Stimulating Technological Innovation in Energy

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A Revolution in Energy Technology is Needed

- Our Addiction to Fossil Fuels Entails
  - Huge Economic Costs
  - Huge Geopolitical Costs
  - Huge Environmental Costs
- This addiction must be overcome for reasons of
  - Security – to assure domestic supply
  - Sustainability – to mitigate global warming
- Market-based incentives are needed but will be insufficient to stimulate urgently needed technological innovation.

A Carbon Charge
(Carbon Tax or Cap-and-Trade)
Market-based Incentive is Necessary

- The price of CO_2 emissions becomes a cost of doing business
- It sends an unmistakable signal to energy users that the market is changing - *IF sustained and* high enough
- But the first laws to be passed are likely to have loopholes, escape clauses, 'exit ramps'

But Even a Strong Carbon Charge will be Insufficient. Public Investment is Needed.

- The need for new technologies is urgent.
- Well-known imperfections in the market for technology support the need for public investment: non-appropriability, etc.
- Recent venture capital is for Commercialization, not for R&D
  - Tends to back technologies with specific subsidies
  - Examples: corn ethanol, California support system

A major R&D program to stimulate innovation in energy technology is both justifiable and essential

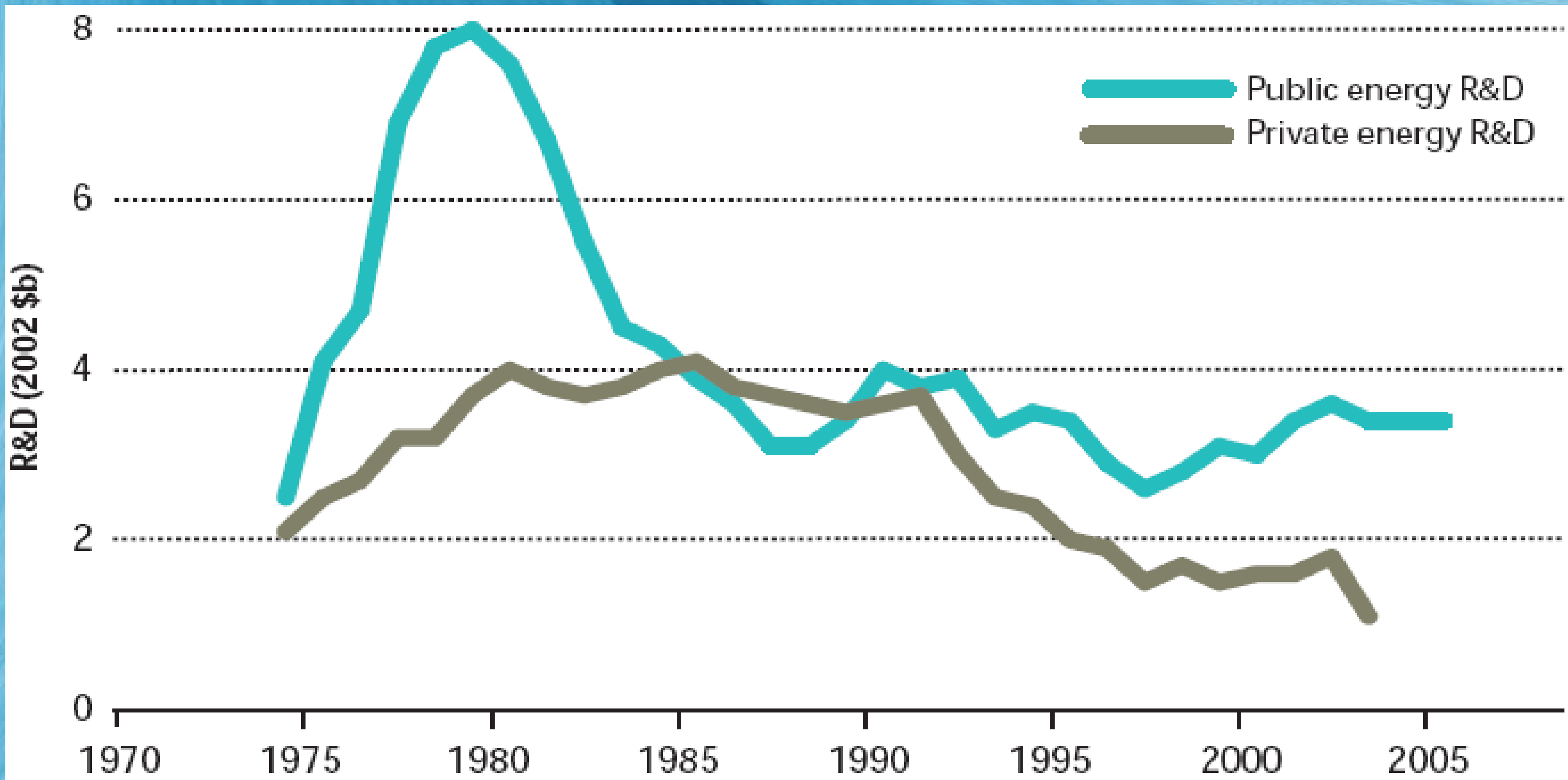
But what would it actually look like? How would it be structured?

