OPINION

A new strategy for energy innovation

The US government must make the Department of Defense a key customer for energy technologies and make greenhouse-gas reductions a public good, say **John Alic**, **Daniel Sarewitz**, **Charles Weiss** and **William Bonvillian**.

Limiting the concentration of carbon dioxide and other greenhouse gases in Earth's atmosphere requires a technological and economic revolution[1,2]. This kind of change takes decades, even if it is driven by powerful market and policy forces — which this one is not. We therefore suggest a new, forceful strategy for the United States, the world leader in innovation and the world's second biggest emitter of greenhouse gases.

The US government must weave into energy policy an understanding of how innovation proceeds. It occurs mostly in private firms and depends on relationships between government and industry. So the government needs to move beyond the smorgasbord of research and development (R&D) programmes and financial subsidies of recent years to treat innovation as a system, with a portfolio of policies adapted to the many technologies needed and their many evolutionary stages.

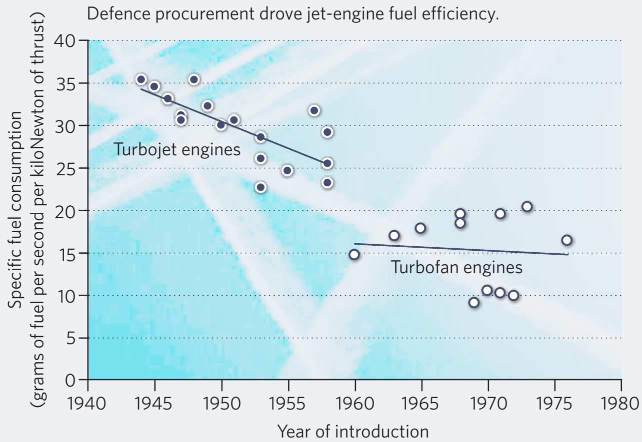
First, Washington should make greater use of a powerful policy tool that it has largely neglected: public-sector procurement. Procurements by the US Department of Defense (DOD) and other agencies were the foundation for major waves of innovation after the Second World War, including those in jet propulsion, Earth-orbiting satellites and digital electronics.

Second, greenhouse-gas reductions should be treated as a public good, like infrastructure investments in public health and safety and, indeed, national defence. This would exploit a historically powerful rationale for spending on innovations that markets will not otherwise supply. The government has often been a primary customer for new technologies that advance public well-being. This approach would provide new political options for tackling problems such as the capture and storage of CO_2 from fossil-fuel-burning power plants and would complement any eventual pricing of greenhouse-gas emissions to induce innovation.

In the US Congress, the prospect of a price on greenhouse-gas emissions hangs by a thread. Even if the Senate votes for such a measure later this summer, legislation may be restricted to the utility sector, and the price will almost certainly start low and increase slowly. The Congressional Budget Office, for example, projects that the cap-and-trade bill passed by the House of Representatives last year would price emissions at US\$20 per tonne of CO_2 equivalents after half a dozen years, and this almost certainly represents the upper limit of legislative forcefulness.

Much more is needed. Advances in energy technologies must penetrate an existing technological and economic infrastructure that took roughly a century to put in place and now represents enormous sunk costs that are protected by powerful vested interests[3].

Many analysts in the United States have pointed to underinvestment in R&D by the US Department of Energy (DOE) since the 1980s as a symptom and a cause of slow energy-technology development. The administration of President Barack Obama has boosted R&D spending (and loans and loan guarantees), channelling more than \$5 billion in economic-stimulus funds to the DOE's non-defence R&D programmes. This is a good start, as are initiatives that include the DOE's Advanced Research Projects Agency-Energy, Energy Innovation Hubs and Energy Frontier Research Centers. These promise a break with the DOE's focus on laboratory science and a move towards developing technologies with more immediate commercial prospects.



HELPING INVENTIONS TAKE OFF

Defence procurement drove jet-engine fuel efficiency.

SOURCE: REFS 6, 7

But past organizational change at the DOE has had little result, and it is doubtful whether DOE-funded R&D alone can catalyse the type of innovation needed. In any case, much of the DOE's R&D budget has funded big physics programmes, which have the potential to be important in the future but have few immediate practical applications. Although advocates see basic research as the wellspring of breakthroughs, many radical innovations, including the jet engine, the microprocessor and the Internet, stemmed mainly from incremental advances that were motivated by anticipated applications.

Competition and cooperation

Basic research is essential for future innovations, but there is a larger issue. For two main reasons, government R&D by itself, almost regardless of its scale, cannot foster innovation on a broad front. The first reason is simply that, although publicly financed research deepens the knowledge base and sometimes leads directly to technological advances, innovation has many sources other than R&D. As Edmund Phelps, winner of the 2006 Nobel prize in economics, put it: "Once in a while there is a big leap which creates the ground for a surge of innovations to follow. Nowadays we realize that an awful lot of innovation just comes from business people operating at the grass roots having ideas on the basis of what they see around them. Nothing to do with science"[4]. Second, R&D is difficult to manage and often unproductive in the absence of strong feedback from customers and users.

The DOE neither buys nor sells goods or services based on energy and climate innovations. It therefore has few incentives to manage R&D in accord with marketplace needs rather than scientific norms. The DOE also has not developed robust connections with companies that are positioned to commercialize energy innovations, although this may be changing. With federal spending on energy R&D on the rise, policy-makers should look beyond the dollars to the institutional setting for innovation.

