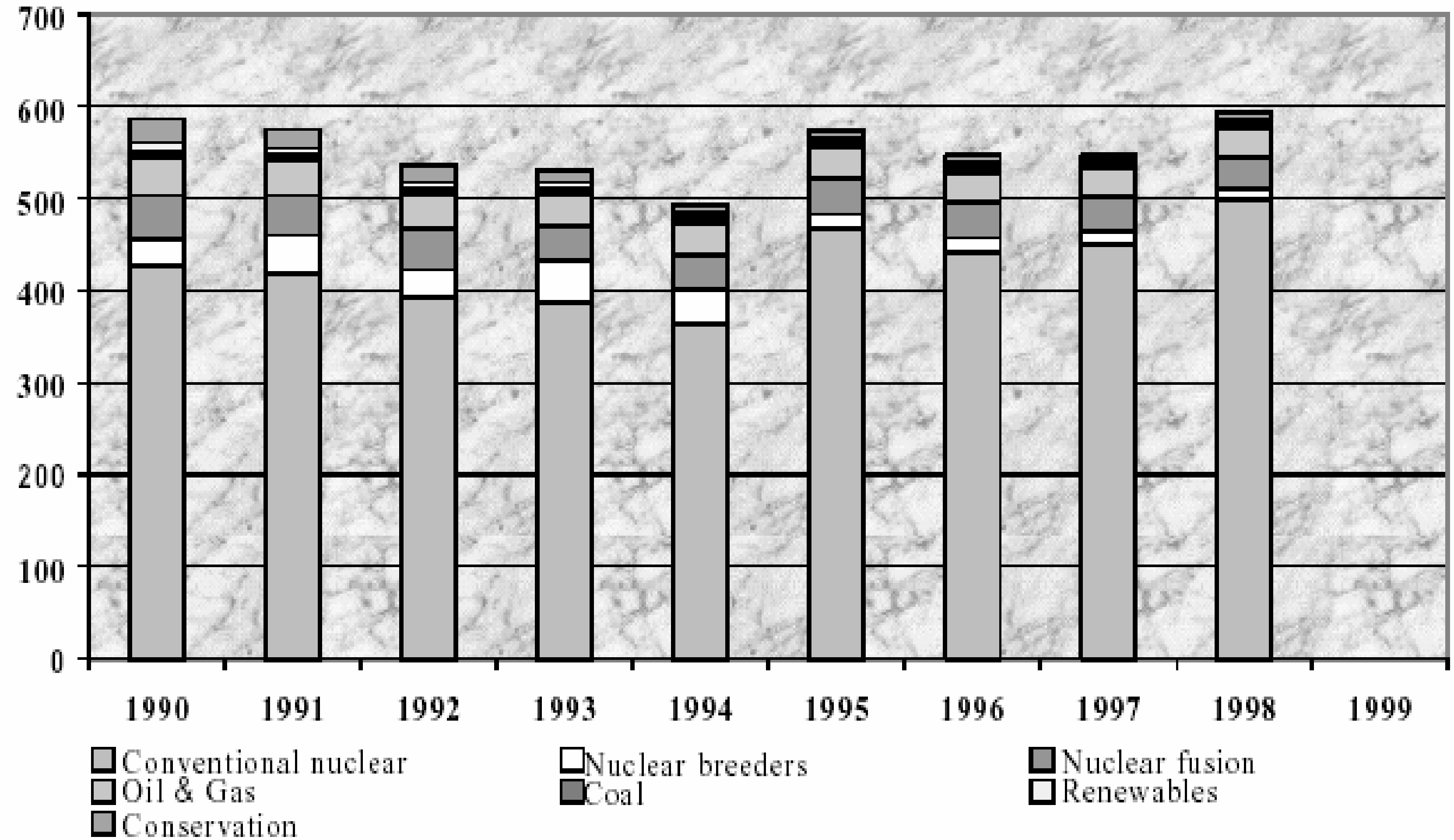



*Chart 5. Evolution of government energy R&D budgets in France, 1990-98 (million US dollars – 1998 constant prices). (Source: IEA, 1999.)*