The Backdrop: Decline in Energy R&D

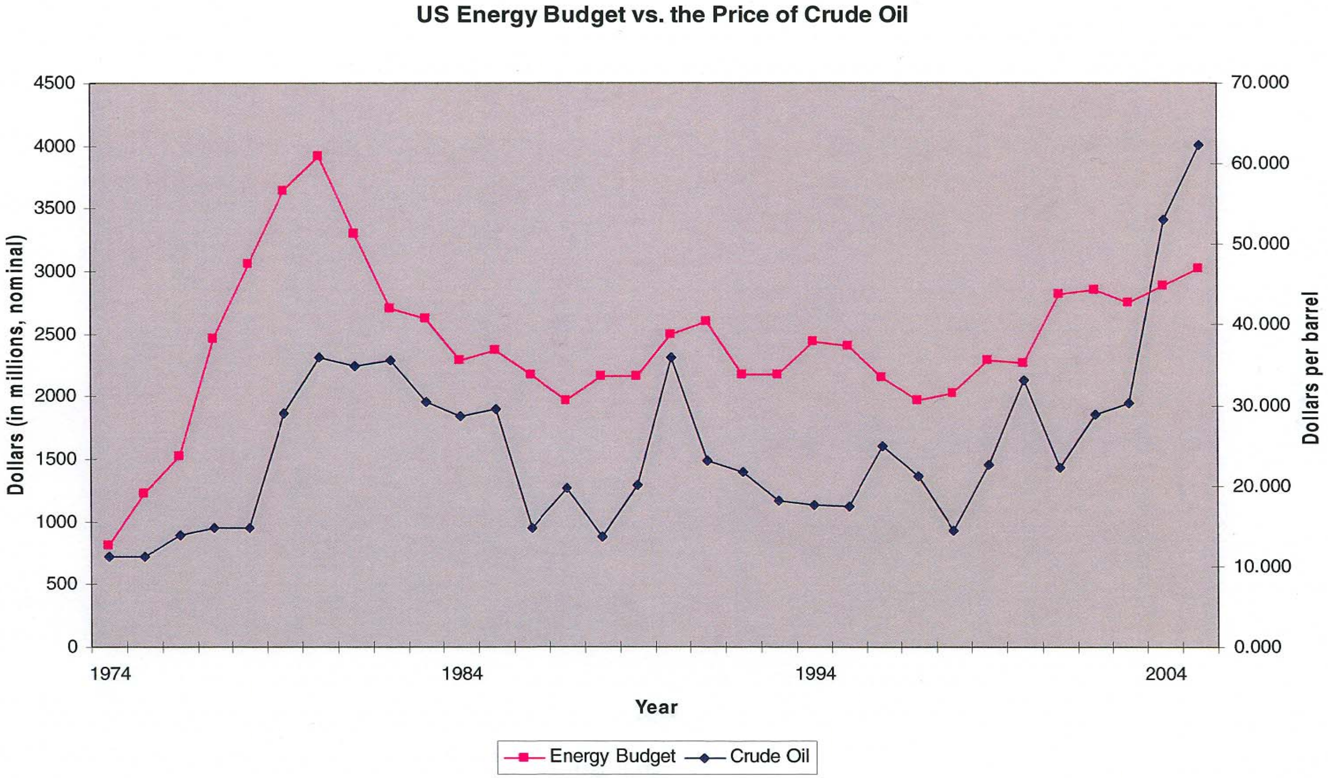
- Today, US federal spending on energy R&D is about half what it was in 1980
  - Energy R&D declined from 10% of all US R&D in 1980 to just 2% in 2005. (in '02 dollars)
  - Between 1980 and 2005, the US decreased its energy R&D investment by 58%.
  - Level of new energy research was about $3.5 billion in '07 -- less than half the R&D spending of the largest US pharmaceutical co.
- Private sector R&D story is similar

