innovation-based business opportunities will drive the market for the necessary generation, storage and distribution of technologies. Surveys show that consumers are increasingly taking an interest in energy efficiency, digital demand and the cost of energy disruptions. Once people question why power cuts are preventing them from working on their computers, utilities will come under pressure to fix their networks.

Manufacturers, in turn, must integrate customer feedback into their R&D roadmaps and improve the coordination of standards, funding and R&D to drive down costs and broaden the market. Related, enabling technologies will be needed, including energy-management systems and communication technologies. Smart-grid systems must be able to interact across centralized and decentralized electrical networks, and support advanced services such as net metering, load aggregation and real-time energy monitoring.

A policy framework will be needed to provide incentives for collaboration between state utilities and federal agencies. Although some of the money would be from the public purse, regulatory agencies should incentivize electricity producers to plan and co-fund the process. Strategies need to be developed for raising money through taxes or through power-usage rates. A public–private national bank that invests in infrastructure should be created to fund repairs and upgrades by lending money on a sustainable basis according to performance metrics.

The smart electricity grid will enhance resilience in the face of extreme weather and promote economic growth by enabling commerce and technology development. The twenty-first-century digital economy fundamentally depends on these investments. ■

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ILLUSTRATION BY PHIL DISLEY

What would you cut?

Four insiders explain how they would make the savings in US science required by the budget sequester.

DAVID GARMAN AND ARMOND COHEN

DOE duplications and managers

Principal at Decker Garman Sullivan; executive director at the Clean Air Task Force

Money-saving reforms can sometimes enhance science. Consider the US Department of Energy (DOE) — the largest funder of research in the physical sciences in the United States. A significant amount of DOE money that is intended for science and engineering never reaches researchers. We suggest three steps that could yield substantial savings and improve results.

First, undertake a rigorous research and development (R&D) portfolio review to illuminate programme duplications, leverage complementary strengths, and focus R&D efforts on the most pressing needs. Basic research has the potential to yield revolutionary rather than evolutionary improvements to energy technology. Yet the department's applied R&D programmes are institutionally isolated from one another in four different offices, each led by a politically appointed assistant secretary. These R&D offices are also isolated from basic science research, which is housed in yet another office in a wholly ▶

different arm of the department, led by a different under secretary.

As a result, projects are often uncoordinated or duplicative. If political will is lacking to smash the silos for fear of offending a particular set of 'stakeholders', then a review is a minimum first step. Fortunately, the new energy secretary, Ernest Moniz, is contemplating just such an assessment.

Second, find the political will to scale back or end the 'technology deployment' programmes that are portrayed as R&D activities, yet contribute little to innovation. Such activities include grants for ethanol-fuel pumps and natural-gas refuelling stations that make nice backdrops for political 'ribbon-cutting', but these projects divert funding that could be spent in pursuit of real technological breakthroughs.

Third, find new work for the legion of DOE micromanagers that prescribe, approve and audit almost every transaction undertaken at a national laboratory. Their salaries come from science budgets. Instead of evaluating success in achieving strategic outcomes, the DOE is reviewing and approving individual funding transactions and audits adherence to department directives. For example, a 2012 review of DOE weapons labs found that workers were "drowning in paperwork and regulations" — conditions that have prompted the departure of world-class scientists and engineers.

We believe that a rigorous effort to 'follow the money' could result in top-line cost savings and more funding for science.

BENJAMIN JONES

Make randomized, controlled cuts

Associate professor, Kellogg School of Management, Northwestern University

Make no mistake: cutting public science funding is a terrible idea. Scientific and technological breakthroughs drive progress in health and human prosperity. But the private sector has insufficient incentive to make the required investments, especially in basic research, an area in which the benefits are not well captured by the individual investor. This points to a central failure of pure market systems and an essential role for government in funding science.

Yet in the United States, the sequester has come — across-the-board federal budget cuts resulting from Congress failing to agree on deficit-reduction legislation. Tighter budgets are difficult. But they are also an opportunity to study how science is funded and to assess where the high returns are. Whatever the size of the pie, and whatever the organization, one can always deploy resources more efficiently. Do we get the best return on each dollar? Of course not. So how do we do better?

There are many paths forward, all uncertain. One option would cut university overhead rates. Another option would leverage federal research funds through matching programmes — calling forth money from non-profit research organizations, private companies or other countries. These ideas sound plausible, but they raise concerns. What if university overhead rates are essential to fund science facilities? What if matching grants result in slower and more bureaucratic science?

The real challenge is that we do not know what to cut. Unless we acquire a deeper understanding of the 'science of science', it is hard to deploy limited resources for their highest return. We need data — rigorous empirical evidence born in experimentation. We need to turn the scientific method on science institutions themselves.

Funding institutions should identify operational features that they are unsure about and then experiment with change. For instance, some programmes can be put into 'treatment' groups, while keeping others in a status quo 'control' group. There are numerous 'operational experiments' from which we could learn and improve science programmes. As just one example, take winners of grants from the US National Institutes of Health. A subset of these beneficiaries could be randomly selected to receive 10% less funding (treatment group 1) and then grants could be awarded to extra projects that scored just below the funding line (treatment group 2). By tracking project outcomes over time, we could determine the causative effects of both dollars and grant numbers on the progress of science, thus informing a better balance between grant size and grant number for future programming.

Crisis can breed opportunity. The opportunity here is to learn how to improve the use of science funding. If we take this moment to experiment with the science of science, a 5% cut could ultimately produce substantial gains.

DAVID GOLDSTON

Grant numbers and NASA centres

Chief of staff of the US House Committee on Science (2001–2006)

The US scientific community seems out to disprove an old adage that nothing concentrates the mind like the threat of a hanging. Even with the sequester in place and further budget cuts looming, little has been done to plan how research can survive in straitened times.

This may sound self-evident, but planning in light of the cuts has been sorely lacking. Budgets are not just about arithmetic; they give shape to the entire research system. One approach would be for federal funding agencies to develop plans to reduce the number of grant recipients and the number of graduate and postdoctoral students they support, over say five years. The White House could provide explicit numerical targets for the agencies, and the proposals would be made public to allow universities and other institutions to prepare. The plans should be specific about how agencies would ensure that funding is made available to younger faculty members as overall grant numbers decline.

> **"Planning in light of the cuts has been sorely lacking."**

Such an organized effort would contrast with what happened a decade or so ago when the budget of the US National Institutes of Health (NIH) was doubled. Inadequate planning led to an unsustainable expansion in the number of faculty members and a building spree, without any relative benefit to younger researchers. This time, the NIH could lead the way, using recommendations from a report that it released last year that highlighted the mismatch between the number of graduate training grants and subsequent available jobs.

Facilities are the other big factor in the budget equation. For years, reports have talked about consolidating NASA centres, for example. The current constellation of the agency's facilities can be explained only by recourse to history or politics, and not by present needs. Austerity should finally provide the impetus for closing some centres. One possibility would be to follow the model that is used to close military bases — an independent commission makes a package of recommendations that Congress then must accept or reject, although this analogy is not exact.

A review of NASA should also take a hard look at whether the International Space Station (ISS) is still worth running. Almost everything to be gained from the station was learned from its building and initial manning; plans to conduct research have been whittled down to almost nothing. Continuing to fly to the ISS may not teach us much more about space than multiple car trips do about driving. However, a related programme to help private companies to learn how to supply the station might be worth preserving.

No cutting will be easy or optimal. But the process needs to be systematic. ■