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ENERGY TECHNOLOGY
INNOVATION POLICY

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Government Policies for Innovation in Energy

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Innovation in energy and the role of government

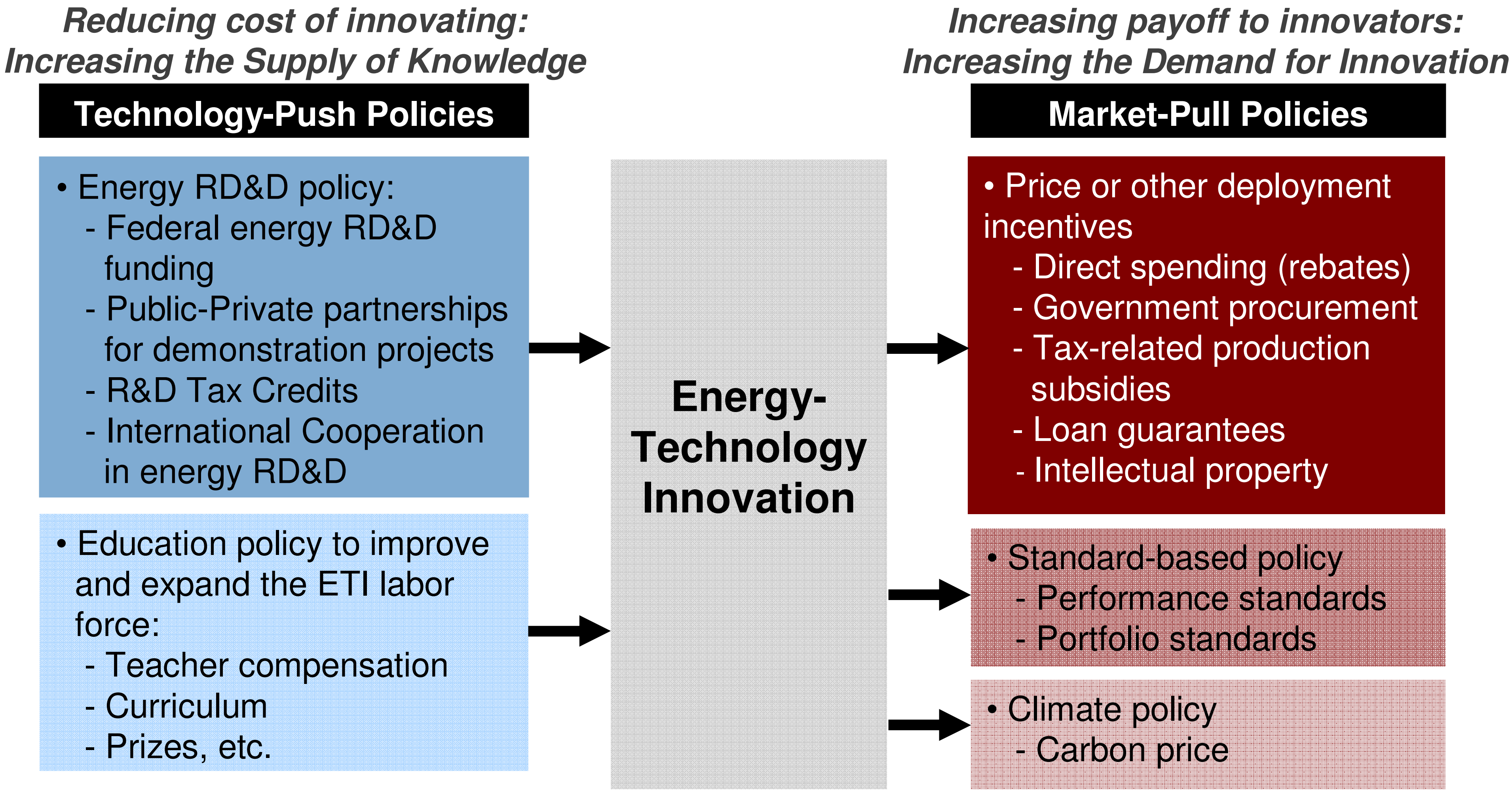
- Innovation encompasses the processes from an idea to a new technology, device, or organizational structure in the marketplace.
- Public, private sectors, and citizens all have roles to play in innovation. But if role of policy is to address market failures, in energy innovation we have a few:
  - Knowledge spillovers
  - Environmental impacts
  - National security

➔in energy innovation, role of government is crucial, but designing and implementing government action is made more difficult by uncertainty

- The impact of RD&D and innovation is uncertain and fat-tailed
- The impact of GHG emissions is uncertain and fat-tailed

and the large, long-lived incumbent infrastructure

Many energy innovation policy tools



Reducing cost of innovating:
Increasing the Supply of Knowledge

Technology-Push Policies

- Energy RD&D policy:
  - Federal energy RD&D funding
  - Public-Private partnerships for demonstration projects
  - R&D Tax Credits
  - International Cooperation in energy RD&D

- Education policy to improve and expand the ETI labor force:
  - Teacher compensation
  - Curriculum
  - Prizes, etc.

Energy-Technology Innovation

Increasing payoff to innovators:
Increasing the Demand for Innovation

Market-Pull Policies

- Price or other deployment incentives
  - Direct spending (rebates)
  - Government procurement
  - Tax-related production subsidies
  - Loan guarantees
  - Intellectual property

- Standard-based policy
  - Performance standards
  - Portfolio standards

- Climate policy
  - Carbon price

Mowery and Rosenberg (1979); Anadon and Holdren (2009)

