HARVARD UNIVERSITY
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June 2009

A Technology Based Greenhouse Gas Reduction Strategy for 2030

USSEE 2009 Conference, Washington DC

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Motivation

An abundant supply of clean and affordable energy is vital to the economic growth, quality of life, and security of the United States. Energy provides essential services for many aspects of modern life. In recent years, however, economic and political factors have stressed the global supply of oil and natural gas, driving the prices of these commodities to new highs and increasing the risk of a damaging energy shock. Meanwhile, increases in greenhouse gas emissions, in part resulting from fossil fuel combustion, are linked by many scientists to global climate change. Combined, these issues create an imperative for change in the Nation's energy systems and infrastructure in order to ensure national energy security while protecting the environment.

President's Council of Advisors on Science and Technology, *The Energy Imperative: Technology and the Role of Emerging Companies.* November 2006

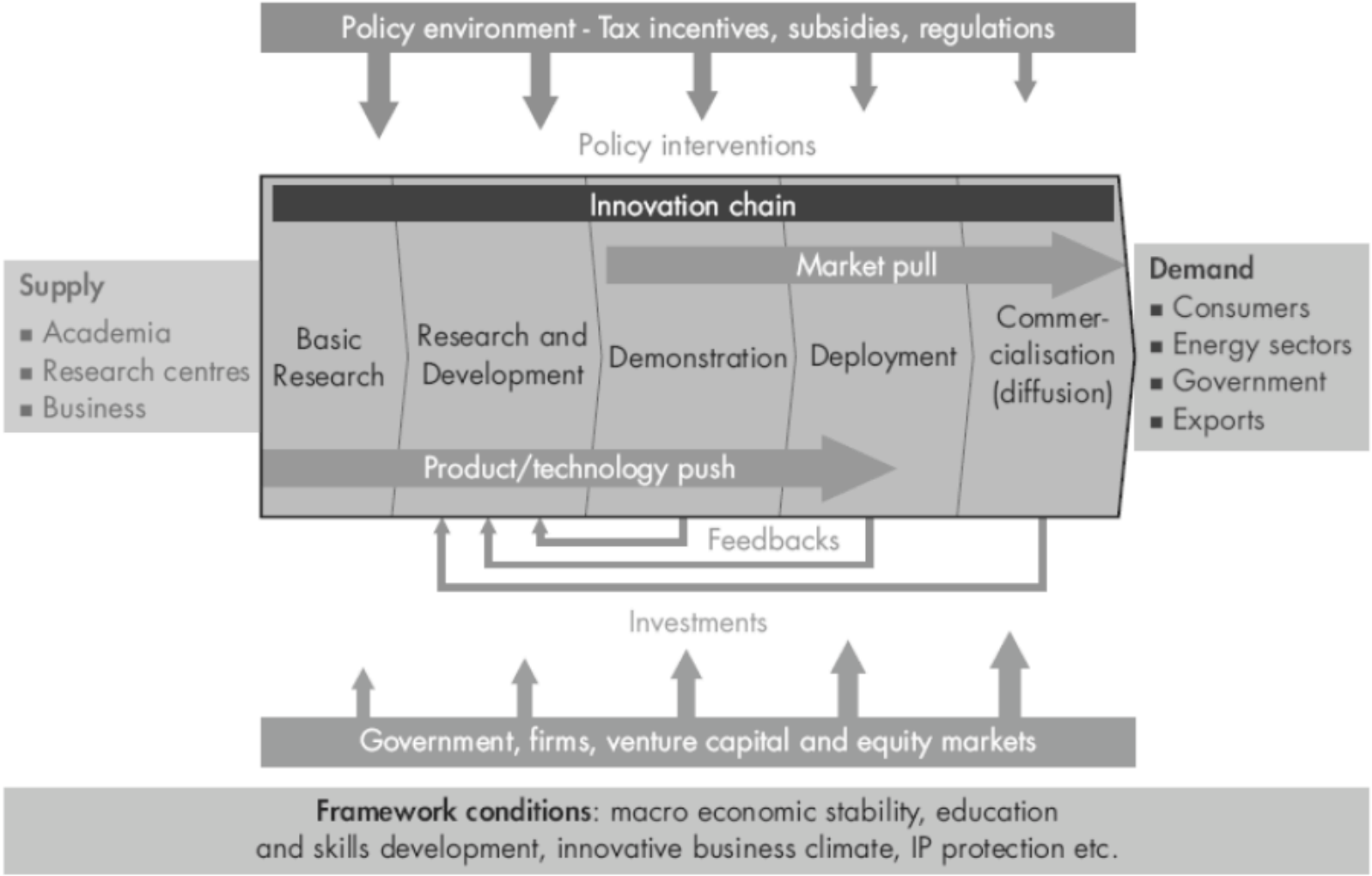
The rationale for energy-technology innovation
Starting point

