Six guiding principles for energy innovation

Decades of experience must inform future initiatives, urge Gabriel Chan and colleagues

This week the EU is marking the tenth year of its Strategic Energy Technology Plan. It is just one of many policy initiatives worldwide to accelerate innovation in energy technologies to lower greenhouse emissions. As the window of opportunity to avert dangerous climate change narrows, we urgently need to take stock of these initiatives—what works and why?

Public investments in energy research, development and demonstration (RD&D) have risen since the lows of the mid-1990s and early 2000s. In 2016, member countries of the OECD spent $16.6 billion (adjusted for purchasing power parity) on energy RD&D compared with $10 billion in 2000. In October, the UK set out its Clean Growth Plan to invest £2.5 billion ($3.3 billion) in low-carbon innovation between 2015 and 2021. In late 2015, the EU and 22 nations pledged to double energy RD&D investment under the Mission Innovation initiative adjunct to the Paris Agreement, although this may be out of reach given the proposed 35% cut in the Trump Administration's 2018 energy RD&D budget.

Different nations are pursuing different strategies and creating new types of institutions. For example, the US Department of Energy (DOE) Advanced Research Project Agency-Energy (ARPA-E) and Energy Innovation Hubs target grants and form research teams, respectively, on key technologies such as affordable energy storage and nuclear reactor modeling. The UK set up the Energy Technologies Institute (ETI), a public-private partnership to, among other things, demonstrate technologies; the Catapults, to bridge universities and industry; and advisory services run by bodies like the Carbon Trust. China is reforming its thousand plus national labs, while also creating new, larger labs.

At the international level, the United Nations Framework Convention on Climate Change (UNFCCC) has created the Technology Mechanism to enable technology development and transfer in developing countries to support the Paris Agreement. Since 2013 the World Bank Group has opened 7 Climate Innovation Centres in developing countries to provide seed financing, policy guidance, networking and technical training. The Kenyan centre in Nairobi, for example, advises start-ups like Future Pump, which is developing solar-powered water pumps.

Most of these bodies can claim successes. However, to learn from collective experience and establish best practices, a comprehensive global assessment of energy innovation programs is needed. As a starting point, we distil six guiding principles to inform public energy innovation initiatives drawn from the scholarly literature and third-party assessments of experience in UK, US and multilateral institutions.

Six principles

1. Give researchers and technical experts more autonomy and influence over funding decisions

Active scientists are best placed to spot bold but risky opportunities that managers miss. For instance, projects directed by US National Labs – currently 4% of their budgets – produce more high-impact publications and commercially-viable technologies than those dictated by DOE headquarters (see Figure 1).[i] It was decentralized funding that supported the early theoretical work at Lawrence Berkeley National Lab (LBNL) on supernovae that paved the way for the detection of 'dark energy' and the 2011 Nobel prize for Saul Perlmutter. Similarly, RD&D investment driven by scientists on strain-engineering strategies for algae at the National Renewable Energy Laboratory (NREL) have enhanced biofuel productivity.[ii]

Public labs that conduct energy RD&D should allocate a significant fraction of their budgets, perhaps up to 10%, to internally-selected projects. They must be given the flexibility to adjust goals as research proceeds. For institutions that fund but do not conduct RD&D, one example of the flexible funding approach is that used by ARPA-E, which employs technical experts as program managers to direct funds and modify or cut projects as they progress.[iii]

2. Build technology transfer into research organizations

Public institutions that fund or perform energy RD&D must collaborate with private owners of energy infrastructure, as well as those that manufacture, deploy and operate novel energy technologies. Otherwise, research may remain siloed and never reach practice. Formal technology transfer programs should be set up to build the necessary connections. This requires strong institutional backing. When political and financial support wanes, technology transfer rates fall.[i]

Formal technology transfer programs have accelerated innovation that builds on the work of DOE National Labs[iv]: a fifth of all new patents in advanced energy storage systems for vehicles since 1994 cite at least one DOE-granted patent.[v] How can this be accelerated? Research universities have shown the value of sustained collaboration through a diversity of channels [vi] and Sandia National Lab has seen the value of allowing researchers up to 2 years' leave to take technology to the private sector. Labs are experimenting with new approaches that should be scaled-up. For example, The Cyclotron Road and Visiting Entrepreneurial Research Fellows programs at LBNL lower barriers to collaboration, and provide facilities, expertise and funding to entrepreneurs.