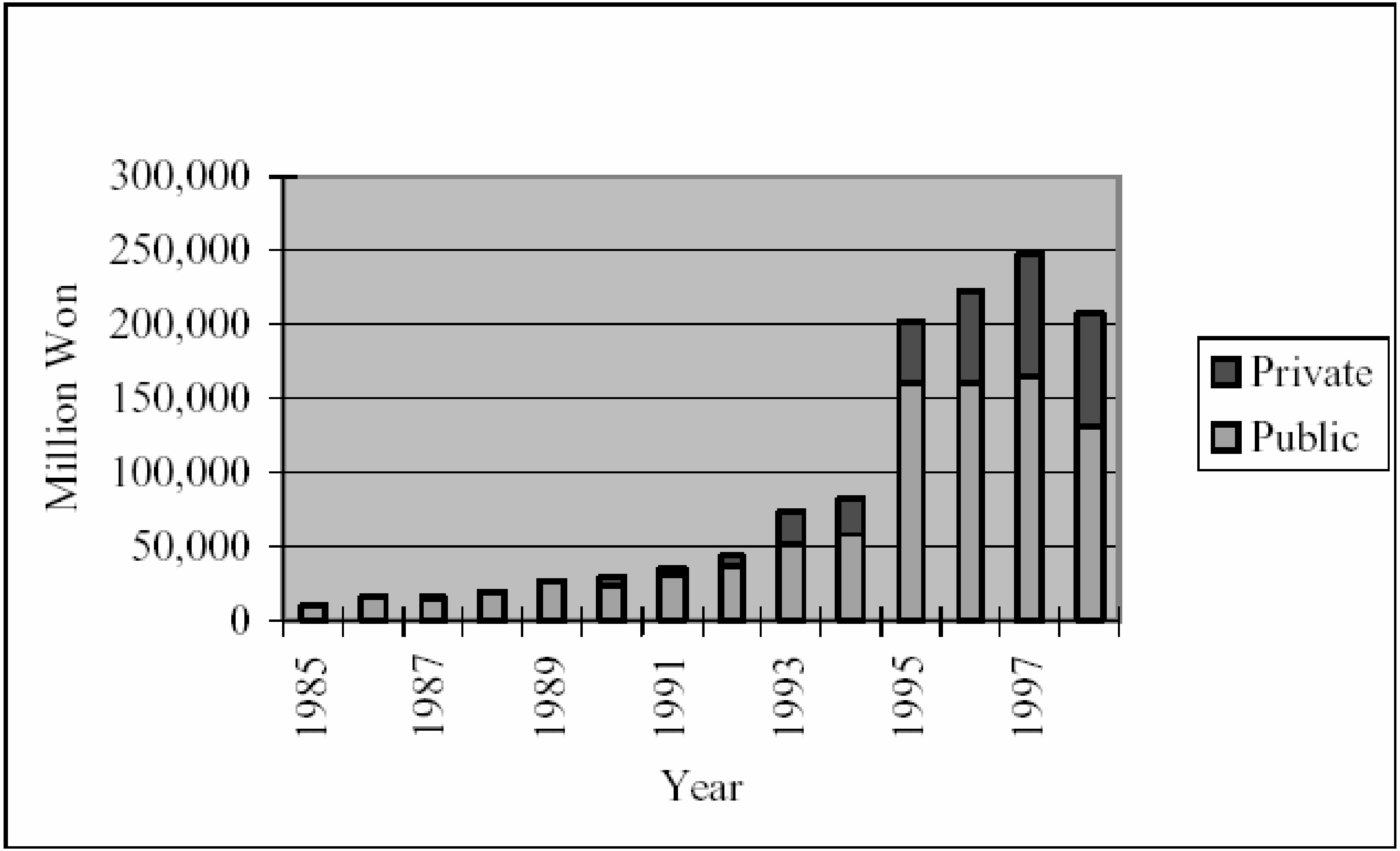
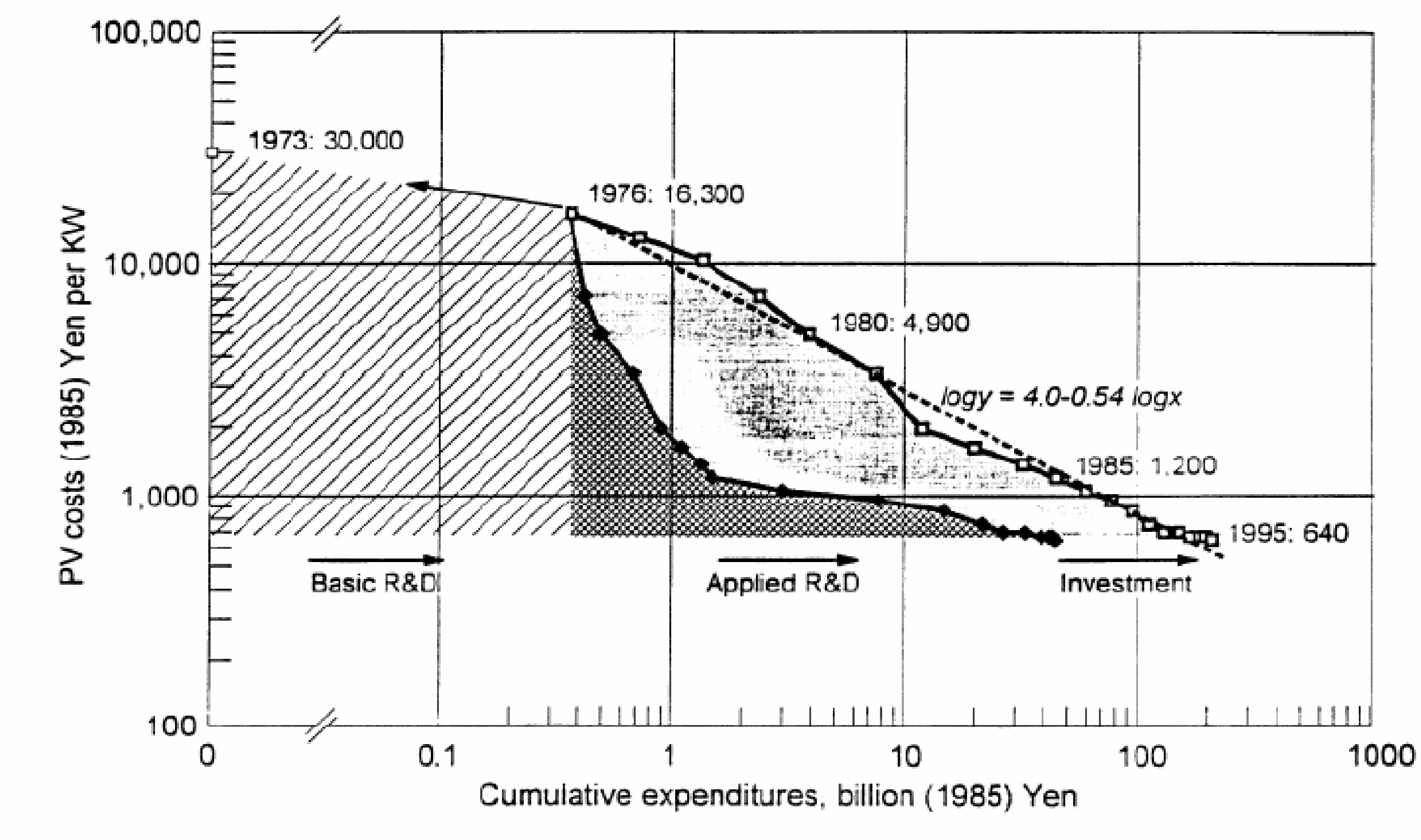


