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ENERGY TECHNOLOGY INNOVATION POLICY

December 12, 2014

Transforming U.S. Energy Innovation

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Energy: A defining challenge for the 21st century

Despite the unconventional oil and gas revolutions, energy reminds a major challenge for the United States and the world

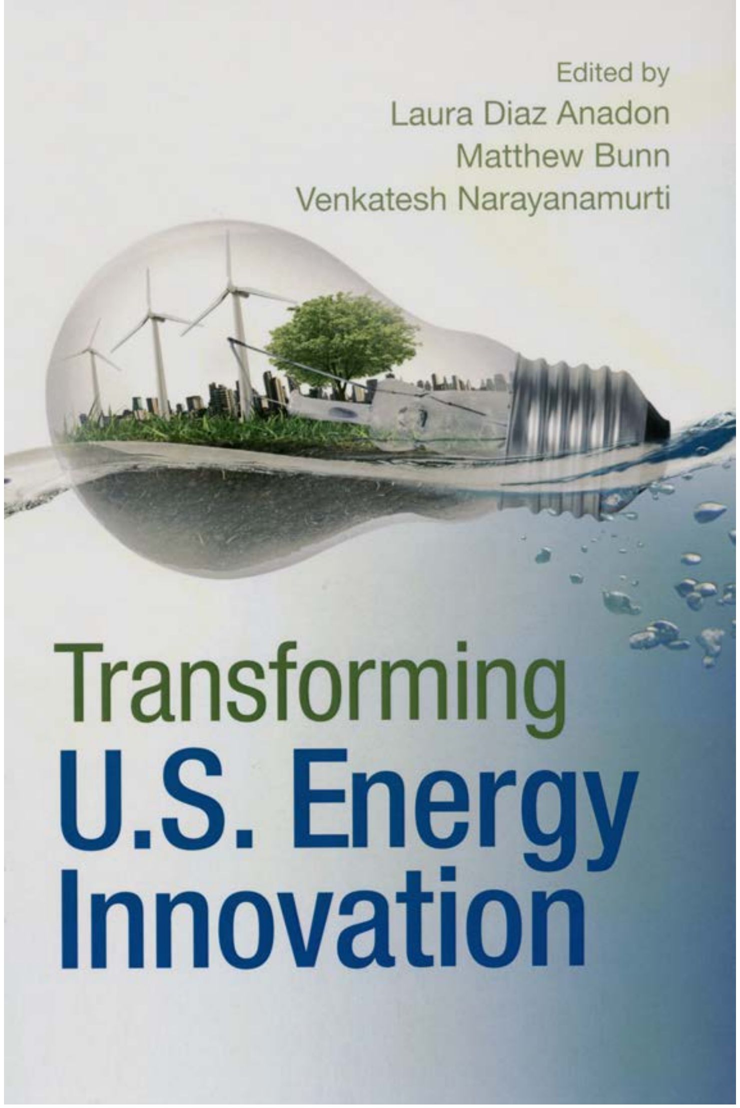
The world must provide more and more energy to fuel growing global economies, while reducing:

- *Environmental impact:* Carbon emissions pose a risk of catastrophic climate disruption; fine particulates cause >3M deaths/yr
- *Economic impact:* Volatile fuel prices cause economic disruption, increased poverty; large wealth transfers to exporting states; opportunity for major U.S. share of global clean-energy markets
- *Security impact*: Current energy approaches pose risks of excessive dependence on volatile regions; resource conflicts; nuclear proliferation; military dependence on hard-to-protect fuels
- *Poverty impact*: Current approaches leave billions in poverty without access to modern energy supplies

These challenges cannot be met at reasonable cost without dramatically improved energy technologies

Even in a time of budget constraints, it is important to make high-payoff, long-term investments

Transforming U.S. Energy Innovation: What's New?



- Expert elicitations in broad range of energy technologies combined with economic modeling to tease out return to RD&D – with uncertainty
- New survey of private sector energy RD&D – and new analysis of DOE-private partnerships
- Case studies of innovation institutions
- New data on developing countries' energy RD&D investments

