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Energy from Fossil Fuels: Challenges and Opportunities for Technology Innovation and Policy Research

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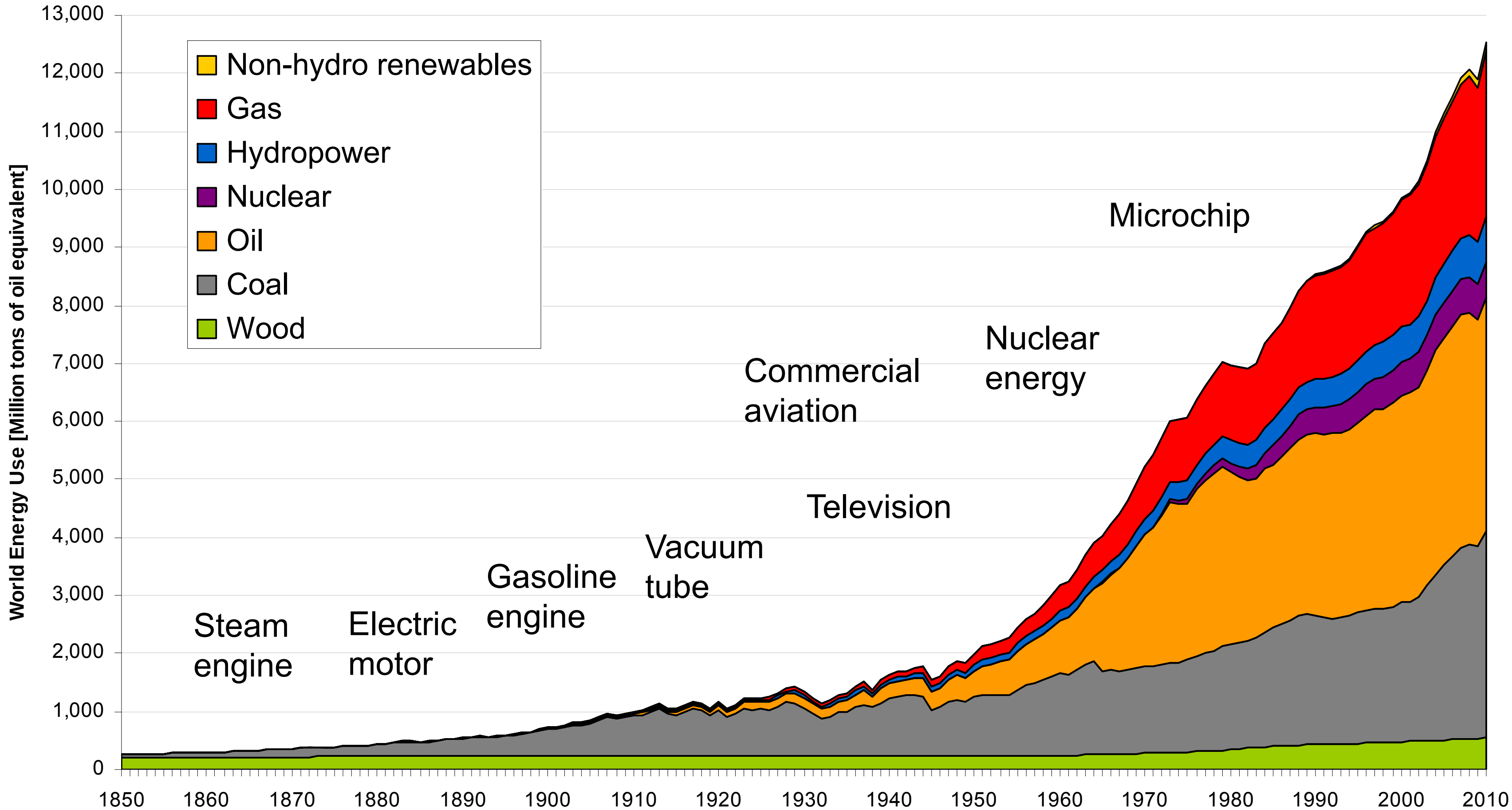
Outline

1. Major energy challenges in numbers
2. The need for and complexity in energy technology innovation
3. Short history of energy transitions
4. Implications for technical research
5. Implications for technology and policy research

1. World energy use by source 1850-2010 …over 80% from fossil fuels



Population in billion: 1.6 2.5 5.5 (1992) 6.9 (2012)

Compiled from data by Gruebler (1999), BP Statistical Review (2011) Nakicenovic & Gruebler (2000)

1. A U.S. look: an environmental challenge

- 86% of U.S. GHG emissions come from the energy sector (5.7 Gt CO_2)
  - 38% of GHG emissions from coal combustion for power (46% of U.S power)
  - 30% of GHG emissions from oil combustion for transport (93% of transport)