Two big lessons can be drawn from innovation experience during the cold war. Government procurement helps to guide and shape technology development, and competition among agencies within the government fosters innovation, in much the same way as competition in economic markets[5]. Government purchases of integrated-circuit chips in the 1960s fostered advances in microelectronics at least as much as did government-funded R&D. In

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anticipation of government purchases (but without R&D contracts from the government), Texas Instruments and Fairchild Semiconductor fabricated the first integrated circuits in 1959–60 and went on to sell chips in large numbers to the DOD and NASA. At first, the government was the only buyer. As costs came down and technical performance improved, commercial markets opened and accounted for four-fifths of sales by 1970.

Procurement likewise spurred early developments in satellite imagery and communications. Along with major industrial firms, entrepreneurial start-ups such as Itek Corporation had key roles in the pioneering surveillance programme by Corona satellites. Telecommunications satellite technology also came mainly from the private sector. The armed forces, again, were the initial customers for gas turbine engines, and even today many commercial jet engines are derivatives of military models. Fuel efficiency improved rapidly, spurred by the military's demand for long-range planes and by commercial airlines, which wanted to reduce their operating costs (see 'Helping inventions take off'). By the 1970s, electrical utilities were purchasing gas turbines for peak power capacity, an application that had not been anticipated two decades earlier.

In all of these cases, intragovernmental competition and cooperation — between the air force and NASA for integrated circuits, intelligence agencies and the military for spy satellites, and the navy, air force and army for gas turbines — and subsequent competition in industry for government contracts, drove innovation. Managers in industry who were seeking government contracts had strong incentives to manage R&D effectively, hire creative engineers and scientists, and find customers with needs that they could satisfy in the huge US military and space establishments. This dynamic continues to operate for gas turbines and satellites. Such intragovernmental competition has sometimes led to the duplication of efforts, as well as other forms of waste, but military spending continues to drive innovations, ranging from new materials to the Global Positioning System.

The DOD is better placed for catalysing rapid innovation in energy technologies than the DOE because the DOD is a major customer for energy-consuming systems and equipment for its roughly 500 permanent installations, as well as for operational equipment (spending $10 billion a year on liquid fuels alone). The scale of the resources that the DOD brings to technology development is impressive. It employs more than 30,000 engineers and scientists in R&D and procurement, and its annual R&D spending comes to about $80 billion, with procurement spending in excess of $100 billion. The DOD thus has the incentives and capacity to be a smart and demanding customer for new energy technologies, as well as a test bed for new ideas such as high-energy-density electrical storage. Although the DOD's implementation of new energy technologies will be limited by its military mission, its internal priorities have already begun to shift in order to control operating costs and reduce energy-related strategic vulnerabilities.

Government procurement, by the DOD especially, could be an initial alternative and a long-term complement to legislated energy price increases or capping greenhouse-gas emissions. As in past technological revolutions, effectively managed procurement programmes would create powerful incentives for private firms to innovate, and would provide feedback for guiding those efforts. Moreover, by creating competition for the DOE, this approach would encourage risk taking and provide benchmarks for performance and accountability.

"Both market pull and technology push are needed. Policy-makers must now effect the revolution outlined here."

A public good

Reducing greenhouse-gas concentrations in the atmosphere is a public good and should be recognized as such, much like other traditional responsibilities of government. A public-good approach would empower the government to take a direct role in moving energy technologies into society to achieve the desired benefit. The designation of this as policy would also commit to action a much broader range of government institutions than just the DOE. This could galvanize technologies that, so far, have received little attention, such as those for directly removing CO_2 from Earth's atmosphere, a process that is technologically possible but costly.

Most immediately, the public-good approach could apply to a key intervention for greenhouse-gas reduction: existing coal-fired power plants. There are a manageable number of these, fewer than 1,500 generating units on about 600 sites. They produce nearly 28% of US greenhouse-gas emissions and one-third of US CO_2 emissions. That's one-fifth more CO_2 than is produced by the roughly 250 million motor vehicles travelling US roads. Moreover, there are technologies for retrofitting, repowering or otherwise reconstructing coal-fired (and natural-gas-fired) plants to remove most of the CO_2 from their emissions. What is needed now is for integrated carbon capture and sequestration to be demonstrated at operating scale. By contrast, substantial reductions in motor-vehicle emissions will occur only as the existing vehicles are replaced by an as-yet unclear mix of emerging technologies.

The Tennessee Valley Authority (TVA), a public corporation, operates 11 coal-fired plants with nearly 60 generating units. Congress could direct and fund the TVA to explore carbon-capture technologies and to move quickly to demonstrate them at an increasing scale. The estimated costs of demonstration projects such as this ($500 million or more per 500-megawatt plant) are not excessive compared with federal expenditure on, for example, the US Navy's Virginia class of submarines (about $2.5 billion each) or H1N1 influenza-virus vaccine supplies (more than $1 billion). The federal government spends $60 billion a year on public infrastructure such as roads and water projects (with state and local governments contributing more than twice that sum). Money is not the obstacle.

For 15 years, the United States has assumed, naively, that putting a price on carbon-based emissions would be politically achievable and that the resultant market forces would drive innovation. This was a simplistic approach. Both market pull and technology push are needed. In recent months, the picture in Washington has darkened. The United States will have either no price on carbon for some time to come or a price that is too low to drive the innovations needed to transform the nation's energy system. Rather than wringing their hands, policy-makers must now effect the revolution outlined here. ■

John Alic is an independent consultant in Avon, North Carolina 27915, USA. **Daniel Sarewitz** is co-director of the Consortium for Science, Policy and Outcomes at Arizona State University and is based in Washington DC, USA. **Charles Weiss** is a professor at the School of Foreign Service, Georgetown University, Washington DC 20057, USA. **William Bonvillian** directs the Massachusetts Institute of Technology Washington Office, Washington DC 20002, USA.
e-mail: john_alic@earthlink.net

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