CASCADES – Criteria for an Effective Energy Technology Innovation Policy

Comprehensive – in innovation stages, policy tools

Adaptable – learning and changing as it proceeds

Sustainable – built to last, including bipartisan support

Cost-effective – most progress per dollar spent

Agile – responding to new opportunities and needs

Diversified – covering all potentially significant technologies

Equitable – among technologies, companies, regions

Strategic – clearly defined goals, plausible paths to them

There are tensions among these – must be balanced

Expert elicitations covered a wide range of technologies

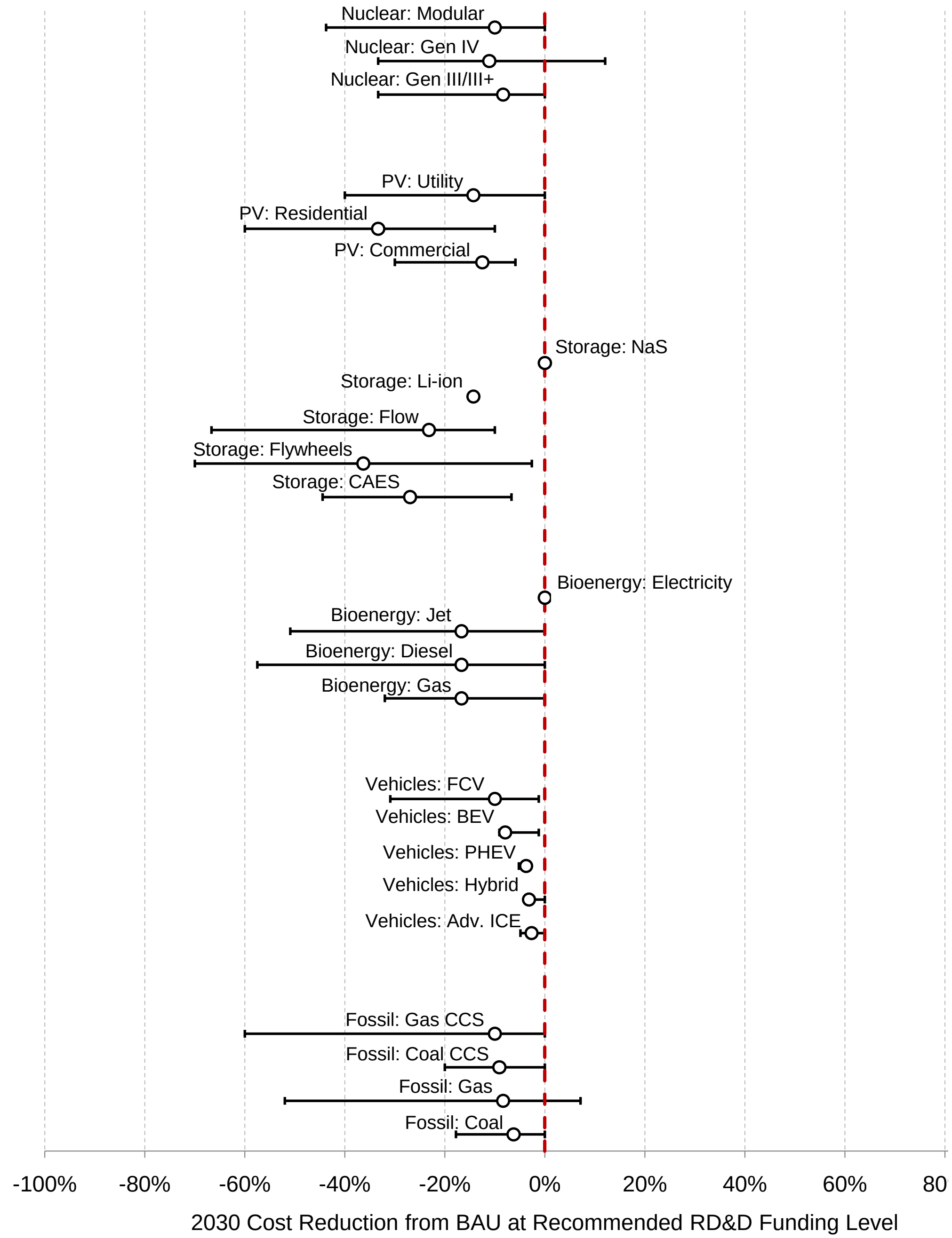
- 4 supply side technology areas
  - *Nuclear energy*: Gen III, Gen IV, modular reactors
  - *Fossil energy*: coal with and without CCS, natural gas with and w/o CCS
  - *Bioenergy:* gasoline, diesel, and jet fuel production through thermochemical and biochemical conversion pathways, and electricity
  - *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 internal combustion engine vehicle, electric vehicle, plug-in electric vehicle, hybrid vehicle, and fuel cell vehicle
  - *Buildings*: commercial buildings, 6 levels of energy efficiency for heating and cooling

➔ *We covered 25 technologies under 4 budget scenarios*

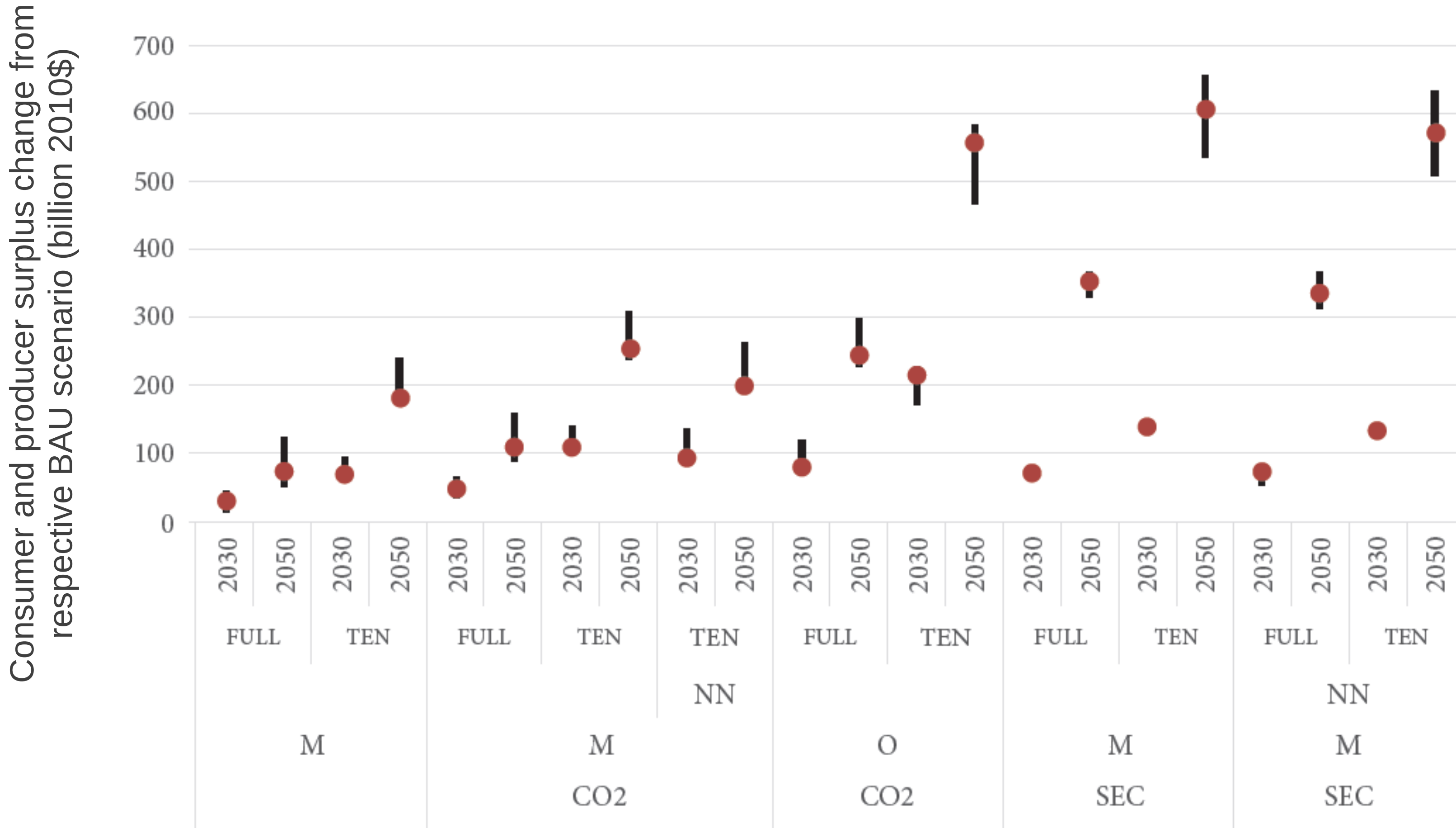
➔ *Insights from ~100 technical experts and 23 high-level reviewers*

