Response to the U.S. House Select Committee on the Climate Crisis Request for Information

Submitted
November 22, 2019

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Table of Contents

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November 22, 2019

The Honorable Kathy Castor
2052 Rayburn House Office Building
Washington, D.C. 20515

RE: Climate Crisis Request for Information

Dear Congresswoman Castor:

Thank you for the opportunity to respond to the U.S. House Select Committee on the Climate Crisis Request for Information. This document represents the work of many of the sustainability researchers in the Julie Ann Wrigley Global Institute of Sustainability (GIOS) at Arizona State University (ASU).

Why are we responding? Arizona State University is a leader in sustainability research and education. With more than 500 sustainability scientists, scholars and fellows from across ASU and beyond, we are unmatched by any other American university in the kind of infrastructure that supports truly transdisciplinary, collaborative, solutions-focused research. Readers will recognize this approach in the many contributions that make up this report.

The depth and breadth of our expertise is available to Congress to answer questions on the climate crisis or any other issues of sustainability writ large. We look forward to the committee's review of our responses to your questions.

Sincerely,

Dave White, Deputy Director
Julie Ann Wrigley Global Institute of Sustainability

ASU #1 in the U.S. for innovation
—U.S. News & World Report

1a. Decarbonizing Transportation

***Question**: What policies should Congress adopt to decarbonize the Transportation sector consistent with meeting or exceeding net-zero emissions by mid-century? Where possible, please provide analytical support that demonstrates that the recommended policies achieve the goal.*

Start with transportation

Transportation generates 29% of U.S. greenhouse gas emissions

The transportation sector generates the largest share of greenhouse gas emissions (28.9% of 2017 greenhouse gas emissions based on Environmental Protection Agency (EPA) 2017 records), and is the only sector where emissions are still increasing.

Several factors unique to transportation make reductions challenging. In contrast with the electric power, industrial, residential, and commercial sectors, energy-using machines in the transportation sector are mobile. They must carry their energy sources with them (except for some electrified rail and pipelines) and refuel in many locations as they move around. The energy density of liquid hydrocarbons and the ubiquity of gasoline and diesel stations makes it difficult to transition away from oil. Thus, transportation remains heavily dependent (over 90%) on a single source of energy. Investing in decarbonization of the transport sector — for both passengers and freight — is uniquely challenging but essential to achieving America's emissions goals.

***Sara Khoeini**, Assistant Research Professor of Transportation Systems*
School of Sustainable Engineering and the Built Environment, Arizona State University

***Michael Kuby**, Professor of Geographical Sciences and Urban Planning*
College of Liberal Arts and Sciences, Arizona State University

Reduce carbon emissions on five fronts

Five ways to reduce carbon emissions

Carbon emissions from the transport sector are determined by a combination of five factors: distance, mode, fuel type, energy efficiency, and load factor. To decarbonize the transport sector, we should

1. Reduce **distance traveled**. Reduce the demand for miles traveled by both passengers (person-miles) and freight (ton-miles), especially in high-emission transport modes, such as airplanes.
2. Switch to lower-carbon **modes of transport**. Change passenger automobile travel to walking, biking and public transit; move freight by truck to lower-carbon train or boat.

3. Switch to **alternative fuels**. Promote fuels that are lower in carbon intensity than oil, such as compressed natural gas, hydrogen, and electricity.
4. Increase vehicle **fuel efficiency**. Expand the use of hybrid gasoline-electric propulsion technology.
5. Increase vehicle **load factors**. Raise the average fraction of the vehicle's capacity that is filled with either passengers or freight. Share more rides for passenger travel; reduce empty backhauls for freight movement.

Decarbonize transport by mid-century

To decarbonize transport by mid-century, ALL of these strategies will be needed. Note that strategies 1, 2 and 5 have the added co-benefit of reducing traffic congestion, while strategies 3 and especially 4 have the advantage of not requiring the American people to change their behavior or lifestyle significantly.

Beware of policies that incentivize the wrong behavior

Implementing policies that incentivize *increased* transport carbon emissions – such as road-widening in Phoenix and many other metropolitan areas – make it harder for the U.S. to reach a decarbonization goal.

***Deborah Salon**, Assistant Professor, School of Geographical Sciences and Urban Planning*
College of Liberal Arts and Sciences, Arizona State University

Ban sales of new fossil-fuel cars and trucks by 2035

Our communities are designed around automobiles

To decarbonize transportation in a single generation, we must be realistic about behavioral and land-use constraints. Existing land-use patterns that evolved around automobiles constrain the ability of most Americans to switch from driving to walking, biking, or public transportation. Longer door-to-door travel times; perceptions about safety, comfort, and weather; inflexibility in linking multiple errands; and the miniscule marginal cost of additional driving trips, all discourage other transportation modes.

We could enforce some unpopular changes to behavior and land use

It would take drastic changes to multiple state and national policies to impact this calculus significantly. The Federal Government could:

- **Raise the gasoline tax** dramatically to fund improved and free public transportation
- **Convert existing roadway lanes** to bus rapid transit and buffered bike lanes
- **Halt new freeway construction**
- **Eliminate free parking**
- Change school funding and mortgage rules so **people are not as incentivized to move to the urban fringe**, or impose urban growth boundaries.

A suite of such policies would lower carbon emissions from transportation substantially and create more livable and safer cities — but are these policies politically feasible and would they work as quickly and effectively as needed?

Or we could achieve massive decarbonization with little behavior change

Alternatively, if the Federal Government banned the sales of new gasoline and diesel vehicles beginning around 2035, as many other countries have announced, we could achieve massive decarbonization with little change in land-use or behavior. Policies could:

- **Require electric utilities to provide charging infrastructure** along highways and at existing multi-family housing.
- Incentivize oil companies to **add hydrogen pumps to stations**.
- Require that **new dwellings come with charge ports**.
- **Extend vehicle subsidies** until economies of scale and technological change lower costs on par with gasoline cars.
- **Invest heavily** in hydrogen production, fuel cell, and battery research.
- Impose a **market-based carbon tax** or cap system.
- Give industries and communities **15 years to prepare**.

People say Americans are addicted to oil, but in fact we are only addicted to cars. It's our cars that are addicted to oil—unnecessarily, unhealthily, and uneconomically.

***Michael Kuby**, Professor of Geographical Sciences and Urban Planning*
College of Liberal Arts and Sciences, Arizona State University

Persuade consumers to convert

Convert to electric vehicles

The United States should enact policies that require converting as many passenger vehicles as possible to electric. This includes individually owned passenger cars, public and industry fleets, ride-share vehicles, buses, taxis, trucks, trains, and airplanes.

Generate clean energy to power electric vehicles

There are many possible sources of electricity for charging electric vehicles, but the source used should be carbon-free. Otherwise, carbon emissions will not reach zero.

Consumers have limited EV options

Consumers need persuasion to select electric vehicles among the available options for both private and public sectors. Only 1.15% of all cars sold in the U.S. in 2017 are plug-in hybrid electric vehicles (PHEV) and battery-electric vehicles (BEV). The selection is limited and most Americans do not understand the differences between them.

In Phoenix, consumers have not been persuaded to convert

A recent study by ASU researchers on attitudes toward new transportation technologies shows that although 75% of respondents are committed to an environmentally friendly lifestyle, only 35% are willing to use a less-polluting means of transportation in the Phoenix metro area. Therefore, the monetary incentives and costs, charging infrastructure, permission to use HOV

lanes, driving range, and information outreach have not yet persuaded enough people to buy clean vehicles.

Low-carbon decisions require economic, tech, info and land-use support

In summary, we must enact policies that will impact people's decision to buy electric vehicles by providing better information, sufficient recharging infrastructure, financial and lane-use incentives, and improved technology.

***Sara Khoeini**, Assistant Research Professor of Transportation Systems*
School of Sustainable Engineering and the Built Environment, Arizona State University

Transition to electric and alternative-fuel vehicles

Different classes of vehicles have different policy considerations

Policy must properly address four distinct classes of transportation machinery.

1. **BEV - Battery Electric Vehicles**: Ground vehicles with modest energy requirements compatible with on-board electricity storage
2. **TEV - Tethered Electric Vehicles**: Ground vehicles with greater energy requirements that are compatible with tethering. TEVs are BEVs that extend their limited driving range by picking up electric power while moving, such as from overhead wires.
3. **AFV - Alternative-Fuel Vehicles**: Ground vehicles with high energy needs in usages that are not compatible with tethering or batteries (personal vehicles in remote locations, work trucks with heavy loads, construction, mining and agricultural machinery)
4. **Aircraft**

Assure BEV-friendly infrastructure for most drivers

For Group 1 above, policies should assure a national network of public, reasonably priced DC-fast chargers (DCFC), provide incentives for installing Level-2 charging in existing homes, require Level-2 charging be installed in all new homes and multi-unit dwellings. The rising cost of non-fossil hydrocarbon fuel (‘renewable gasoline’) combined with the declining cost of BEV technology will soon make BEV ownership attractive without ongoing public subsidy.

Install TEV electric truck lanes on interstate highways

For Group 2, dominated by long-distance trucking, policy should include developing a standard installation of at least one electric truck lane throughout the U.S. interstate highway system.

Switch to cleaner-burning fuels for other ground vehicles

Group 3 requires energy storage denser than what can be achieved by batteries or hydrogen, and so must use liquid hydrocarbon fuel. Fortunately, cleaner-burning fuels, such as dimethyl-ether (DME), are sufficiently energy dense (roughly half that of diesel fuel) for these applications.