US Public/Private Energy R&D Trends

Source: Nemet and Kammen (2007)

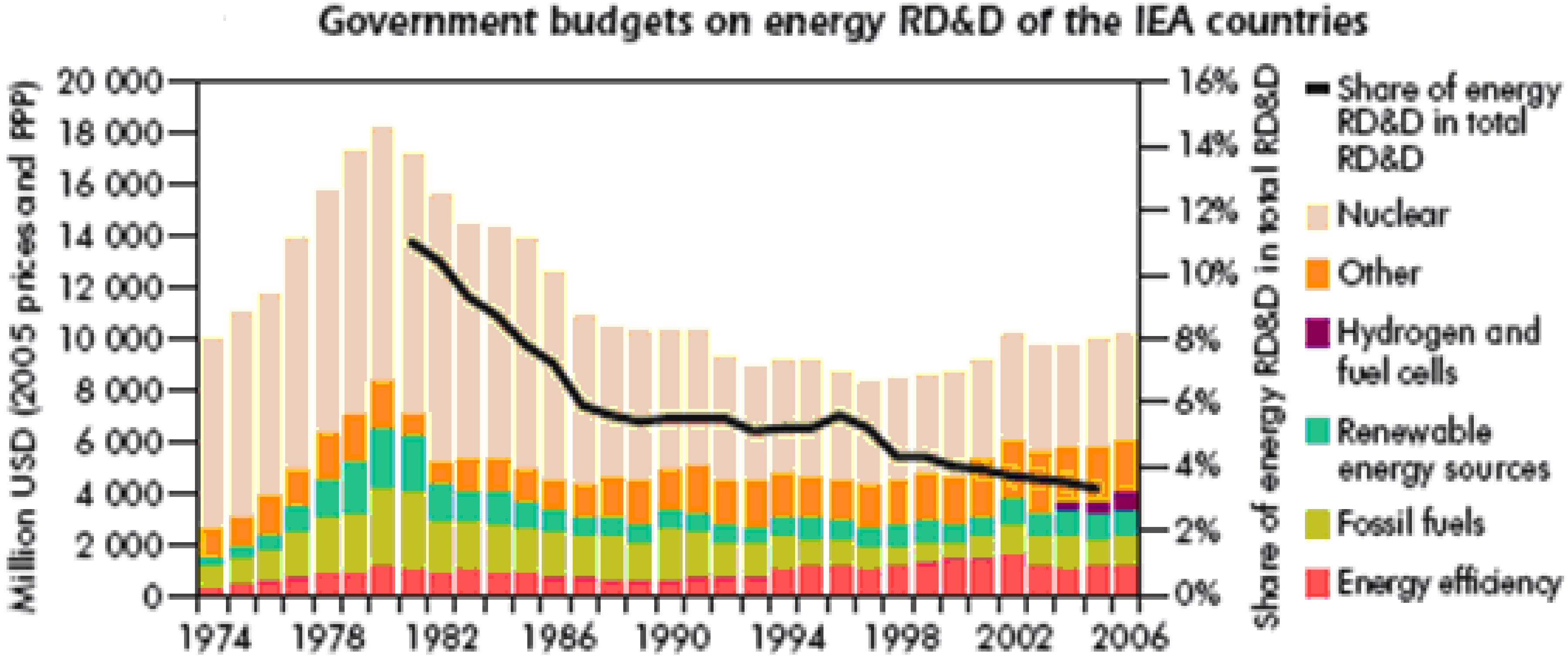


U.S. Energy R&D Spending vs. Price of Crude Oil



-- Neal, Smith, McCormick, *Beyond* Sputnik*: National Science Policy in the 21st Century,* University of Michigan Press, 2008. Original Sources: Oil prices based upon the yearly average prices per barrel from the Federal Reserve Bank of St. Louis, taken from the Dow Jones and Company data, http://research.stlouisfed.org/fred2/data/oilprice.txt; Energy R&D spending is from the International Energy Agency, http://www.iea.org/Textbase/stats/rd.asp.

IEA: OECD Countries – Similar R&D Decline



Note: RD&D budgets for the Czech Republic not included due to lack of available data.

Source: IEA 2007a, OECD 2007a.

US Private Energy Sector R&D Investment is Small Compared to that into Sectors with Significant Innovation:

Innovating industries -

- The biotech industry invests 39% of its (small) annual revenue,
- Pharmaceuticals invest 18%,
- Semiconductors invest 16%.

Established industries:

- Electronics industry invests 8% of sales
- Auto industry invests 3.3%.

Overall US Industry Average R&D Investment Is 2.6% of Sales

The private energy sector invested on-average less than 1% of annual revenue in R&D from 1988-2003

Experts: Multiply Energy R&D

Recommendation	*Multiplier*	*US Private R&D*	*US Public R&D*	*Total US R&D*
Current Level	X1	$1.2B	$3.6B	$4.8B
PCAST (2007), NCEP (2004) ACI (2006), Stern Review (2006)	X2	$2.4B	$7.2B	$9.6B
Council on Competitiveness	X3	$3.6B	$10.8B	$15.4B
Davis and Owen, Schock, CEPR	X4	$4.8B	$14.4B	$19.2B
Nemet and Kammen, high estimate	X10	$12B	$36B	$48.B

Is an R&D Increase Justified?

- Precedents for increased government spending on similar scale (in 2002 dollars)