Experts estimates of impact of increased RD&D on technology improvement

- Median impact largest for solar PV, batteries, and bioenergy
- Median impact smallest for vehicles technologies and fossil energy

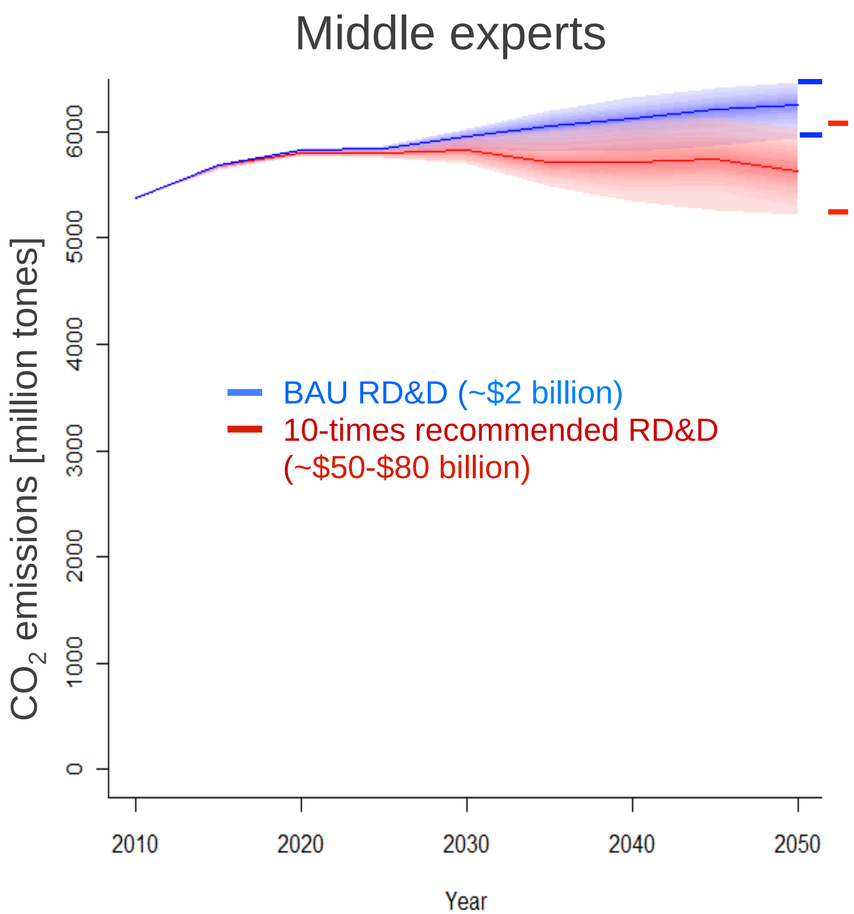


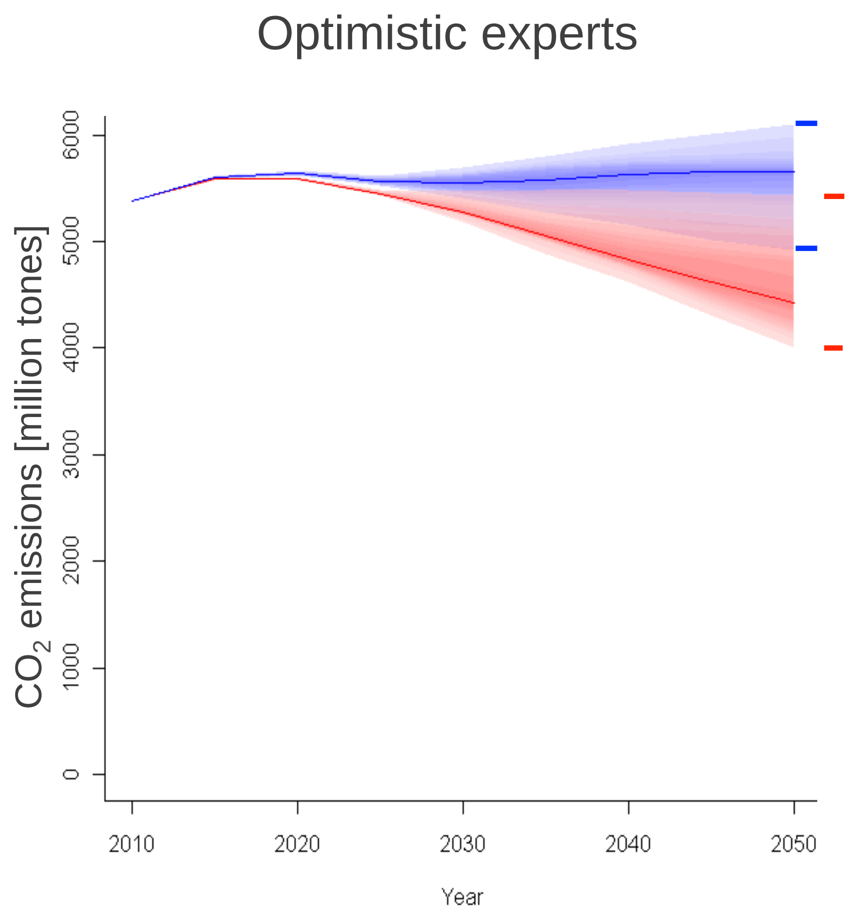
Huge returns to increased RD&D investment