Switch to renewable hydrocarbon fuel for aircraft

Aviation (Group 4) demands the higher energy density of kerosene-like fuel. It must be recognized that even with maximum deployment of electrification, anticipated economic growth will result in demand for 100 to 150 billion gallons of renewable liquid hydrocarbon fuel per year (roughly 1/3 of what we use today).

Policies for a transition to electric and renewable-fuel vehicles

- **Provide research and investment support** for the industrialization of substitute renewable fuel from biomass (and from direct air capture if and when viable)
- Establish regulations that **require an increasing fraction of renewable fuel** in the overall mix, reaching 100% by 2050
- **Protect against fraudulent substitution** of fossil fuel for renewable hydrocarbon fuel.

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired Adjunct Professor, School for the Future of Innovation in Society, Arizona State University*

Maintain progress on fuel economy

Restore and maintain strong fuel economy standards

Congress should continue to provide strong oversight of EPA's implementation of fuel economy standards and override lagged or reversed policy implementation. They should draft explicit legislative amendments that override any roll-backs in these standards.

Level the market for consumer vehicles

Congress should draft explicit legislative amendments that eliminate differences in compliance requirements among different vehicle classes. Consumer preferences should operate within a levelized market in which all vehicles contribute to decarbonization goals.

Research the path to carbon-zero

Research the most effective pathway to zero-carbon transportation

Compare and evaluate the pace, cost and impacts of decarbonization of transportation by 2025. Emphasize a variety of fuel/technology options, including (i) conversion to all-electric vehicles, (ii) advanced plug-in hybrids with traditional gasoline, (iii) an optimized combination of electric vehicles and plug-in hybrids utilizing synthetic liquid fuels derived from captured and converted carbon dioxide.

Call on governmental researchers and fund non-government researchers

Request the Congressional Research Service (CRS) and Government Accountability Office (GAO) to enlist the participation of non-Congressional researchers in these analyses, which require numerous assessments of technological, economic and cultural feasibility. Congress can specify line item funding for these analyses to be sponsored by the Department of Energy or another federal agency in the appropriations process.

***Elisabeth Graffy**, Professor of Practice, School for the Future of Innovation in Society and the Consortium for Science, Policy and Outcomes, Arizona State University*

Clean energy vehicles facilitate solar energy adoption

Charge electric vehicles in the daytime, when solar energy is abundant and cheap

A key policy for decarbonizing transportation is to incentivize businesses and utilities to create infrastructures for charging electric vehicles during the daytime when most light vehicles are

sitting in workplace parking lots. This will help both ensure EV charging is carbon neutral and facilitate solar energy adoption by growing electric power demand in the middle of the day.

Incentivize innovative ways to exchange electricity between cars and the grid

Incentivizing innovation by researchers, businesses, and utilities in the dynamic exchange of vehicle-to-grid electricity enables automobile batteries to serve as excess storage capacity for the grid.

***Clark Miller**, Director, Center for Energy and Society*
Professor, School for Future of Innovation in Society, Arizona State University

Counter the one-driver, one-car narrative

Privately owned cars are cheap, comfortable and convenient

One of the biggest challenges in decarbonizing the U.S. passenger transport sector is that for most Americans, most of the time, oil-powered, privately owned cars are remarkably inexpensive. On a per-mile basis, a recent unpublished analysis estimates median cost per mile for owned cars at $0.39 when including fixed costs, and just $0.17 when including only the marginal cost of driving. Owned cars are also more convenient, more comfortable, more private, safer, and faster than any other transport mode. This is no surprise since for decades, America has invested in building a vast transportation infrastructure network that is specifically designed for cars, and provided that network to American car owners nearly free of charge.

Carbon pricing will not change how Americans travel

The gap in both service level and price between owned cars and other transportation modes, therefore, is enormous. For most Americans, most of the time, a carbon tax will not change their transportation choice. If they are forced to pay more money to drive, it likely won't be enough to change how they travel, and many of them will be angry about it.

Invest in infrastructure for low-carbon alternative transportation

How do we counter the usual one-driver, one-car narrative? To change peoples' transportation choices, policies need to go far beyond a carbon tax to include large investments in a vast infrastructure network that is designed specifically for low-carbon alternatives to cars. This means investing in pedestrian, bicycle, and transit infrastructure in a big way.

Adapt existing car-focused infrastructure

Transportation investments will be most successful in achieving decarbonization goals if they revise the existing car-focused infrastructure to be designed for pedestrians, bicyclists, and transit users. This is currently happening in limited ways, especially in dense urban areas. Car parking along urban streets is slowly being removed from city centers (e.g., New York City, Copenhagen), and replaced by bicycle parking, bicycle lanes, transit lanes, and wider sidewalks.

***Deborah Salon**, Assistant Professor, School of Geographical Sciences and Urban Planning*
College of Liberal Arts and Sciences, Arizona State University

1b. Decarbonizing Electric Power

***Question**: What policies should Congress adopt to decarbonize the electric power sector consistent with meeting or exceeding net-zero emissions by mid-century? Where possible, please provide analytical support that demonstrates that the recommended policies achieve the goal.*

Innovate for clean energy policies

Four key takeaways

Decarbonizing electric power will require a collaborative effort with innovations in technology, regulation, utility business models, and end-use energy. If policy changes focus on only one of the elements, it will be difficult to achieve the cross-sector transformations needed to realize a resilient, low-carbon economy.

1. Direct CRS or GAO to **evaluate state experimentation** with decarbonization.
2. Legislatively **incentivize rapid uptake and sharing of best practices** among states that cap/prevent future carbon emissions from new construction.
3. Legislatively incentivize or **mandate transitions that eliminate emissions** from existing power plants, perhaps through a performance-based standard.
4. Incentivize or **mandate diversified, resilient innovations** that decarbonize existing infrastructures while experimenting with novel hybrid systems, such as wind/solar-storage and multi-objective options, such as uniting regenerative or renewable agriculture and clean energy.

Pass new legislation that focuses on clean energy innovation

Congress should, through committee staff and the Congressional Research Service (CRS), review state energy innovation policies and take a fresh look at the Clean Power Plan/Affordable Clean Energy (CPP/ACE) rule. Their goal should be to investigate options for passing legislation that focuses on clean energy innovation, whether independent of or correlated with climate legislation. Experience with the CPP/ACE demonstrates that existing legislation is insufficient to reach decarbonization goals by mid-century, and new or amended legislation is required.

Incentivize behavior change

Congress should refocus on questions about where the greatest opportunities exist for institutional implementation of clean energy transitions and on how to focus policies that incentivize decision making and behavior change accordingly. Our research on electric utilities (investor-owned, public, cooperatives, etc.) indicates that legal and market forces impel changes in the energy sector toward renewable, low carbon power; this progress cannot be assumed and is only informally monitored as a policy matter.

Pilot hybrid power systems

Legislatively encourage more extensive pilots of hybrid power systems, such as those taking place in Arizona through Arizona Public Service.

Legislate building codes

Use legislation to expand and accelerate trends in local and state building codes that require expansion of renewable, zero net-carbon power to correspond with all new residential construction. This does not address the needs of built infrastructure but caps future carbon emissions, a significant concern as population grows.

Account for wildfire and other risks

We need to better understand the association between enhanced wildfire risks and high-voltage transmission lines in the American West - under hotter, drier conditions - as a factor in designs for decarbonization. This may, for example, influence where, when and how high-voltage lines are added to networks and when distributed low- or no-transmission infrastructures are utilized.

Whereas distributed energy systems may not be superior to other system designs in any absolute sense, prospects for decarbonization through higher-penetration renewables, combined with more extensive high-voltage transmission systems, may be contra-indicated under climate-changed conditions. Market-based mechanisms focused on outcomes/performance, rather than process or technology choices, should be required to take resilience, economic and safety risks into account, not just decarbonization outcomes.

> ***Elisabeth Graffy**, Professor of Practice, School for the Future of Innovation in Society and the Consortium for Science, Policy and Outcomes, Arizona State University*

Create an ecosystem that fosters change

Performance-based regulation

We recommend that Congress create an ecosystem that fosters the transition of utilities and economies to low- and no-carbon. One example is a performance-based regulation (PBR) model implemented in Rhode Island and under discussion in Hawaii and other 18 states and the District of Columbia.

This change to performance-based incentives and penalties can change utility business practices to better emphasize growing societal and national interest in clean and resilient power that is also reliable and low-cost. Setting national targets for renewables or no-carbon energy could help align states and utilities towards a common goal.

> ***Nathan Johnson**, Director, Laboratory for Energy and Power Solutions*
> *Assistant Professor, The Polytechnic School, Ira A. Fulton Schools of Engineering, ASU*

The science of transition

Renewable energy costs are going down

Renewable energy has significantly decreased in cost and will continue to do so. Onshore wind power currently has the lowest levelized cost of any utility scale power generation system. Daytime peaks in solar power in some markets is already leading to coal, nuclear, and some natural gas baseload generators becoming economically unviable.

Energy storage solutions are needed

However, wind and solar power face intermittency challenges and cannot meet 24/7 baseload demand; energy storage solutions are necessary to transition to a net-zero emissions world. Battery storage does not scale and poses its own environmental hazards, so batteries do not represent a meaningful step forward in environmental sustainability.