3. Focus demonstration projects on learning

Many viable technologies stumble at the demonstration stage when they reach the 'valley of death': companies are reluctant to finance pilots of new, risky technologies, such as carbon capture and storage (CCS), making it impossible to scale them up without public support. Demonstration projects are expensive and often judged harshly. For example, the US Synthetic Fuel Corporation fostered technologies in the 1980s to create liquid fuels from substitutes like coal. The program's failure to meet its goal of dramatically reducing oil imports was used to argue against public investments in demonstration projects that 'pick winners'. Yet the project created useful knowledge. For example, the SFC's Cool Water plant demonstrated technology that is being considered for CCS.[vii]

Policymakers should set goals for demonstration projects based on the knowledge they will generate regarding the cost and performance of future technologies.[vii] Other important features include: an exit strategy to halt projects that miss milestones; design that acknowledges the possibility of failure while keeping other options open; involvement of a broad pool of private actors; and mechanisms to track and disseminate generated knowledge. [viii]

4. Incentivize international collaboration

International cooperation can accelerate innovation beyond the capabilities of a single nation. Pooling costs enables projects of greater scale, lessens duplication and allows regional specializations to be integrated. But more needs to be known about how to do this effectively. Few multilateral collaborations go beyond holding meetings and issuing joint statements. Possibilities for deeper collaboration range from loosely coordinated pledges for domestic actions, such as Mission Innovation, to shared platforms for technology development, such as the International Energy Agency's (IEA) Technology Collaboration Programmes, to integrated cooperative RD&D, such as the ITER project to build the world's largest magnetic fusion device jointly between 35 countries.

Partnering nations with specific technical expertise with those keen to exploit it can be fruitful. For example, the US-China Clean Energy Research Center has helped US companies such as 3M test technologies in China to improve the energy efficiency of buildings. The pace and scale of construction in China meant that US companies learned more about real-world effectiveness than they would have done working only in the US.

Barriers remain: collaborators must negotiate rights before outcomes are known, partners may lack trust, and domestic political support can fluctuate. Face-to-face interactions, long-term strategies and well-designed management plans are essential.[ix]

5. Adopt an adaptive learning strategy

Lessons must be drawn from a diverse range of experiences, because energy innovation occurs in many different industrial and funding contexts. Efforts vary in their primary goals, such as competitiveness, security and environmental protection, as well as in their implementation strategies.

Mechanisms for evaluating and adapting programs should be designed into institutions from the outset. There are many ways to measure innovation policy outcomes (e.g., from money invested, number of papers, citations, patents, and startups generated, to economic measures like productivity and qualitative measures through surveys), and public agencies should store and track data on operations and outcomes and release them to independent researchers. New groups may be needed, in consultation with experts. For example, the UK's Behavioural Insights Team created in 2010 incorporates insights from behavioural psychology into policies such as those that encourage energy-efficient heating and lighting systems. International institutions like the IEA, the International Renewable Energy Agency, the UNFCCC Technology Mechanism and the World Bank could help governments learn from others and develop strategies for adapting energy innovation programs.

6. Keep funding stable and predictable

Government funding for energy innovation is, in many cases, volatile**.** For example, between 1990 and 2017, political shifts meant that each year, one average, one in five DOE technology areas saw a budget change greater than 30% (up or down) (see Figure 2).[x] Fluctuations in funding erode the cost-effectiveness of programs by precluding strategic, sustained, high-risk-high-reward investments. A slashed budget for renewables in the 1990s led to decades of experience being lost during layoffs at the National Renewable Energy Laboratory.

Institutions have evolved just as erratically. In the UK, each Prime Minister since 2000 has focussed on a different one. Tony Blair created the UK Carbon Trust, Gordon Brown the ETI, David Cameron the Catapults, and Theresa May has created a Faraday challenge for batteries as part of the Industrial Strategy Challenge Fund. While experimentation has benefits, there are also costs. Learning how to work with new programs and people takes time and effort for researchers, companies and policymakers. For example, early engagers with the UK Carbon Trust applied for grants and incubator support only to see the program's scope reduced in 2011 to providing advice and certification services.