Innovation systems approach emphasizes interactions and information

Example of Innovation policies

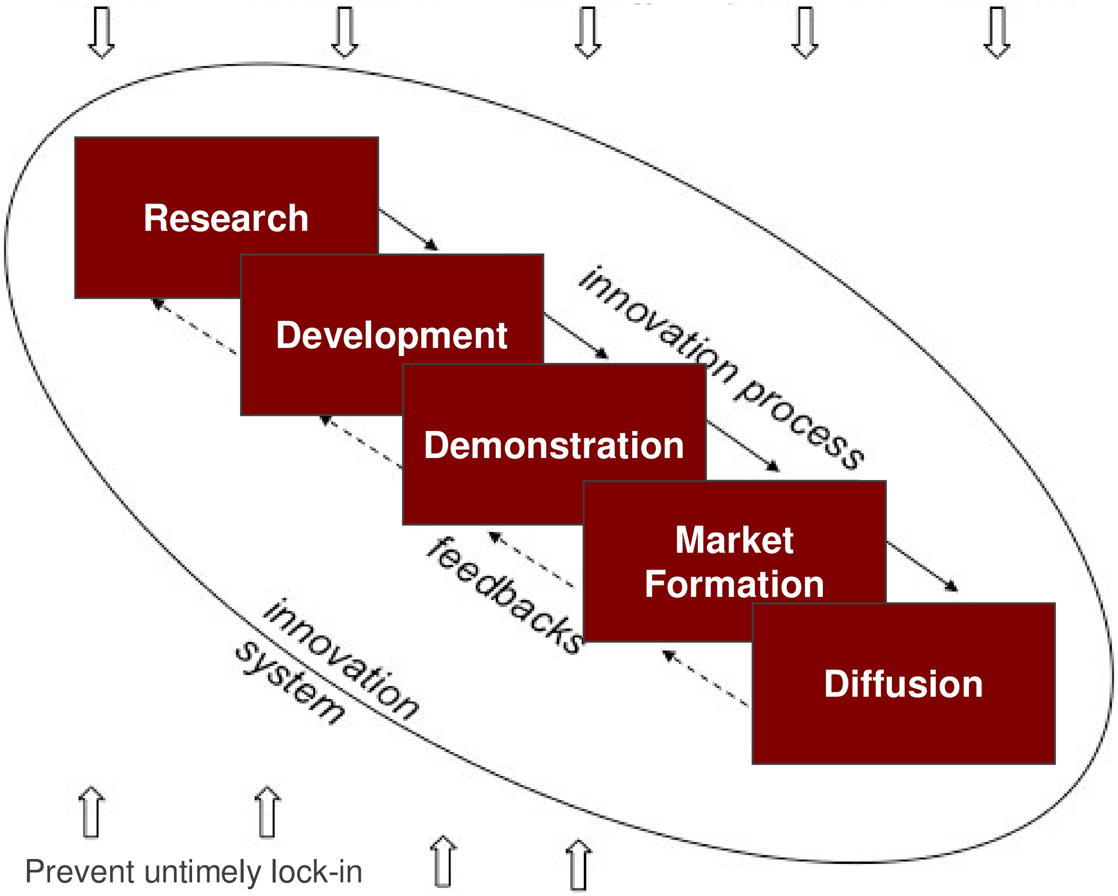
Investing in testing & lab facilities

Joint university-industry grants

Underwrite incremental risk of new technology

Public procurement

Price or quantity mechanisms



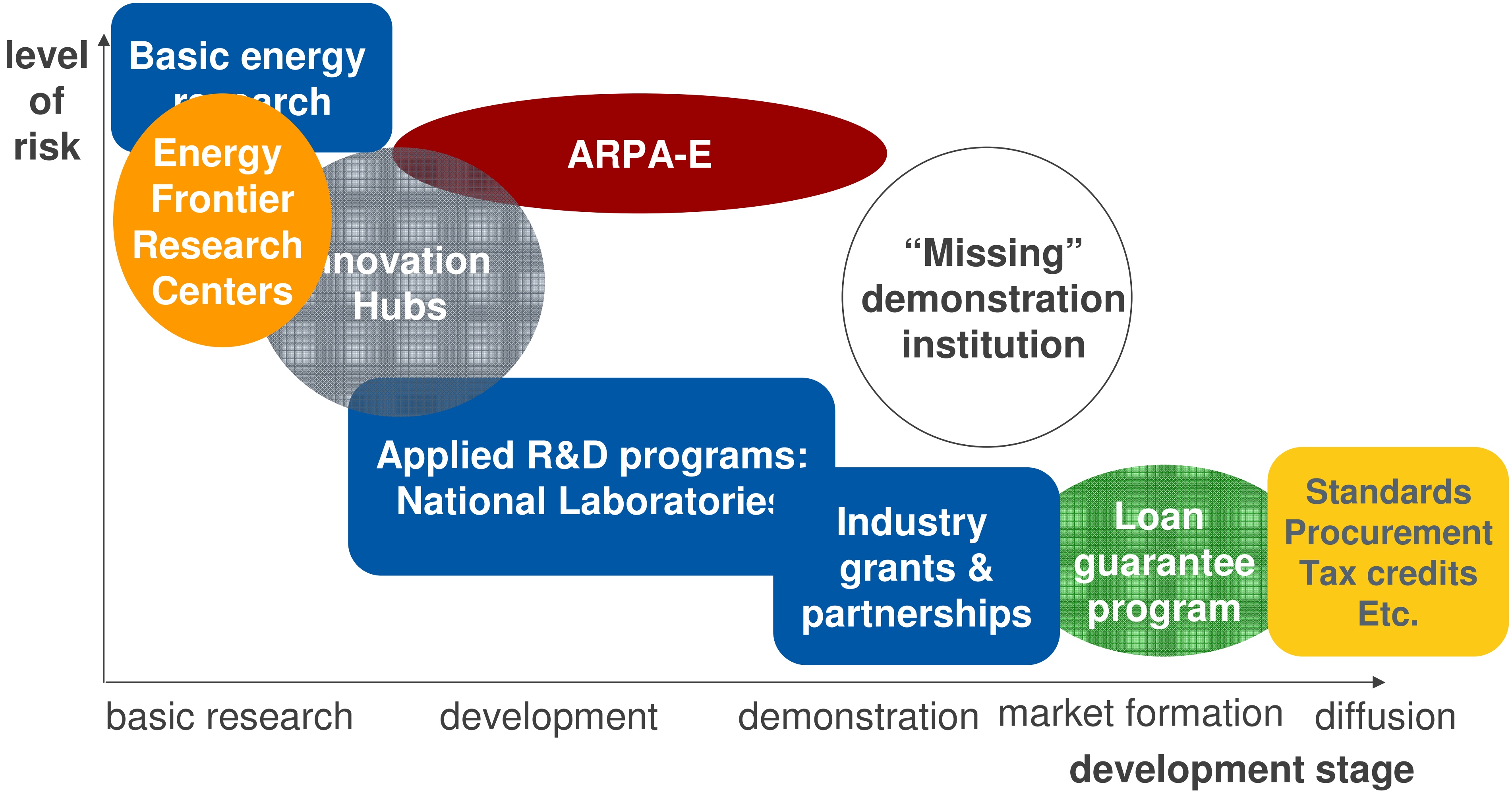
Example of Innovation Systems approaches

Prevent untimely lock-in
Manage interfaces among actors
Stimulate physical & knowledge infrastructure
Create conditions for learning and experimenting

Global Energy Assessment (forthcoming 2011)

ERD3 Project: Transforming U.S. Energy Innovation

Question: how to accelerate energy innovation in the United States to meet the environmental, economic, and security challenges



level of risk

Basic energy research

Energy Frontier Research Centers

nnovation Hubs

ARPA-E

“Missing” demonstration institution

Applied R&D programs: National Laboratorie

Industry grants & partnerships

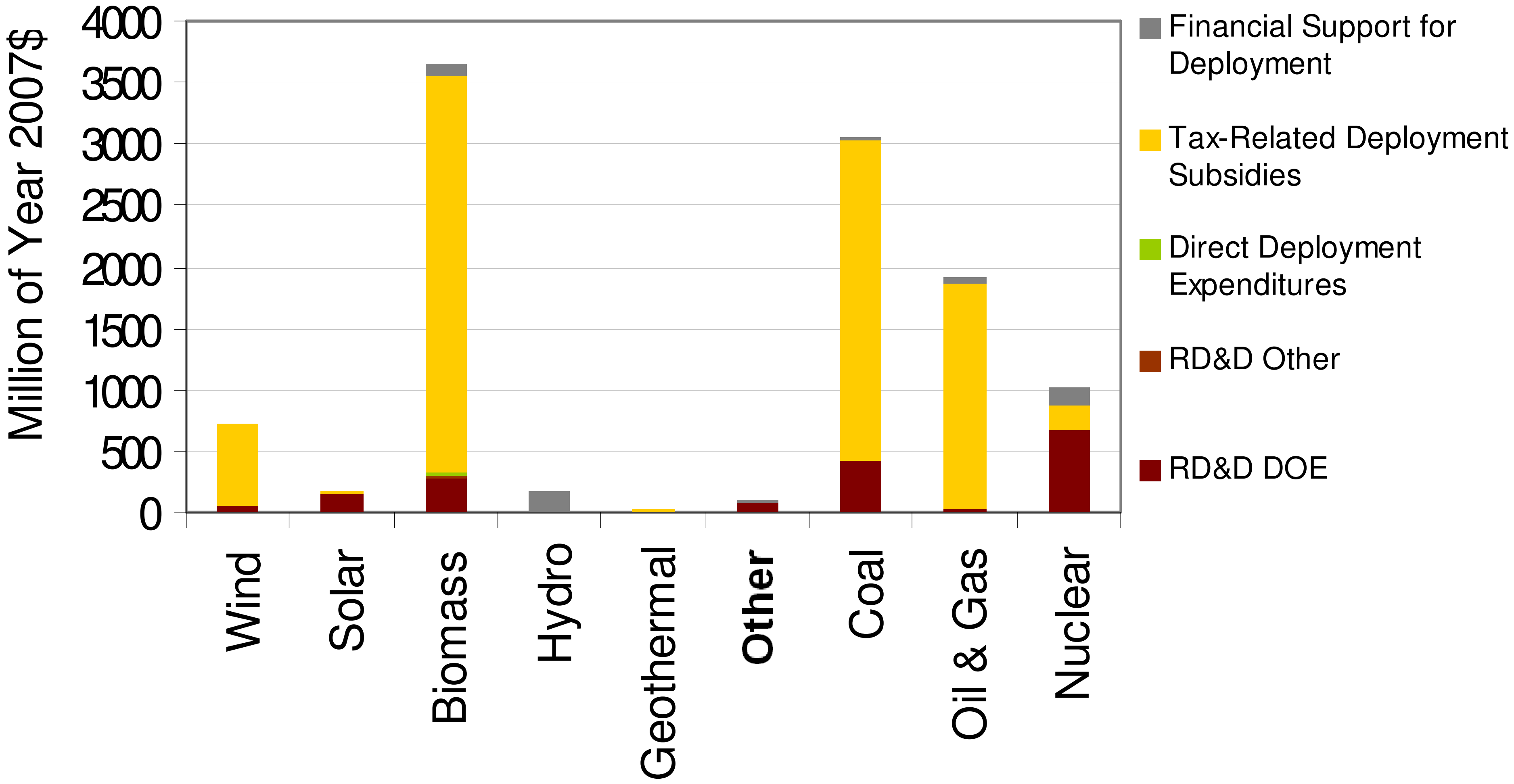
Loan guarantee program

Standards
Procurement
Tax credits
Etc.