  - Apollo Program ($185 billion over nine years),
  - Carter/Reagan defense buildup ($445 billion over eight years),
  - Doubling National Institutes of Health ($138 billion over five years)
  - Ballistic Missile Defense ($145 billion over the first six years - actual dollars).

NB: These are examples of the needed size and scope of an r&d increase, not the way such a program should be organized

Is an R&D Increase Justified? (2)

- Historic rate of return implies that Energy R&D is an economically worthwhile investment:
  - U.S. Dept. of Energy in 2001 reported its 20 most successful energy savings projects saved 35 times their total cost.
  - 1997 PCAST report estimated that potential benefits from energy research, development and demonstration could result in a multi-decade 40 to 1 return on federal investment
    - Combines: energy efficiency, energy savings, plus new technology
  - Social rate of return on federal R&D overall has-been typically 5 to 1 over a decade (Tassey 2007)

IEA: Investments Required for CO_2 Reductions are Huge:

- The International Energy Agency (IEA) 2008 report estimates
  - stabilizing CO_2 emissions at current levels in 2050 will require a total worldwide investment of $17 trillion ($400 billion per year), including both R&D and implementation.
  - Reducing emissions to 50% below 2005 levels, the goal that the G-8 leaders committed to in July 2008, will require a total worldwide investment of $45 trillion ($1.1 trillion per year) in R&D and implementation

More Money is Essential, but is Not the Whole Answer

Energy is an established, complex sector. In such sectors, technological innovation is more complicated than in new sectors like information.

The toughest step is market launch.

