Commentary

Is Net Zero Carbon 2050 Possible?

John Deutch1,∗

John Deutch is an emeritus Institute Professor at the Massachusetts Institute of Technology where he has been a member of the faculty since 1970. He has served as Chairman of the Department of Chemistry, Dean of Science, and Provost. In the Carter Administration, he served as Director of Energy Research (1977–1979), Acting Assistant Secretary for Energy Technology (1979), and Undersecretary (1979–1980) in the U.S. Department of Energy. He has been a member of the President’s Nuclear Safety Oversight Committee (1980–1981), the White House Science Council (1985–1989), the President’s Committee of Advisors on Science and Technology (1997–2001), and the Secretary of the Energy Advisory Board (2008–2016). John Deutch has published widely on technical and policy aspects of energy and has been a member of the board of directors or the technical advisory committees of several energy companies.

Does achieving a goal of net zero CO₂ emissions by 2050 assure that the world will meet the 2015 Paris Agreement target of keeping global warming below 2°C? If so, is it possible for the U.S. and the world to achieve the net zero 2050 goal? Unfortunately, the answer to both questions is “no.”

Skepticism that the pace and magnitude of anthropogenic greenhouse gas (GHG) emission reductions are not sufficient to meet the 2°C target has turned attention to the net zero emissions goal—achieving a balance between reducing emissions into the atmosphere and removal of CO₂ from the atmosphere through new “negative emissions” technologies.

Many are advocating adopting a strict goal of net zero CO₂ emissions by the year 2050 to supercharge a decisive new effort to avoid pervasive climate damage. Several jurisdictions have passed laws mandating the goal.1 Ten states, including Massachusetts, New York, and California, have set a goal of a zero-carbon economy mid-century.2 The European Union has adopted a decarbonization strategy to achieve a net zero economy by 2050.3 Climate leaders are actively backing mid-century zero carbon initiatives.4,5 Leading private firms and organizations are committing to net zero operations by 2050.6 If the Democrats win the White House and Senate in November, the climate and energy community should expect that President Biden will propose a major initiative calling for the U.S. economy to be net zero by mid-century.

Are such goals realistic, or are they aspirational? If the goals are aspirational, will they lead to greater effort or, when they are shown to fail, will they contribute to even greater cynicism about government among investors and the public? How does the net zero by 2050 goal relate to the goal to maintain average temperature increase below 2°C or preferably 1.5°C by 2100?

The average global temperature increase at any time is proportional to the logarithmic change in atmospheric CO₂ concentration, c(t): δT(c) = ε ln(c/c₀)ln(2)^−1. The equilibrium climate sensitivity, ε, is the temperature increase from a doubling of the concentration; if ε = 3, ε/ln(2) = 4.33. The equilibrium climate sensitivity, ε, exhibits high statistical variation because of climate feedback mechanisms7 and lies between 1.5 and 4.5.10

In 2020 the CO₂ concentration will be about 400 ppmv, creating warming of about 1.1°C over that during preindustrial time. The temperature increase in 2100 will be determined by the concentration c(2100). The quantity Δc = [c(2100) – c(2050)] is the carbon budget for the period between when net zero is achieved in 2050 and the concentration in 2100 corresponding to an adopted climate ceiling. Suppose the world seeks to remain below a 1.5°C, 2°C, or 3°C ceiling at the end of the century. Adopting the equilibrium climate sensitivity ε = 3.0, the concentration c(2100) must remain below 449 ppmv, 503 ppmv, and 635 ppmv, respectively. If the equilibrium climate sensitivity is replaced by the transient climate sensitivity ε₉ ~1.9, the concentrations must remain below 480 ppmv, 5.76 ppmv, and 830 ppmv.