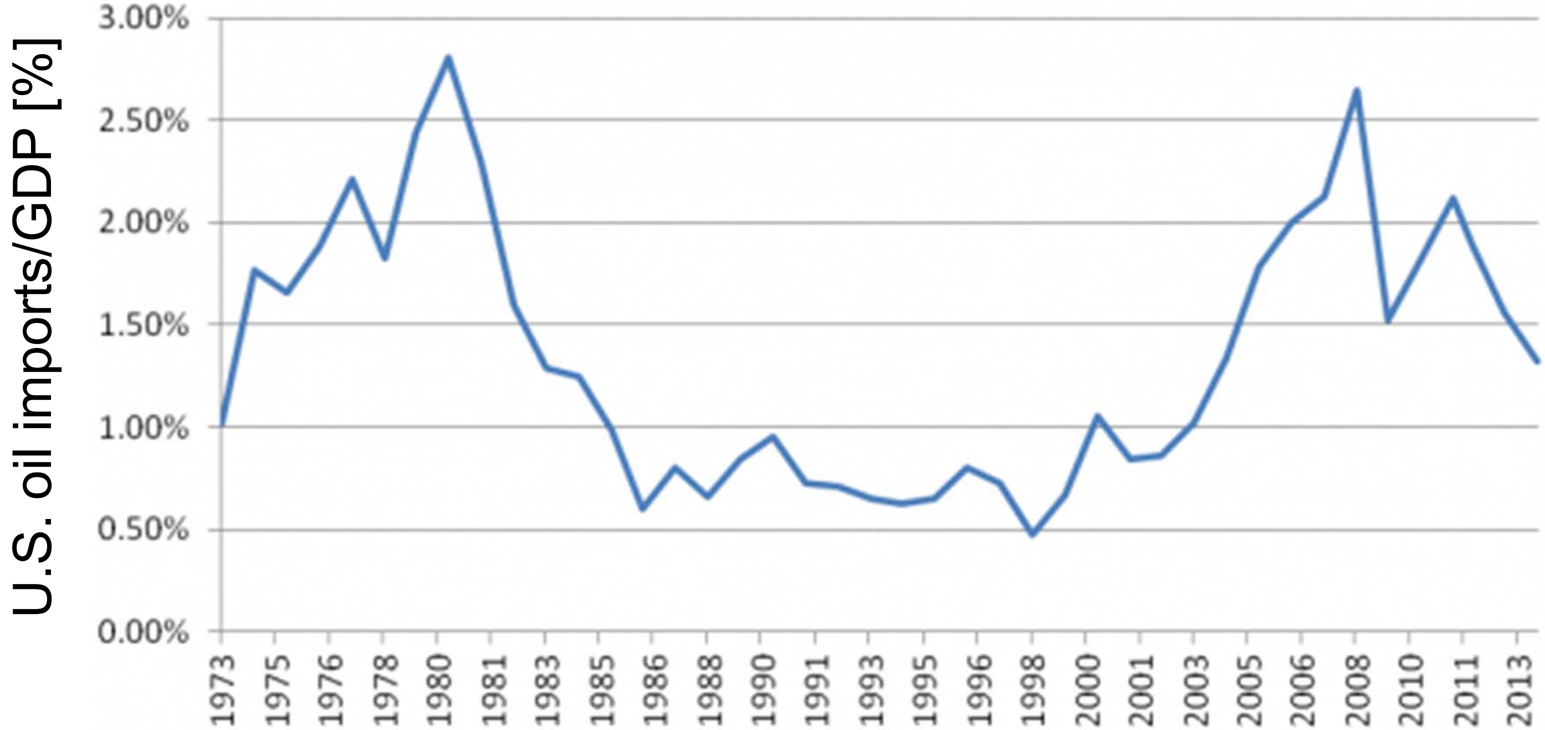
EPA(2012). US GHG Inventory

1. A U.S. look: health (and economic) damages

- Health damages (premature mortality and morbidity) from PM, SO_2, NO_x
  - $62 billion annually from coal power
  - [$0.7 billion from gas power]
  - $56 billion annually from oil in transportation

NRC (2010). Hidden Costs of Energy

1. A U.S. look: economic challenges



- Even though oil imports have come down, as a fraction of GDP they are still higher than any time since 1983
- Crude oil imports have decreased by 16% since 2005