Rather than overhauling institutions for energy innovation with political transitions, existing programs should be continuously evaluated and updated. New programs should only be set up if they fill needs not currently met.

Let's learn from experience on how to accelerate the transition to a cleaner, safer and more affordable energy system.

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To appear in a Box:

Country	Selection of new institutions funding and enabling energy innovation	Use-inspired basic research	Applied R&D	Demons-tration	Market formation and deployment
United Kingdom	UK Carbon Trust (2001-)				$
	UK Energy Research Center (2004-)	Non-technology, social science research			
	Energy Technologies Institute (2007-)			$	
	Env. Transf. Fund/International Climate Fund (2008/2011-)				$
	Technology Strategy Board/Innovate UK (2008/2014)[1]			$	
	Catapults[2] (2011-)			$	
United States	Energy Frontier Research Centers (2008-)	$			
	ARPA-E (2009-)		$		
	Energy Innovation Hubs[3] (2009-)	$			
	Cyclotron Road (2015-)		$		

Box or SI? : Selected set of new institutions funding and enabling energy innovation in the U.K. and the United States since 2000. Institutions included are those that either constituted a significant investment (how big of a program they were), or that were (our judgement) novel in their design. In some cases, the institutions shown met both criteria. Institutions are organized by country, year of inception, and their general area of focus from basic research through market formation, including information provision. Updated and adapted from Anadon (2012). Legend of symbols denoting main features of the various institutions: $: provision of funds; circles: direct private sector involvement in decision-making; house: creation of new entity during the funding; person: provision of expertise in the form of business or technical advice.

1 The Catapults are a part of Innovate UK; we list them separately because Innovate UK has activities in grant making and strategy-setting that go beyond the Catapults.

2 There are 10 Catapults, 3 of which fall squarely in the 'energy' category (energy systems, offshore wind, and transport) and two of which fall in that category more indirectly (future cities and high value manufacturing)

3 Of the 5 Hubs that were initially created, one (on buildings) was cancelled, with the four Hubs remaining on fuels from sunlight, storage, critical materials, and light water reactor modelling.

Figure 1

From 2016 *Nature Energy* article on the Labs (current citation "i") : Anadon, LD, Chan, G, Bin-Nun, A, Narayanamurti, V. 'The pressing energy innovation challenge of the U.S. national labs.' Nature Energy 1, 16117 (2016) doi:10.1038/nenergy.2016.117