Hydrogen fuel cells can smooth daily demand curves

Hydrogen fuel cells, when combined with dedicated renewable systems, can smooth daily demand curves and overcome the grid intermittency challenges that result from wind and solar generators. Energy for electrolysis to produce hydrogen for fuel cells must be produced using dedicated renewable generation; this means that a hydrogen fuel cell system must be developed. The benefits of hydrogen fuel cells go beyond the grid and can be utilized for many types of systems including transportation.

Develop multi-use solar farms that also raise agricultural yields

A shortcoming of utility-scale solar farms has been the land is not multi-use, a benefit that wind turbine generators promote. However recent research demonstrates that newer thin-film solar panels can be installed over agricultural fields and actually raise yields. This system allows for dual use of agricultural land without lowering crop yields. This also raises potential incomes to rural farmers and encourages the ongoing use of the land for agriculture.

***Deborah Strumsky**, Assistant Professor, School of Sustainability and School for the Future of Innovation in Society, Arizona State University*

Transparent plans facilitate accountability and evaluation

Utilities must publish and annually update their plans

Electric utilities must say how they will be carbon neutral by mid-century. Congress should require that all electric utilities (investor-owned, cooperative, and publicly owned) create, publish, and annually update plans to transform their electricity operations to carbon neutrality by mid-century.

This effort builds capacity within and without utilities for developing and analyzing energy transition plans; would ensure transparency of those plans to all stakeholders; would allow outside stakeholders to hold utilities accountable for their actions; create data to enable regulators and researchers to evaluate plans, their impacts, and their costs; and would strengthen overall planning efforts.

Plans should be clear and comprehensive

Plans should include clear carbon emission reduction pathways, coherent technology investments, estimated costs, economic implications, and social and environmental implications.

***Clark Miller**, Director, Center for Energy and Society*
Professor, School for Future of Innovation in Society, Arizona State University

Renewable electricity is the lynchpin of the carbon-neutral economy

A transition will require governmental support on a massive scale

Treating electricity as a separate energy 'sector' obscures the scale and criticality of the decarbonization challenge. Renewable electricity is the lynchpin of the carbon-neutral economy. Yet, replacing existing generation capacity with wind, solar (maybe nuclear) power is not enough. The frantic rate of construction will require government support on the scale that built the transcontinental railroad system over a century ago.

Policy to support transition

Policy must take two forms: (1) **accelerate permitting** for construction of renewable energy systems and their requisite high voltage transmission connections, and (2) support the immense **capital formation** required to finance this build-out.

Policy must ensure this massive publicly supported investment be spent in the U.S. and that renewable electricity equipment be **manufactured in the U.S.** wherever feasible.

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired Adjunct Professor, School for the Future of Innovation in Society, Arizona State University*

1bi. Clean Energy Standard

***Question**: If you recommend a Clean Energy Standard, how should it be designed?*

Prioritize aging systems, regional collaboration

Replace aging systems first

Decarbonizing electric power and cultivating an energy transition away from fossil fuels toward renewable and other green sources of energy are critical for meeting climate change mitigation targets. A Clean Energy Standard (CES) or Renewable Energy Portfolio Standard (REPS) would make measurable progress toward this transition. A successful CES/REPS policy should prioritize replacing aging fossil fuel systems nearing end-of-life with renewable energy options.

We recommend **setting a clear end-point goal** for the electric power industry in the U.S. of achieving carbon neutrality by a specific date, in order to provide a clear signal of policy intent.

Align policy at local and regional scales

Congress should build coalitions that include state regulatory bodies and utilities to enable regulatory and policy alignment at various scales. Failing to align at local and regional scales can lead to policy backlash, which is one of the leading causes for CES/REPS policy failure. Coalitions can build resilient long-term support for clean or renewable energy standards. They are important for managing the social and environmental justice of a transition by allowing these policies to be adapted to local economic, livelihood, and environmental conditions.

Develop better national and regional grid management systems

Infrastructure modernization includes developing improved national and regional grid management systems and assessing the national capacity for energy storage at both diurnal and seasonal scales which would include pumped-hydro storage and compressed air storage. These are important for integrating intermittent energy sources. An 'electric power sector' does not exist in a carbon-neutral economy. Infrastructure modernization is enabled but also made more complex by the growing role that electrification is having in transportation and other sectors.

> ***Joshua Loughman**, Director, Engineering Projects in Community Service*
> *Ira A. Fulton Schools of Engineering, Arizona State University*

Treat electricity the same as industry

Treat electricity the same as other industrial activity

Recognizing that **two thirds of future electricity output will be used as or to make fuel** of some type (battery charging, hydrogen synthesis, hydrocarbon fuel synthesis) it is more effective, flexible and simple to treat electricity generation just as any other industrial activity.

Two regulatory paths to eliminating fossil carbon emissions

Regulation may limit either the **economy-wide aggregated emissions** of fossil carbon (as in cap-and-trade) or the **fraction of fossil carbon per individual facility**'s exhaust. Though the trajectory of reduction will be slightly different, the ultimate result of decarbonization (elimination of fossil carbon emissions) will be complete by the target date.

> ***Clark Miller**, Director, Center for Energy and Society*
> *Professor, School for Future of Innovation in Society, Arizona State University*

1bii. Interstate Transmission of Renewable Energy

***Question**: How can Congress expedite the permitting and siting of high-voltage interstate transmission lines to carry renewable energy to load centers?*

Improve infrastructure, refine policy

Two key takeaways

1. Decarbonizing electricity relies on rapidly developing or **improving infrastructure in three areas** to accommodate scale and diversity of electricity demand by 2050.
    a. High-voltage direct current **transmission networks**
    b. Renewable **fuels manufacturing** (produced without fossil fuels)
    c. **Transportation networks** (pipelines, railways, and other modes) nationally and internationally to locations where power is produced

2. Decarbonization within the Intergovernmental Panel on Climate Change (IPCC)-based timeframe relies on **policy and regulatory refinements that ensure strategic focus and coherence** among several domains, some existing and some needing to be created.
    a. Policy that is fragmented, too narrow, or out of date will prevent decarbonization from occurring or create perverse outcomes.

A high-voltage direct-current network

Stable long-distance transmission

An extensive high-voltage direct-current (HVDC) power network is absolutely essential to the carbon neutral economy. Computers, LEDs, solar cells and electric vehicles all run on direct current (DC) power, and long-distance transmission from wind and solar sources may be more stable through HVDC.

Policy considerations

Policies fostering acquisition of rights-of-way, simplification of permitting processes and assurance of low-cost capital are needed, but transmission siting may be easier to navigate. Unlike alternating current (AC) transmission used today, HVDC lines can be buried and run underwater in environmentally or aesthetically critical areas (though at considerably higher cost).

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired Adjunct Professor, School for the Future of Innovation in Society, Arizona State University*

Transporting renewable fuels as a means of interstate transmission

Retool existing infrastructure

Changes in electricity transmission will not completely decarbonize electric power. To decarbonize swiftly enough to meet IPCC timelines, while sustaining maximum flexibility and stability, some retooling of existing infrastructure must occur. Power plants that rely on hydrocarbons can be upgraded to use renewable fuels.

What are renewable fuels?

Renewable fuels can be liquid, solid, or gas and are not sourced from or produced with fossil fuels. They do not introduce new carbon into the system, but may be part of strategies that draw down atmospheric carbon. Biofuels are renewable if no fossil fuels are used in their production and the biomass source is renewably grown. Liquid fuels created from carbon dioxide, that are captured from the atmosphere and use solar, wind, or tidal energy to drive synthesis processes are renewable.

Fuels serve a role that transmission does not

Renewable fuels can decarbonize the electricity system by replacing natural gas and powering fuel cells. They serve a role that transmission does not by repurposing a large segment of existing infrastructure and allowing easy transportation of no-net carbon fuels anywhere in the country or around the world.

It's easier to transport fuels than to transmit electricity

Transporting fuels such as coal, natural gas, petroleum products, and even fissile (nuclear) materials, is much easier than transmitting electricity; options such as pipeline, truck, rail and ship. At least 5% of the electricity carried over distances through transmission wires is lost in travel. Electricity rarely travels more than 100-200 miles. In the U.S., fuels are typically transported to load centers where they are converted to electricity.

Fuels have an inherent storage value

Decarbonizing the power sector can include producing renewable fuels in regions where solar- and wind can drive their production, and transporting those fuels to load centers for power generation using decarbonized transportation. In fact, renewable fuels can be used both to decarbonize power and transportation.

One benefit of this approach is the inherent energy storage value of fuels; this is an integral, but not often considered, part of today's energy landscape. A second, related benefit is the possibility of developing an entirely new industry of overseas renewable energy exports, as a co-benefit of decarbonizing domestic electric power.

Support all forms of interstate transmission, including transport

To support a timely and cost-effective decarbonization of electric power, and specifically the interstate transmission of renewable energy, policies should support all forms of renewable energy transport, including transmission lines, pipelines, rail, road, ship, or air.

While the transport modes differ, they can all benefit from expedited permitting, such as siting pipelines for renewable fuels, reconsidering restrictions on vehicle-based transportation of renewable fuels, and fast-tracking approvals via the relevant agencies (e.g. FAA). Supporting all modes of renewable energy transport is also likely to spur innovation and unforeseen benefits in what has largely been a glacially-slow changing landscape.

***Ivan Ermanosky**, Research Professor*
School of Sustainability, Arizona State University

1c. Decarbonizing Industry

***Question**: What policies should Congress adopt to decarbonize the Industry sector consistent with meeting or exceeding net-zero emissions by mid-century? Where possible, please provide analytical support that demonstrates that the recommended policies achieve the goal.*

Reduce, reuse, replace

Target two kinds of carbon use

In developing strategies to decarbonize industry, Congress can adopt targeted policy approaches for industries that use carbon in two ways.