Levi (2013). Council on Foreign Relations

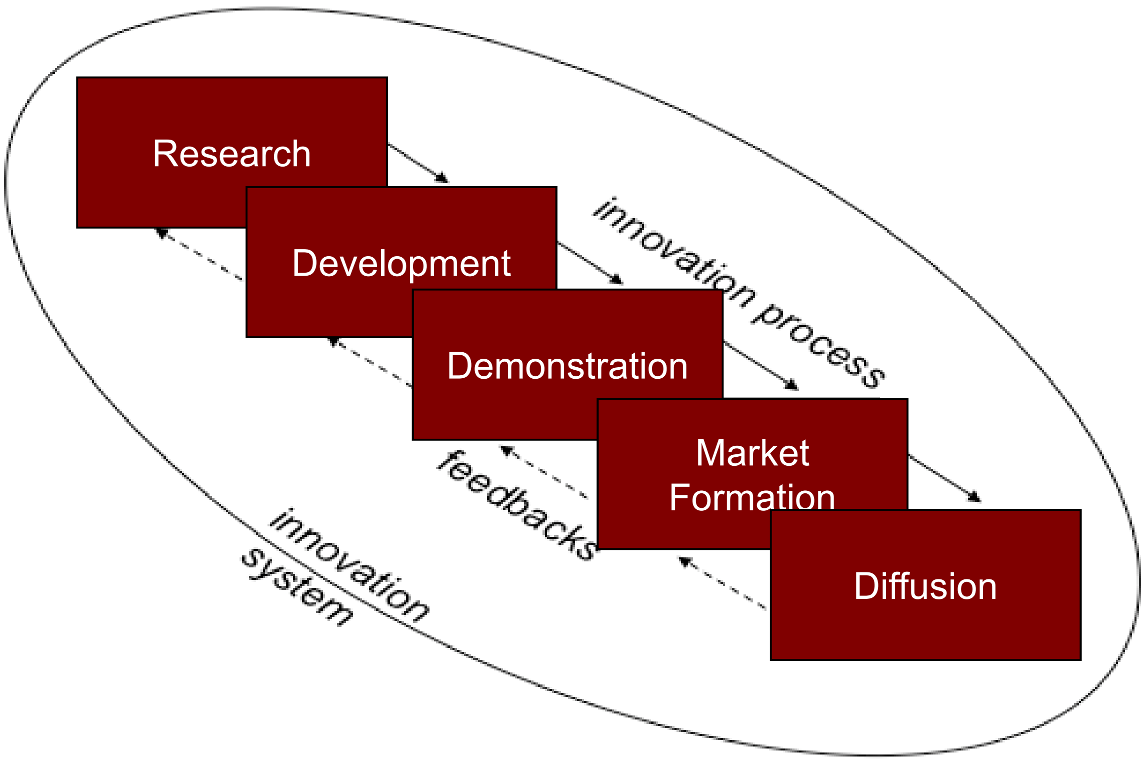
2. The need for energy technology innovation

- Consensus that new and improved energy-supply *and* end-use technologies will be necessary, e.g., CO_2 emissions

$$CO_2 = Population \frac{GDP}{Population} \frac{Energy}{GDP} \frac{CO_2}{Energy}$$

- Not so much consensus about what policies should be put in place to accelerate this innovation because we do not know enough about:
  - **the impact of previous policies on innovation**
  - **the possible impact of future policies on various factors**