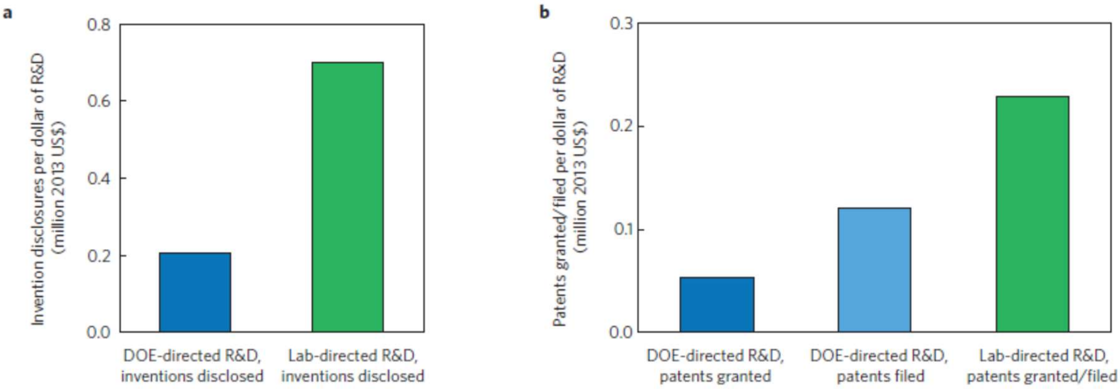

Figure 2 | DOE- and Lab-directed technology-transfer outcomes. (**a**) Number of inventions disclosed and (**b**) patents granted/filed per million 2013 US$ at the Labs for DOE-directed R&D funding (blue) and Lab-directed R&D (LDRD) funding (green) averaged over the period 2007–2012. For LDRD leading to patents, some Labs report granted patents and some report filed patents; the sum of reported granted/filed patents is included in the green LDRD patents bar. For completeness, DOE-directed R&D leading to patenting is displayed both in terms of granted patents (dark blue) and filed patents (light blue). There are no notable trends in these ratios over this period. Data from the US Department of Commerce on technology-transfer outcomes[14], National Science Foundation data on DOE R&D obligations[15], and DOE spending data on LDRD[50]. Data for technology-transfer outcomes includes the several non-National Laboratory DOE facilities with relatively small R&D budgets, whereas data for R&D obligations covers only 16 of the 17 National Laboratories (National Energy Technology Laboratory is not included). The source data and calculations underlying this figure can be found in Supplementary Data 1.

Figure 2:

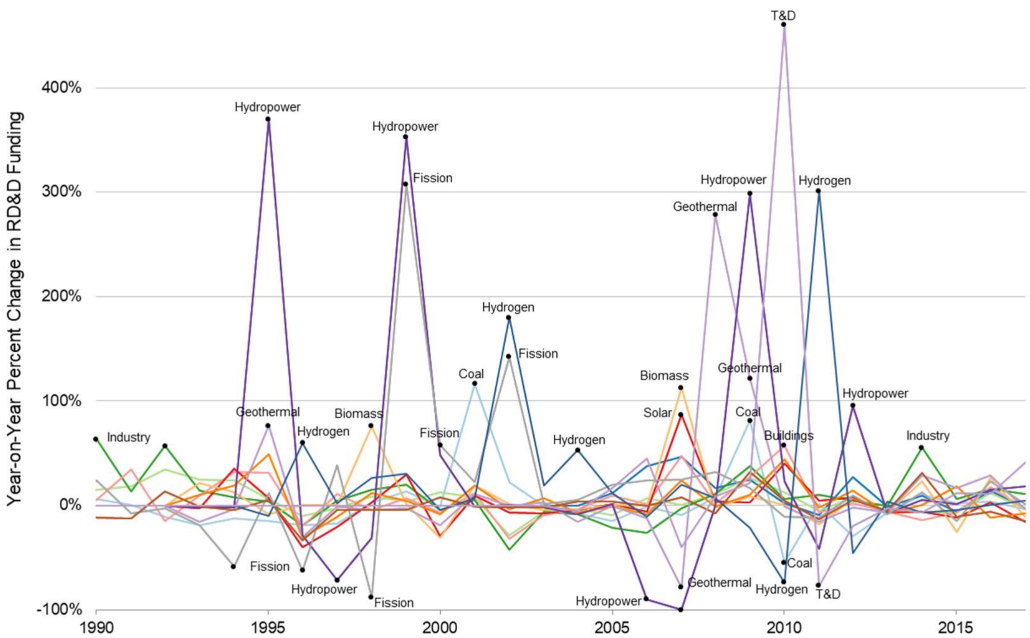

Figure 2: Year-to-year volatility of US DOE support for RD&D in fourteen technology areas between 1990 and the 2017 enacted budget request (excluding ARRA). There has been reduced volatility in the past few budget cycles due to the Continuing Resolution process; however, the Trump Administration's requested 2018 budget, would reduce funding significantly from 2017 levels. Year-on-year changes greater than 50% are labelled. The fourteen technology areas shown received $2.8 billion in funding in the 2017 enacted budget: coal ($203.5 bil), carbon sequestration ($220.3 mil), transportation ($307.0 mil), industry ($258.0 mil), buildings ($199.1 mil), solar ($207.6 mil), biomass ($205.0 mil), wind ($90.0 mil), geothermal ($69.5 mil), hydropower ($84.0 mil), fission ($599.3 mil), fusion ($380.0 mil), hydrogen ($102.8 mil), and transmission and distribution ($209.7 mil). Petroleum ($21.0 mil) and gas ($43.0 mil) are excluded because they comprised less the 1% of the applied RD&D budget in the last 10 budget cycles. Updated and adapted from current citation "x": Anadon, LD, Chan, G, Lee, A. 'Expanding, and improving targeting of, U.S. investment in energy innovation: an analytical approach. In 'Transforming U.S. Energy Innovation'. Eds. Anadon, LD, Bunn, M, Narayanamurti, V. *Cambridge University Press*, Cambridge, United Kingdom (2014).

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