Energy Technology Presents Difficulties for Innovation Theory

- Technologies for energy supply and use pervade the economy
  - Huge Scale: $1.5+ Trillion/year in US alone
- Fossil fuels are convenient and cheap, if you don't count externalities
- Entrenched 'legacy' technologies, backed by
  - Vast subsidies and tax advantages
    - $500 Billion from 1950-2003
  - Public investments in infrastructure
  - Politically powerful companies
  - Public expectation of low-cost energy
  - Established patterns of expertise and regulation

The US has a "Covered Wagon" Culture

We're good at completely new things:

- Don't like your neighborhood?
- Take a covered wagon over the mountain to new territory!
- This is the case in technology --
  - We're good at launching completely new things that create new functionality
  - We're not good at going back over the mountain in the other direction - at rediscovering established territory and bringing innovation to it
  - We do biotechnology, we don't go back and fix the health care delivery system.
  - Yet there are huge gains to be had, not just from the new but also from fixing the old

U.S. Innovations Like to Land in "Unoccupied Territory." Energy is "Occupied Territory"

- We pack our Metaphorical "Technological Covered Wagons" and Go West, leaving Legacy Problems Behind

<u>The bad news</u>:

- Established sectors are complex and hard and often have established, cost-efficient incumbents
- We're used to launching technology in <u>open fields</u>
  - That's what we did in computing
  - New energy must <u>parachute into occupied territory</u>
  - And will be shot at

- Alternative technologies do exist at all stages of research and development
- But most of them must be competitive immediately upon market introduction against subsidized legacy competitors that don't pay for environmental or geopolitical costs

It's a 'Non-Level Playing Field'

A Public Strategy for Energy Technology Should be...

- <u>Very Large</u> in Scale and Scope
  - Comparable to Apollo Project in Size and Scope
  - But NOT in Form or Organization
- <u>Private Sector</u> Led
  - Public-Private Partnerships
- <u>Technology Neutral</u>
  - Avoid technology lock-in
  - The opposite of the present pattern of subsidies to specific subsidies with powerful lobbies
    - <u>'No Lobbyist Left Behind'</u>
- <u>International</u> in Scope and Conception
- <u>Organized around Obstacles to Market Launch</u>

We Have Developed a Four Step Analysis:

- 1. *Launch Pathways:* Group technologies to be implemented into categories based on launch characteristics
- 2. *Tie to Policy Packages:* Use these launch pathways to guide federal innovation policy roles:
  - Bundle policies, available across technologies, so as to be as technology neutral as possible.
- 3. *Gap Analysis:* to identify gaps between existing institutions in the U.S. innovation system
- 4. *Recommendations for Institutional Innovations* to fill these gaps

Market Launch Categories

1. **Experimental technologies requiring long-term research**
   - Examples: Fusion, Hydrogen Fuel Cells
2. **Disruptive innovations that can be launched in niche markets** where they are competitive, and achieve gradual scale-up building from this base.
   - Examples: Solar photovoltaics and wind for off-grid power, light-emitting diodes
3. **Secondary innovations - uncontested launch:** components in larger systems that face immediate market competition based on price, but are acceptable to the system manufacturer.
   - Examples: Batteries for Plug-in Hybrids, Enhanced Geothermal, On-Grid Wind & Solar

Energy Technology Launch Categories – Special Obstacles

4. **Secondary innovations - contested launch:**

   component innovations having inherent cost disadvantages and facing political and non-market economic efforts to block their introduction.

   - **Examples: Carbon Capture and Sequestration, Biofuels, Nuclear Power**

5. **Special Financing Requirements:**
   - **Examples:**
   - **(a) Conservation and end-use efficiency -- Improved IC engines, Building Technologies, Appliance Standards**
   - **(b) Advances in manufacturing technology and scale-up of manufacturing for all types of energy technology so as to drive down production costs**
   - **© Large-scale demonstrations: enhanced geothermal, carbon capture and sequestration**

6. **Special Infrastructure Requirements:**
   - **Examples: Wind energy, Carbon Capture and Sequestration, biofuels**

A Few Especially Promising and Important Technologies

- Carbon Capture and Sequestration (CCS)
  - Critical for Coal-Burning Countries: US, China, India
  - Capture CO2 from Smokestack of Power Plants, Cement Plants, Pipe it to Underground or Undersea Storage
- Enhanced ("Hot Rocks") Geothermal
  - Pump Water Deep Underground and Let it be Heated by Underground Rocks, and in this way
  - Derive Renewable Energy from Underground Heat Even if there is no Natural Water Near the Rocks – greatly expanding the possible locations for geothermal