basic research | development | demonstration | market formation | diffusion

development stage

U.S. government energy-related expenditures in 2007 show inertia towards incumbents and power of some interest groups

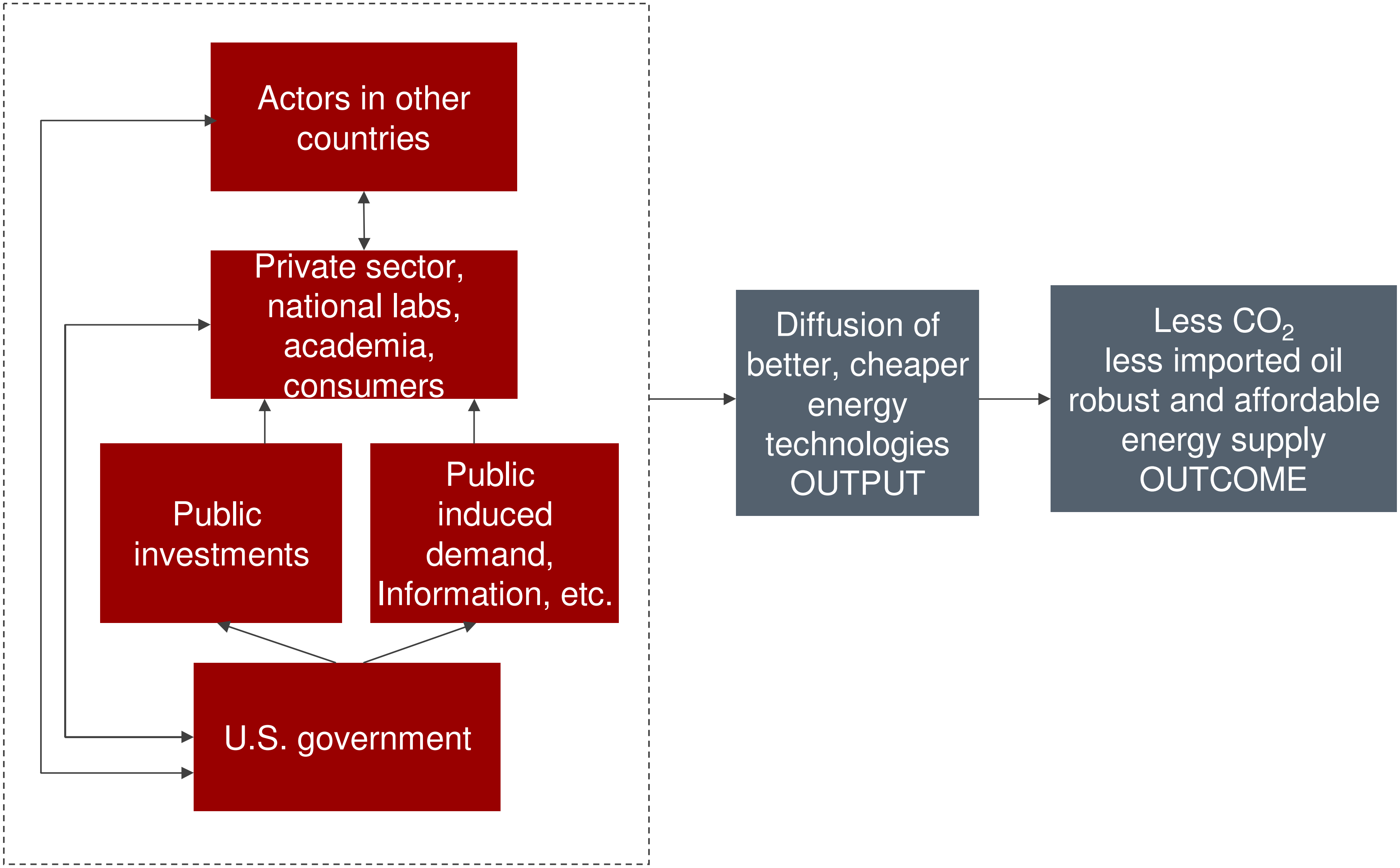


Data from Federal Financial Interventions and Subsidies in Energy Markets 2007 (EIA) & Gallagher and Anadon; Anadon & Holdren (2009)

Outline: 4 studies

- **Public investments in energy RD&D.** How can we think about constructing portfolios of public energy RD&D investments accounting for uncertainty and market interactions?
- **Private actions in energy innovation.** Can we start taking into account innovation in the private sector to design partnerships with firms and ways of promoting private sector innovation?
- **Institutions.** Are there lessons to be extracted from government innovation institutions that can be used to improve them or design new ones?
- **Understanding innovation in emerging economies.** Innovation is global, but we know little of how technologies mature and improve in other markets. How do we take into account innovation dynamics in emerging economies?

Towards informing energy innovation policy



Actors in other countries

Private sector, national labs, academia, consumers

Public investments

Public induced demand, Information, etc.

U.S. government

Diffusion of better, cheaper energy technologies OUTPUT

Less CO_2
less imported oil
robust and affordable energy supply
OUTCOME

Public investments in energy RD&D

Research question
From the perspective of using a risk analysis framework

- What can we say about the level and allocation of energy RD&D investment required to have *acceptable* results on metrics we care about:
  - CO_2 emissions
  - CO_2 prices (if climate policy adopted)
  - oil imports
  - geographic distribution of electricity cost that makes policies feasible
- Our approach is to incorporate technical uncertainty to allow us to quantify the uncertainty around the benefits and use decision metrics such as:
  - Probability of CO_2 price below a reasonable level, e.g., \$30/tonCO_2
  - Probability of a very high CO_2 price, e.g., \$100/tonCO_2,
  - Mean and standard deviation of a resulting oil imports, etc.

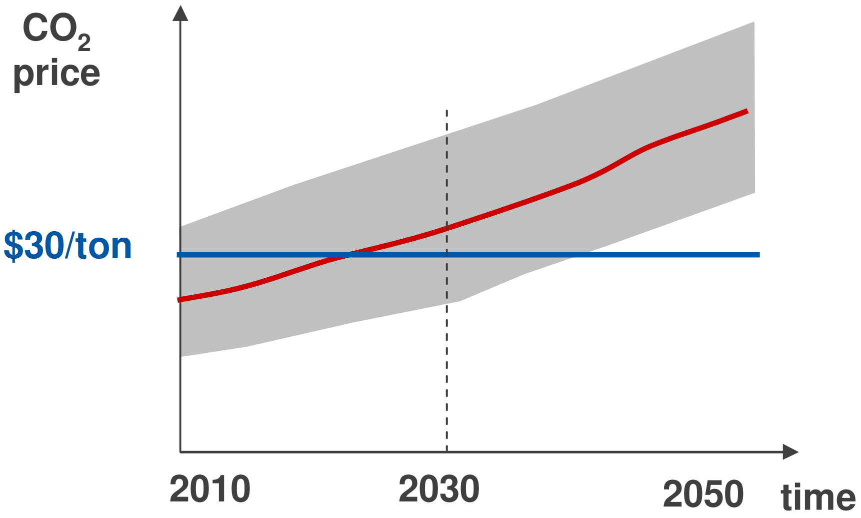
  … under a range of investment portfolios and assumptions

Government agencies need analytic tools to design energy research, development, and demonstration funding programs