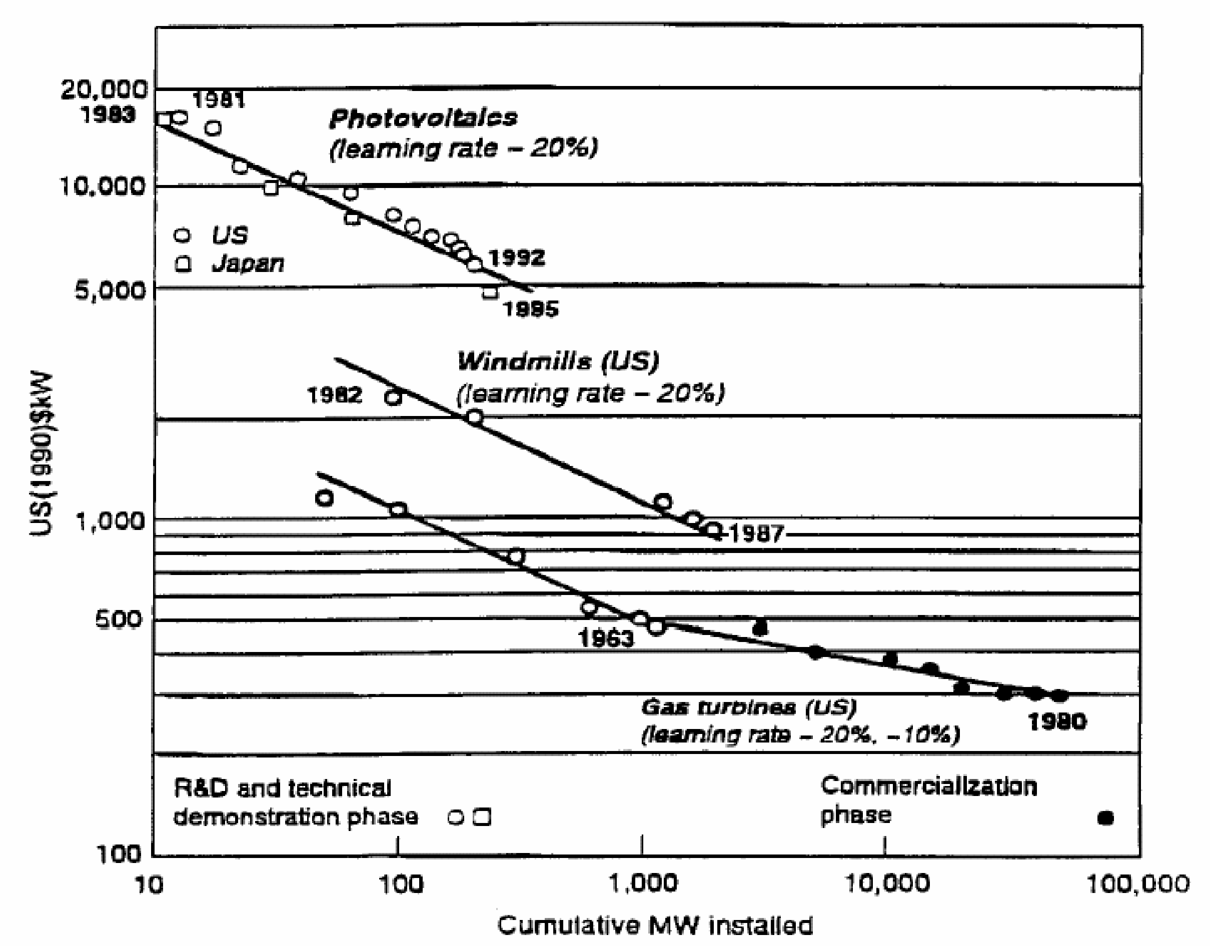

*Chart 6. Total energy R&D expenditure in the Republic of Korea, 1985-98.*

# Measures of performance: Learning

Learning based on cumulative investment in R&D, demonstrations, and commercial niche markets (from Gruebler, Nakicenovic, & Victor, “Modeling Technological Change”, *Annual Review of Energy & Environment*, 1999, pp 545-69)



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



# Closing the rich-poor gap: Cooperation

# 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

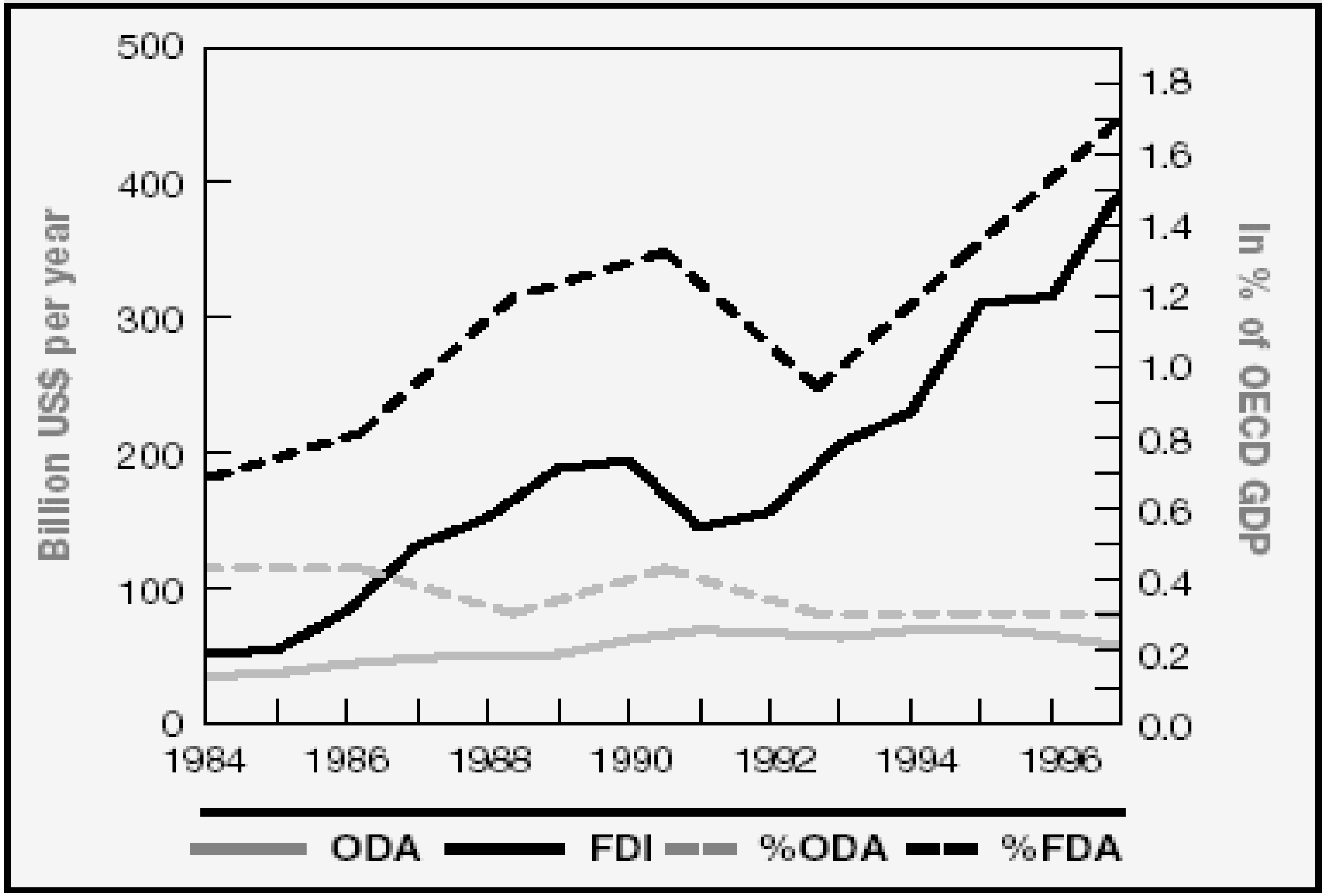
*BENEFITS FROM ENERGY-TECHNOLOGY IMPROVEMENTS IN ALL COUNTRIES*