An extreme scenario for achieving net zero in 2050 is for emissions into the atmosphere to continue between 2020 and 2050 at the constant annual rate of 2.5 ppmv per year and then abruptly fall to zero in 2050. The resulting concentration, c(2050) = 475 ppmv, lies well within the carbon budget envelope.
for various 2100 outcomes presented above. A detailed discussion of the relationship of the probability of remaining below a specified temperature ceiling and variability in climate sensitivity is given by Lowe and Bernie.¹¹

However, the statistical variation of climate sensitivity adds an additional complication. For example, the IPCC reports that the equilibrium climate density lies in the range of 1.5 < ε < 4.5. If this statistical variation arises from feedback, the probability density for δT will exhibit a “fat tail,” which is much more consequential and threatens to exceed the temperature ceiling.¹² Achieving the net zero 2050 goal does not assure staying below a global warming temperature ceiling.

**A Plausible Pathway to Net Zero 2050 for the U.S.**

Global net zero requires eliminating all CO₂ and eventually all other GHG emissions, notably CH₄ and N₂O, from every end-use sector. It means essentially restructuring the global energy system for all energy use: power, transportation, manufacturing and industrial operations, residential and commercial buildings, and land use for agriculture/husbandry/forestry. It is an enormous undertaking because of the sheer scale of the activities, representing a substantial fraction of global GDP, and the size of the investment to make the changes. There are extensive international trade flows that carry fuels and goods and services among all nations that operate with differing economic, political, and social systems. These flows influence where emissions occur. Time also presents a challenge. At the scale requiring change, 30 years is a very short time.

The annual cost is daunting. The European Union estimates it will require an investment of 2.8% of GDP to achieve net zero by 2050. The IEA and International Monetary Fund have recently presented an ambitious global sustainable recovery plan for the energy sector, which suggests spending $1 trillion per year for each of the next three years or about 1% of the $100 trillion annual global GDP. The U.S. annual GDP is about $20 trillion, with 3.5% allocated to all investment, of which about ½ (or $350 billion) is spent on energy. The U.S. fair share of an initiative of the size proposed by the IEA is $200 billion annually. Adding this amount to the present level of U.S. energy investment is clearly affordable, although a hard sell at a time when the country is recovering from the COVID-19 economic downturn. The U.S. and other wealthy countries arguably could bear the enormous net zero transition cost.

The United Nation’s Framework Convention on Climate Change (UNFCCC), the governance structure available for global climate policy and programs, has not been given the authority and responsibility for planning and implementing a global net zero program. Nor does the UNFCCC have the financing or technical capability to address a problem of this scope. Its principal virtue has been and will continue to be providing a venue and a process—the annual Conference of the Parties (COPs)—to engage over 100 member countries who have different interests and priorities. It is hopeless to expect that the UNFCCC’s incremental approach, followed for almost half a century since the 1992 Kyoto Protocol, could effectively lead a global net zero initiative. Indeed, it is disappointment with progress resulting from the highly acclaimed 2015 Paris Agreement COP 21 that has led to an urgent call for the different net zero approach.

Moreover, it is unreasonable to expect that rapidly growing emerging economies in Africa, Asia, and elsewhere that have social and economic goals allocate available resources toward a net zero 2050 goal. Progress will require major resource transfer from developed economies, but they have not honored their past commitments, and there remains much debate about mechanisms for managing such assistance.

In sum, net zero in 2050 is possible for the U.S. but extremely unlikely for many rapidly growing emerging economies. Of the world’s ten largest CO₂ emitters, in addition to the U.S., Japan, Germany, South Korea, Saudi Arabia, and Canada also can afford to comply; Russia’s participation is questionable. However, with most of the major global emitters adopting the net zero 2050 goal, staying below 2°C until 2100 is possible for the world.

John Podesta and Todd Stern properly urge that the best way forward is for the U.S., hopefully along with other wealthy countries, to take the lead by committing to net zero in 2050.⁴ A more feasible goal would be to set the net zero 2050 goal for North America. If successful, it would be a powerful model for stitching together a climate policy coalition to bridge the interests of developed and developing nations.