- The benefits in 2050 under the FULL recommended funding scenario are between \$80 billion and \$350 billion compared with the BAU scenario depending on policy and technology assumptions

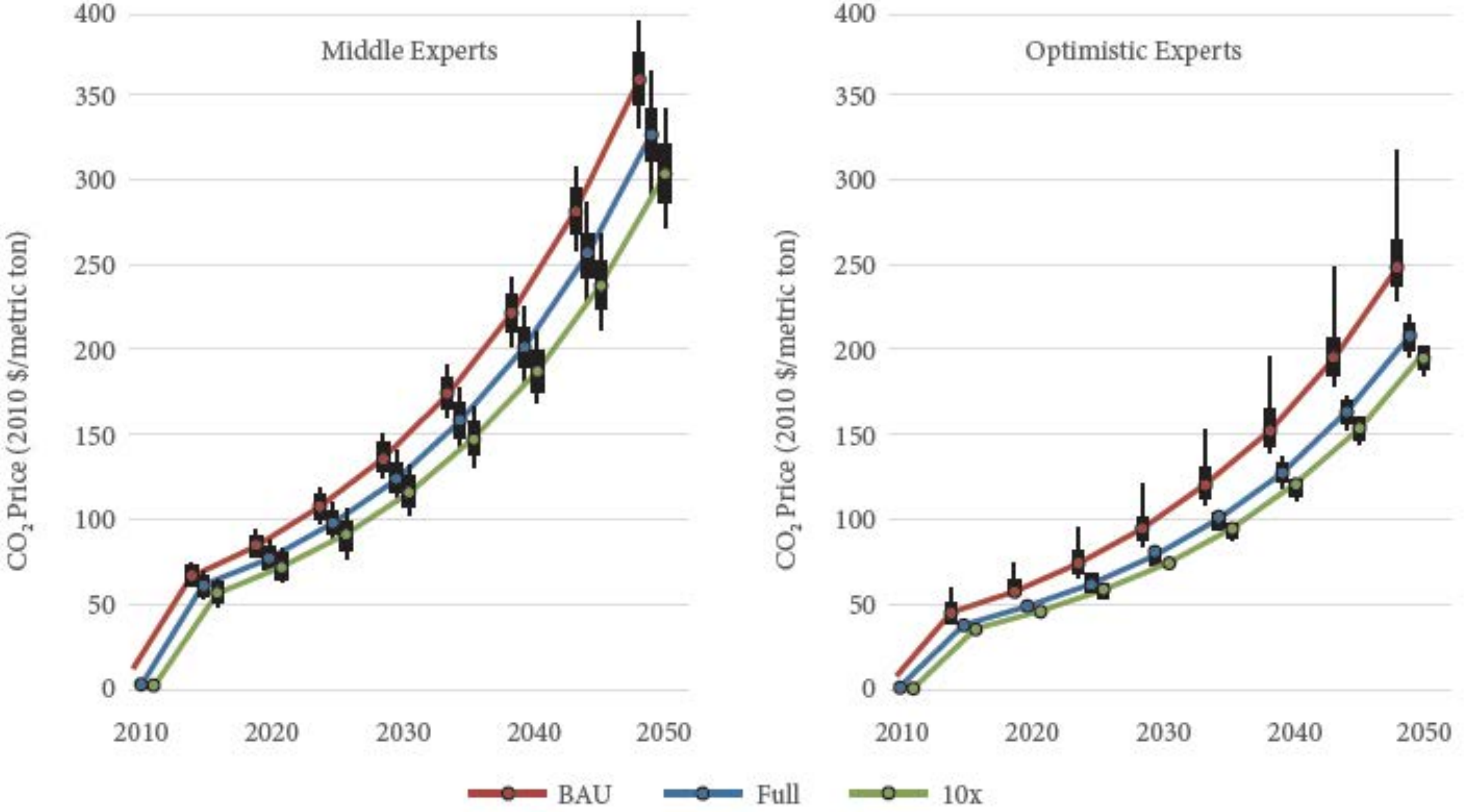
Impact of RD&D on CO_2 emissions



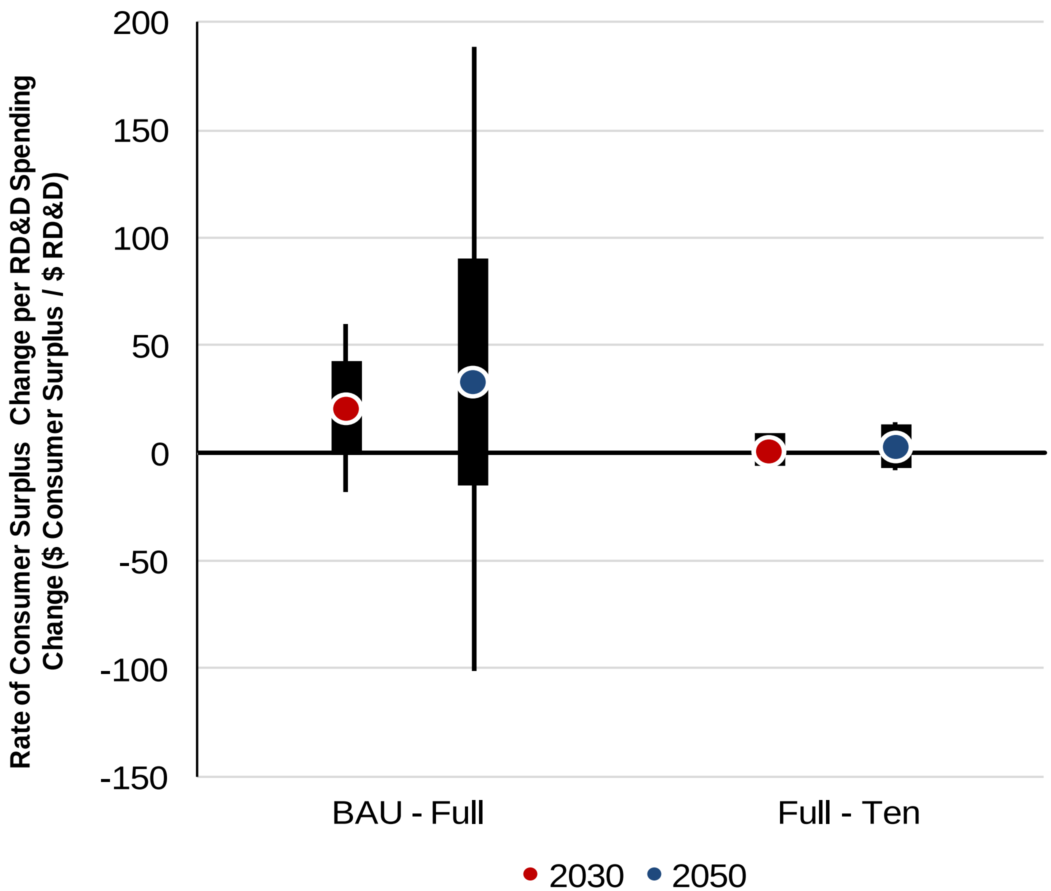


Even if all the optimistic experts are right and the government makes very large RD&D investments, a demand-side policy is also needed