2. Innovation goes well beyond invention or R&D

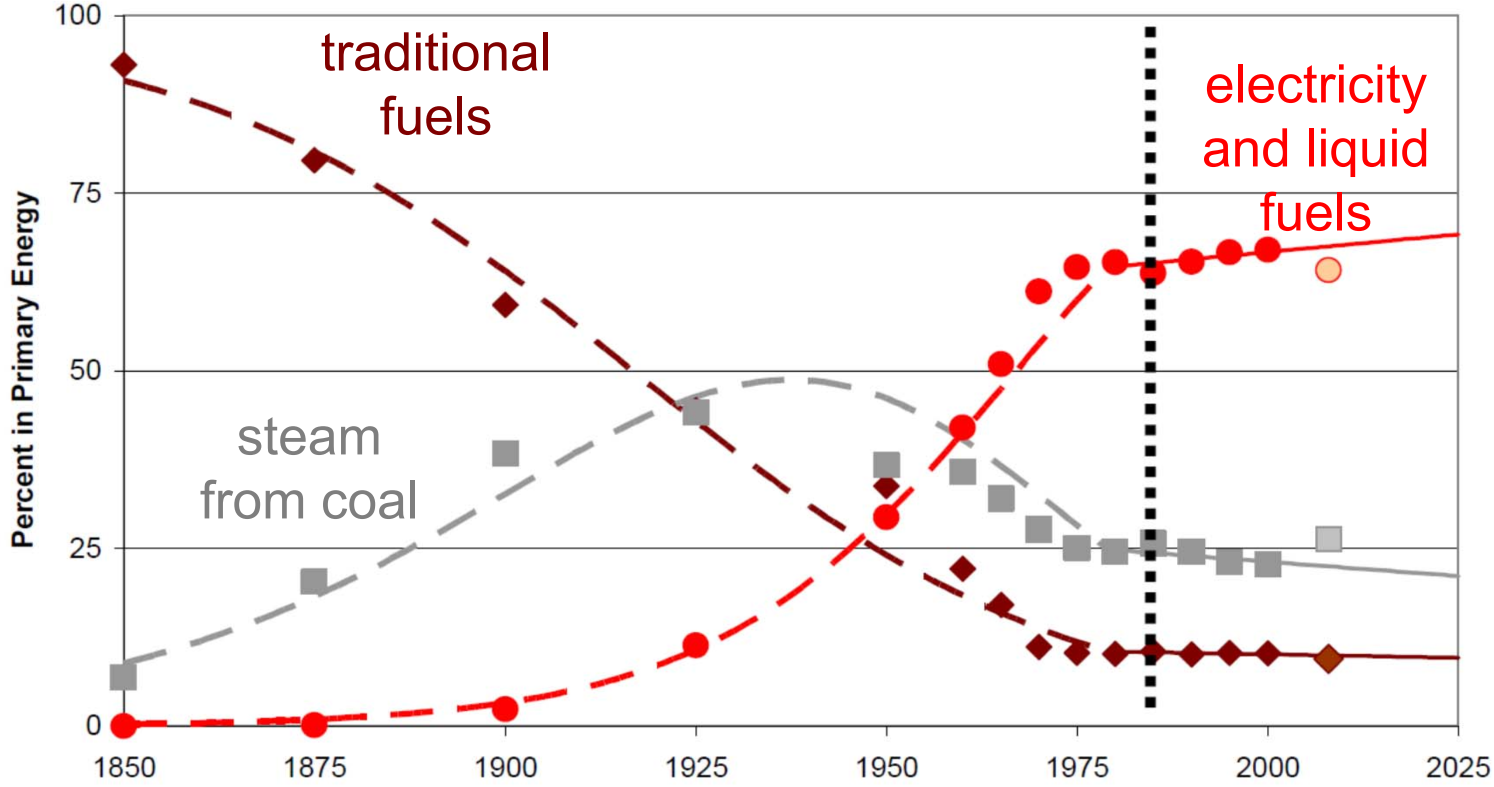


Global Energy Assessment (2012), Chapter 24 on
Policies for the Energy Technology Innovation System

2. Innovation in energy technologies is complicated by:

- Multiplicity of actors
  - Academia, NGOs, private firms, financial institutions, entrepreneurs, different government levels
- Institutions (norms, culture, policies)
  - WTO, IPR, risk-taking appetite, behavior and norms (e.g., turning lights off, big houses and cars, etc.)
- Heterogeneity of technologies and clusters
- Scale and capital intensity (primarily for supply-side)
- Ubiquity, interconnectedness, and technology clusters (lock-in)
- Commodity nature of electricity and fuels

3. Two grand historical energy transitions



- Transitions took place over 70-120 years
- New technology clusters provided performance benefits

Global Energy Assessment (2012). Chapter 24 and Gruebler & Wilson (2013) Cambridge University Press, forthcoming

3. Two examples of more recent innovation in energy-supply technologies

- Brazilian sugar cane ethanol
  - Sustained government program over 27 years
    - Research in agricultural yields, conversion technologies, and vehicles
    - Mandates and subsidies for adoption
  - Substituted 40% of all gasoline in Brazil
- Shale gas extraction
  - Sustained program for over 20 years
    - Gas Research Institute, an industry consortium, funded by a gas pipeline surcharge combined with DOE research over two decades
    - Demand-pull support using tax credits over 12 years
  - Persistence of entrepreneur George Mitchell
  - Pipeline and end-use technologies did not need to be modified
  - Makes up 34% of total extraction (about 24 Tcf)

➔ In both cases governments provided coordinated and stable support and strong partnerships with the private sector

