Rescue US energy innovation

President Trump has proposed severe cuts to US government spending on energy research, development and demonstration, but Congress has the 'power of the purse' and can rescue US energy innovation. If serious cuts are enacted, the pace of innovation will slow, harming the economy, energy security and global environmental quality.

Laura Diaz Anadon, Kelly Sims Gallagher and John P. Holdren

The Trump Administration has proposed a 57% reduction in US government investments in energy research, development and demonstration (RD&D) at the Department of Energy (DOE), from US$3.8 billion allocated for fiscal year 2017 (FY2017) under the continuing resolution to US$1.6 billion in the FY2018 request (unless otherwise stated, all dollar figures are given in constant 2015 US dollars). These severe reductions, if enacted by Congress, would reduce the pace of US energy-technology innovation, ultimately harming the US economy, energy security, environmental quality and the capacity of the world's second largest emitter of greenhouse gases to do its share in reducing the emissions that are driving global climate change. This abdication of leadership would adversely affect not just US interests but global interests as well.

Since the President's initial budget request in May, the relevant appropriation committees on both sides of Congress have considered it in the context of developing their own spending bills. Both the House and Senate must pass spending bills, and then these must be reconciled in conference before a final version is sent to the President to be signed into law, if he does not veto it. The House passed its bill in late July, and it imposes draconian cuts on the Advanced Research Projects Agency for Energy (ARPA-E) and on the renewable energy and energy efficiency programmes. The proposal by the Senate appropriations committee appears to 'save' ARPA-E but would still impose cuts across all the energy technology offices, ranging from a 39% cut to fusion to a 7% cut to renewables and efficiency (a complete comparison is available online[1]). Recognizing that there will be a continuing negotiation between the Trump Administration and the Congress on Trump's FY2018 budget, we seek here to put the proposed cuts into historical perspective, to elucidate the flaws in their rationales and to elaborate on the harm they would cause. We focus on the President's request because the arguments and evidence that we present still apply to proposed cuts in Congressional bills, and because President Trump still has veto power over the bill.

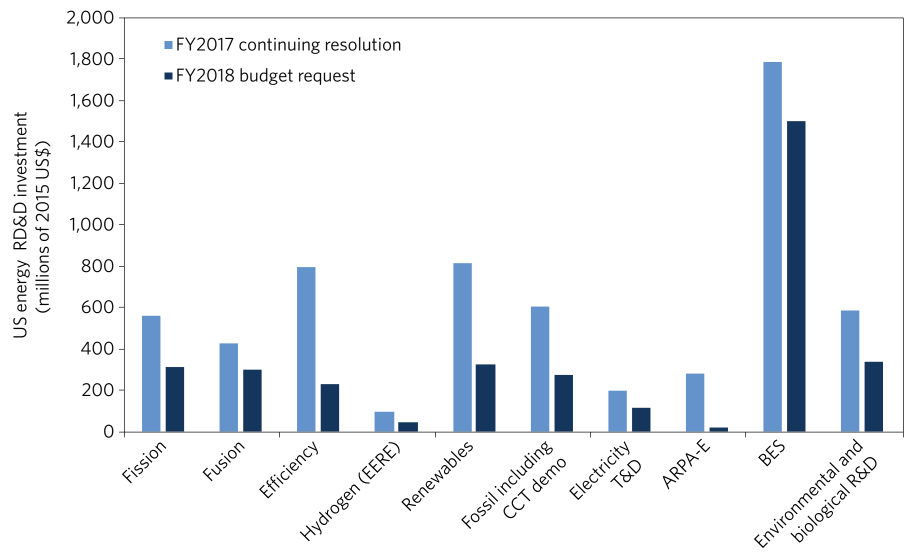

Fig. 1 | Present and proposed investments in energy RD&D at the US Department of Energy. Shown here are the proposed Trump administration investments for FY2018 (dark blue) compared with the FY2017 appropriations (light blue), in constant FY2015 US dollars. EERE, energy efficiency and renewable energy; CCT, carbon capture technology; T&D, transmission and distribution; BES, Basic Energy Sciences. Data from ref. [3].