- 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

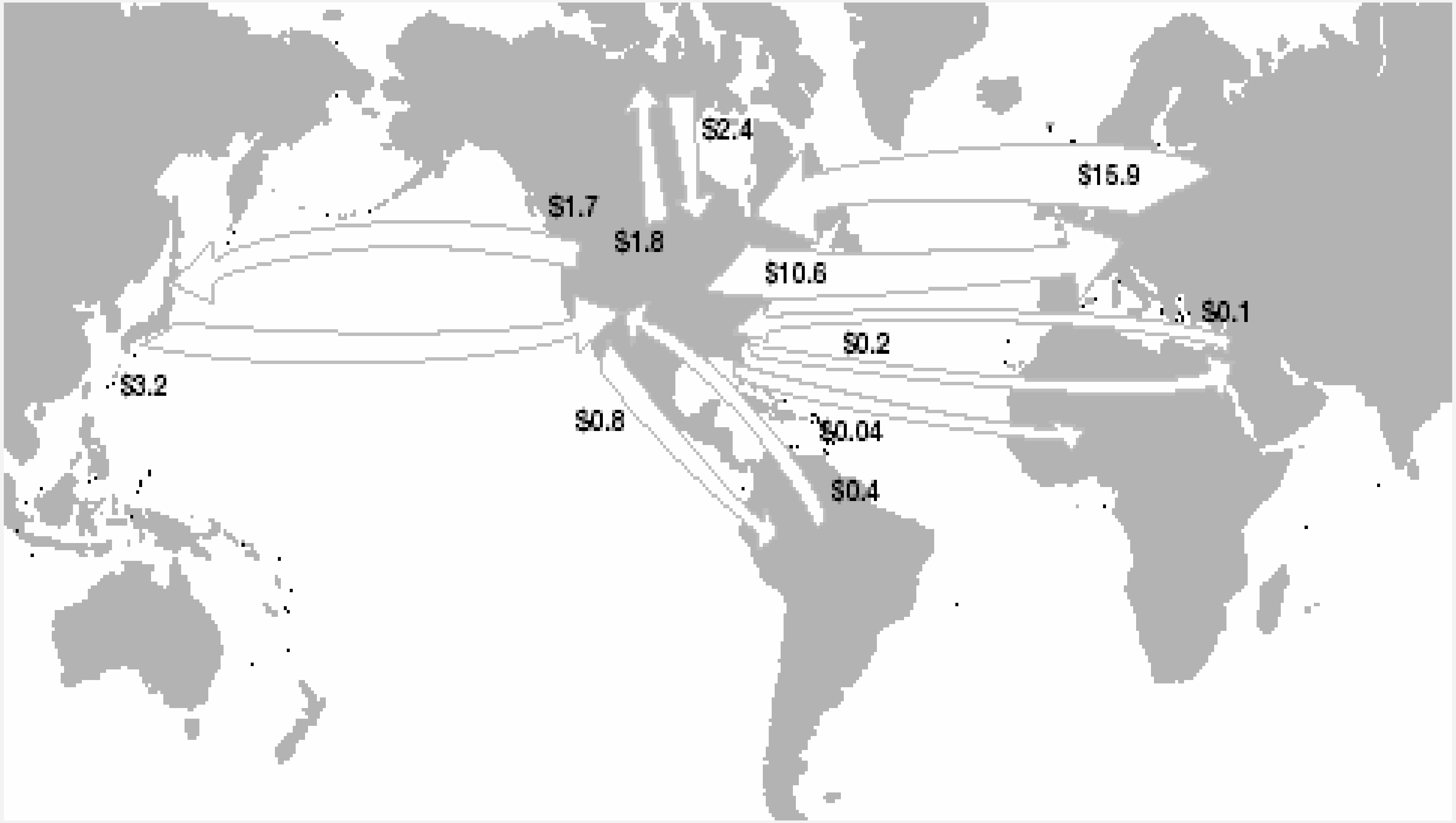
**FIGURE 1.3. FOREIGN DIRECT INVESTMENTS AND OFFICIAL DEVELOPMENT ASSISTANCE, 1984–97, IN US$ AND AS SHARE OF OECD GDP**




*Source: World Bank, 1999.*

Overview Figure 19.
**Industrial R&D spending flows of U.S. and foreign affiliates, by world region: 1998**

Billions of dollars




See appendix tables 4-48 and 4-50.