Both of These Technologies Require Expensive Demonstration Projects at Full Scale to Demonstrate Safety and to Derive Techno-Economic Parameters

After Identifying Gaps in the U.S. Innovation System, We Recommend Establishing and Funding:

- 1) Advanced Research Projects Agency for Energy (*ARPA-E)*: A translational R&D entity
- 2) A *wholly-owned government corporation* for "back end" elements:
  - Sharing the financing of carefully monitored, full-scale demonstrations of large engineering projects
  - Encouraging and incentivizing industry consortia to cut costs of manufacturing technologies and processes
  - Speed the scale-up of manufacturing production capacity
  - Financing installation of conservation, efficiency and related new technologies in residential and commercial markets
- 3) *A Think-Tank* to develop a detailed "roadmap" for the requirements for the development and launch of particular energy-related innovations (including consideration of social and environmental impact), and to recommend policies to facilitate them

ARPA-E for Translational Research has now been Established and Funded with $400 million from the "stimulus package"

- The Right-Left concept: identify a challenge on the 'right side' of the pipeline and then nurture the science breakthrough on the 'left side' to get there
- Move from breakthrough to innovation
- Hybrid model blends university researchers with startups and smaller firms
- Small, flexible, flat, non-hierarchical, collaborative networks, with turnover, risk-taking culture, and great talent in the ARPA-E staff

The ARPA-E model for translational research (cont'd)

- Needs research funding at a scale to make a difference
  - Stimulus bill: $400 million initial appropriations
- Needs careful structuring as an Island-Bridge model:
  - An "ISLAND" FREE FROM BUREAUCRATIC STRESSES AND PRESSURES
  - But with a BRIDGE BACK TO THE DECISIONMAKERS WHO CAN IMPLEMENT ITS DISCOVERIES
- ARPA-E structure is still being worked out within the US Department of Energy.

A Program Commensurate with the Scope of the Energy Problem can be Realized Only with Leadership

- This is the toughest Technology Implementation Task the U.S. has faced
- We have to do it right
  - Addressing a broad range of technology and the whole Innovation Process . . .
  - Not with favored technologies ("Silver Bullets")
  - Not by Pork Barrel ("No Lobbyist Left Behind")
  - Despite likely opposition from powerful incumbent technologies
- Public attitudes toward energy and the public role in supporting innovation will need to be changed.

The Need for Technological Innovation in Energy is a Global Problem and Requires an International Solution

But there's a Tension between

- The need to provide incentives to innovation by private corporations
- The need to encourage adoption of improved technology by developing countries – especially carbon capture and sequestration (CCS) when this is ready
- The aspirations of China and India to become major innovators in energy technology
- Reluctance of countries reliant on coal to accept higher energy costs resulting from carbon capture and sequestration (CCS)

This Raises Both Challenges and Opportunities

- Cooperative, pre-competitive research on problems that will not directly result in proprietary goods and services
- Possible relaxation of intellectual property requirements (or soft loans and technical assistance) for transfer of technology