Historical perspective

Figure 1 depicts the Trump administration's proposed FY2018 budgets for fossil fuel, fission, fusion, renewables and energy efficiency RD&D, as well as for the Basic Energy Sciences and Biological and Environmental Research categories in DOE's Office of Science, compared with appropriations in FY2017. Amid other striking reductions, ARPA-E, which supports high-risk/high-return research on particularly innovative energy-technology improvements[2], is singled out for complete elimination, although US$20 million is provided to close out the programme. Moreover, the Trump budget would also eliminate DOE's loan guarantee programme for early commercial use of advanced technologies, the advanced-technology vehicle-manufacturing programme, the programme for weatherproofing (weatherizing) of low-income housing, and state energy grants.

We have tracked US DOE investments in RD&D at the programme level since 1978 (ref. [3]), and it is clear in that historical context that the proposed cuts to US government energy RD&D would be unprecedented in many respects. As shown in Fig. 2, Trump's proposed cuts in aggregate are greater than the Reagan-era cuts of 1982, which were the most severe single-year cuts to US energy RD&D budgets since 1978. The FY1982 cuts in the appropriations for total energy RD&D were 36%, compared with President Trump's proposed 57%. Reagan's FY1982 budget resulted in a 4%

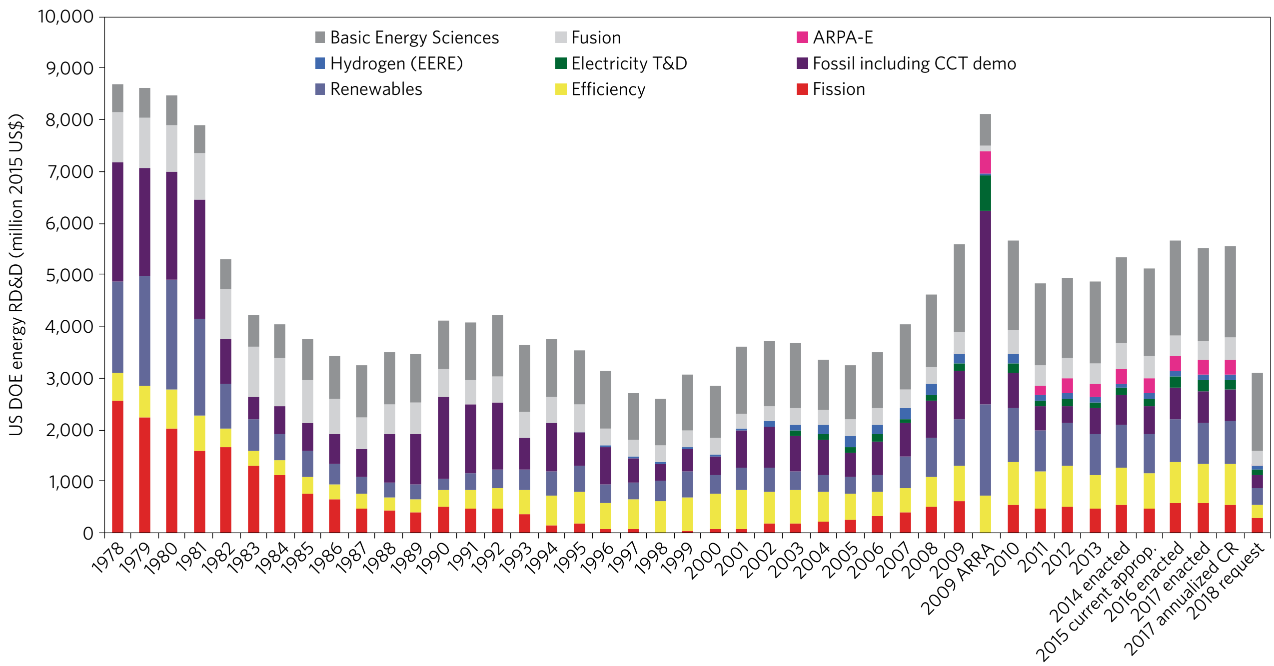

Fig. 2 | Historic funding for energy RD&D. The breakdown of funding for energy RD&D (defined here as for the 'applied' programmes at DOE and ARPA-E) and for research in Basic Energy Sciences and fusion at DOE from 1978 until the FY2018 budget request. For the most recent 5 years, the final status of the budget is provided (for example: enacted; continuing resolution (CR; that is, the continuing funding based on the previous year's allocation), current appropriation (approp.); budget request). Investments are shown in constant 2015 US dollars. The second entry for 2009 (2009 ARRA) includes funding for energy RD&D from the American Recovery and Reinvestment Act (ARRA) of 2009, also known as the one-off stimulus package that was passed in response to the financial crisis.Other abbreviations as in Fig. 1. Data from ref. [3].

increase for Basic Energy Sciences, rather than Trump's proposed 16% cut. Reagan initially cut efficiency and renewables by 51% and 54%, respectively, compared with Trump's proposed 71% and 60%.

Flawed rationales

The Reagan cuts were motivated by a combination of plummeting oil prices in the early 1980s, indications that the costs of synthetic fuels (synfuels) technologies were larger than originally predicted, and the belief that the private sector would do most of the energy RD&D that was warranted. Although we would not have agreed with the last rationale even in 1982, the justification for the still steeper cuts in Federal energy-innovation funding now proposed by the Trump Administration has become flimsier in the meantime. Not only are oil prices now rising again, but the complementary roles of government and private-sector funding in energy-technology innovation are better understood now, and, perhaps most importantly, there is now an immensely powerful 'public goods' argument for government investments to accelerate low-carbon innovation and thus address the challenge of climate change.