1. Industries that utilize carbon **directly in products** and processes, such as the plastics industry and others relying on petrochemicals
2. Industries that utilize carbon primarily **through power generation**.

Encourage or require a circular economy

Congress should enact policies that encourage or even require a 'circular economy.' This economy utilizes carbon more efficiently and incentivizes the use of *recycled* carbon—carbon captured from smokestacks, the atmosphere, or from waste streams—instead of utilizing new fossil-based carbon.

To succeed, Congress can consider policies that disincentivize and even penalize the development of new fossil carbon. This combination of policies could rapidly restructure industries that use or produce hydrocarbons.

***Elisabeth Graffy**, Professor of Practice, School for the Future of Innovation in Society and the Consortium for Science, Policy and Outcomes, Arizona State University*

Decarbonizing through a circular carbon economy

The take-make-waste industrial model is wasteful

Current industrial enterprises are extremely wasteful; they follow a linear, take-make-waste model of production and consumption that is overly carbon intensive. Using less carbon or emitting as waste, can be realized by developing sustainable circular industries that use end-of-life waste as a new supply input.

A framework example from the chemical industry

While the notion of a circular carbon economy has become popular, implementing it remains a challenge. ASU's Global Kaiteki Center is developing a shared roadmap for the Circular Economy in the chemical industry, focusing on plastics. Its purpose is to develop a circular economy technology innovation framework that addresses how the plastic/polymer chemical industry can innovate through new products, new manufacturing processes, and re-use, re-processing, re-forming and other circular activities. We have developed a draft sustainable

innovation framework and begun to map and apply this framework across the global plastic value web, including diverse technology and processes.

***George Basile**, Professor of Practice*
School of Sustainability, Arizona State University

Decarbonizing industry by decarbonizing fuel

Reduce hydrocarbon use in high-heat industrial processes

Many high-heat industrial processes rely on energy-intensive fuels such as natural gas and cannot be electrified using available technology. Therefore, in these cases, decarbonizing industry means decarbonizing fuel.

Decarbonizing fuel

Decarbonizing fuel means using hydrocarbon fuel that is not derived from fossil carbon or using hydrogen from non-fossil sources. Note that hydrogen today is produced by steam reformation of natural gas.

Policy considerations

A policy to decarbonize fuel could follow one of a few paths.

- A Renewable Fuel Standard (RFS) that requires an increasing renewable-derived fraction of hydrocarbon fuel, reaching 100% by or before 2050.
- Set emissions standards that require a decreasing fraction of fossil carbon in any exhaust stream falling to zero in 2050.
- Anticipate or even encourage a shift in which hydrogen from renewable sources (presently electrolysis of water using non-fossil electricity) is substituted for hydrocarbon fuel in many applications.

Focus on performance outcomes, not only how the energy is used

Recognizing the need to encourage innovation in both improving and replacing processes, policy can focus on performance outcomes as a way of cutting across a great deal of diversity in how industrial energy is used, and applying only to the source or form of that energy.

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired Adjunct Professor, School for the Future of Innovation in Society, Arizona State University*

1d. Decarbonizing Buildings

***Question**: What policies should Congress adopt to decarbonize the Buildings sector consistent with meeting or exceeding net-zero emissions by mid-century? Where possible, please provide analytical support that demonstrates that the recommended policies achieve the goal.*

Low-carbon building, measurement and rating

Rate buildings on how they are used, not how they were designed

Several sustainability rating systems have been developed to tackle the critical issue of decarbonizing buildings. Unfortunately, most such systems rate the buildings based on how they were designed, not on how they're actually performing during use, which is where most of the impact is. For instance, the literature shows that LEED certified buildings often do not save energy compared to traditional buildings, which is a critical missed opportunity.

Meter buildings for energy and water use, indoor environment quality

If you can't measure it, you can't improve it. To rate buildings based on their performance, a necessary policy would be metering all buildings for energy and water use, as well as indoor environmental quality. This would produce the needed data to base sustainability ratings on actual, rather than intended performance.

Reuse demolished building materials for cost and carbon savings

A recent ASU study shows that construction and demolition waste makes up the majority of solid waste in landfills globally. Therefore, switching to a circular economy would allow the reuse of demolished building materials. There are significant design and construction implications, as well as material sourcing challenges related to the circular economy. However, other industries, such as plastics and textiles, have been at the forefront of circular economy solutions. The construction industry can learn from these first-movers and create a significant impact on the global waste problem.

Hire integrated teams to design and build for improved building performance

A policy that has begun to be implemented around the nation is to understand how to select the team that will design and build the facility. ASU's Del E. Webb School of Construction was part of changing the Arizona legislation to allow innovative practices in quantifying improved performance for integrated teams. ASU faculty have co-authored national/federal guidance on such methods and regularly train governments on integrated delivery best practices.

***Mounir El Asmar**, Co-Director, Sustainable Construction, National Center of Excellence on SMART Innovations, and Associate Professor, Del E. Webb School of Construction, ASU*

Decarbonize building operations

Decarbonize emissions from building operations

Most of the carbon (dioxide) emitted by buildings is generated during its operations. Therefore, decarbonization of buildings depends on eliminating fossil fuel combustion within buildings. For residential and commercial buildings, the fuel used is dominantly natural gas (EIA Energy Outlook), most of which is used for space heating and cooking.

Lawmakers could prohibit sale of gas-, LPG- and oil-fired heaters, stoves and ovens (except in carefully defined circumstances) to force their replacement with electric counterparts (heat pumps and resistive heat) in 10 to 15 years. In addition, eliminating the use of incandescent lighting will significantly reduce both primary electricity and air conditioning loads.

Updated building codes will reduce future energy needs over time

Policy should drive building codes that reduce energy needs for heating and cooling through solar design (where feasible), improved insulation and high-efficiency appliances. As buildings are replaced much more slowly than the electrical and mechanical systems within them, this will have a delayed impact, but will reduce future costs and energy needs.

> ***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired Adjunct Professor, School for the Future of Innovation in Society, Arizona State University*

2. Leading the Decarbonization Transition

> ***Question:** What policies should Congress adopt to ensure that the United States is a leader in innovative manufacturing clean technologies; creating new, family-sustaining jobs in these sectors; and supporting workers during the decarbonization transition?*

Transitioning to Clean Technology Manufacturing

Invest in research infrastructure

Transitioning to clean technology manufacturing is intrinsic to a well-crafted climate policy. The rapid build-out of renewable energy technologies and accompanying retooling of industry will generate millions of mid- and high-skill jobs. Congress should invest extensively in U.S. research infrastructure in cutting-edge clean technologies, such as advanced photovoltaics, batteries, other electricity storage technologies, vehicle-to-grid technologies, smart grids, smart building energy management, carbon-neutral fuels, carbon dioxide removal technologies, and other innovative technologies to ensure that the U.S. has a strong supply of both innovative ideas and innovators working in clean energy technologies.

Invest in technology development programs and partnerships

Congress should also invest in technology development programs and manufacturing innovation partnerships that ensure movement of technologies from laboratory to startup companies to large-scale manufacturing. Congress should create clean energy manufacturing

redevelopment zones designed to harness the power of industry clusters and enable communities to facilitate planning for long-term economic transitions in areas that are economically dependent on fossil fuel energy technologies.

***Clark Miller**, Director, Center for Energy and Society*
Professor, School for Future of Innovation in Society, Arizona State University

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired*
Adjunct Professor, School for the Future of Innovation in Society, Arizona State University

3. Environmental Justice and Decarbonization of Sectors

***Question:** What policies should Congress adopt to ensure that environmental justice is integral to any plan to decarbonize these sectors?*

Protect and engage vulnerable communities

Expand the Emergency Planning and Community Right-to-Know Act

Congress passed the Emergency Planning and Community Right-to-Know Act in 1986, which focused on chemical emergencies largely in response to the gas tragedy at the Union Carbide facility in Bhopal, India in 1984. This act could be extended to protect vulnerable communities that could suffer under decarbonization efforts.

An environmental justice framework reduces harm and engages stakeholders

More importantly, environmental justice should be an added motivation and framework for accelerating decarbonization with the potential of reducing environmental harms to vulnerable populations (outcome equity) and engaging all stakeholders in the decision making processes (process equity). An environmental justice framing of decarbonzation can also inform which communities should benefit and be prioritized in the near-term as a means of compensation for past environmental injustices.

***Christopher Boone**, Dean and Professor, School of Sustainability and*
Professor, School of Human Evolution and Social Change, Arizona State University

Acknowledge uneven effects when enforcing policies

Enforce policies already in place

Congress needs to enforce the policies already in place. The Clean Water Act and Clean Air Act provide long-term, consistent support for environmental and social policies that are framed around the acknowledgement of climate change.

Put equity and attention to vulnerability at the center of policies

More importantly, equity and attention to vulnerability need to be at the center of these policies. The Clean Power Plan is a good example of a directive that acknowledges the uneven effects

politically, economically, and socially (as well as environmentally) for different groups of people, from coal miners to poor communities who don't have access to electricity.

> ***Jennifer Richter**, Assistant Professor, School for the Future of Innovation in Society and Assistant Professor, School of Social Transformation, College of Liberal Arts and Sciences*

Maintain data, participation, and analysis over the long term

Environmental justice concerns consistently emerge from decisions regarding the design and implementation of transportation, electricity provision, industrial activity and the built environment. Despite the diversity of policies in this arena, three major recommendations can be made moving forward.