**Achieving Net Zero in 2050 in the U.S.**

The path to net zero in the U.S. requires a transition to an essentially all electric economy. Such a transition begins with deep decarbonization of the electricity system by leveraging the tremendous penetration of renewable electricity generation—notably wind and solar. Additional measures are required to meet load demand when variable renewable electricity has penetrated beyond about 70%. The measures consist of over-building renewable generation capacity, deploying storage systems, adding power transmission lines, and demand-side management (paying consumers to shed load in times of extreme capacity shortage).
The CO₂ abatement costs are reasonable for substantial reductions but increase very sharply beyond 80% reduction. The reason is that unit capital cost plateaus with increasing penetration, but the capacity factor drops sharply.13

When deep carbon free electricity is attained and scalable, the next step is to electrify the transportation sector to the extent possible. Together, these two steps would reduce U.S. GHG emissions by at most 80%. Displacing the additional 20% of CO₂ emissions that come from agriculture and some industrial activities—buildings, construction, and manufacturing with electricity will be more challenging.14 At higher levels of emissions reductions, net negative emission technologies will be required to reach net zero, preserving fossil fuels for certain uses, e.g., aircraft fuel, chemical production, agriculture, and livestock.

Innovation has an important role in the net zero initiative.15 Progress must continue on energy efficiency and clean energy technologies. Negative emission technologies, such as afforestation/reforestation, bioenergy, and direct air capture of CO₂ (DAC), are at early stages of technology readiness but important for atmospheric CO₂ removal. An aggressive and well-financed research, development, and demonstration effort will be required to meet the 2050 target date. So far, despite years of effort, it has not proven possible to deploy two large-scale zero carbon energy technologies: commercial nuclear power and carbon capture utilization and storage (CCUS). The bioenergy and DAC negative emission technologies require available CCUS options. Practical and economic CCUS options would also open opportunities, albeit perhaps expensive for clean coal and natural gas electricity generation. It is worth underscoring that successful innovation will require the integration of technical advance with economics, regulatory compliance, and good business practice. New high-payoff negative emission technologies will require significant R&D to establish low cost. Successful deployment will still require integration with the broad innovation matters mentioned above.

The U.S. Mobilization Gap
The net zero initiative presently consists of high-level goals, passionately advocated for by committed climate policy individuals and organizations, which stress the need for leadership, a whole-government approach, and mobilization of public and private entities to meet the global existential climate change threat.

However, there is no concrete plan for achieving net zero by 2050 that lays out a schedule for advancing the needed new negative emission technologies, designing the extensive regulatory and market changes required for an all-electric economy, rebalancing federal and state authorities and responsibilities, and dealing with trade issues between net zero U.S. and GHG-emitting countries.

It is unlikely that the transition to an all-electric economy requiring enormous capital turnover can be accomplished by incremental steps. 30 years is not a long time to bring about changes of this scale. Fundamental change is necessary in executive branch agency organization, in the private sector where investment decisions between competing firms are based on price signals, as well as congressional oversight. The extent and pace of change is comparable to what is required in wartime, supported by public understanding and support.

Massive commitment of new resources and effective mobilization of government, the private sector, and energy consumers are necessary for a U.S. net zero 2050 initiative to be successful. If so, the U.S. will have regained its position as a global climate leader and can play a large role in international climate matters. The most important foreign climate initiative the new U.S. administration could take in 2021 is to form partnerships to reduce emissions with the largest Asian emitters, India and China; although, given the bipartisan U.S. distrust of China, such cooperation is problematic. In addition, the U.S. should join with the IEA and IMG to facilitate financing for lesser developed, at risk, nations.

If the preconditions of new resources and mobilization are not credibly in place, a U.S. net zero 2050 initiative will not succeed and a net zero initiative should not be attempted.