Consider the government–academia–industry symbiosis that is now understood to drive energy-technology innovation[4]. Industry funds about 70% of all R&D in the United States, and the Federal government funds less than 30% (ref. [5]). A similar split prevails in energy RD&D, although exact figures are elusive because of definitional and reporting issues. In terms of research stage, government funds the lion's share of basic research and early-stage applied research, whereas industry funds most late-stage applied research and an even larger share of development and demonstration. Most of the government-funded research is performed in universities, where a huge side benefit is the role of that research in teaching and training the students and post-graduate researchers who will populate the next generation of scientists, inventors, entrepreneurs and professors, in a virtuous cycle.

Public–private cooperation on energy innovation has been particularly effective in the United States[6]. Perhaps the most striking example is the shale-gas revolution, which came about as the result of early shale fracturing and directional drilling technologies developed by the Energy Research & Development Administration (later the DOE), the Bureau of Mines and the Morgantown Energy Research Center, the Eastern Gas Shales Project (a public–private shale drilling demonstration programme in the 1970s), public subsidization of demonstration projects including the first successful multifracture horizontal drilling play in West Virginia in 1986, and Mitchell Energy's first horizontal well in the Texas Barnett shale in 1991, among other collaborations[7].

As serious studies involving energy-industry leaders as well as academic and government experts have long agreed, there is a crucial role for government support of energy innovation even beyond the early research stages — that is, in late-stage applied RD&D and accelerated deployment — when there are strong public-goods reasons. That is, the government may need to bring new technologies that address those public goods to the point where they can compete with entrenched incumbent technologies that do not address them. This was one of the most important conclusions of a study of R&D challenges for the twenty-first century conducted 20 years ago by the Council of Advisors on Science and Technology (PCAST), with strong industry participation[8]. That study found that many public-goods rationales exist for moving beyond the incumbent fossil-fuel-based technologies dominating US and world energy supply, including reducing the potential for conflict over access to oil, and improving air quality and thus public health. But the reason that is most demanding and thus most deserving of government engagement, in partnership with industry, is climate change. Although practically every major study since the 1997 PCAST study, using newer information and different analytical tools, has agreed[9–11] and called for increases of two-fold to five-fold (or even greater) in government support for energy-technology RD&D and accelerated deployment[10,12–16], the Trump administration clearly does not agree.