Collect, maintain and publicly share high-quality data

First, the continued collection of and public access to high-quality data is a basic requirement for the pursuit of environmental justice across these arenas. Congress must guarantee adequate funding, human resources, and institutional support dedicated to the collection, public distribution, and maintenance of data essential to any environmental justice analysis. These data should include, at a minimum, information on race and ethnicity, gender, income, language use and educational attainment, environmental quality, mobility and access, and employment and health indicators.

Early and ongoing public participation improves outcomes

Second, any policy moving forward ought to include significant provisions for early and ongoing public participation in policymaking that go beyond existing norms of formalized participation included only at the end of policy processes. Ad hoc or incomplete inclusion of affected communities will erode the legitimacy and long-term political feasibility of any resulting proposals. As demonstrated in multiple state efforts to pursue carbon policies, including through carbon pricing (see both California and Washington State), excluding environmental justice communities concerns from the initial planning slowed or derailed subsequent climate policy efforts.

Mandate sustained analysis of environmental justice over time

Finally, sustained analysis of the environmental justice implications of any proposed policy should be mandated as a requirement for federal funding support. This would include a recognition of long-term climate risks in addition to the more immediate costs and benefits of any policy recommendation. This type of blanket process requirement will reduce risks that future policies will deepen rather than reduce environmental injustice.

> ***Sonja Klinsky**, Associate Professor, School of Sustainability, Arizona State University Observer to the UN Framework Convention on Climate Change negotiations since 2009*

Environmental justice is intrinsic to good policy

Pollution will decrease as new solutions replace old processes

To a large extent, environmental justice is intrinsic to a well-crafted climate policy. Mass deployment of electrified vehicles will vastly improve urban air quality. Many high-polluting industries such coal mining, coal-fired power generation, oil and gas extraction and oil refining

will simply cease to exist. That said, there are many other historical injustices that might be addressed as part of a climate policy so long as the stability and effectiveness of the overall policy is not jeopardized.

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired*
Adjunct Professor, School for the Future of Innovation in Society, Arizona State University

Invest in research

Study the human, social, and ethical dimensions of decarbonization

The most important policy Congress could adopt to ensure social and environmental justice associated with long-term decarbonization would be to invest in a substantial research program on the human, social, and ethical dimensions of decarbonization. No such program currently exists. Currently, the nation knows remarkably little about the social, economic, and justice implications of future changes in energy systems required to achieve decarbonization nor how strategies might be designed to improve the justice of outcomes and processes needed to protect the lives and livelihoods of all Americans.

***Clark Miller**, Director, Center for Energy and Society*
Professor, School for Future of Innovation in Society, Arizona State University

4a. Carbon Pricing and National Climate Action Plan

Question: *What role should carbon pricing play in any national climate action plan to meet or exceed net zero by mid-century, while also minimizing impacts to low- and middle-income families, creating family-sustaining jobs, and advancing environmental justice? Where possible, please provide analytical support to show that the recommended policies achieve these goals.*

A carbon price should be immediate, long-term, consistent and economy-wide

Carbon pricing sends an economy-wide signal

Carbon pricing should be a central element of any national climate action plan because it sends an economy-wide signal, but setting a carbon price alone is inadequate. Evidence to date demonstrates that carbon pricing through policies, such as cap-and-dividends, cap-and-trade, or carbon taxes, can help jurisdictions send sustained signals towards lower-carbon economies.

Economy-wide pricing plans are more effective than sector-specific ones

Sector-specific pricing plans are far less effective than economy-wide schemes for several reasons.

1. Sector-specific schemes require more intense regulation and oversight.
2. They may miss initially unforeseen emission reduction opportunities.
3. They can increase political tensions, as industries vie for special treatment.
4. In the case of cap-and-trade schemes, sector-specific programs can offer fewer opportunities for industries to find price differentials, which then reduces their incentive to reduce emissions.

It is essential that any carbon pricing scheme be economy-wide and apply uniformly to all activities and industries.

A nationwide carbon price alone is inadequate

However, a nationwide carbon price alone is inadequate. This is first because corporate lobbying routinely weakens them, thus reducing the signal they are able to send. Secondly a crucial issue in the design of the policy involves how the revenue is spent. If it is well-designed, the revenue generated through a carbon price can help align the pricing scheme with efforts to protect low income and environmental justice communities.

Use carbon price revenues to address environmental justice concerns

For instance, despite having a very low carbon price, the Regional Greenhouse Gas Initiative (RGGI) cap-and-trade system for New England and the Mid-Atlantic States still generated sufficient revenue subsidize weatherization and energy efficiency programs that allowed low-income populations to benefit financially while also reducing emissions.

Similarly, the California pricing scheme included explicit investments in and for environmental justice communities, which allowed them to directly benefit. Both examples demonstrate the importance of attention to the use of revenues and their potential to systematically address any environmental justice concerns that arise from the policy design.

An additional design option to protect low income low- and middle-income families is to provide them with a carbon tax credit as is done in the province of British Columbia.

Adopt an economy-wide policy that generates benefits for all

Congress should adopt a clear, immediate, long-term, consistent and economy wide-carbon pricing policy that includes mechanisms to use revenues to increase energy efficiency and facilitate wide low carbon development in ways that will generate benefits for all, including environmental justice communities.

Eliminate subsidies for production and consumption of fossil fuels

Moreover, Congress should systematically pursue the elimination of both production and consumption fossil fuel subsidies. As amply demonstrated, including through studies conducted by the International Monetary Fund, fossil fuel subsidies contort the price of energy and systematically result in lower energy efficiency and perverse market incentives. These subsidies have resulted in an artificially constrained market of energy providers and has hampered the development of fair competition between fossil-based energy and other energy sources including solar, wind, and other renewables.

***Sonja Klinsky**, Associate Professor, School of Sustainability, Arizona State University*
Observer to the UN Framework Convention on Climate Change negotiations since 2009

In a capitalist global economy, price ignites progress

With an overwhelmingly capitalist global economy, the one policy action that provides foundational energy to ignite rapid progress on virtually all of the topic areas is a national (indeed, international) price on carbon.

A national carbon price would drive every industry to which it is applied

While behavioral psychology indicates that there are many effective methods to motivate behavior change, economics is a well-proven, strong driver that motivates most every company, organization and individual. A near-term, revenue-neutral national price on carbon with built-in fee escalation would drive innovation and emissions reductions in every industry to which it is applied, as well as those industrial and consumer activities indirectly impacted.

Implement then expand H.R. 763

H.R. 763, the Energy Innovation and Carbon Dividend Act, is a bi-partisan, ready-to-go, solid piece of legislation to get this climate action started. Importantly, its ‘fee and dividend’ design returns the revenue to taxpayers and benefits an overwhelming majority of lower-income Americans while strongly influencing the economy towards an internationally competitive, clean-economy future. This policy should be implemented for CO_2 and then be rapidly expanded to include other powerful greenhouse gasses, such as those generated from synthetic fertilizers, landfills, dairy operations and wastewater treatment, as well as refrigerants.

Higher education institutions are already implementing carbon pricing

A handful of higher education institutions, including Arizona State University, have been experimenting with internal carbon pricing in order to lead the way, model innovative solutions, and develop implementation experience, results, and lessons learned with a variety of methods of carbon pricing. While formal research is just beginning, the experiments and experiences to date are documented in the Internal Carbon Pricing in Higher Education Toolkit. While these higher education efforts are important, major efficiencies, certainty, and massive scaling of climate impact would follow from a consistent national carbon pricing policy.

> ***Michael S. Dalrymple**, Director, University Sustainability Practices and Senior Sustainability Scientist, Arizona State University*

Provide tax credits to low- and middle-income families

Market dynamics are already rapidly shifting energy investment choices to low- or no-carbon options (like EVs and solar energy). To offset the impact of carbon taxes on low- and middle-income families, these families could be provided with tax credits equal to a portion of their carbon tax payments and extra incentives to enable them to transition off carbon fuels.

> ***Clark Miller**, Director, Center for Energy and Society*
> *Professor, School for Future of Innovation in Society, Arizona State University*

Factor in risk and uncertainty in determining a price to insure against climate change

Among economic actors, economic incentives are key to behavior change

The rapid transition to a low-carbon economy will only happen if there are adequate incentives to reduce emissions. Incentives are key to changes in behavior, and for economic actors incentives are reflected in wages and prices. The pricing of emissions of carbon and other greenhouse gases is not the only component of climate policy, but it is certainly the most important.

With climate change, uncertainties abound

Certain aspects of climate change, such as global warming, increased extreme weather and wildfires, ocean acidification, destruction of coral reefs and other ecosystems are well understood and can be forecast with high confidence. Other aspects of climate change are highly uncertain, such as future monetary damages and impacts on health, civil unrest, emigration, and national security.

There is also uncertainty about how quickly emissions can be reduced, how much it will cost, and which technologies will be most cost effective. Development time and cost are also unknown to directly capture and sequester atmospheric carbon dioxide. It is also uncertain how quickly technological advances could reduce both of those costs. It is unclear if technologies for cooling the planet through solar radiative management can be successfully deployed, and what risks such deployment might entail.

Given all these uncertainties, it is extremely difficult to forecast which technologies might be needed and at what scale. In order to create the near- and long-term changes in the behavior

required by consumers, businesses, entrepreneurs, investors, and asset owners, the only feasible approach is to create appropriate incentives.