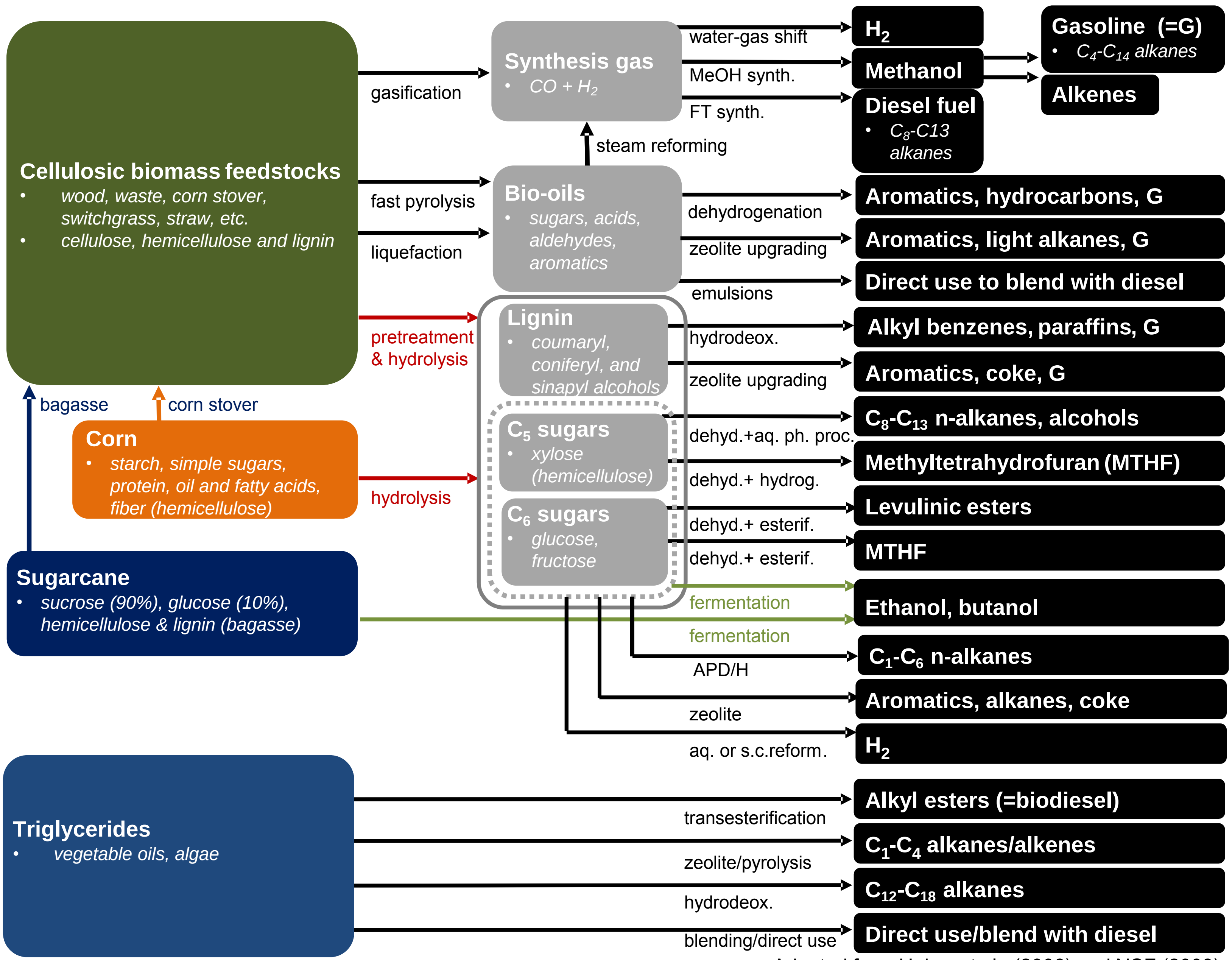
Meyer, Mytelka, et al. (2012). Global Energy Assessment, Chapter 24 case studies; MIT Future of Natural Gas (2011)

4. The future of transportation is still uncertain

- Liquid fuels
  - Thermochemical and biochemical conversion of biofuels
  - Solar H_2 to liquids or fuel cells
  - Compressed natural gas
  - Gas to liquids
  - Coal to liquids
  - Coal and biomass to liquids…
- Hybrid electric vehicles
- Plug in hybrid and electric vehicles
  - Greater role for low carbon electricity (e.g., renewables, nuclear, storage, coal with CCS...)
- More mass transit…

➔ Niche markets, using existing infrastructure, and developing complementary technologies could facilitate adoption

4. Many routes for making biofuels



Adapted from Huber et al., (2006) and NSF (2008)