1. In law: Denmark, France, New Zealand, Norway (2030), Sweden (2045), U.K.
2. Podesta, J., Goldfuss, C., Higgins, T., Bhattacharya, B., Yu, A., and Costa, K. (2019). Fact Sheet: A 100 Percent Clean Future. Center for American Progress. https://www.americanprogress.org/issues/environment/reports/2019/10/10/475651/fact-sheet-100-percent-clean-future/.
3. Climate Action. 2050 long-term strategy. https://ec.europa.eu/clima/policies/strategies/2050_en.
4. Podesta, J., and Stern, T. (2020). A Foreign Policy for the Climate. Foreign Aff. https://www.foreignaffairs.com/articles/united-states/2020-04-13/foreign-policy-climate
5. Krup, F., Keohane, N., and Pooley, E. (2019). Less than Zero. Foreign Aff. https://www.foreignaffairs.com/articles/2019-02-12/less-zero
6. Klaus Schwab, World Economic Forum, January 14, 2020.
7. Christiana Figueres, former Executive Secretary, UNFCCC.
8. Among these are Shell, BP, Barclays Bank, and Harvard University.
9. Interestingly, fires are expected to have an effect, but it is not known if the effect is cooling or warming.
10. Collins, M., Knutti, R., Arblaster, J., Dufresne, J.-L., Fichefet, T., Friedlingstein, P., Gao, X., Gutowski, W.J., Johns, T., Knirrner, G., et al. (2013). Long-term Climate Change Projections, Commitments and Irreversibility. In Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, eds. (Cambridge University Press), pp. 1029–1136.
Brandon J. Hopkins is a National Research Council postdoctoral fellow at the U.S. Naval Research Laboratory (NRL) focused on advancing next-generation electrochemical energy systems. Hopkins received his PhD at the Massachusetts Institute of Technology (MIT) where he worked on aqueous metal–air batteries. As a master’s candidate at MIT, he was part of the Joint Center for Energy Storage Research (JCESR) where he created gravity-driven flow batteries using semi-solid suspensions. He received his bachelor’s degree from Harvard University and interned at Akamai Technologies, Inc. and Lawrence Livermore National Laboratory.

Debra Rolison (left) heads and Jeffrey Long (center) and Joseph Parker (right) are members of the Advanced Electrochemical Materials Section at NRL. They design, synthesize, characterize, and prototype 3D-structured, ultraporous, multifunctional, hold-in-your-hand nanoarchitectures for such rate-critical applications as catalysis, energy storage and conversion, ultrafiltration, and sensors. They recently demonstrated that reformulating zinc into a monolithic sponge form-factor allows Zn-based batteries to be cycled at high rate to high specific energy without forming cell-shorting dendrites. They received their PhDs in Chemistry from the University of North Carolina at Chapel Hill in 1980, 1997, and 2010, respectively.

Structural batteries, i.e., batteries designed to bear mechanical loads, are projected to substantially increase system-level specific energy, resulting in electric vehicles with 70% more range and unmanned aerial vehicles (UAVs) with 41% longer hovering times.1,2 By storing energy and bearing mechanical loads, structural batteries reduce the amount of conventional structural materials required by devices. Two approaches to enable this concept have emerged since the first structural-battery prototypes were reported in 2004.3 One approach emphasizes monofunctional materials with decoupled functions; i.e., one material bears loads, another electrochemically stores energy. The other approach focuses on using multifunctional materials with coupled functions; i.e., materials that bear loads and electrochemically store energy. By performing a meta-analysis on reported structural batteries, we show here that decoupled structural batteries (relying on monofunctional materials) generally achieve higher elastic moduli and specific-energy values than coupled structural batteries (relying on multifunctional materials). We use the equation for flexural rigidity to demonstrate that decoupled structural batteries also have a fundamental advantage because they position load-bearing components on their outermost surfaces; i.e., the casing. This design choice gives decoupled structural batteries greater flexural rigidity than their coupled counterparts, which distribute load-bearing components throughout their volumes. Our analysis suggests that next-generation structural batteries should look to energy-dense aluminum–air and zinc–air batteries.