- U.S. Department of Energy uses recommendations from individual technology programs and the presidential priorities
- Interested parties (coal, nuclear, environmentalists) lobby to increase government support for their research
- Tools to build portfolios of investments to reduce the risk of not meeting policy goals are needed
- But building analytical tools is difficult because returns to RD&D are unknown ex ante (measuring returns to historical public RD&D is also difficult)
  - Factor decomposition (Nemet, 2007; McNerney & Trancik, 2010)
  - Monitoring precursors (Martino, 1987)
  - Expert elicitation (Henrion & Morgan 1990; Baker & Keisler, 2009)

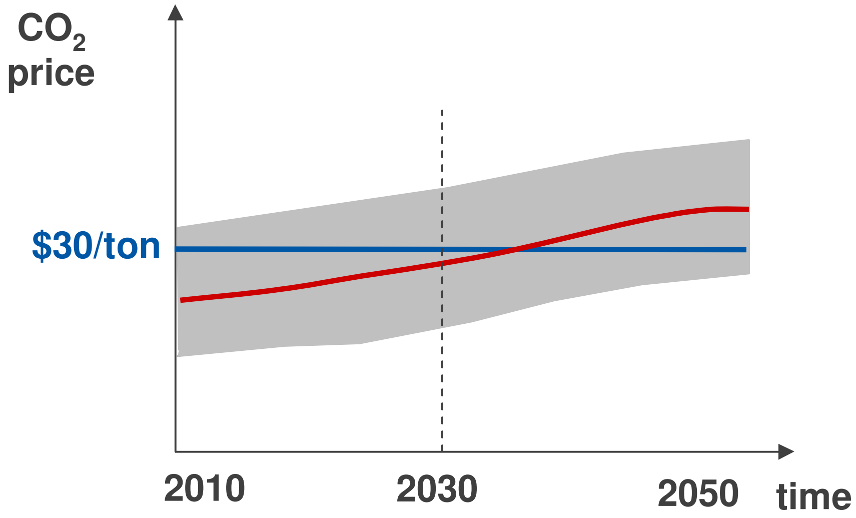
From elicitations to quantifying benefits of portfolios accounting for uncertainty

Business as usual RD&D scenario



e.g.,30% probability of carbon price in 2030 below $30/tonCO$_2$

Enhanced RD&D scenario



e.g., 70% probability of carbon price in 2030 below $30/tonCO$_2$

- We combined expert elicitation with energy economic modeling and Latin hypercube sampling simulations

From expert elicitations to uncertainty around R&D portfolio investment benefits

Step 1

Expert elicitations
RD&D $ ➔ $/kWh

- Estimate uncertainty around technology performance and cost in 2030 with BAU RD&D investments
- Recommend RD&D budget through 2030
- Provide new estimates with enhanced RD&D in 2030

Step 2

Setting up MARKAL Simulation

- Three types of input on cost and performance for each technology area
- Estimate correlation between technologies and over time
- Intra- and interpolate for data over time

Step 3.

Impact of policies & market conditions
$/kWh ➔ e.g. ton CO_2

- Different investment portfolios and amounts
- Different oil and natural gas prices
- Construct key policy and market scenarios including carbon caps, clean electricity standards, and CAFE

Investment portfolios cover a wide range of technologies
Our elicitations cover 25 technologies and 4 RD&D budgets

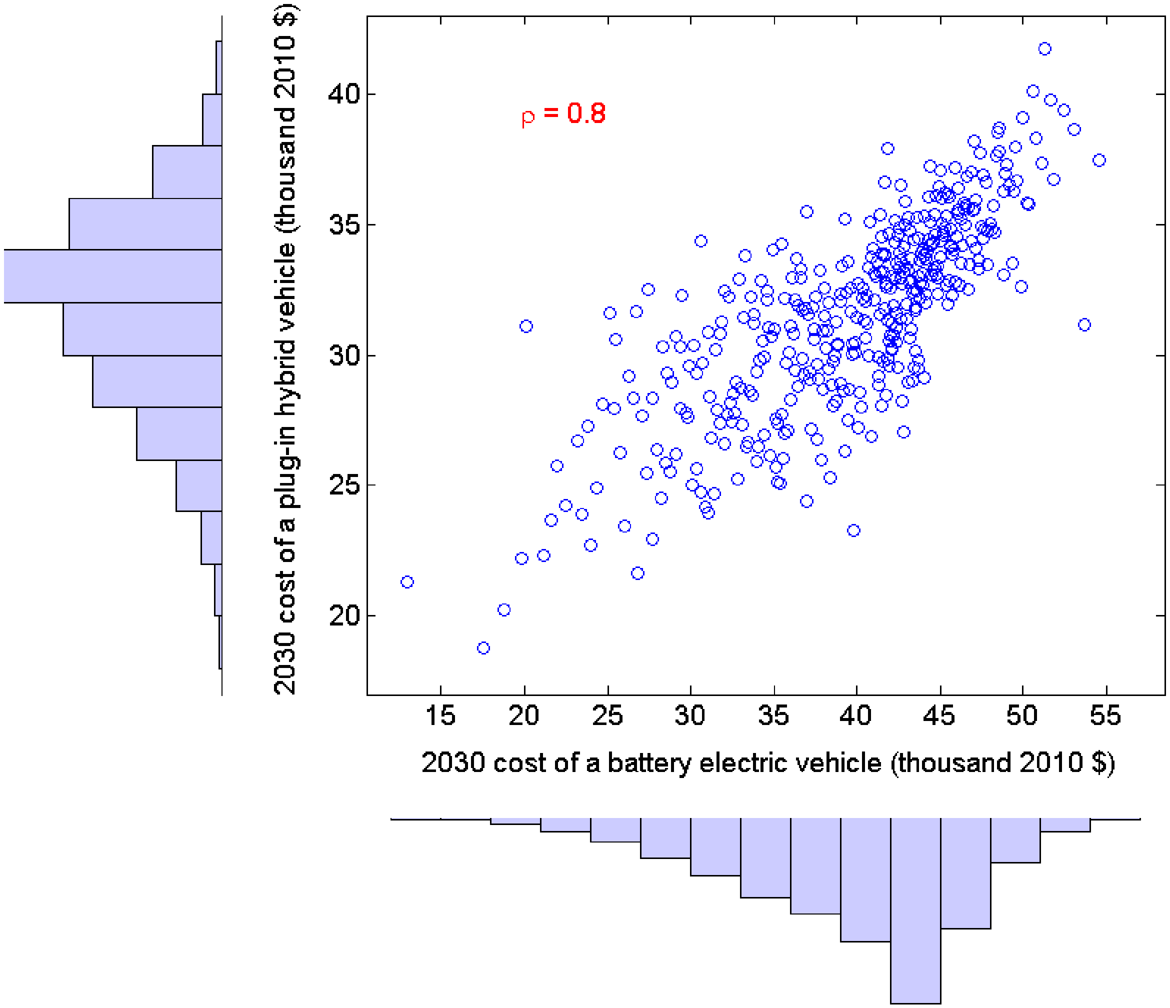
- 4 supply side technology areas
  - *Nuclear energy*: Gen III, Gen IV, modular reactors
  - *Fossil energy*: coal with and without CCS, natural gas with and w/o CCS
  - *Bioenergy:* gasoline, diesel, and jet fuel production through thermochemical and biochemical conversion pathways, and electricity
  - *Photovoltaic energy*: residential, commercial, and utility scale
- 1 enabling technology area
  - *Utility scale energy storage*: compressed air storage, 2 types of batteries, flow batteries
- 2 demand side technology areas
  - *Vehicle types*: advanced ICE, electric vehicle, plug-in electric vehicle, hybrid vehicle, and fuel cell vehicle
  - *Buildings*: residential and commercial buildings, 6 levels of energy efficiency for heating and cooling

Representing uncertainty and dealing with computational limits for a large number of technologies

- Latin Hypercube Sampling (LHS) algorithm from Iman and Conover (1982)
  - Each (marginal) distribution of technology costs is partitioned into equal probability strata. Within each strata, the (marginal) distribution strata is sampled exactly once in the entire analysis.
  - We believe that there is dependence between some technology costs, we design the study to select combinations of Latin Hypercube marginal distribution draws for each technology to have a desired (rank) correlation matrix.
  - Algorithm works stochastically, so we iterate until the maximum absolute difference in any one specified rank correlation is below a specified threshold (0.05 for 400 runs).
- Sampling done either with traditional LHS or with van der Waerden scores version of LHS - i.e., samples at median of strata
  - no major differences; Morgan and Henrion (1990) recommend van der Waerden
- 400 samples per scenario define distributions in our implementation