*Science & Engineering Indicators – 2002*

**TABLE 12.2. THE ENERGY INNOVATION CHAIN FOR SUSTAINABLE ENERGY TECHNOLOGIES**

| | Research and development (laboratory) | Demonstration (pilot to market) | Early deployment (technology cost buy-down) | Widespread dissemination (overcoming institutional barriers and increasing investment) |
|---|---|---|---|---|
| Key barriers | • Governments consider R&D funding problematic<br>• Private firms cannot appropriate full benefits of their R&D investments | • Governments consider allocating funds for demonstration projects difficult<br>• Difficult for private sector to capture benefits<br>• Technological risks<br>• High capital costs | • Financing for incremental cost reduction (which can be substantial)<br>• Uncertainties relating to potential for cost reduction<br>• Environmental and other social costs not fully internalised | • Weaknesses in investment, savings, and legal institutions and processes<br>• Subsidies to conventional technologies and lack of competition<br>• Prices for competing technologies exclude externalities<br>• Weaknesses in retail supply financing and service<br>• Lack of information for consumers and inertia<br>• Environmental and other social costs not fully internalised |
| Policy options to address barriers | • Direct public funding (national or international)<br>• Tax incentives<br>• Incentives for collaborative R&D partnerships | • Direct national or international support for demonstration projects<br>• Tax incentives<br>• Low-cost or guaranteed loans<br>• Temporary price guarantees for energy products of demonstration projects | • Temporary subsidies through tax incentives, government procurement, or competitive market transformation initiatives | • Phasing out subsidies to established energy technologies<br>• Measures to promote competition<br>• Full costing of externalities in energy prices<br>• 'Green' labelling and marketing<br>• Concessions and other market-aggregating mechanisms<br>• Innovative retail financing and consumer credit schemes<br>• Clean Development Mechanism (see text) |

*Source: Adapted from PCAST, 1999.*

# Recommendations of the 1999 PCAST study

Increase US federal funding for international cooperation on $ERD^3$ from $250M (1997) to $500M in FY2003, $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

# What more do we need to know?

## 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).

## 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.

# What more do we need to do?

## Some conclusions of the 2001 WEC Study Group

- In half of 18 countries considered in detail, gov't ERD&D expenditures declined significantly between 1985 and 2000

  USA, w ~40% of world total, declined sharply; Japan increased by 45%.

- Private sector performance more difficult to assess.
- Cuts in ERD&D fell disproportionately on fossil and nuclear.
- 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 RD&D programs are not commensurate in scope and scale with the energy challenges & opportunities the 21st century will present."

- The 1999 PCAST conclusion about scope of strengthened international cooperation on ERD&D is correct.

# 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."

# My own conclusions & recommendations

- The energy challenges of this century – above all, that of providing the affordable energy needed to achieve, expand, & sustain prosperity for all while avoiding intolerable disruption of global climate – cannot be met without a huge increase in the global energy-innovation effort. I believe we need a doubling or tripling of public & private investment in ERD&D and a tripling or quadrupling of international cooperation in ERD$^3$, mostly on the N-S axis.
- This will not happen without a price incentive that persists. The most effective way to achieve this would be through a global carbon tax or equivalent cap-and-trade approach.
- Implementation of the expanded innovation effort will require greater reliance than heretofore on partnerships, not only among countries but among branches of gov't, sectors (public, private, academic, NGO), and disciplines.

# Supplementary materials

# Key references

J. Dooley & P. Runci, "Adopting a long view to energy R&D…", Battelle PNNL-122115, February 1999, http://www.globalchange.umd.edu/publications/PNNL-12115.pdf

PCAST, Panel on International ERD3, Powerful Partnerships, June 1999, http://www.ostp.gov/html/P2E.pdf