- There is a need for energy-technology improvements that:
  - Make energy reliable and affordable
  - Emit fewer pollutants (e.g. SO_2, NOx, mercury, CO_2)
  - Reduce negative impacts on water, land, and food resources
  - Lead to increases in high-technology exports and jobs
  - Promote environmentally sustainable economic development
  - Reduce the risks of proliferation

Market Failures Justify Government Role	Public-goods (knowledge spillovers, defense) Lumpiness of investments (need large and sustained efforts) Environmental externalities, etc
Range of Policies Can Spur Energy Research, Development, Demonstration and Deployment	Investments Tax incentives – e.g. production tax credit Renewable portfolio standards, CAFE standards, etc

The United States needs to develop and deploy better ways of producing and using energy, but how?

The Innovation System



IEA 2008

Our approach

Expert Elicitation

- Identify energy technologies
- Recommend RD&D budget based on current needs
- Estimate technology capacity, performance and cost with enhanced RD&D in 2030

Technology based macro-economic analysis

Run scenarios for recommended RD&D budget in MARKAL

Technology RD&D Recommendations

- Technology portfolio
- RD&D budget

RD&D Budget Results

- Estimated energy cost
- Estimated technology deployment

1. List of technologies and research areas
2. RD&D budget
   - Basic research
   - Applied research
   - Demonstration
   - Early deployment
3. Expected cost and performance
   - Baseline (no change in budget)
   - Enhanced (change in budget)

Industries
Based on DOE budget February 2008 proposal categories

- Clean coal technology
- Natural gas technologies
- Petroleum – oil technology
- Hydrogen technology
- Biomass and biorefinery systems
- Solar energy
- Wind energy
- Smart grid
- Geothermal technology
- Water power
- Vehicle technologies
- Building technologies
- Industrial technologies
- Nuclear energy
- Transmission and distribution
- Storage

Survey overview (1 of 3)

- Part 1. Background data
  - Purpose: provide common starting point for experts; ensure methods are understood
  - Briefing for experts
    - Current costs and performance
    - Current federal spending and total venture capital and private equity investments
  - Explanation of bias and overconfidence
    - Probabilistic estimates
    - Warning to beware of overconfidence and bias
- Part 2. Self assessment of expertise
  - Purpose: experts must think about their technology knowledge; provide weights that can be used to combine data pool

Survey overview (2 of 3)

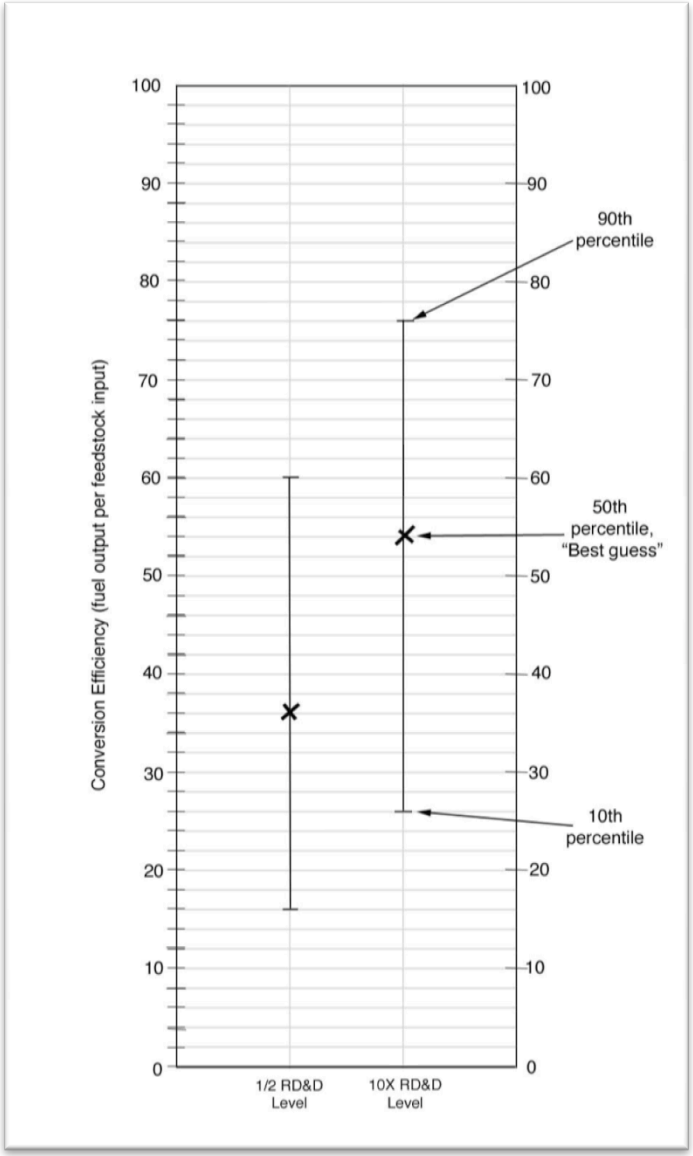
- Part 3. Baseline costs & performance
  - Purpose: collect expert opinion on current and future cost and performance if current federal spending does not change
- Part 4. Budget
  - Purpose: obtain expert opinion on total budget; determine how budget should be allocated
  - Budget amount (X = current spending)
    - 0.5X, X, 1.5X, 2X, 2.5X, 3X
  - Budget allocation
    - Specific technology areas
    - Research needs within the innovation chain