The Trump administration's proposal to slash the federal government's energy RD&D investments seems to be based on three propositions: the human role in whatever global climate change is going on is uncertain; that being so (and the hazards to humans and ecosystems from fossil-fuel-driven air pollution, oil spills, ground-water contamination and acid precipitation, among others, being likewise negligible), expansion of the incumbent fossil-fuel technologies should be the energy strategy of choice; and, to the extent that any advances over those technologies should be thought desirable, the private sector can be relied upon to pay for the needed innovation. On climate change, the strongest statement came from Trump's Office of Management and Budget Director Mick Mulvaney, who announced[17], "We're not spending money on [climate change] any more. We consider that to be a waste of your money."

None of these propositions finds much support in the extensive, international, peer-reviewed literature addressing these topics[18,19]. The multi-trillion-dollar externalities of the incumbent fossil-fuel technologies are extremely well documented[20,21]. Furthermore, the economic literature shows that the private sector will never invest as much in basic research and early-stage applied research as the interests of society require (because of high uncertainty about realizing any economic returns and the long lead time for any that do materialize), and even less so where important public goods are involved that are not reflected in the marketplace[22].

History tells us that it is exceedingly unlikely that the private sector will come to the rescue. After growing steadily during the late 1970s, private energy R&D peaked around 1985 and declined steadily after that (concurrent with the declines in federal investments), eventually dropping to less than half of the 1985 peak[23]. Today, the R&D intensity (the percentage of sales invested in R&D) in the energy industry is only 1%, far lower than the 10–15% in the pharmaceutical and information technology industries[24]. But even if, optimistically, the private sector continues investing in energy R&D at current levels, the proposed cuts would still cause total US energy RD&D investments to be much lower and, crucially, less adventurous. In other words, the high-risk/high-return investments exemplified by the types of research funded by ARPA-E will go missing.

Other countries are not likely to make up the shortfall either, as the magnitudes are too large to overcome. The US government is by far the largest public investor in global clean-energy RD&D, accounting for 43% of global public investments. China's overall public investments are larger than those of the United States when their state-owned enterprises are included; but without them, China's government investments are just one-fifth the size of the US government investments. The European Union's investments are even smaller than China's[25].

Harm done by Trump cuts if enacted

The Trump cuts in federal support for energy-technology innovation, if enacted through appropriations, could noticeably slow the pace of energy-technology innovation in the United States. The consequences would include a diminution of the stream of future benefits to US residential, commercial and industrial consumers in the form of cost savings from improved efficiency of energy end-use; reduced competitiveness of US energy technologies in global markets; reduced start-up creation and job generation in energy industries; the continuation and even worsening of the public-health and environmental burdens resulting from fossil-fuel-derived conventional pollution; and, of course, much less prospect of attaining the deep reductions in US greenhouse gas emissions required for the United States to do its share in addressing global climate change.

Increases in US oil and gas production as a result of the shale revolution and the rise of more affordable renewable electricity generation have moved the United States closer to energy independence than it has been since before the Arab–OPEC oil embargo of 1973 (although it must be added that energy security, and not energy independence, should be the policy goal in this realm); US net energy-import dependence in 2016 was under 12%, and only 8% of the US negative trade balance was due to the energy sector. Similarly, the US$7 billion (in 1999$) invested by DOE in energy efficiency and fossil fuels between 1978 and 2000 resulted in a benefit to consumers and firms of US$30 billion by 2000 (not including reductions in damages from conventional pollutants or climate mitigation)[26]. At ARPA-E, one-third of the grants between 2009 and 2016 went to small US companies and start-ups; 56 new companies were established and US$1.8 billion in follow-on funding was attracted as of February 2017 (ref. [27]). Also, although it is too soon to fully understand the impact of the Obama Administration's public–private energy-innovation hubs, early assessments are positive[28].

A slowdown in the pace of energy-technology innovation in the United States could be catastrophic to the competitiveness of US energy technologies in global markets, where other countries are speeding up their efforts. Using many energy technologies originally developed in the United States and Europe, China is now the largest global manufacturer of solar panels and wind turbines, and it is positioning itself to capture newer markets, such as electric vehicles[29].