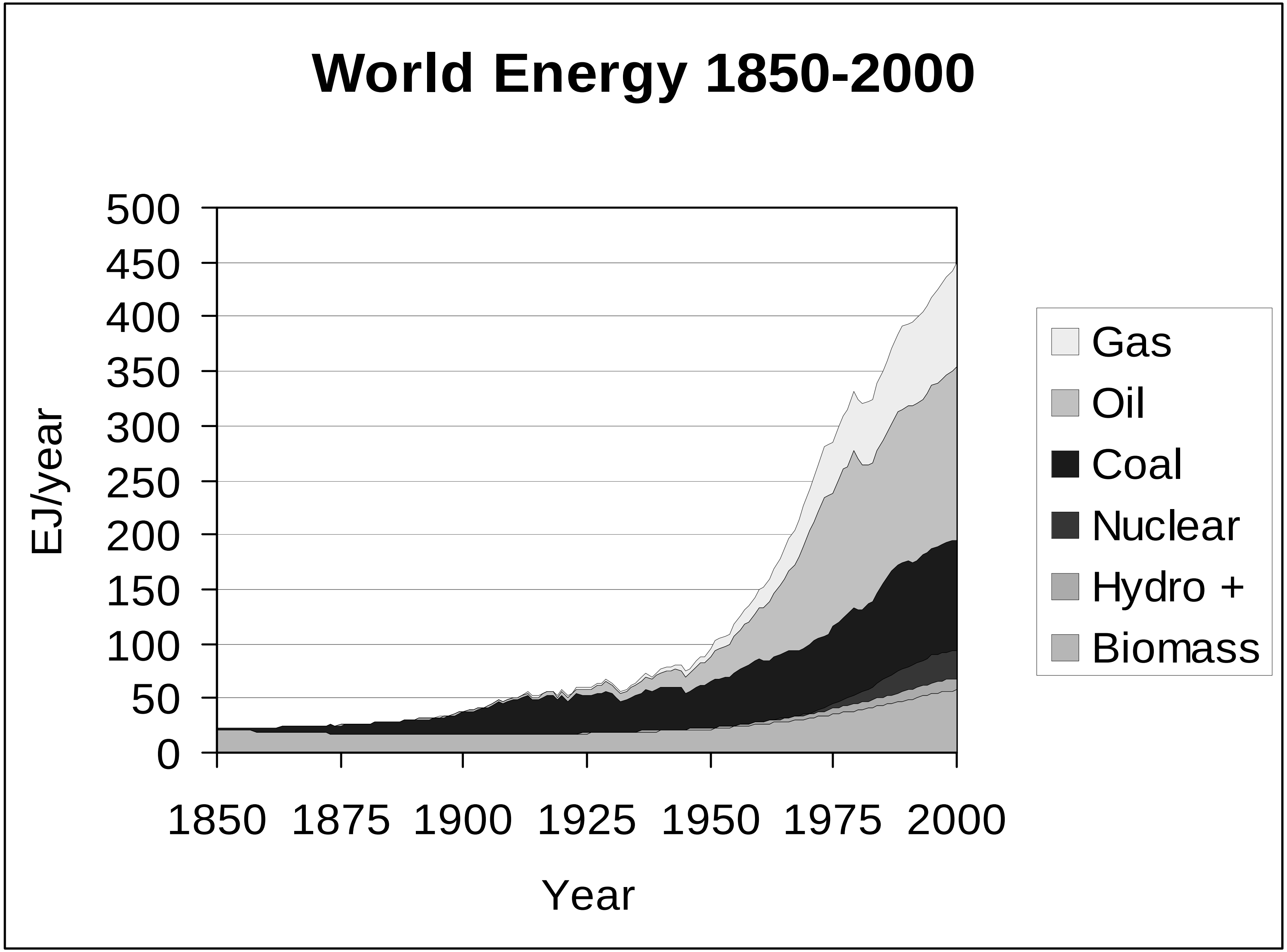
J. Holdren & S. Baldwin, "The PCAST Energy Studies: Toward a National Consensus on Energy Research, Development, Demonstration, and Deployment Policy", Annual Review of Energy and Environment, vol. 26, 2001: http://bcsia.ksg.harvard.edu/BCSIA_content/documents/AREE_HoldrenBaldwin01.pdf

J. Dooley, "U.S. National Investment in Energy R&D, Battelle PNWD-3108, July 2001, http://www.globalchange.umd.edu/publications/PNWD-3108.pdf

World Energy Council, ERD&D Study Group, Energy Technologies for the 21st Century, August 2001, http://www.worldenergy.org/wec-geis/publications/report…

A. Sagar and J. Holdren, "Assessing the Global Energy Innovation System", Energy Policy, vol. 30, 2002, http://bcsia.ksg.harvard.edu/BCSIA_content/documents/AssessingEnergy.pdf

American Assoc for the Advancement of Science, Guide to R&D Funding Data, http://www.aaas.org/spp/rd/guide.htm


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

## A "thought experiment": How much does C-free energy need to grow in the 21st century?

| | 2000 | 2050 | 2100 |
|---|---|---|---|
| BAU population, billions | 6.1 | 9.8 | 11.1 |
| BAU GDP, trillion ppp-2000 $ | 45 | 170 | 440 |
| BAU primary energy, EJ | 450 | 1120 | 1800 |

To avoid a doubling of the pre-industrial CO2 concentration, conventional fossil primary energy must not exceed 530 EJ in 2050 and 340 EJ in 2100. It follows that:

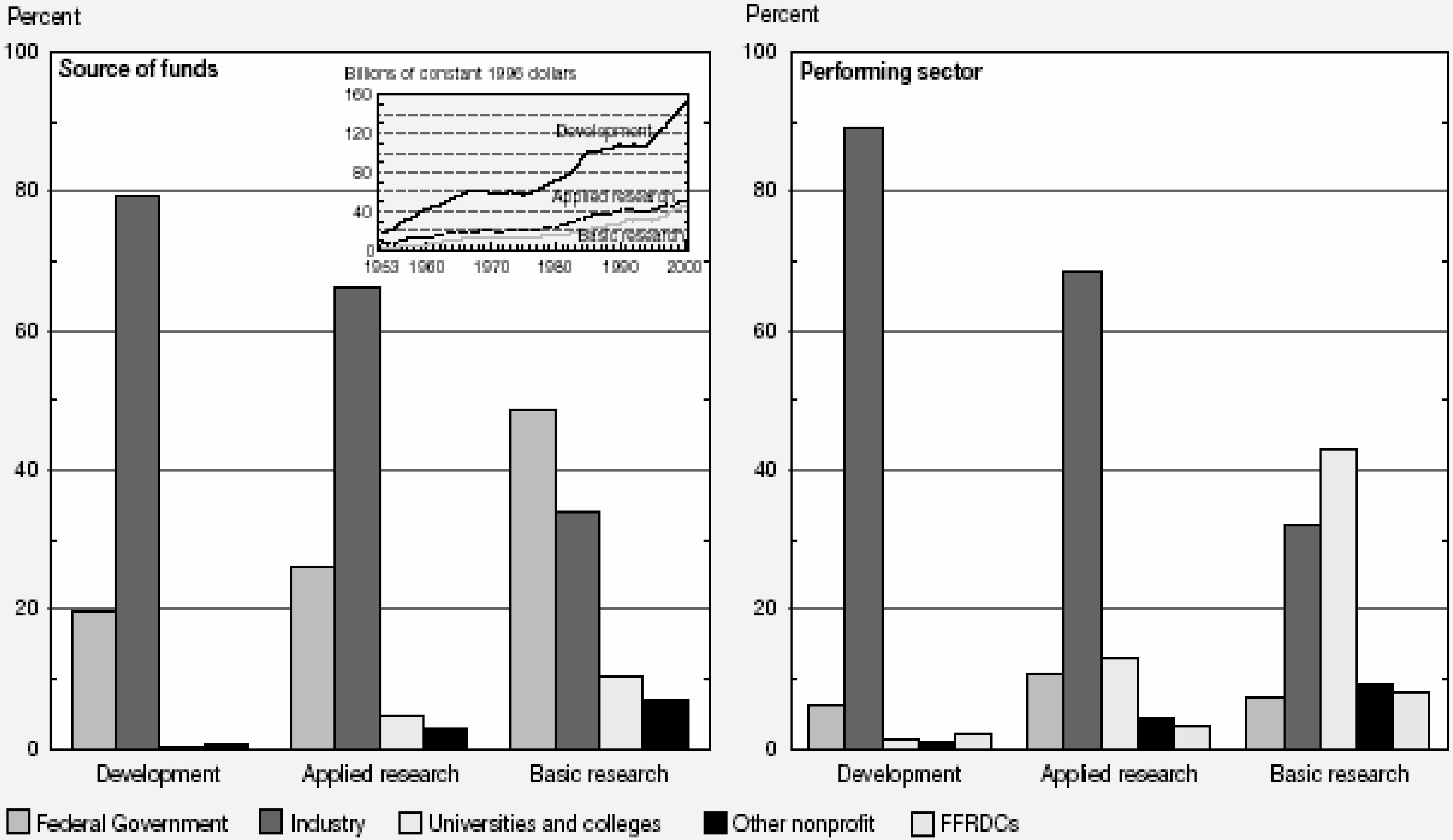
| | | | |
|---|---|---|---|
| C-free energy under BAU | 100 | 590 | 1460 |
| ...if E/GDP falls 1.5%/yr | 100 | 340 | 740 |
| ...if E/GCP falls 2.0%/yr | 100 | 140 | 310 |