Survey overview (3 of 3)

- Part 5. Post enhanced RD&D performance and cost
  - Purpose: collect expert opinion about cost and performance with modified federal spending
  - Assess sensitivity to varied spending levels
  - Identify specific, novel technologies
  - Identify spillover technologies
- Appendices
  - Technology descriptions
  - Explanation of how answers will be converted into MARKAL inputs

Expert Elicitation
Anticipated results

- Written survey per industry
  - 5-15 experts
- Current opinion in the scientific community
- Sensitivity of performance and cost ranges to RD&D spending
- RD&D allocation by technology development stage
- Budget tradeoffs within industry
- Probability distribution functions (PDFs) of technology cost and performance
  - Business as usual
  - With enhanced RD&D investment



Some lessons learned so far
Background information must be selected with care

- It can distract experts from the task at hand
  - *Problem:* Learning rates, experience curves, and deployment data lead reviewers to assume costs decrease with learning.
  - *Solution:* Present current data for information (cost, performance) of interest.
- It can mislead experts
  - *Problem:* Presenting only U.S. DOE budget data lead reviewers to question whether RD&D was being pursued by other agencies to support energy technology innovation.
  - *Solution:* Present all available federal research budget information, explaining which is relevant to the industry and technology of interest.

Some lessons learned so far
Questions should not be too specific

- It can "lead" experts
  - *Problem:* Asking for input on how to reduce future technology prices and increase capacity and/or efficiency levels lead reviewers to exclude less desirable outcomes even if they thought they were more likely.
  - *Solution:* Ask for future price, capacity, and efficiency.
  - *Problem:* Asking for opinion on specific technology (e.g., gasification + catalytic cracking to produce biodiesel from miscanthus) did not encourage reviewers to propose "novel" technologies.
  - *Solution:* Ask for recommended technologies for the industry of interest.

Some lessons learned so far
Questions should not be too vague

- It can confuse experts
  - *Problem:* Reviewers found it difficult to answer open ended questions because the scope was beyond their experience (e.g., “What should federal spending be?”)
  - *Solution:* Offer a range of specific options (e.g., 0.5X, 1X, 1.5X, 2X, 2.5X, 3X the current spending level).
  - *Problem:* Open ended questions are open to misinterpretation (e.g., “What diesel substitutes will be commercially viable in 2030?” lead to broad and specific answers)
  - *Solution:* Reword the question to define context (e.g., expected oil price in 2030)

How we will use our survey results
Overview

- Publish elicitation results
  - Participants will not be identified with their answers
- Evaluate scenarios for recommended RD&D budgets
  - PDFs of technology cost and performance
  - Expected change in technology cost and performance (2030) if RD&D budgets are implemented
  - Results
    - Estimated technology deployment time and market share
    - Estimated energy cost
    - Estimated greenhouse gas emissions
  - Sensitivity analyses possible
    - Alternative policies
    - Deployment constraints; hurdle rates; learning curves
    - Market risk – fossil fuel prices

Our research method contributions

- Consistent method for all industries
  - Obtaining expert opinion of cost and performance
  - Portfolio analysis
- Impact assessment
  - RD&D spending on innovation chain
  - Innovation chain on cost and performance
- Detailed budget and portfolio justification
  - Current research needs
  - Tradeoff between technologies per industry
  - Tradeoff between industries in the market

Energy Technology Innovation Policy Project
Energy Research and Development, Demonstration and Deployment (ERD3)

- Thank you to the Doris Duke Charitable Foundation
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http://belfercenter.ksg.harvard.edu/project/10/energy_technology_innovation_policy.html?page_id=213