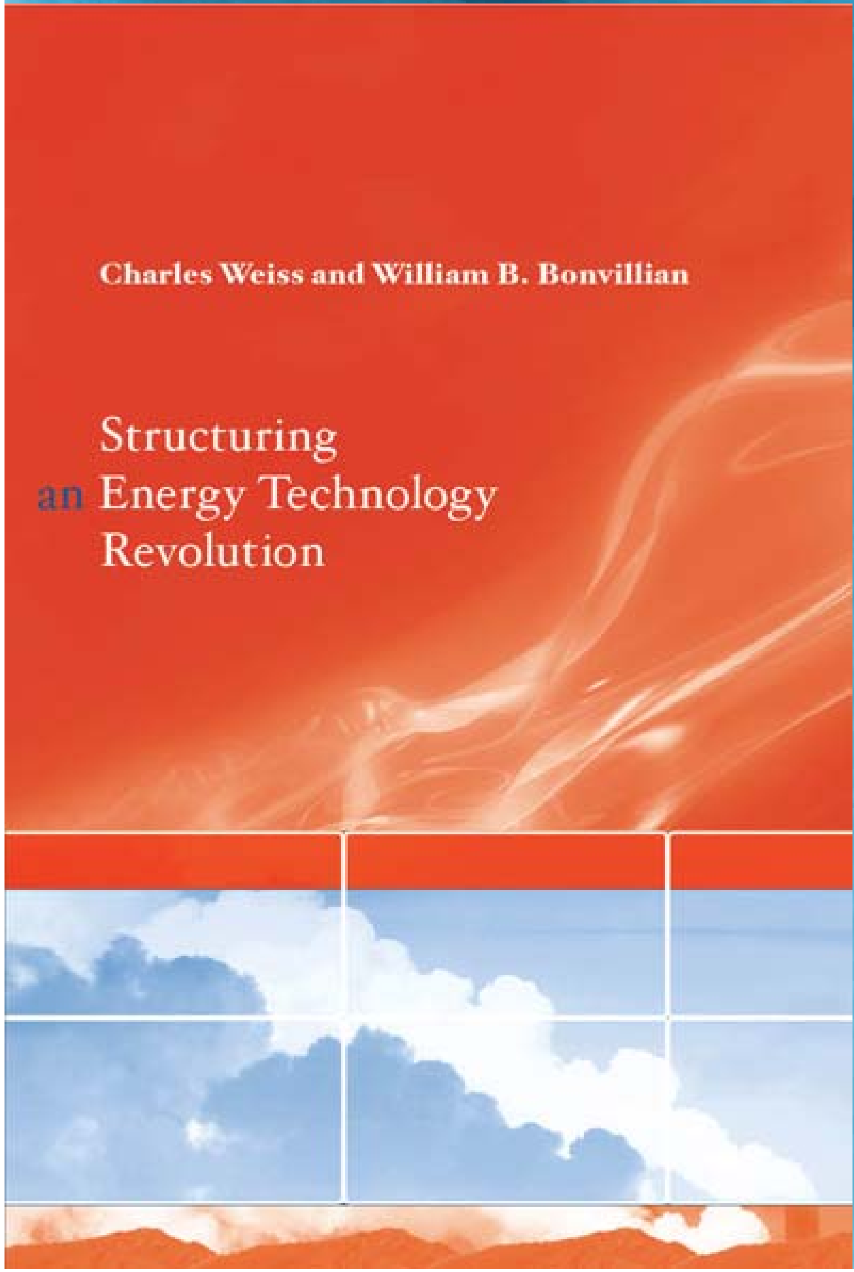
A Potential Breakthrough in US Policy

- The House of Representatives, with the support of the Administration, has passed a climate change bill, including a cap-and-trade regime and ‘border adjustments.’
  - ‘Border adjustments’ will force interest in carbon charges in countries that do not have them – but raise difficult issues for the WTO regime.
- On the negative side, support to the President’s proposed program of energy research and development was sharply reduced.
- Action in the Senate is still pending.

The U.S. is in no moral position to lecture other countries, despite this welcome change in U.S. policy.

Even so, we all live on the same planet and must work together to solve this serious problem.

You Can Read All About It:



"Yes we can! Indeed, this is a book for these times. Providing new vocabulary and new categories, the authors advance the urgently needed conversation about how government can spur the innovations in the energy system that will mitigate climate change. Anyone interested in seeing real progress made by biofuels, renewable electricity, nuclear power, carbon dioxide capture and storage, or auto and building efficiency should read this book."**Robert H. Socolow**, Professor, Mechanical and Aerospace Engineering, and Co-Director, The Carbon Mitigation Initiative, Princeton University

"This book provides, in a single volume, a clear and beautifully written review of innovation theory and energy technology. It then uses these insights to propose a practical framework for designing a national policy on energy and climate that draws both on theory and on the authors' extensive practical insights into what can actually be achieved through public policy. Anyone interested in designing an energy policy that actually works, escaping ideological battles and the passions of single-technology advocates, should read this book." **Henry Kelly**, President, Federation of American Scientists