Table. Total R&D as Percent of Gross Domestic Product (GDP), 2001 (selected nations)

| Nation | Total R&D / GDP Ratio | Gov't R&D / GDP Ratio | Industry R&D / GDP Ratio |
|---|---|---|---|
| Sweden | 4.27% | 0.90% | 3.07% |
| Finland | 3.40% | 0.87% | 2.41% |
| Japan | 3.09% | 0.57% | 2.25% |
| South Korea | 2.96% | 0.74% | 2.14% |
| **United States 1** | **2.82%** | **0.81%** | **1.87%** |
| Switzerland 2 | 2.63% | 0.61% | 1.82% |
| Germany | 2.49% | 0.78% | 1.64% |
| France 2 | 2.18% | 0.84% | 1.15% |
| Netherlands 2 | 1.94% | 0.70% | 0.97% |
| **European Union** | **1.93%** | **0.65%*** | **1.06%*** |
| United Kingdom | 1.90% | 0.57% | 0.88% |
| Canada 1 | 1.85% | 0.61% | 0.74% |
| Australia 2 | 1.53% | 0.71% | 0.70% |
| Italy 2 | 1.07% | NA | NA |
| Spain | 0.96% | 0.38% | 0.45% |
| | | | |

SOURCE: OECD, Main Science and Technology Indicators, 2003.

Figure 4-12.
**National R&D expenditures, by source of funds, performing sector, and character of work: 2000**