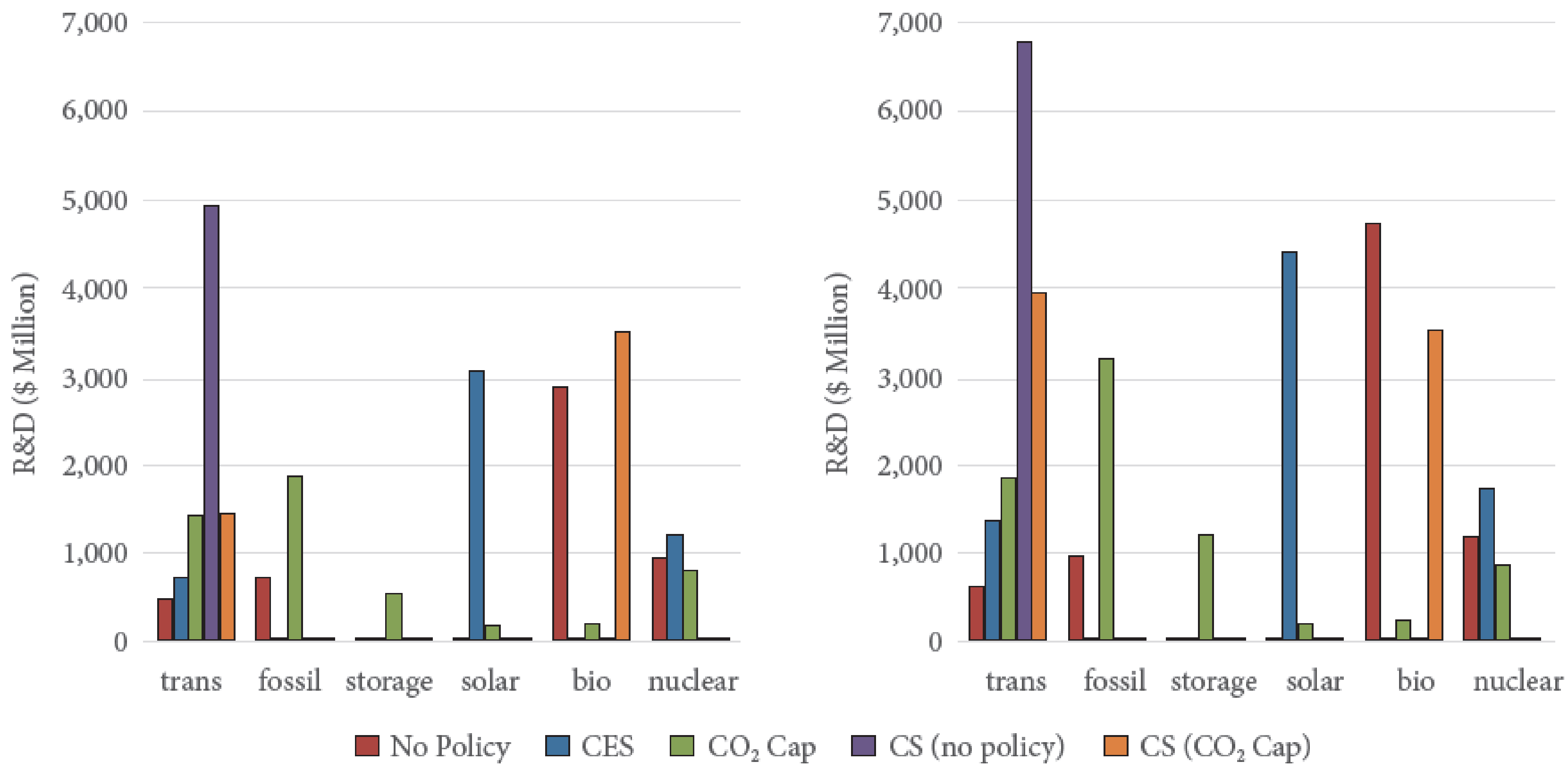
5. Supporting the design of public energy R&D portfolios: managing the uncertainty

- The design of the portfolio of current technology programs does not consider technical uncertainty
- Nor does it consider the possible complementarity and substitutability among technologies (market interaction)
  - E.g., complementarity of solar and storage, partial substitutability of nuclear and coal with carbon capture and storage and of biofuels and vehicle electrification