Morgan and Henrion (1990) and Webster et al. (2004)

Accounting for the fact that improvements in some technologies are likely to be related (across-technology rank correlation)



- Sampling distribution for electric and plug-in hybrid vehicles
  - Drawn using LHS with Iman and Connover method to induce Gaussian copula dependence for ρ= 0.8
  - Marginal distributions (provided by experts) are preserved

Clusters of technologies where improvements are likely to be related

Cluster 1

Liquid fuels and electricity from coal and biomass through thermochemical processes

Cluster 2

Liquid fuels from biomass using biochemical processes

Cluster 3

Nuclear Gen III/III+, Gen IV technologies and modular nuclear reactors

Cluster 4

Photovoltaic for residential commercial, and utility scale applications

Cluster 5

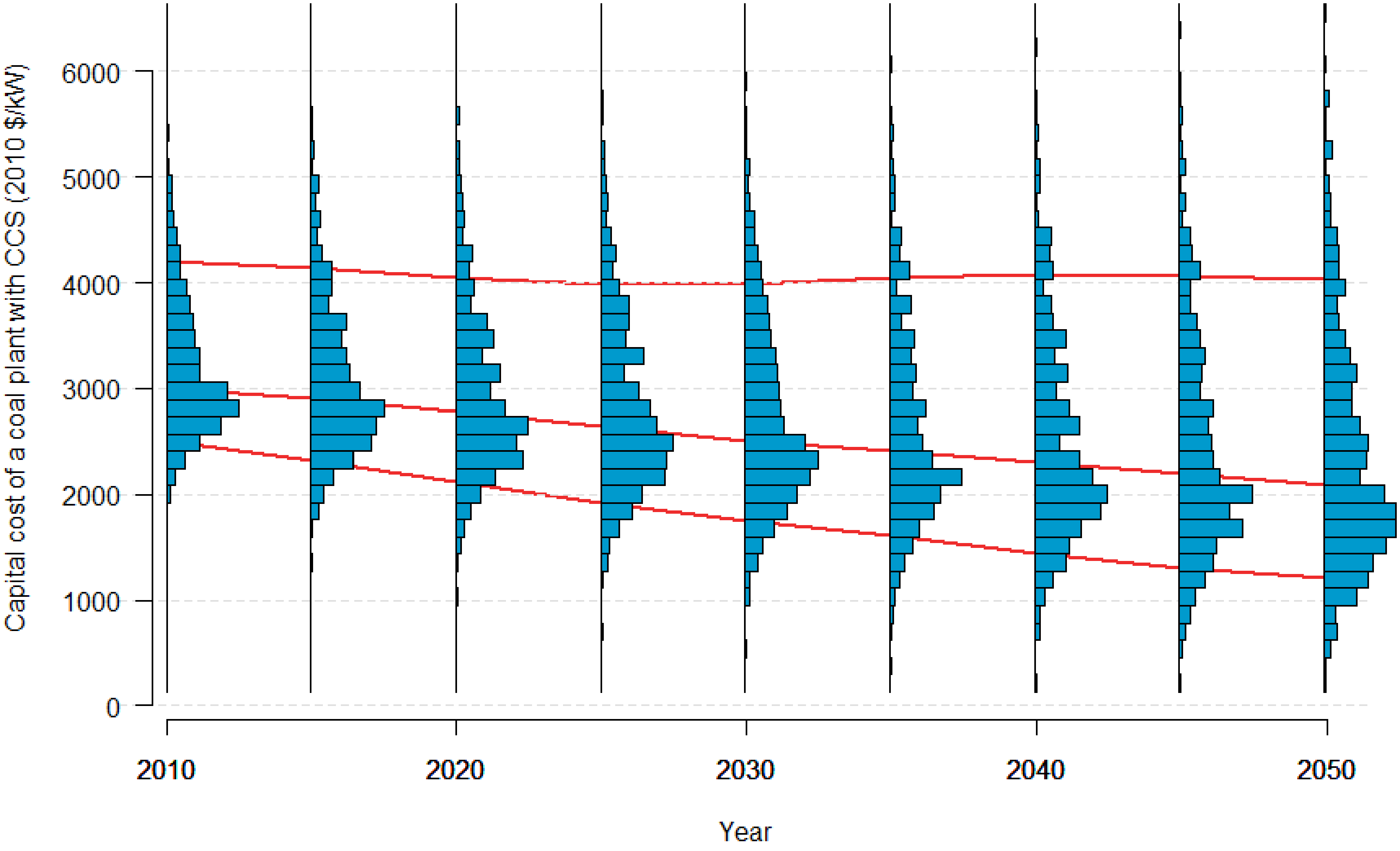
Different types of compressed air energy storage technologies

Cluster 6

Vehicles and batteries for utility scale energy storage

A low cost in 2010 is likely to be associated with a low cost in 2030

Example: coal with carbon capture and storage



Evaluating the benefits of different budgets and how they change by “expert type” and policy and market conditions

- Evaluating the benefits of different budgets
  - Business-as-usual
  - ½ recommended budget
  - Recommended budget
  - 10 times recommended budget

  … and robustness of benefits depending on “expert types” to bound the problem

- Impact under different conditions:
  - Policies (examples)
    - Carbon price
    - Clean electricity standard (Obama’s goal of 80% clean power by 2035)
  - Markets (examples)
    - High oil and gas prices
    - High oil and low gas prices

Private sector innovation

More information about private sector energy RD&D needed

- Not enough information to incorporate impact of market-pull policies on improved technologies (Hicks, 1932) in models
  - Empirical studies have shown impact of energy prices on patents (Popp, 2002), but hard to translate to technology improvements
- Not enough information about R&D in the private sector over time by technology area
  - Necessary to prioritize R&D and design demand pull policies
- There is better information about VC investments in energy technology, but we don't know how much of it is R&D

Country /Region	Corporate energy R&D investments	VC investments in clean tech
USA	$2.8 billion in 2005 (102 entities, breakdown by nuclear, fossil, and other)	$2.2 billion in 2005 $3.9 billion in 2009
EU-27	$2.7 billion in 2007 (136 entities but better breakdown by technology)	$1.4 billion in 2009

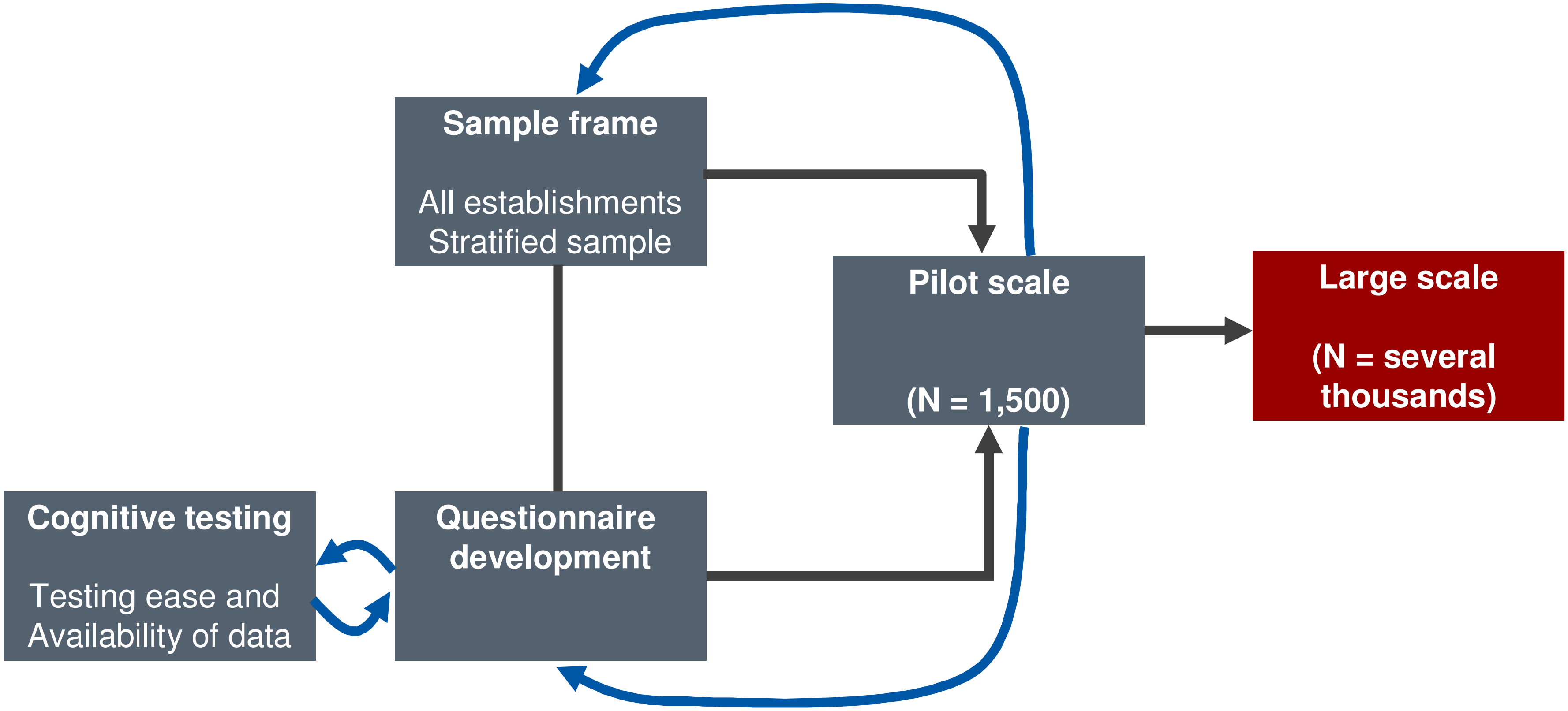
(NSF, 2009; JRC, 2010; BNEF, 2010)