"The authors have taken on the enormously important task of describing a workable public policy framework that is needed for transforming our energy system to a fully sustainable state. Finally, a book that not only covers all the critical issues and technology options, but also describes them in a manner which is objective, rational, and digestible."**Jefferson W. Tester**,Kroll Professor of Sustainable Energy, Cornell University

"This extraordinary book by Charles Weiss and William Bonvillian offers a four-step framework for analysis and action to meet America's need for secure, sustainable, and affordable clean energy. The most technologically advanced and innovative nation on the planet has seemed unable to meet this need because our traditional innovation processes are inadequate. Generating, distributing, and using energy in 21st century America, because of its scale, complexity, and in-place infrastructure, is totally unlike the narrow goals of the oft-cited Apollo Project. Furthermore, the multitude of technologies and the potential for unpredictable breakthroughs rules out a classical technology roadmap. Weiss and Bonvillian combine experience, analysis, and *realpolitik* to present a roadmap not for energy technology itself, but for the public-private process to fund, produce, and insert energy innovations into the economy."**Charles M. Vest**, President, National Academy of Engineering, President Emeritus, MIT

"For a variety of reasons: geologic, geographic, geopolitical, and environmental預 n energy transformation is already underway, but it will take massive investments, technological breakthroughs and thoughtful management as the transition proceeds. As the new Administration (and world leaders) grapple with the dual challenges of energy security and climate change, technology, timing, and scalable delivery systems will be key components in any solution. Weiss and Bonvillian lay out a comprehensive roadmap for guiding policymakers through somewhat uncharted terrain by identifying pathways to successful development and deployment of innovative technologies and make a persuasive case for global cooperative efforts. This is a must-read for sustainable energy futurists!"**Frank Verrastro**, Director and Senior Fellow, Energy and National Security Program, Center for Strategic and International Studies

Reserve Slides

Step Two: Policy Packages Matched to Launch Categories

- (1) *Front End Support:*
  - Needed for all technologies
  - Examples - research and development (R&D), technology prototyping and demonstrations (P&D), public-private R&D partnerships, monetary prizes to individual inventors and innovative companies, and support for technical education and training
- (2) *Back End Incentives* (carrots) to encourage technology deployment:
  - Needed for secondary (component) technologies
  - Examples - tax credits for new energy technology products, loan guarantees, price guarantees, government procurement programs, new product buy-down programs

Step Two, cont'd - Policy Packages for Promoting Energy Innovation

- (3) *Back End Regulatory and Related Mandates* (sticks):
  - For secondary technologies - contested launch
  - Prospect of political battles since launch will be contested
  - Examples: standards for particular energy technologies in building, construction, and comparable sectors, renewable portfolio standards, fuel economy standards, emissions taxes, general and technology-specific intellectual property policies.

Step Three: Identify the Gaps in Existing Energy Innovation System

- "Front-End" - RD&D -
  - Translating Research into Innovation
  - Carefully monitored demonstrations of engineering-intensive technologies (Carbon Sequestration, Biofuel Processing)
  - Improved manufacturing processes
- "Back-End" - deployment
  - Manufacturing scale-up
  - Launching into the economy
  - Installation of conservation technology
  - Financing infrastructure standup
- "Roadmapping"

(2) The Government Corporation

- Helps assure commercial involvement and projects that meet commercial standards
- Insulates demonstrations from Congressional interference
- Draws talent from the commercial and financial sectors and compensates them accordingly - not a gov't bureaucracy

The Government Corporation (cont'd)

- Promotes industry consortia to cut manufacturing costs through process improvements (SEMATECH Model)
- Supports Financing to Speed Production Scale-Up
- Enhances the flow of credit to conservation, efficiency and related new technologies in residential and commercial markets. ('Fannie Mae' GSE Model)

(3) The Roadmapping Think Tank

- Should be tied to industry consortia, with access to private, academic, and public sector expert leaders on energy technologies (SEMATECH Model)
- Develops common packages of "Back End" incentives for groups of technologies so as to help promote technology neutrality