Trajectory of CO_2 prices under a strict CO_2 limit

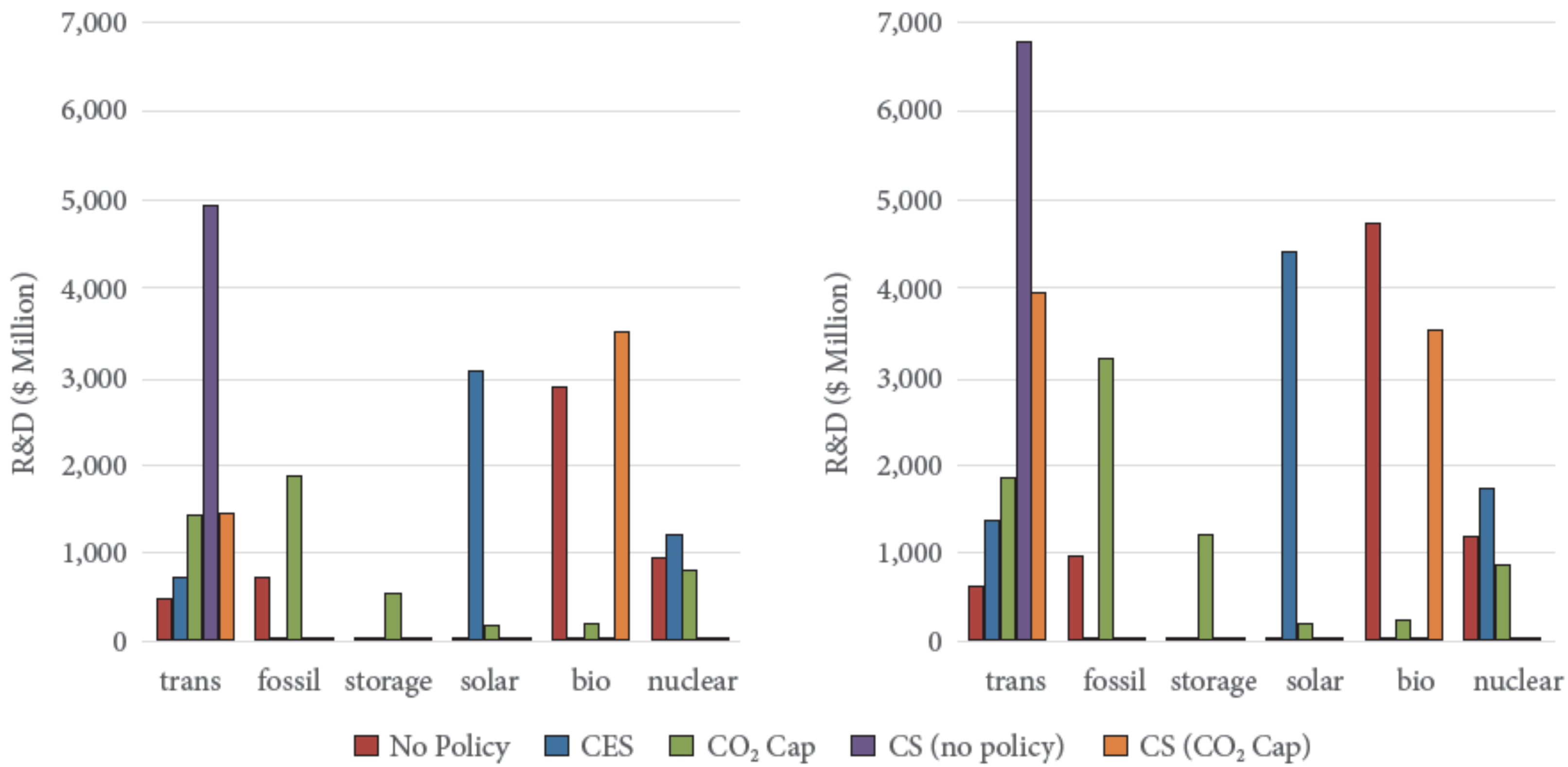


Decreasing marginal returns to RD&D investments



- Strong decreasing marginal returns on benefits beyond recommended “full” budget accounting for technical uncertainty (2050 timeframe)
- Consumer surplus increases per RD&D$ from BAU to full (less than 30% probability of no positive impact)

Optimized RD&D allocation for a $5 and $7 billion total budget under different policies



- Under a federal clean energy standard (CES) policy solar PV RD&D would play a larger role in the portfolio, and under a no policy case biofuel RD&D would play a larger role

How much to invest, on what

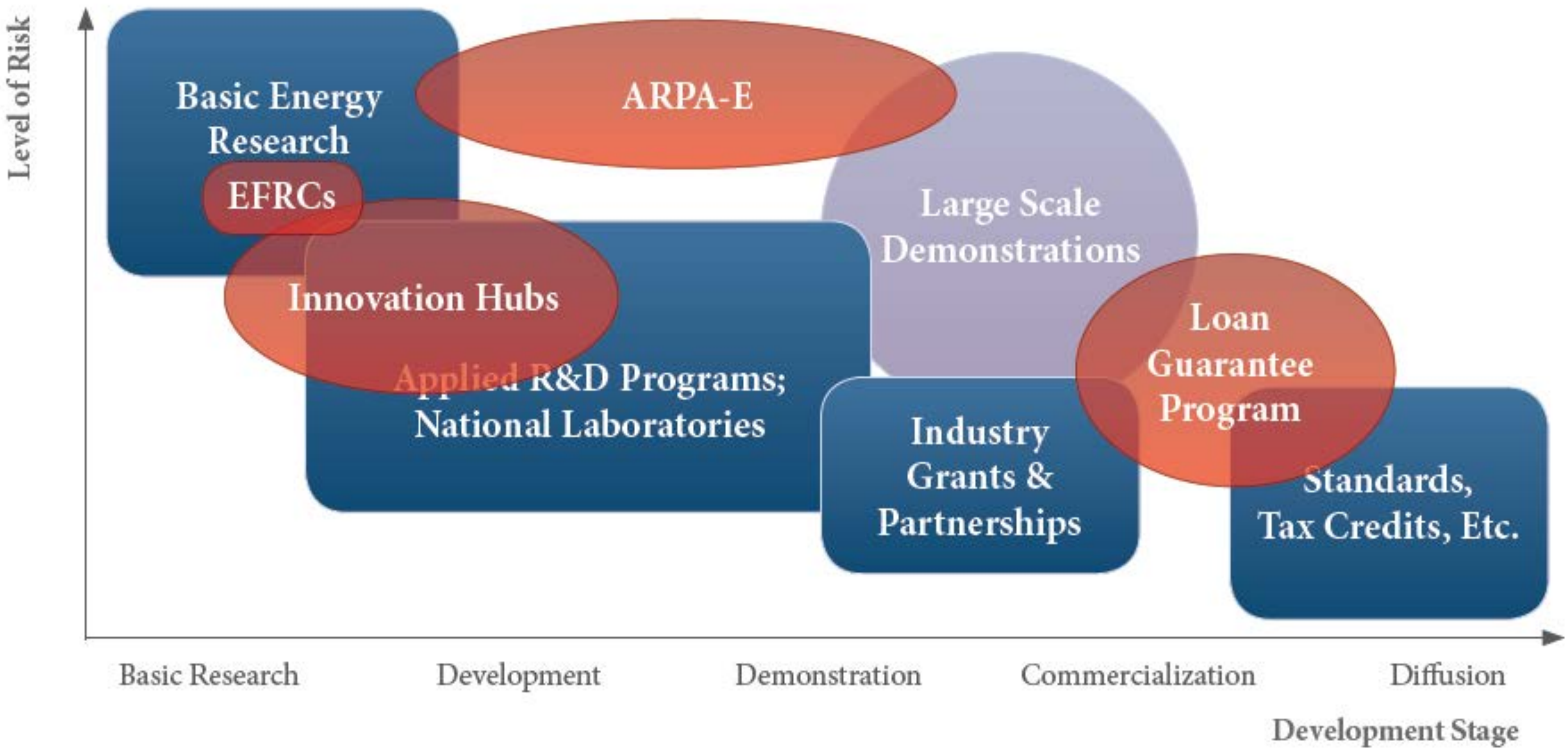
- *Both* a dramatic increase in energy RD&D investment *and* demand-pull policies to build markets for new energy technologies are needed
  - Based on the elicitations and the modeling we recommend a 2-fold increase in energy RD&D from $5 to $10billion/year
    - *Wide range of options for complementary funding for energy RD&D outside of regular appropriations, as suggested by PCAST*
  - Investment in broad portfolio of technologies and stages of development needed to maximize chance of success
  - Optimal allocation of RD&D investments depends on policy, creating another reason for supporting a portfolio of technologies (and for tackling policy uncertainty)
  - Largest percentage increases recommended for solar PV, storage, buildings, and bioenergy; largest total investments for nuclear, CCS and vehicles