Calculating an appropriate carbon price

Considerable research has been done to estimate the required carbon price. See, for example, "A winning trade," by David Bailey and Greg Bertelsen, as well as "Declining CO_2 Price Paths," by Kent Daniel, Bob Litterman, and Gernot Wagner.

The conservative case for a carbon price

Carbon taxes differ in terms of details of implementation and use of proceeds, but a widely supported proposal from the Climate Leadership Council addresses the issue of impacts on low- and middle-income families, protection of trade exposed industries and global coordination. Concerns about creating family-sustaining jobs and advancing environmental justice can be addressed by channeling some of the substantial revenues from a carbon tax toward achieving those goals.

> ***Robert Litterman**, Founding Partner and Chairman of the Risk Committee, Kepos Capital*
> *Member, Board of Directors, Julie Ann Wrigley Global Institute of Sustainability, ASU*

4b. Carbon Pricing and Decarbonization of Sectors

> ***Question:** How could sectoral-specific policies, outlined in questions 1-3, complement a carbon pricing program?*

An economy-wide scheme will be more effective

Sector-specific pricing plans are far less effective than economy-wide schemes because entities in similar activities will have similar costs and so little incentive or benefit to trade between those entities. It is essential that any carbon pricing scheme be economy-wide and apply uniformly to all activities and industries.

> ***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired*
> *Adjunct Professor, School for the Future of Innovation in Society, Arizona State University*

5a. Innovation for Climate Solutions - Where Should Congress Focus

Question: *Where should Congress focus an innovation agenda for climate solutions? Please identify specific areas for federal investment and, where possible, recommend the scale of investment needed to achieve results in research, development and deployment.*

Foster innovation, adaptation and resilience

Transform the electricity and fuel industries

To transform the electricity and fossil fuel industries to carbon neutrality, Congress should develop an agenda that includes innovations in governance and policy, organizations, markets, and social practices. This innovation agenda should work to develop carbon neutral fuels and foster research into removing carbon from the atmosphere.

Reduce risks from extreme weather events

Finally, the innovation agenda should include solutions for climate adaptation that enables individuals, households, communities, cities, and regions to reduce their risks from extreme weather events. We describe some of these areas of innovation in more detail below.

Invest in photovoltaic advancements and efficiencies

Invest in advanced photovoltaics

Congress should provide major new investment in the construction of research and educational infrastructure in advanced photovoltaics (PV) technologies. The market is rapidly creating opportunities for high-tech PV solutions that will benefit U.S. manufacturers of all scales, especially in startups and small-to-medium-sized PV enterprises serving diverse specialized markets.

To support this innovation, Congress can foster a robust research and advanced educational infrastructure similar to the semiconductor industry, by supporting essential research and training, foundry capabilities to manufacture experimental equipment, and advances in photovoltaic materials. These efforts will continue to advance U.S. technological and manufacturing leadership, such as is demonstrated in thin film PV.

Invest in high-efficiency cells

Especially crucial is continued investment in high efficiency cells. While existing PV cells are at record high efficiencies in manufacturing, major additional progress is needed. To reach the volume of PV worldwide needed by decarbonization, without further efficiency gains, will require higher costs, economically and environmentally. Increases in efficiency lead directly to cost declines in PV systems (including so-called soft costs and balance of systems costs) and proportionally reduce the environmental, land use, material use, and other environmental life cycle dimensions of terawatt-scale PV deployment.

***Clark Miller**, Director, Center for Energy and Society*
Professor, School for Future of Innovation in Society, Arizona State University

Advance solar technology to meet demand

As of 2019, 0.5 terawatts peak of solar panels have been installed globally, representing only about 1% of the global electricity capacity. Fifty terawatts of solar panels would meet only one-third of the projected 2040 global energy demand. So, we need to produce and install about 100 times more solar panels in the next 21 years to rein in carbon emissions and climate change.

Opportunities for innovation

The sheer scale of this mission creates roadblocks and also opportunities for investment in innovation. Some of the concerns are:

1. Many of the raw materials used in solar panels are scarce. For example, all the known silver reserves on our planet would allow a maximum wattage of 12 terawatts peak of solar panels, far short of the 50 terawatts peak needed by 2040. We need to **substitute earth-abundant materials for scarce materials**.
2. Energy consumption in producing solar panels is high. We need to **produce solar panels more efficiently**.
3. Recycling of solar panels uncommon. We need to **develop new recycling technologies**.
4. Storage of solar energy insufficient. We need to **build terawatt-scale storage technologies**.
5. The cost of solar systems is too high. We need to **reduce costs**.

We must develop new solar technologies based on low-cost, earth-abundant, energy-efficient materials and processes. Without breakthroughs in these areas, today's solar technologies will barely make a dent on our energy mix or carbon emission.

***Meng Tao**, Professor, School of Electrical, Computer and Energy Engineering*
Ira A. Fulton Schools of Engineering, Arizona State University

Reduce food waste

Methane emissions are caused by landfill emissions

Federal support for states and municipalities to divert food waste at multiple levels would go a long way in dealing with climate change emissions and other critical food systems problems. Landfills in the U.S. are the 3rd largest source of anthropogenic methane emissions in the country. Methane is a much more potent greenhouse gas than carbon dioxide (104 times greater). Methane emissions arise from the breakdown of organic matter. EPA estimates that 15% of all municipal solid waste is food waste.

Recover scarce phosphorous from wasted food

Wasted food also represents a critical loss of phosphorus. High-quality, mineable phosphate rock is used as an amendment to soils to grow food at the industrial scale. As mineable phosphate rock is considerably limited, phosphorus recovery from waste streams will be needed at many levels.

Collect and compost household food waste

Solutions include financial support for the development of municipal food waste collection and composting systems (which exist in some cities in the U.S. and Canada), and support for consumer education on food waste (our lab recently completed a successful 5-week educational intervention in households in the Phoenix, Arizona, area, resulting in a nearly 50% reduction in food waste (or .5 lbs/wk).

Help families eat healthfully and save money

It is estimated that roughly 60% of household food waste is avoidable, and reducing household food waste represents a considerable opportunity to help individuals and families eat more healthfully and save money simultaneously. These and other solutions are necessarily expensive and balance personal and social responsibility approaches to a problem that exists among consumers and across the supply chain.

***Christopher Wharton**, Assistant Dean of Innovation and Strategic Initiatives*
School of Nutrition and Health Promotion, College of Health Solutions, Arizona State University

Remove carbon dioxide from the atmosphere

Invest in carbon removal technologies

Congress should make public investments in exploring and developing both the technologies of carbon dioxide removal and the governance frameworks (policy, legal, regulatory, etc.) necessary to ensure that these technologies develop in a way that protects the public interest and recognizes ongoing public trust obligations. According to the IPCC and other scientifically credible sources, decarbonization requires removing anthropogenic carbon dioxide associated with fossil fuel combustion, both at point sources and from the ambient atmosphere.

Governance issues are equally critical

While further basic and applied research is needed to understand the technical feasibility of most carbon dioxide removal strategies (including direct air capture, ocean alkalinity enhancement, and regenerative agriculture), federal investment must go beyond the technologies associated with these activities.

Governance issues are equally critical and ought to be recognized as part of any innovation agenda for climate solutions. Balancing public goods and public interests with development of circular carbon economy options around sustainable, ethical design that accommodates the full lifecycle and fate of captured carbon dioxide is part of this.

***Elisabeth Graffy**, Professor of Practice, School for the Future of Innovation in Society and the Consortium for Science, Policy and Outcomes, Arizona State University*

An integrated approach will help people and businesses adjust to disruption

The need to invest in adaptation is increasing

In 2018, the planet's atmosphere passed 400 parts per million of carbon dioxide, meaning that we will need to spend an increasing share of resources on climate adaptation. Finding strategies to enhance the capacity of cities and rural regions to adapt to new and changing climate regimes will be an important focus in the upcoming decades.

Stable social outcomes require innovations in behavioral science

Understanding and coping with climate adaptation will require investments in innovations in social and behavioral science as well as new technologies. A significantly more integrated approach will be required to achieve stable social outcomes. Innovations will be needed to enhance behavioral and decision making processes by people and business and to help them adjust to shifting economic externalities and environmental stressors and their potential to disrupt social order.

***Deborah Strumsky**, Assistant Professor, School of Sustainability and School for the Future of Innovation in Society, Arizona State University*

Consider a range of possible futures

Encourage diverse solutions rather than a single silver bullet

Central to an innovation agenda for climate solutions is creating opportunities for achieving desirable outcomes under a range of possible futures. Determining which outcomes are desirable and possible is the messy task of our democratic institutions.

An innovation agenda for climate change should therefore adopt a pluralistic approach that encourages diverse solutions, rather than attempting to identify single 'silver bullet' technologies. The objective is not to discover a 'solution' to climate change, but rather to improve current solutions and future conditions in a way that increases prosperity and well-being for all.

Three future-focused strategies

1. Adopt decisive **reductions in loss of life** from climate-related disasters as a direct measure of effective climate solutions.
2. Put innovation at the center of the climate adaptation policy agenda.
3. Develop **innovative financial products**.

The example of blended investment

For example, public-private partnership using blended investment can provide much needed capital for local communities and cities to develop solutions. Financial services can be given to rehabilitate degraded land and returning soil to productive use. Investors see a return based on repayments on the loans or dividends from equity investments in activities, such as farming, that happen on the restored land.