Concerning energy RD&D explicitly focused on reducing greenhouse gas emissions, 22 countries including the United States established the Mission Innovation consortium in Paris in December 2015 with the aim of doubling their public funding of clean-energy R&D over the space of 5 years. If the United States does not honour its pledge (which accounted for 43% of the baseline), other countries will have less incentive to honour theirs. The global public good of stabilizing the climate simply compels cooperation and cost-sharing.

Prioritize improving not slashing

Our critique of the proposed cuts is not to suggest that there are no options for improving the effectiveness of US government investments in energy RD&D. On the contrary, the past 10 years have seen considerable institutional innovation in the US energy RD&D space, the emergence of new analyses on the effectiveness of different energy RD&D programmes, and the application of new decision-support methods for energy RD&D investments.

Research has found, for example, that the productivity of DOE investments in energy innovation can be improved through more effective use of the DOE's national laboratories and increased use of partnerships. In particular, increasing lab-directed research funds at the margin, assisting the interaction of lab researchers with the private sector, and providing new contracting mechanisms by the labs may improve their already important inputs[30].

The ARPA-E model has produced very promising outputs in its 8 years of operation[31]. As innovation necessitates timescales exceeding that duration[32], it should be given at least another 5–10 years to demonstrate that a portfolio of high-risk investments can, in fact, produce substantial rewards.

As for DOE-wide improvements, the Administration should renew the appointment of a joint Undersecretary for Science and Technology to reduce siloing of investments across all programmes and to dissolve the divisions between basic and applied research[6]. Finally, new analytical approaches to energy innovation policy could lead to better decisions on the allocation of energy RD&D investments across technology areas, leading to a more coherent and strategic portfolio approach[16,33].

Having said this, every study we know of has concluded that these kinds of improvements need to be accompanied by a substantial increase in total public funding for energy-technology innovation, if the immense challenges at the intersection of energy supply, the economy, public health and the global climate are to be met. Deep cuts would be folly. ❐

Laura Diaz Anadon[1], Kelly Sims Gallagher[2]* and John P. Holdren[3]

[1]Department of Land Economy, University of Cambridge, Cambridge CB3 9DT, UK. [2]The Fletcher School, Tufts University, Medford, MA 02155, USA. [3]John F. Kennedy School of Government, Harvard University, Cambridge, MA 02138, USA. Laura Diaz Anadon, Kelly Sims Gallagher and John P. Holdren made equal contributions.