Recommendations for areas covered by elicitations and modeling

DOE program	FY 2009 appr.	Mean of experts (std. dev.)	Median of experts	Min of experts	Max of experts	ERD3 recs.	Percent change over FY 2009 appr.
Bio-energy	214	680 (286)	640	300	1,000	680	218%
Energy storage	23[a]	240 (391)	120	50	2,000	240	943%
Nuclear	466	1800 (1,397)	1,200	800	8,000	1,200	158%
Fossil and CCS	701	2300 (1,980)	2,000	600	7,500	1,000	43%
Buildings	144	680 (315)	700	200	1,000	680	372%
Vehicles (inc. fuel cells)	432	2050 (3,050)	1,000	400	10,000	1,000	131%
Solar PV	143	337 (226)	300	200	1,000	400	180%
Total	2,123	8,159	5,960	2,350	29,500	5,200	145%

- Total areas not covered by elicitations (e.g., ARPA-E, BES, wind) = $4.8 bn
- Grand total recommendation for energy RD&D: $10 billion

Range of energy innovation institutions supported by the U.S. government



- ‘Old institutions’ in blue, newer institutions in red, and non-existing institution in purple

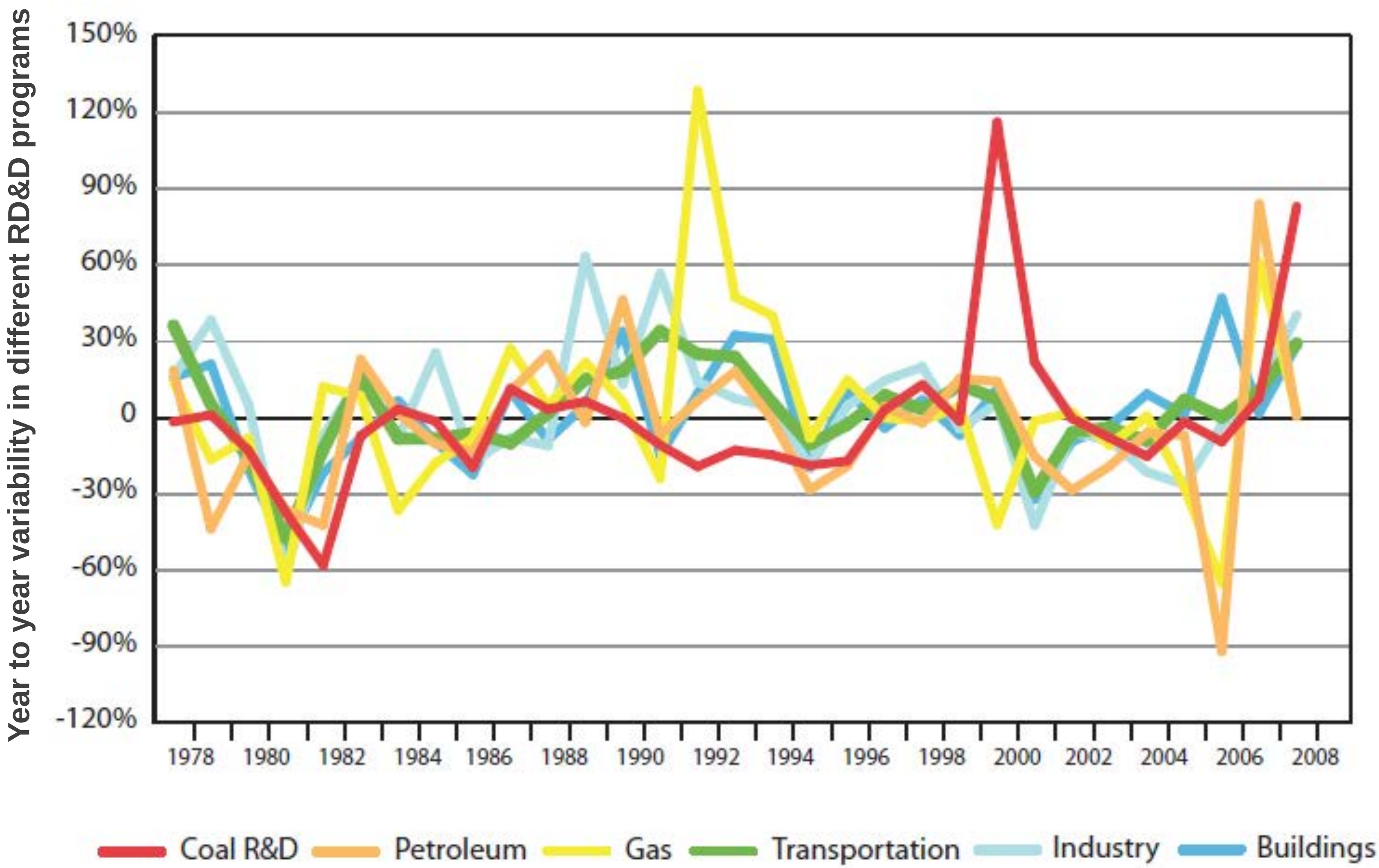
Energy innovation institutions

- To be fully effective, U.S. energy innovation institutions need:
  - Clear mission
  - Visionary and technically excellent leaders
  - Stable funding
  - Broad, flexible authority – with accountability – for management
  - Culture of technical excellence and willingness to take risks on uncertain but potentially high-payoff ideas
  - ARPA-E appears to be achieving many of these goals – but achieving them elsewhere will require major changes in approaches to running the national laboratories
- An institution for implementing technology demonstrations is likely to be needed
  - Needs to be implemented in a way the private sector sees as replicable – current DOE structures likely inadequate
  - Clean Energy Deployment Administration possibility