***Netra Chhetri**, Associate Professor, School for the Future of Innovation in Society and School of Geographical Sciences and Urban Planning, Arizona State University*

Principles for Energy-Climate Innovation Strategy

Given in testimony before the U.S. Senate Committee on Energy and Natural Resources, December 2, 2009, by Professor Daniel Sarewitz and Independent Consultant John Alic.

Decarbonization is a public good

Recognize decarbonization of the energy system as a public good akin to national defense, provision of clean water and sewage treatment, and protection from natural disasters. In providing public goods in the absence of viable markets, the U.S. government has often spurred technological innovation, notably in military and intelligence technologies during the Cold War and in public health.

Encourage interagency competition

Encourage interagency competition, within limits, among government bodies charged with responding to climate change and fostering energy-climate innovation. Innovation occurs in response to 'environmental pressures' such as those created by market forces and public policies (e.g., regulation). And just as market competition encourages innovation by business firms, competition within government encourages innovation by agencies. Although too much competition within government leads to wasteful overlap and duplication of effort, DOE's monopoly over energy has not been conducive to either technological advance or policy development.

Tailor policies to technologies

Tailor innovation policies to particular technologies and suites of technologies. The U.S. government can call on many well-proven policy tools in addition to R&D for stimulating innovation. By most accounts, for example, procurement of integrated circuits for military and space systems had more impact on early innovations in microelectronics than government R&D, while DoD's insistence on non-proprietary technologies had powerful long-term effects on computing and computer networks.

Rely on private firms for innovation

Rely on private firms for innovation. Government has been a 'smart customer' for military technological innovations, outlining requirements and offering incentives in the form of possible future contracts for design, testing, and production of defense and intelligence systems. For energy, the U.S. government has relied too heavily on the DOE laboratory system, which has some excellent research capabilities, many of them closer to pure science than to practical energy technologies, but has not had strong and stable incentives to develop and maintain effective working relationships with innovative firms.

Consider indigenous innovation in developing economies

Seek international agreements and arrangements conducive to indigenous innovation in developing economies such as China and India. Many countries will have to take action if greenhouse gas emissions are to be controlled. Among the most powerful incentives for action is the prospect of home-grown innovations that can become a source of business profits, jobs, and exports. Viewing other countries primarily as passive recipients of 'technology transfers,' or as export markets for U.S.-based firms, would slow worldwide technological advance and hinder adoption of greenhouse gas-reducing innovations.

> ***Daniel Sarewitz**, Center Director, Consortium for Science, Policy, and Outcomes, ASU*
> *Former House Science Committee Staff Member*

5b. Innovation, Public-Private Partnerships, and Private Investment

Question: *How can Congress incentivize more public-private partnerships and encourage more private investment in clean energy innovation?*

Institutions must collaborate for sustainable futures

Most major institutions are poorly equipped to innovate by themselves

Acting individually, most of today's major institutions are poorly equipped to innovate toward a carbon-intelligent economy.

- Today's biggest **businesses**, in general, do not have internal mechanisms to plan or innovate for a sustainable future. For example, only recently have plastic producers become somewhat sensitized to global plastic waste even as they build more plastic global-production capacity.
- **Governments**, on the other hand, can see growing systemic pressure from sustainability issues, but lack the rubber-meets-the-road ability of business to drive sustainable practices and processes.
- **Universities** have been exploring and developing potential solution pathways for over 20 years, but do not typically engage in ways with government and business in ways that enable globally-co-development or informed actions that support institutional change.

We need a new class of partnerships between major institutions

We need a new class of partnerships between our key institutions where the partnership and innovation outputs are directly aimed at supporting action for sustainable, carbon-intelligent futures.

Partnership examples based at Arizona State University

Examples of such partnerships are currently underway at ASU, including entire schools focused on creating this form of collaborative, solutions-focused engagement such as the School of Sustainability and the School for the Future of Innovation in Society. Similarly, a novel set of collaborative applied-research and solutions-oriented innovation centers have also been developed, for example The Global KAITEKI Center and The Sustainability Consortium.

The Global KAITEKI Center (https://sustainability.asu.edu/kaiteki/) is specifically collaborating on an Innovation Framework and Innovation Roadmap for Sustainable Circular Economy in partnership with one of the world's largest materials company, as well as a new framework to deliver and measure increasingly high levels of social value via sustainable and carbon-smart business-innovation efforts.

These sorts of collaborations, which directly involve key motivated decision makers from the very beginning and aim at functional and innovative outputs that support action need to be expanded and multiplied across academia, business and government.

***George Basile**, Professor of Practice*
School of Sustainability, Arizona State University

Incentivize renewable energy adoption and research

We would like to see incentives extended to companies and individuals adopting renewable energy use. Additional incentives and grants could go to companies and universities working on storage technologies for solar systems.

***Andreas Spanias**, Professor, School of Electrical, Computer and Energy Engineering*
Ira A. Fulton Schools of Engineering, Arizona State University

Long-term private investment demands assurance of stable policy

Such partnerships are absolutely essential to climate policy. The tremendous levels of long-term capital investment demanded by decarbonization will not be possible without assurance of stable policy and low borrowing costs for decades to come.

***Mike Tamor**, Henry Ford Technical Fellow for Energy Systems and Sustainability, Retired*
Adjunct Professor, School for the Future of Innovation in Society, Arizona State University

Make partnership a requirement for federal grant eligibility

Several approaches can be used to incentivize partnerships. The most direct is simply to require partnerships to be eligible for federal investments or grants. Few federal research programs, for example, require partnerships between universities, national laboratories, and/or companies. In fact, usually the requirements make such partnerships more difficult. Removing barriers to partnerships is therefore another approach.

Create federal programs that require partnerships. Create business tax incentives that foster private investment in clean energy innovation.

***Clark Miller**, Director, Center for Energy and Society*
Professor, School for Future of Innovation in Society, Arizona State University

6. Reducing Emissions and Capturing Carbon in Agriculture

Question: *What policies should Congress adopt to reduce carbon pollution and other greenhouse gas emissions and maximize carbon storage in agriculture?*

True cost accounting in food production

Take a holistic policy approach

Congressional efforts to prioritize policies linking greenhouse gases and carbon storage in agriculture should adopt a holistic food system approach and move past the practices of narrowly focusing on production elements or biophysical dimensions.

Examine externalities, values and rewards

Decision makers are better served if armed with analysis of positive and negative externalities in the current system spanning from field to fork – waste streams and nutrient cycling – and how the values placed on outcomes are assessed and rewarded. Critical goals in agriculture involving greenhouse gas management require inclusive, comprehensive examination of how the wider system functions and adapts, and which actors and institutions are needed to innovate better solutions.

Examine flows between natural, productive, human, and economic capitals

Case studies from the U.S. and abroad have used Total Cost Accounting (TCA) to evaluate crop and livestock systems using such an approach. Complex relationships are analyzed among stocks and flows between natural capital and productive capital (involving energy, water use, soil health, plant and animal genetics, infrastructure) as well as human and economic capital (including nutritional outcomes, economic constraints and returns, skills and training levels, risk management and incentive signals, working conditions).

Better, more resilient policy adds value to human well-being

The agri-food value chain connects processes and drivers across production, manufacturing, distribution marketing, and retail, household and institutional consumption, and ultimately waste streams management. The potential for better, more integrative and resilient policies in the face of climate and other challenges lies with improving our understanding of the outcomes in terms of changes to the ‘four capitals’ described above, and how value is added to human well-being as measured across environmental, economic, health and social impacts.

In planning for the next farm bill, Congress should seek input on and evaluate Total Cost Accounting practices and food systems research to make programmatic changes in U.S. farm programs incorporating their findings into stronger and more sustainable farm program policies.

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Former Deputy Secretary, U.S. Department of Agriculture (2009-2013)

***Suzanne Palmieri**, Director of Strategic Initiatives, Swette Center for Sustainable Food Systems*
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Soil Health is the North Star

How healthy soil stores carbon at three time scales

Healthy soils draw down enormous amounts of CO_2 from the atmosphere, and hold the carbon in three time pools: days, decades and centuries (or longer). The days pool helps plants grow, but is too short to help with climate crisis mitigation. The decades pool, where carbon is sequestered as dead roots, is extremely helpful in climate crisis mitigation. This pool gives us decades to re-tool our energy systems to convert to clean sources. The centuries pool is the most effective and durable. This pool sequesters carbon in the form of dead microbes, which in turn make up the actual structure of healthy soil. We have seen soil carbon, a meter in depth, in the Washington Palouse, a soil that is 40,000 years old.

Store carbon and improve crop production with no-till and drill-seeding methods

Plowing is the most destructive management tool with regard to soil health; plowing releases soil carbon at scale. No-till, with cover crops, and drill seeding (without the use of glyphosate) is the best suite of tools to help restore soil health in row crop production.

Save money, improve soil productivity with AMP livestock grazing method

The fastest way to regenerate soil is with Adaptive Multi-paddock (AMP) grazing – emulating the way the bison and the Great Plains grasslands co-evolved over millennia. There are many examples of this soil regeneration, which also improves water cycle restoration, and farmer economic bottom line (due to lower input costs, and higher productivity of the soils) in the film series: www.carboncowboys.org.

Inspire and incentivize farmers to create change; don't force them

All of the above can be incentivized via the Farm Bill. Most American farmers do not use these regenerative methods; getting them to change is a big deal, and needs to be done with care. Incentivizing the farmers with favorable crop insurance, farm improvement loans, and knowledge exchange via extension services are all good ways to create change. Inspire them to change.