Reasons for undertaking a survey of energy innovation in U.S. businesses

- Learning about the beneficiaries of energy innovation
  - We have low bound estimates of overall investment
  - Can help to build support for innovation policies
- Learning about the process of innovation
  - Can help shape what policies may be more effective at stimulating private sector innovation in different types of firms
- Distribution of investment in energy innovation
  - Would help identify gaps for governments to fill
  - Partnerships with the private sector make up a large fraction of support, but are not treated strategically
    - Grants and cooperative agreements make up a large fraction of applied energy RD&D investments (around $3 billion in 2008) and an even larger fraction of investments in energy science research
- Pilot survey experience provides learning for future studies

Design of U.S. private sector energy innovation survey

Screener and follow up



Sample frame

All establishments
Stratified sample

Pilot scale

(N = 1,500)

Large scale

(N = several thousands)

Cognitive testing

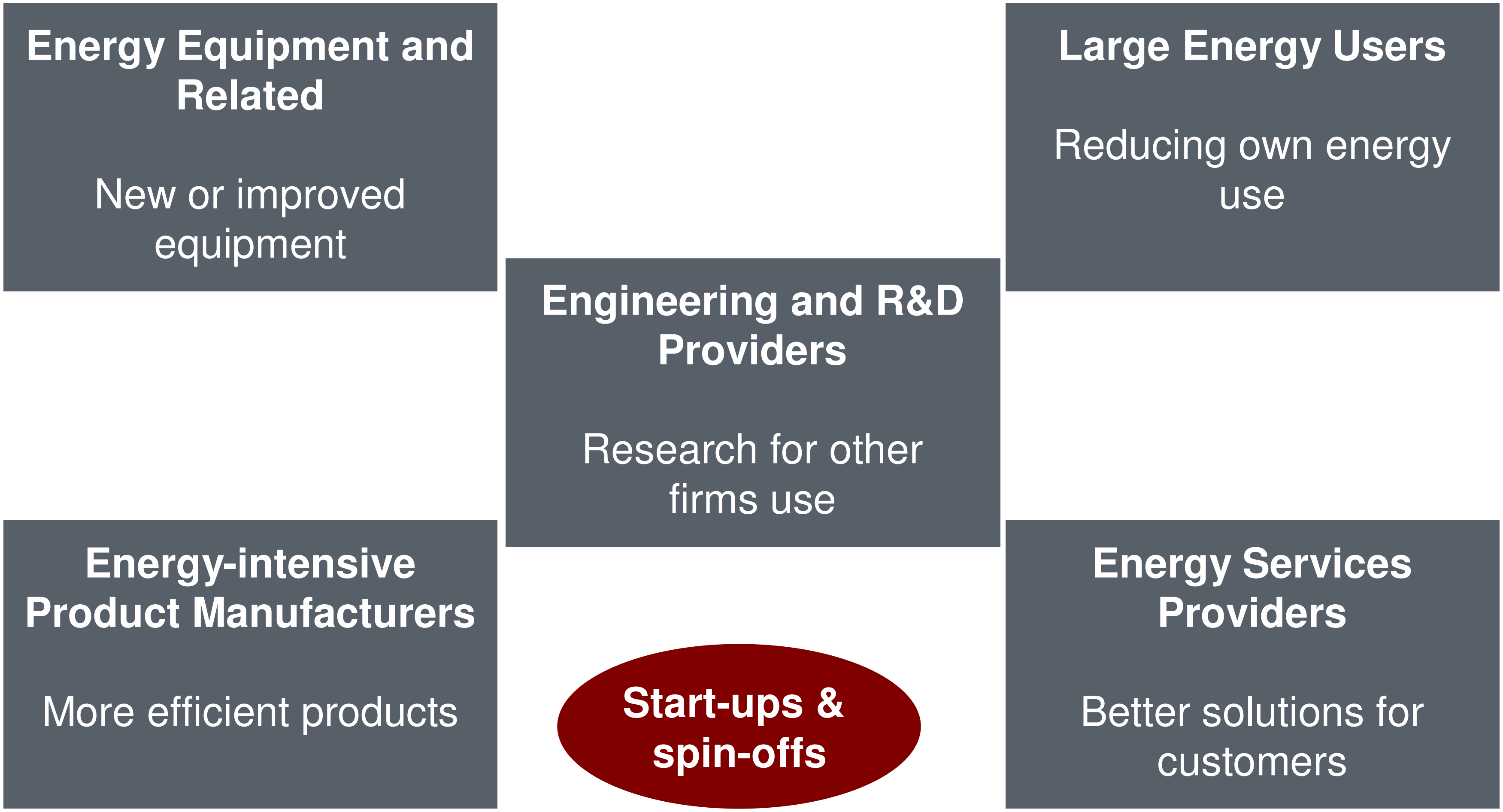
Testing ease and
Availability of data

Questionnaire development

Aim is to cover entities who benefit from energy innovation

Stratified survey of U.S. business establishments

Type of firm maps to the use of innovation:



Energy Equipment and Related

New or improved equipment

Large Energy Users

Reducing own energy use

Engineering and R&D Providers

Research for other firms use

Energy-intensive Product Manufacturers

More efficient products

Start-ups & spin-offs

Energy Services Providers

Better solutions for customers

Insights about energy innovation in businesses
Prevalence of energy innovation

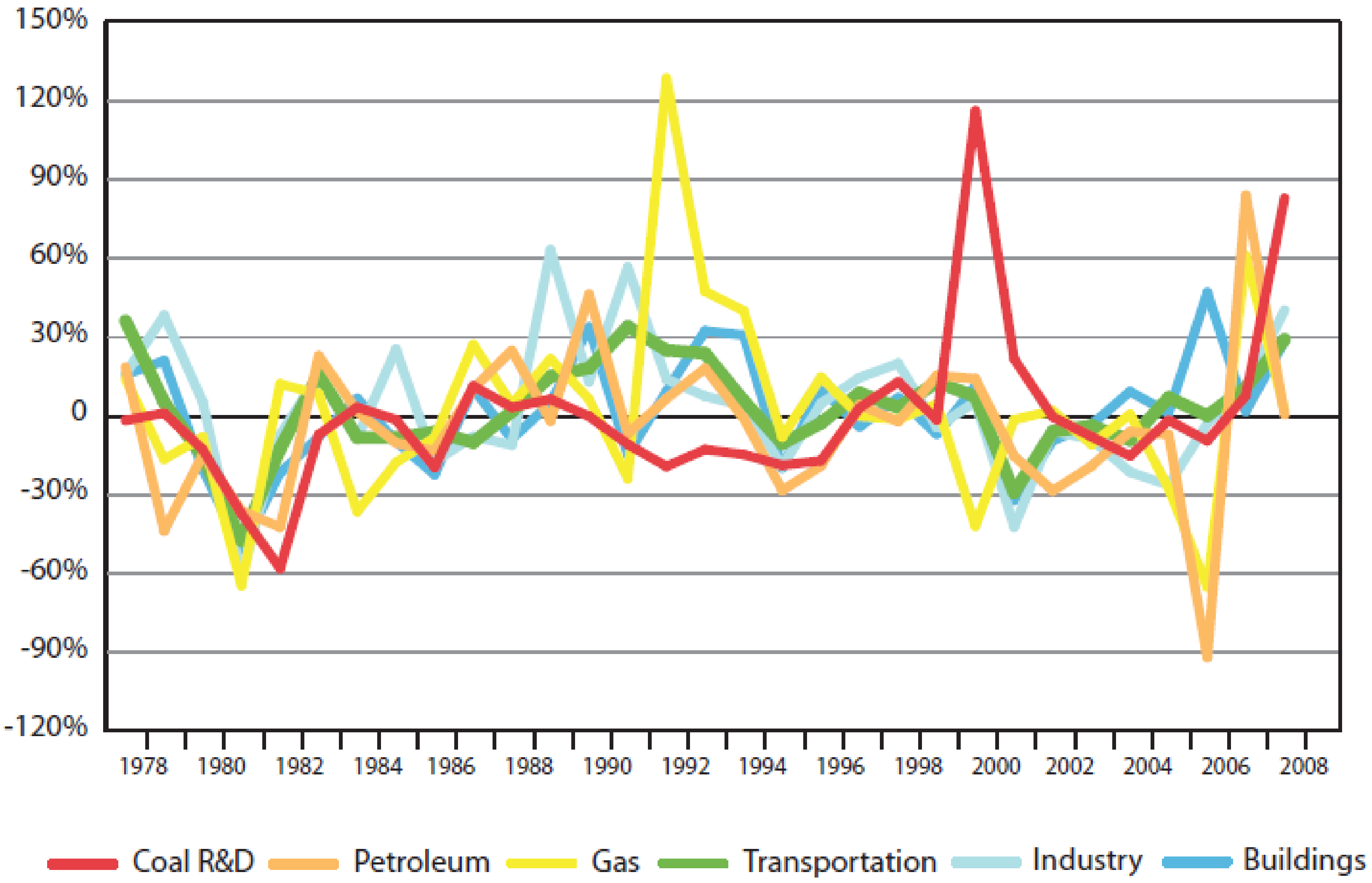
- Accounting for the stratification, about 16% of firms were involved in energy innovation
  - Abundance of beneficiaries of innovation
- Most firms expected to recoup investment in the short term; others did not measure formally
  - Further evidence supporting short-term vision of firms
- The entities that defined themselves as startups were investing most of their initial capital in R&D
  - VC capital important, but demonstrating successful non-IT business model for clean tech would be necessary for sustainable investment
- Lessons for larger survey

Insights about value of government policies
Process of energy innovation

- Governments, academia, and national labs are the information sources that are most cited guiding ETI efforts in firms, together with energy prices
- Survey allowed the identification of most effective policies to stimulate energy innovation in private sector
  - Larger survey will allow breakdown by sector
- Materials science and electrical and electronic engineering are important fields of science contributing to innovation
- Analysis of startups indicate that innovation personnel often has experience working in larger companies in the same industry

Studying energy innovation institutions

Large volatility in U.S. policy deters innovation
Every year there is a 1/3 chance that budget will change by 27%



(Narayanamurti, Anadon, Sagar, 2009)

New energy innovation institutions increase the urgency of the need to learn about how to make them effective

- We do not know much about how efficient institutions like the national labs are, and how to improve them and new institutions like the Energy Innovation Hubs and the Energy Frontier Research Centers
- 2 case studies through semi-structured qualitative interviews to find appropriate models for new innovation institutions and identify their constraints
  - Emphasis on increasing linkage between scientific information & public use
- National Renewable Energy Laboratory (NREL)
  - U.S. national laboratory under the Department of Energy (one of 17)
  - Mission is to develop and transfer knowledge and innovation in renewable energy technologies to the market
- Semiconductors Research Corporation (SRC)
  - Non-profit, industry-funded group
  - Funds university research related to semiconductors

Opportunities to unlock potential at the U.S. national laboratories and other new innovation institutions

- Strengthening links between fundamental and applied research
- Removing incentives for reinventing management structure every few years
- Putting mechanisms in place to reduce budget volatility, and increasing funds directed by lab directors
  - This would allow institutions to respond more quickly to promising research areas, possibly increasing the range of expertise
- Increasing contact between researchers and those handling contracts
- Building on the experience of a pilot program for bringing in VC investors in the laboratories, which had a short time frame, but can be used as a foundation for future programs
- Recording learning from projects and results

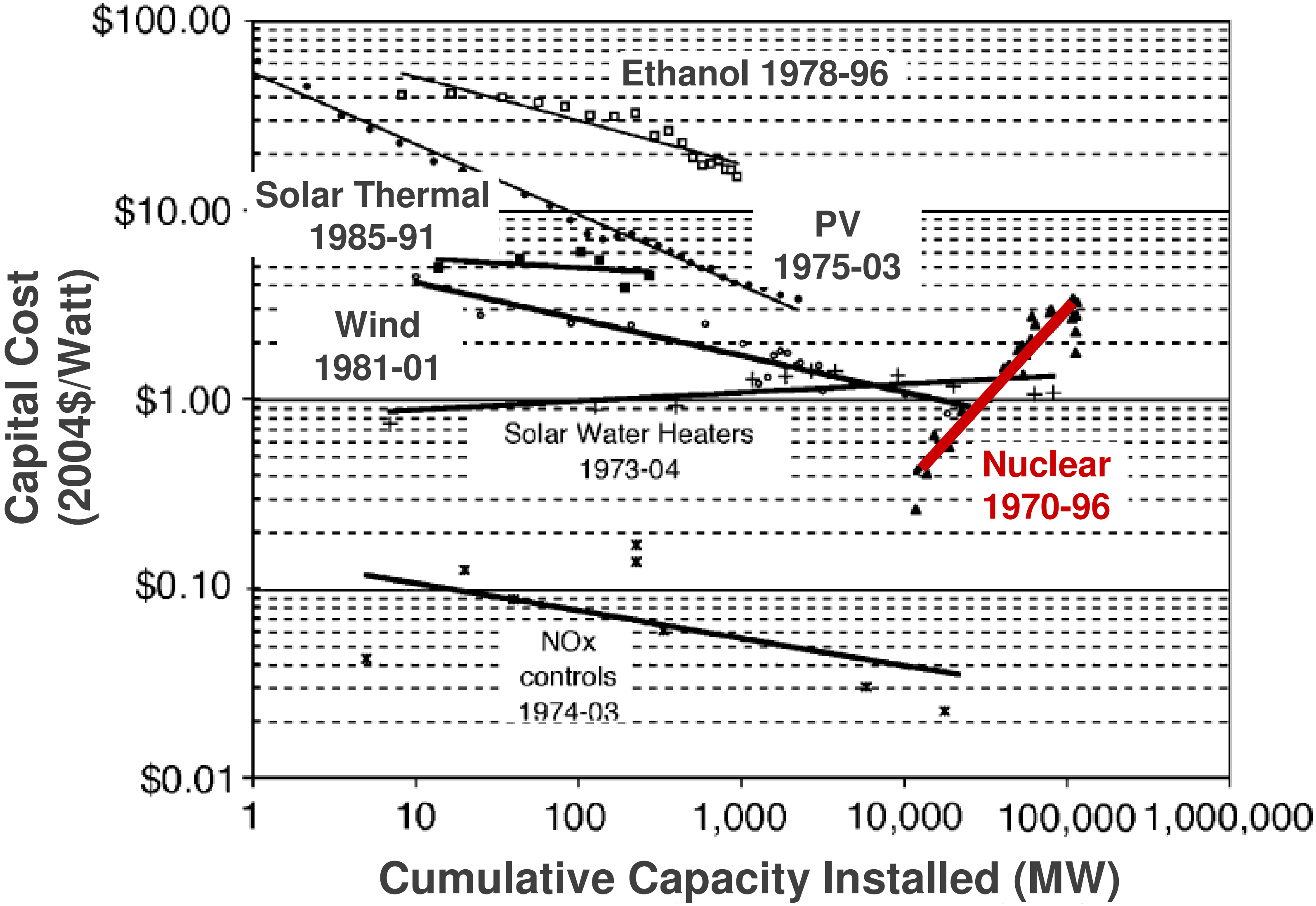
Lessons from the industry consortium for semiconductor research