Narayanamurti, et al (2009); Narayanamurti, et al. (2011)

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)

Energy innovation institutions (II)

- Some of the recommendations for the national laboratories:
  - Take a system view with a portfolio of clearly defined missions in research and innovation for future energy technologies
  - Integrate basic and applied efforts – “use-inspired” research
  - Restructure contracting to allow for increased lab autonomy with strengthened accountability
  - Utilize active management strategies to link research and application
  - Increase interaction between users (private sector), scientists at the labs, and DOE program managers—encouraging the flow of technical and market knowledge
  - Expand lab-directed research and development funding
- Some of the recommendations for NREL:
  - DOE and Congressional action to stabilize mission and budget
  - Fix contracting procedures and other facts that limit NREL technical staff autonomy (comparable to Office of Science labs)
  - Increase use of lab-directed funds to level permitted by legislation
  - Expand incentives for entrepreneurship

Energy innovation institutions (III)

- Some recommendations for other institutions:
  - Institutionalize and sustain funding for ARPA-E, the Innovation Hubs, and the Energy Frontier Research Centers
  - Define a clear mission at DOE to develop a workforce by funding graduate and post-doctoral education through enhanced strategic engagement with research-intensive universities

Survey of private sector energy innovation

- Private sector energy innovation is far more widespread than previously understood
  - Low bound of 2.4% of all business establishments working to develop new energy technologies or reduce their own energy use (>120,000 firms, much higher than even improved recent NSF data)
  - Detailed estimates of total private energy RD&D investment by industrial sector would require a full-scale, not pilot, survey
- Expected prices are the key motivator for private sector innovators
  - More important, for example, than R&D tax credits – highlights need for demand-side policies that increase profitability of clean technologies
  - 2/3 of energy innovators mostly investing for return within 2-4 years – highlights need for government support for long-term RD&D
- Energy-related startups invest about 75% of their capital in innovation, and often have personnel from established firms

Analysis of DOE partnerships with private firms

- DOE spends billions on thousands of cooperative agreements and grants with private firms
  - >$800M/yr
  - Major portion of overall energy RD&D effort
- DOE does not have a strategy for what types of agreements to use under what circumstances, and does not collect data needed to learn by doing
  - Program managers make decisions independently – with little data available on past experience, or criteria for judging between one type of agreement and another
- Short-term funding, competitive bidding rules, paperwork and bureaucracy inhibit genuine strategic partnerships with private firms

Working with the private sector

- DOE needs to know the record of what has worked and what has not in order to make its work with the private sector more effective

Working with the private sector (II)

- Private markets will fund R&D, demonstration, and deployment of new energy technologies only if potential for profit justifies it and risks are acceptable
  - Substantial carbon prices are essential for motivating private R&D and deployment of low-carbon energy technologies
  - Public-private partnerships may be needed for large-scale technology demonstrations for some technologies, to reduce remaining risks to the point that private markets can take over
  - Broad range of government policies matter – IP, trade, immigration, etc.
- DOE needs a strategic approach to partnership with the private sector, and needs to learn as it goes
  - Need to design cooperation approaches to best advance technology goals – develop consistent approach
  - Should develop strategic partnerships where justified by goals
  - Collect, analyze, and make available to managers data on what works and what does not, under what circumstances

International ERD3 cooperation

- Large potential opportunities from ERD3 cooperation:
  - Sharing costs of expensive projects
  - Exchanging, cross-fertilizing ideas
  - Lower costs, different opportunities possible in other countries
  - Increased potential for penetration of key markets
  - But need to consider competition, not just cooperation
- Competition stiffening, and other countries are making huge investments:
  - United States has gone from trade surplus to trade deficit in energy technology trade (1% annual export growth compared to China's >20%)
  - Government-controlled ERD3 investments in BRIMCS countries (including state-owned enterprises) appear to be as large or larger than all of OECD combined – mostly China
  - Chinese firms already have large shares of solar and wind manufacturing; will soon join the ranks of major nuclear exporters; investing in electric vehicles, carbon sequestration… major state support

International ERD3 cooperation (II)

- The U.S. government does not have a coordinated approach and has many agencies and actors involved in cooperation, and many agreements
  - Single, top-down approach would likely do more to stifle than to promote innovation
  - U.S. has many different approaches to international energy technology cooperation with many different goals – from reducing emissions to expanding U.S. market share to combating poverty – no one set of criteria and approaches is adequate
- The U.S. government should combine bottom-up and top-down approaches to managing international cooperation
  - Establish an interagency committee to plan, coordinate international ERD3 cooperation at the top level at OSTP
  - Set aside funds in each agency funding energy RD&D for international projects suggested from the bottom up
  - Collect and analyze data on what is going on and what works, to enable learning-by doing

Transforming U.S. energy innovation

- Past energy transitions have taken decades – the world does not have that kind of time
- The job is daunting – because of the sheer scale of the energy system, the time it takes to turn over, the difficult politics involved (domestically and internationally)…
- The United States needs a strategy for energy technology and climate leadership, including:
  - Greatly expanded, targeted investments in energy RD&D
  - Policies that create a substantial carbon price and overcome other market barriers to new energy technologies
  - New approaches to working with the private sector, strengthening energy innovation institutions, and cooperating with other countries

Only a focused, integrated strategy with multiple elements will do the job

The Transforming U.S. Energy Innovation Team

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Thank you for your attention, the ERD3 Advisory Board and Kelly Sims Gallagher and for advice, Tom Alfstad, Paul Friley, and Savvas Politis for their work in MARKAL, Pat McLaughlin for invaluable help editing, and the Doris Duke Charitable Foundation for financial support.

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