- There is also little transparency about the technical assumptions

➔ Recent studies and reports from the NRC (2007), PCAST (2010), and OMB (2013)—among others—have highlighted the need for analytic tools to support the decision making process given the complexities and interrelationships

➔ We combined transparent technology-detailed probabilistic expert elicitations, energy-economic modeling, and optimization

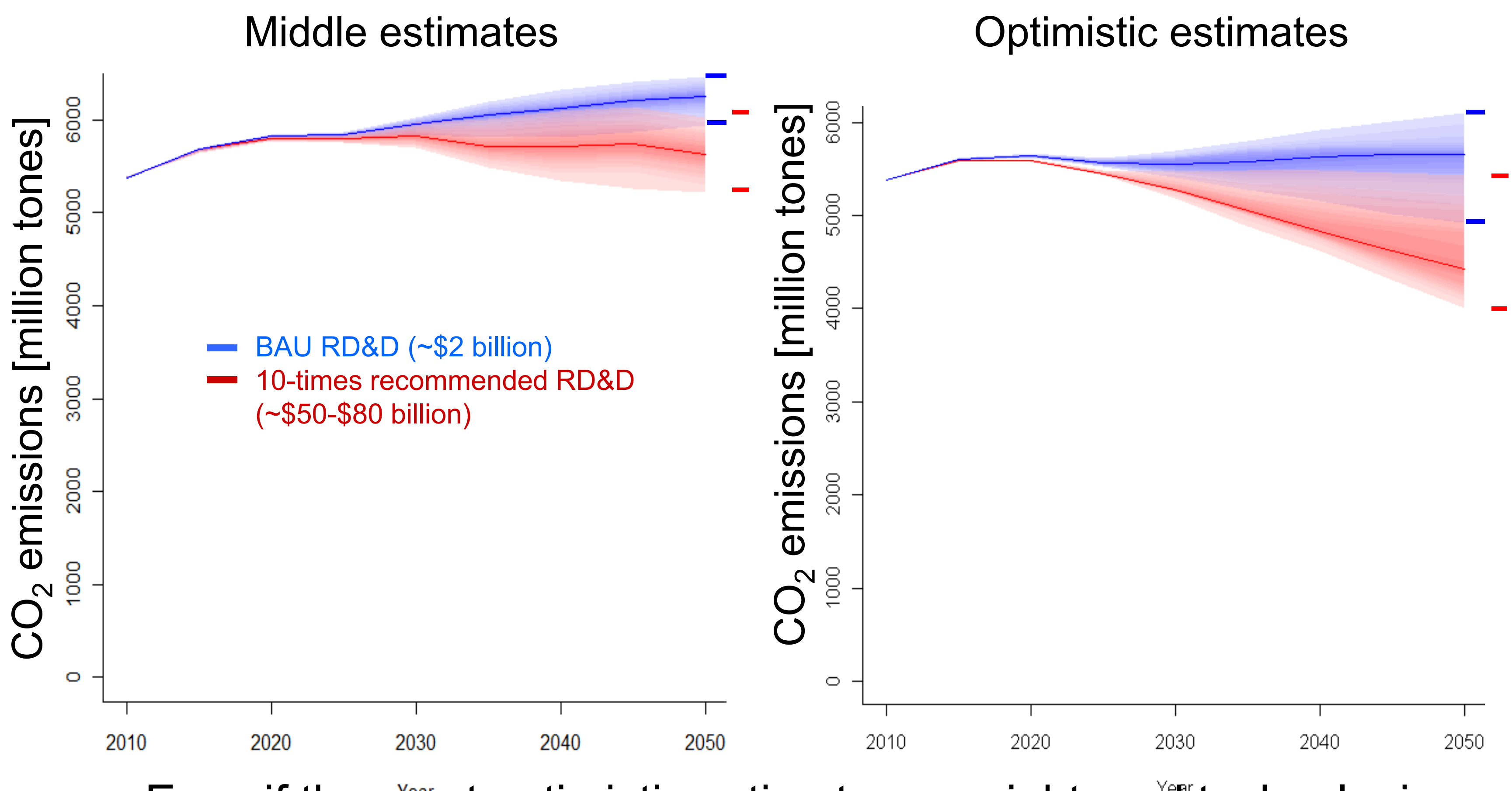
5. Returns to increasing public energy RD&D are expected to be large and depend on policy