**e-mail: Kelly.Gallagher@tufts.edu*

Published online: 25 September 2017
DOI: 10.1038/s41560-017-0012-0

References

1. *FY18 R&D Appropriations Dashboard: R&D Budget and Policy Program* (AAAS, 2017); http://go.nature.com/2gGrxVJ
2. NAS. *An Assessment of ARPA-E*. (National Academies Press, Washington DC, 2017).
3. Gallagher, K. S. & Anadon, L. D. *DOE Budget Authority for Energy Research, Development, and Demonstration Database* https://doi.org/10.6084/m9.figshare.5339497 (2017).
4. Gallagher, K. S., Grubler, A., Kuhl, L., Nemet, G. & Wilson, C. *Annu. Rev. Environ. Resources* **37**, 137–162 (2012).
5. *Science and Engineering Indicators* (National Science Board, 2016); http://go.nature.com/2vLVpKG
6. Narayanamurti, V. & Odumosu, T. *Cycles of Invention and Discovery: Rethinking the Endless Frontier*. (Harvard Univ. Press, Cambridge MA, 2016).
7. Trembath, A., Jenkins, J., Nordhaus, T. & Schellenberger, M. *Where the Shale Gas Revolution Came From* (Breakthrough Institute, Oakland, CA, 2012).
8. President's Council of Advisors on Science and Technology. *Federal Energy R&D for the Challenges of the 21st Century* (Executive Office of the President of the United States, Washington DC, 1997); http://go.nature.com/2eGCyWu
9. *Energy Future: Think Efficiency. How America Can Look Within to Achieve Energy Security and Reduce Global Warming* (American Physical Society, 2011); http://go.nature.com/2xao8sT
10. *A Business Plan for America's Energy Future* (American Energy Innovation Council, Washington DC, 2010); http://go.nature.com/2jH9naO
11. *Post Partisan Power: How a Limited Approach to Energy Innovation Can Deliver Cheap Energy, Economic Productivity, and National Prosperity* (American Enterprise Institute, Brookings Institution & Breakthrough Institute, Washington DC, 2010).
12. *Ending the Energy Stalemate: A Bipartisan Strategy to Meet America's Energy Challenges* (NCEP, Washington DC, 2004).
13. Kammen, D. F. & Nemet, G. F. *Issues Sci. Technol.* **22**(suppl.), 84–88 (2005).
14. President's Council of Advisors on Science and Technology. *Accelerating the Pace of Change in Energy Technologies Through an Integrated Federal Energy Policy* (Executive Office of the President of the United States, Washington DC, 2010).
15. Anadon, L. D., Chan, G. & Lee, A. in *Transforming US Energy Innovation* (eds Anadon, L. D. *et al.*) Ch. 2, 36–75 (Cambridge Univ. Press, Cambridge, 2014).
16. Chan, G. & Anadon, L. D. Improving Decision Making for Public R&D Investment in Energy: Utilizing Expert Elicitation in Parametric Models Univ. Cambridge Energy Policy Research Group Working Paper 1631, Cambridge Working Paper in Economics 1682 (2016); http://go.nature.com/2j2NKS9
17. Greenfieldboyce, N. Trump's budget slashes climate change funding. *The Two-Way* (16 March 2017); http://go.nature.com/2j24mth
18. IPCC *Climate Change 2014: Synthesis Report* (eds Core Writing Team, Pachauri, R. K. & Meyer, L. A.) (IPCC, 2015).
19. Holdren, J. P. *The Science Supporting the Climate Action Plan: Testimony before the Committee on Science, Space, and Technology, US House of Representatives* (2014); http://go.nature.com/2eFEkao
20. *The True Costs of Fossil Fuels* (IRENA, 2016); http://go.nature.com/2xaosYu
21. Coady, D. *et al. How Large Are Global Energy Subsidies?* WP/15/105 (IMF, 2015); http://go.nature.com/2gNcSeV
22. Nordhaus, W. *Schumpeterian Profits in the American Economy: Theory and Measurement* Research Paper no. 10433 (NBER, 2004).
23. Nemet, G. & Kammen, D. *Energy Policy* **35**, 746–755 (2006).
24. Jaruzelski, B. & Dehoff, K. *The Customer Connection: The Global Innovation 1000* (Booz Allen Hamilton, New York, 2007); http://go.nature.com/2eFuOUp
25. Myslikova, Z., Gallagher, K. S. & Zhang, F. *Mission Innovation 2.0*. CIERP Discussion Paper 14 (The Fletcher School, Tufts Univ., Melford, MA, 2017); http://go.nature.com/2wIag62
26. US National Research Council. *Energy Research at DOE: Was It Worth It? Energy Efficiency and Fossil Energy Research 1978 to 2000* (National Academies Press, Washington DC, 2001); http://go.nature.com/2eFWaKg
27. US DOE. *ARPA-E Impacts Vol. 2* (ARPA-E, 2017); http://go.nature.com/2f3j9zn
28. Anadon, L. D. *Res. Policy* **41**, 1742–1756 (2012).
29. Gallagher, K. S. *The Globalization of Clean Energy Technology: Lessons from China* (MIT Press, Cambridge, MA, 2014).
30. Anadon, L. D., Chan, G., Bin-Nun, A. & Narayanamurti, V. *Nat. Energy* **1**, 16117 (2016).
31. National Academies of Sciences, Engineering, and Medicine *An Assessment of ARPA-E* (National Academies Press, Washington DC, 2017).
32. Grubler, A. et al. *Global Energy Assessment*. Ch. 24 (Cambridge Univ. Press, Cambridge, 2012).
33. Anadon, L. D., Baker, E. D. & Bosetti, V. *Nat. Energy* **2**, 17071 (2017).