- Funded in 1981 with the initial mission to help the U.S. compete in the international semiconductor market and prepare human capital
- Today it has subsidiaries focused on nanoelectronics, precompetitive energy technologies (mainly PV) funded by different industry subgroups and with different research timeframes
- Member companies fund the work, serve on SRC evaluation boards, and interact with the academics who perform the research

  ➔ system guarantees that companies can be actively involved in getting what it wants from the process (they can also leave)
- SRC experience can be used to increase private sector involvement in roadmapping activities, to create industrial liaisons, and to develop the workforce for the energy industries of the future
- Nonetheless, the importance of aligning technology push and market pull policies is paramount

Technology diffusion and learning in emerging economies

Technology costs over time
Learning, and "forgetting" curves increasingly used to inform policy



Nemet (2007); Bunn (2010)

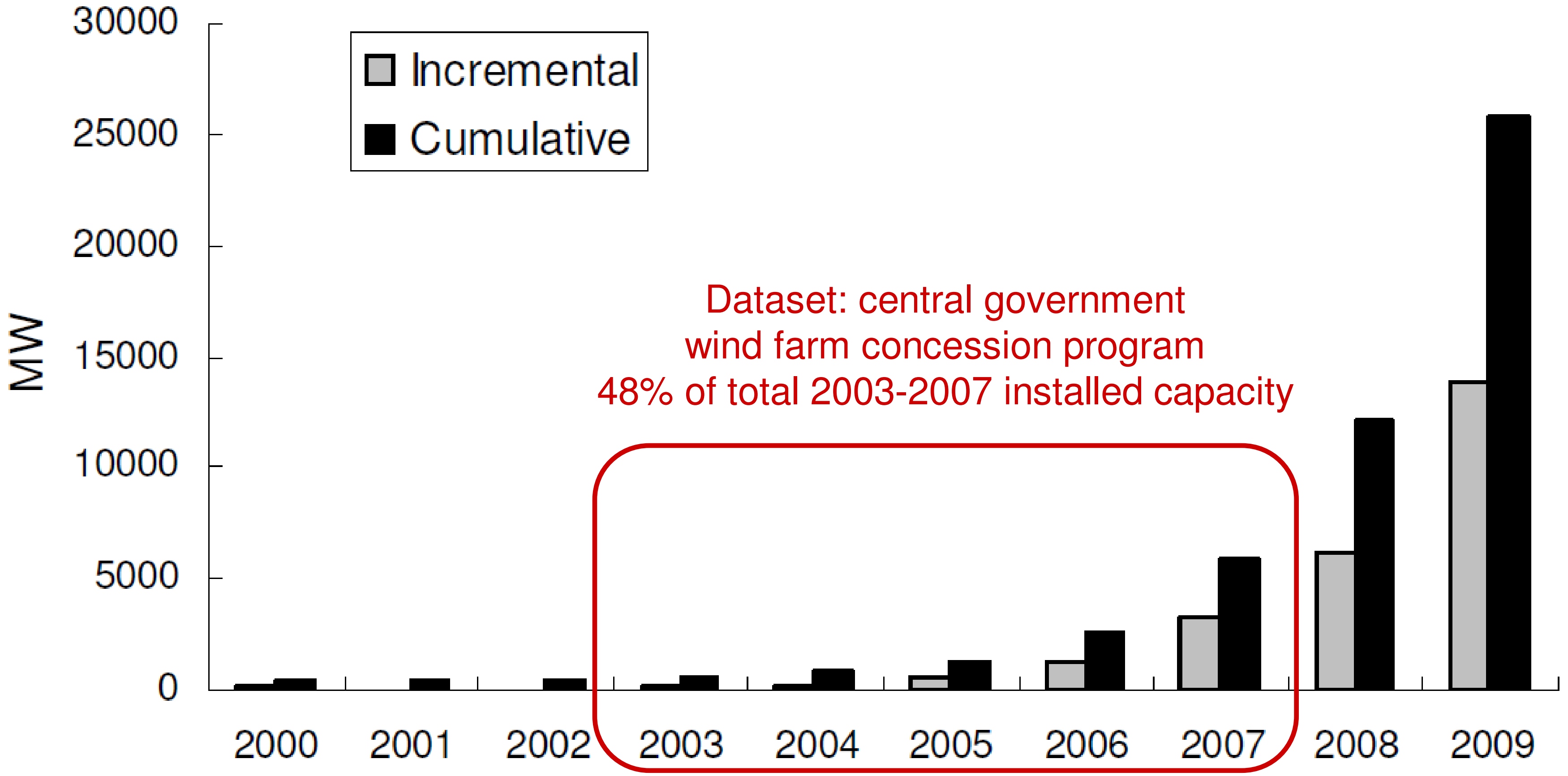
Factors contributing to reductions in technology costs important to design innovation policy

- Learning by searching within a sector (RD&D)
- Knowledge spillovers from other sectors
- Economies of scale
  - unit, plant, manufacturing, organizational, firm, industry, and inter-industry level
- Economies of scope
  - sharing of knowledge, facilities, equipment, and other inputs such as marketing and design services between products
- Learning-by-doing or by using
  - changes in the productivity of labor enabled by experience of production

Literature on evolution of energy technology costs outside of North American and European markets is lacking

- Severe in renewable energy technologies, partly due to low diffusion outside of core markets
  - only one analysis of technology diffusion and cost over time in emerging economies, sugar cane ethanol in Brazil (Goldemberg et al., 2004)
- Important to understand cost dynamics of “mature technologies” in other markets to estimate climate mitigation costs
- Important to understand role of policies in other countries
- Many important control variables (construction index, wind resource quality, wind farm size, localization rate) absent from most analysis
- Case of wind power
  - Range of learning-by-doing rate estimates for electricity cost ($/kWh) reported in the United States and in several E.U. countries ranged from -3% to 20% for the same time span (Junginger et al., 2005)

Installed wind capacity in China



Dataset: central government
wind farm concession program
48% of total 2003-2007 installed capacity

Qiu and Anadon (2011)

Some preliminary conclusions on modeling wind diffusion in China and on using learning curves

- Joint learning rates for wind between 2003 and 2007 were around 4%, in the low end of learning rates in Europe and the United States reported in the literature
- At the project developer level intra-firm learning was not significant
  - learning by doing and technology adoption could benefit all developers
  - during the wind expansion phase both regulators and developers were learning how to permit and build a farm
  - public information platform for the concession programs available
- Novel metric for knowledge stock addresses some of the problems of using R&D investments and patents (e.g., it incorporates exogenous technical change), although it could be improved
- Wind farm economies of scale and turbine localization rate are associated with significant cost reductions (other covariates important)
- The concession program itself is associated with cost reductions

Qiu and Anadon (2011)

Concluding remarks

- Environmental externalities from energy, knowledge spillover from innovation, and uncertainty in outcomes and damages make energy innovation policy challenging
- There are a multiplicity of actors and “joints” that need to be working
- Analytic tools and empirical data are badly needed to improve the science of policy for energy innovation (e.g., impact of demand pull, diffusion in other countries, priorities for R&D partnerships, etc.)

U.S. energy innovation policy

- Strategy and alignment of push and pull policies are lacking
  - Supporting coal and natural gas reduces impact of policies supporting renewables
  - Supporting R&D but not demonstration projects wastes resources
- Researchers and entrepreneurs have had little certainty
  - Volatility in government R&D
  - Uncertainty in industry R&D tax credits
  - Uncertainty in production tax credits
- No emphasis on spending funds wisely or learning from previous institutions or projects

Although things are starting to change

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