- Optimal allocation of a $5 billion and $7 billion energy R&D budget, respectively, under different policies and different criteria.
- In recent work we show the largest returns to solar, storage, and biofuels

Anadon et al. (2011) Belfer report; Anadon et al. (2013) Cambridge University Press. Forthcoming; new work in Chan & Anadon (2013)

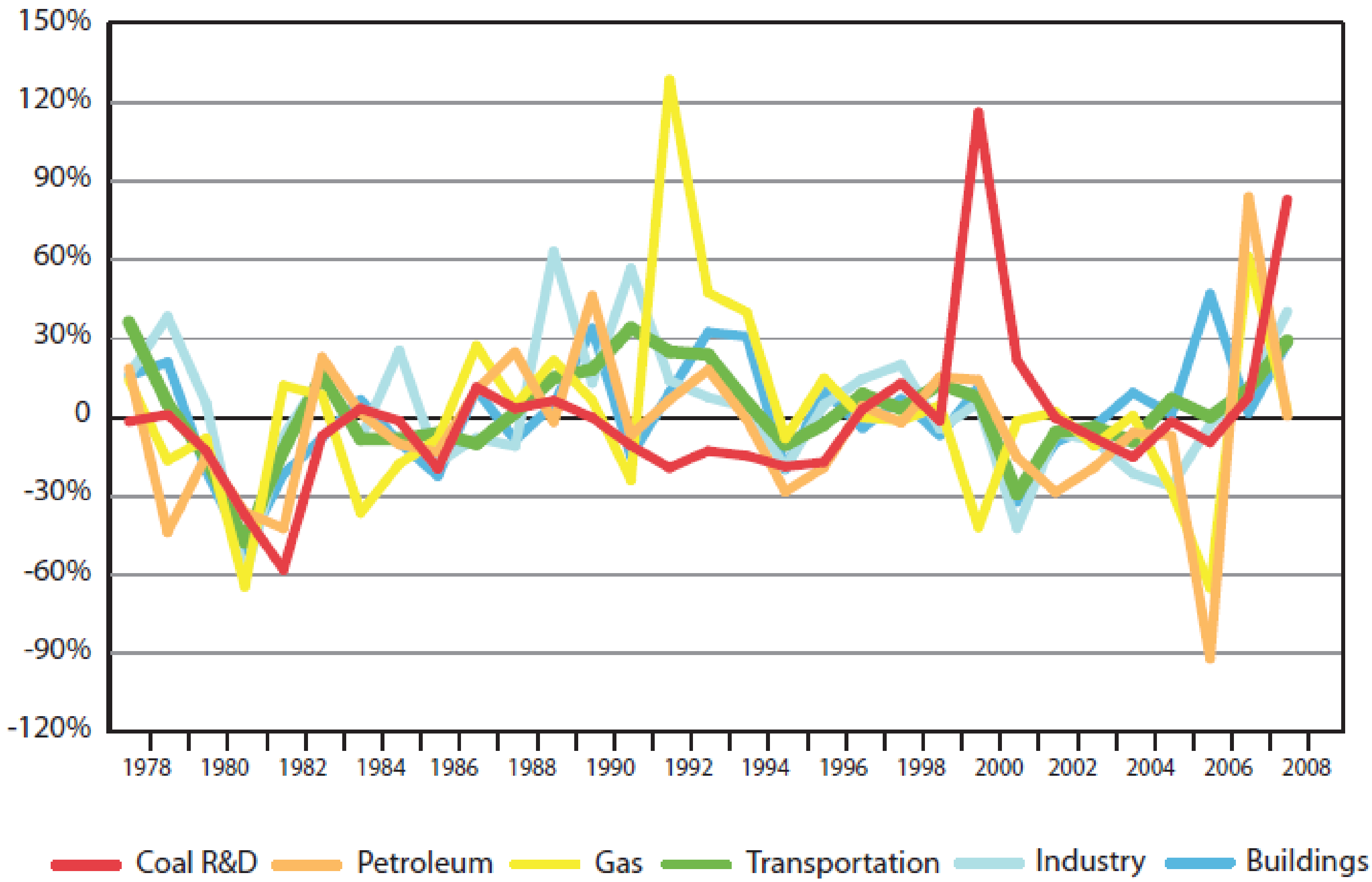
5. But energy RD&D is not enough



- Even if the most optimistic estimates are right, and technologies do as well as they possibly can, and the government makes very large RD&D investments, a demand-side policy is needed

Anadon et al. (2011) Belfer report; Anadon et al. (2013). Cambridge University Press, forthcoming.

5. And there is significant volatility in government energy R&D funding



- Every year one in three programs had its budget change by ±27%

Narayanamurti, Anadon & Sagar (2009) Issues in Science & Technology; new work in Anadon et al. (2013) Cambridge University Press, forthcoming.

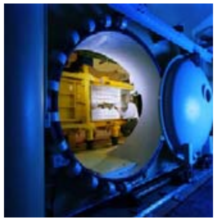
5. Policies at the federal level have room for improvement

- A national strategy and more coordination across agencies is needed,
- As are:
  - stable (and adaptive) demand-side policies
  - increased and more stable RD&D investments
    - more focus on solar, storage and biofuels
  - restructuring of innovation institutions
  - increased interaction with the private sector
  - consideration of material, water, and land requirements in policy making
- Similarly, the history of energy innovation shows that a long-term view for research is needed

Narayanamurti, Anadon & Sagar (2009) Issues in Science & Technology; Anadon et al. (2011) Belfer report; Anadon et al. (2013), Cambridge University Press, forthcoming; Anadon (2012). Research Policy

5. Many factors contribute to innovation

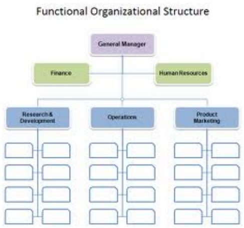
- Learning-by-doing or by using



- Learning-by-searching

- Knowledge spillovers from other sectors

- Economies of scale



- Economies of scope

- Materials and labor costs

5. Other examples of how detailed technology and policy research can be used to support policy

- Historical data gathering and empirical regression analysis:
  - Extent to which wind quality, economies of scale, learning by doing, local manufacturing, and materials prices affected wind in China (Qiu & Anadon, 2012, Energy Economics)
  - Impact of renewable policies on patents, domestic manufacturing, and deployment (role of complementary sectors) (Choi & Anadon, 2013, Technology Forecasting & Social Change)
- LCA + spatially-resolved scenario analysis of policies
  - Incorporating an analysis of the water and land implications of different liquid fuels highlights the possible side effects of the Renewable Fuel Standard (Jordaan, Anadon, et al. 2013, Environmental Science & Technology)
  - Estimating China's regional water intensity of energy products and how they match with China's energy plans (Chao & Anadon, 2013, Environmental Science & Technology, R&R)
- Electricity models and Approximate Dynamic Programming
  - Accounting for learning changes R&D and capacity investment strategy in solar (Santen & Anadon, 2013, Computational Management Science conference and more forthcoming)

5. Some other promising areas of technology and policy research to promote energy innovation

- Technology-detailed policy-relevant work
  - collaboration of technical & policy researchers to understand the pathways of historical technology breakthroughs
- Interaction between researchers & technology users
  - particularly for use of technology in other cultures (LBL work of Ashok Gadgil)
- Increased focus on understanding other inputs in technology and policy research
  - CO_2-water-land-food-pollution (and health) impacts of policies
- Use of computational social science to better understand drivers of individual technology adoption
- Institutional research to find ways to get rid of the basic/applied research divide to support and conduct transdisciplinary R&D toward the public good (Narayanamurti, Odumosu, Vinsel, 2013, IS&T)

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ENERGY TECHNOLOGY INNOVATION POLICY

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