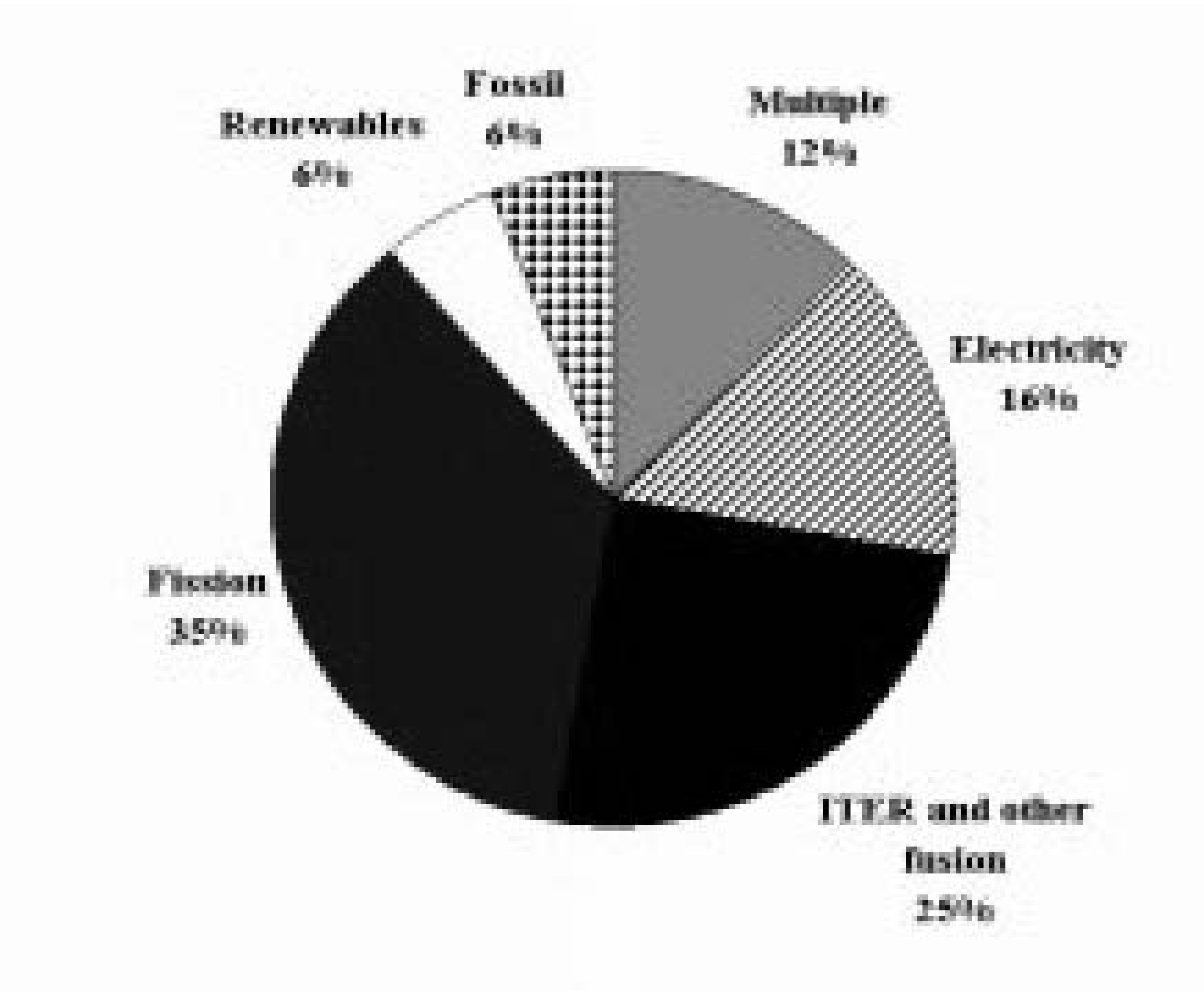


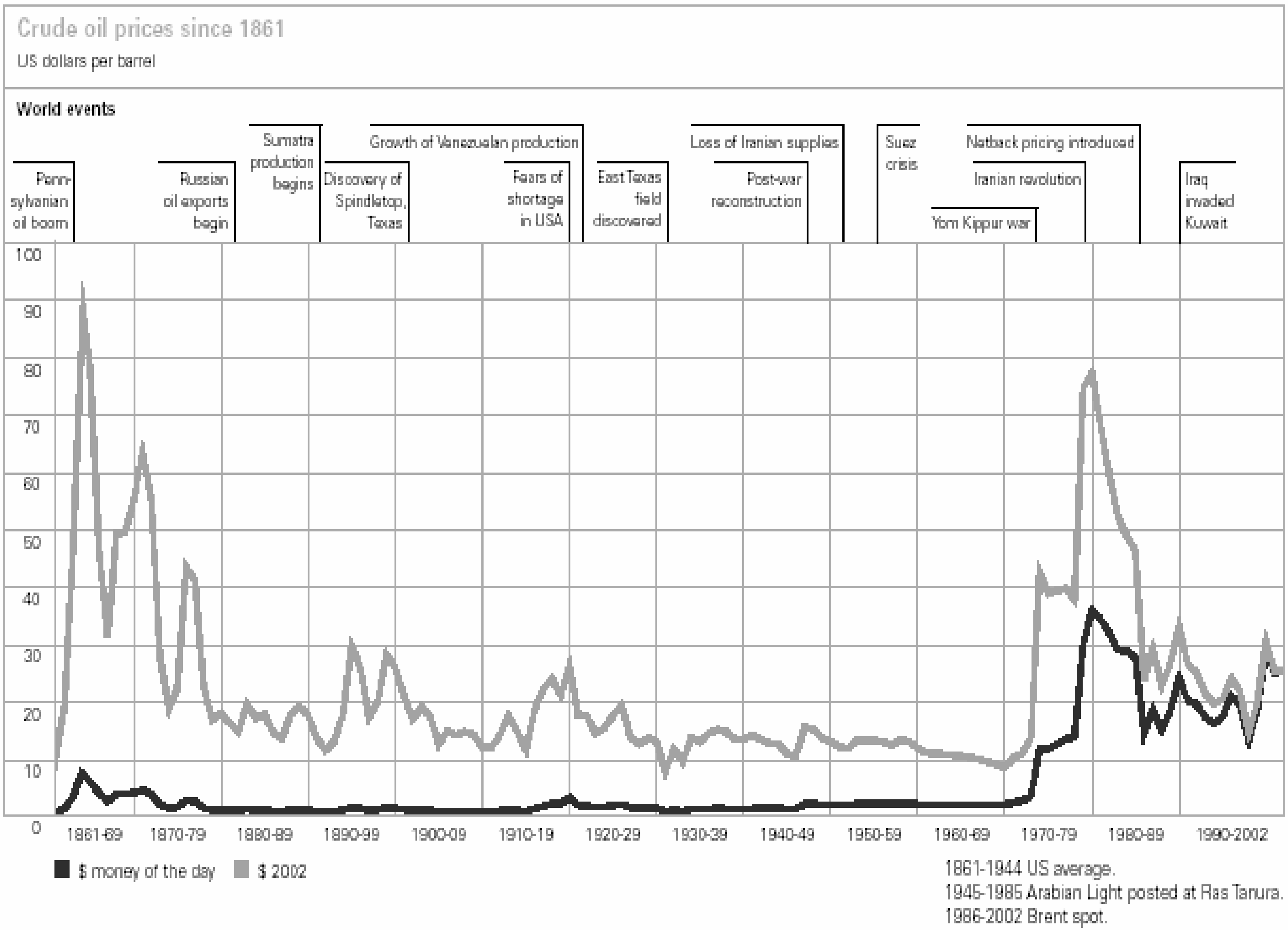

FFRDCs = Federally Funded Research and Development Centers

See appendix tables 4-7 through 4-18.

*Science & Engineering Indicators – 2002*

# Sectors of US federal gov’t ERD3 collaborations, 1997





Crude oil prices since 1861
US dollars per barrel
World events
Penn-sylvanian oil boom
Russian oil exports begin
Sumatra production begins
Discovery of Spindletop, Texas
Growth of Venezuelan production
Fears of shortage in USA
East Texas field discovered
Loss of Iranian supplies
Post-war reconstruction
Suez crisis
Yom Kippur war
Netback pricing introduced
Iranian revolution
Iraq invaded Kuwait
100
90
80
70
60
50
40
30
20
10
0
1861-69
1870-79
1880-89
1890-99
1900-09
1910-19
1920-29
1930-39
1940-49
1950-59
1960-69
1970-79
1980-89
1990-2002
$ money of the day
$ 2002
1861-1944 US average.
1945-1985 Arabian Light posted at Ras Tanura.
1986-2002 Brent spot.