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Director, Producer, and Writer of Carbon Nation and Carbon Cowboys Films

Support transitions to regenerative practices

Congress can, through the Farm Bill and other legislative actions, promote transitions in the food and fiber sector that reduce greenhouse gas emissions and enhance the contribution of farmers and ranchers to climate solutions through regenerative practices, including soil carbon farming.

Invest in developing practices with lower petrochemical inputs

Conventional agriculture depends on petrochemical inputs and heavy machinery powered by fossil fuels, both of which contribute to climate change. Congress can substantially increase federal investments in existing programs focused on helping farmers and ranchers develop and adopt sustainable agricultural practices.

Incentivize revenue diversification through sustainable practices

Revenue diversification for farmers and ranchers makes their long-term financial viability possible. Incentivizing market compatibility between land use practices that reduce greenhouse gas emissions, capture and store carbon on-site, and site investments in renewable technology are win-wins for agriculture and for society. For instance, economic incentives that reward no-till or permaculture practices on livestock pastures and cropland with preferential leases for wind or solar leases and installations (as opposed to fracking or mining) would improve carbon outcomes.

Evidence does not support expectation of widespread adoption of BECCS

Many scenarios involving Bioenergy with Carbon Capture and Storage (BECCS) or regenerative agriculture rely on assumptions that farm and ranch management practices that have historically been pursued as conservation or agro-environmental strategies can be dramatically and quickly scaled up through widespread adoption and that market incentives can be readily designed and applied for permanent carbon storage in biological and soil resources. These assumptions are not supported by historical evidence.

Conservation behavior change and its benefits are impermanent

Conservation practices tends to be adopted slowly, are subject to individual preferences (i.e., cannot be strictly enforced), and the environmental benefits are not permanent. Incentive-based conservation behaviors can change quickly when incentives change, and climate changes are creating conditions that can threaten the integrity of natural systems intended to store carbon. Fires, floods, wind, pests, and extreme heat, cold and drought all hold implications for the carbon-holding capacity of agricultural and rangeland resources.

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Biochar as a Soil Amendment

Make biochar from crop and forestry residues, manure

Biochar, created by burning organic waste in oxygen-deprived chambers, is a carbon-rich form of charcoal that has a number of uses.

Biochar holds water and nutrients and improves agricultural productivity

If incorporated into soil, biochar enhances soil's ability to retain nutrients, and improves water-holding capacity of soils. Some of the most remarkable and best-understood benefits of biochar include its positive effects on agricultural productivity.

Biochar absorbs chemical runoff, stores carbon and lowers other emissions

Biochar reduces runoff chemicals, such as pesticides and herbicides, from agricultural land. It is also one of the best options for permanently sequestering carbon, while simultaneously lowering methane (CH4) and nitrous oxide (N2O) emissions from soil.

Biochar is a cheap, low-risk and high-reward strategy

Every ton of biochar applied to the soil is equivalent to 0.61 to 0.80 tons of carbon (i.e. to 2.2 to 2.93 tons of CO_2) sequestered. So, biochar's potential for carbon sequestration provides an intriguing case for global carbon dioxide mitigation. At a time when geo-engineering is attracting growing interest as an option for keeping global warming below 20C, carbon sequestration possibilities of biochar are seen as a promising route to climate mitigation. It is a lower-risk, low cost and high reward strategy than other carbon sequestration options currently under discussion.

Invest in biochar research to maximize carbon storage and agricultural production

Assessments of the potential of biochar to reduce carbon pollution and other greenhouse gas emissions and maximize carbon storage in agriculture depend heavily on the way that biochar is produced and the type of feedstock used. Congress should fund investment in research to provide the broader evidence and support for biochar use. For example, not all crops respond to biochar the same way and not all soils show broad improvement with biochar application; even when the biochar appears fit for the purpose. Current knowledge about the effects of adding biochar to agricultural system is not sufficient to support large-scale production and use.

***Netra Chhetri**, Associate Professor, School for the Future of Innovation in Society and School of Geographical Sciences and Urban Planning, Arizona State University*

Reducing Emissions and Capturing Carbon in Agriculture

Substitute renewable fuels in agricultural machinery and use non-petroleum fertilizers

In regard to fossil carbon emissions from agricultural machinery and fertilizer synthesis, direct carbon emissions from agriculture will be reduced dramatically by the substitution of renewable fuels in agricultural machinery and the use of non-petroleum-based fertilizers.

Ensure that carbon is sequestered for thousands, not tens or hundreds, of years

In regard to possible carbon sequestration, agricultural (or forest) sequestration must be treated with extreme caution. True sequestration must guarantee that captured carbon is in a form that does not require monitoring and is not re-released for thousands of years. While agriculture and forestry are useful in capturing carbon, these natural forms are stable for only tens or a few hundreds of years and must be converted to a more stable form ('artificial anthracite') in order to claim a permanent offset to atmospheric carbon.

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7. Adapting to Climate Change Impacts

Question: *What policies should Congress adopt to help farmers, ranchers, and natural resource managers adapt to the impacts of climate change?*

Incentivize farmers to maintain soil health and runoff mitigation

Healthy soils curb toxic algae blooms from farm runoff

Farmers are at the front lines of land use at scale in the U.S. When their soils are healthy, rivers and large bodies of water do not experience toxic algae blooms from farm runoff. Farmers should get financial incentives to reduce their farm runoff to zero – and the quickest way would be for them to farm without nitrogen fertilizer. Regenerative agricultural practices would enable this.

Healthy soils reduce downstream flooding and water treatment costs

When soils are healthy, they absorb massive amounts of rain during the extreme events we are now getting used to. When the water drains properly into soils, there is much less flooding downstream. The water, when it does reach the cities, is cleaner, and thus saves water treatment plant costs. When farmers' healthy soils absorb all the rain, they recharge the local aquifers over time, a benefit to future generations. Congress should pay farmers for the cost savings of their actions to protect their soils now and for future generations.

Rebuild soils through regenerative agriculture

Every decision involving farms should go through the filter of soil health. Our nation's soils are in critically bad condition: our farming practices have created massive soil erosion and the soil will not last. We must rebuild our soils, via regenerative agriculture for national security, food security, and economic security.

Peter Byck*, Professor of Practice, School of Sustainability and Walter Cronkite School of Journalism and Mass Communication, Arizona State University*
Director, Producer, and Writer of Carbon Nation and Carbon Cowboys Films

Prioritize soil quality to capture carbon

First, soil health and quality is the key factor that underpins agricultural and rangeland productivity, sustainability, and resistance and resilience to climate change. Carbon sequestration in agroecosystems is an especially important of soil and environmental health.

Decrease carbon losses through sustainable management practices

First, sustainable management practices, such as no-till, crop stubble retention, and the use of cover crops, are all well-known methods to decrease carbon losses. The top meter of soil around the world contains three times more carbon than the atmosphere and losses of soil carbon has contributed to between 10-20% of the total anthropogenic emissions. Management practices ultimately decide whether the remaining soil carbon will be retained and whether soils can act as a future carbon sink. Tillage reduces soil aggregates which are responsible for

carbon sequestration, the ability of a soil to retain water and nutrients, and contribute to a healthy soil microbiome.

Organic fertilizers increase soil fertility and reduce soil pathogens

A second principle factor is the use of inorganic fertilizers, in the rate and timing of application. Inorganic fertilizers drastically alter carbon cycling in an agricultural soil, speeding up the decomposition of 'older' carbon to CO_2. This occurs in pulses that correspond to fertilizer application. Inorganic fertilizer use appears to contribute to the prevalence of plant pathogens and their ability to infect plants.

Organic fertilizers that combine the addition of both carbon and nitrogen (e.g. compost fertilizers) result in a slower release of nitrogen and have been shown to increase soil fertility by increasing organic carbon, water holding capacity, and the prevalence of soil aggregates. Organic fertilizers also appear to reduce soil pathogens and their ability to infect host plants.

Policy considerations

To tackle issues related to climate change adaptation in agriculture requires a concerted effort focused on the following.

- Education of farmers and corporations on soil fertility and health is integral.
- Incentives should be monetized, for example through the monitoring of soil organic carbon pools (which is inexpensive, rapid, and easily performed at USDA outreach posts).
- Farm insurance should be tied to the ability of an agroecosystem to enrich soil carbon pools.
- Loss of soil carbon is directly tied to losses in productivity which impact crop valuations.
- Assessment of soil carbon is critical for determining the resistance of cropland to a climate-induce impact (e.g. flooding, drought, plant disease).

As the soils of this nation allow for the highest agricultural productivity in the world, it is up to us to responsibly manage this national resource to ensure food security for future generations.

***C. Ryan Penton**, Associate Professor, Science and Mathematics*
College of Integrative Sciences and Arts, Arizona State University

Fund development of local-scale adaptation innovation

Innovation is integral to societal response

Innovation, a process through which new (or improved) technological and institutional arrangements are brought into practice, has always been an integral part of the societal response to the multiple stresses from the natural world. It will continue to be central to climate change adaptation, which depends on the ability and willingness of individuals, institutions, and societies to learn from experience and make beneficial changes—to innovate—in order to thrive in their environment.

Farmers and ranchers excel at innovation

Far from being a new activity undertaken in response to climate change, farmers, ranchers, and natural resource managers excel at the kinds of innovation-led adaptation that have lessened

their vulnerability to climatic and other challenges and allowed them to flourish in changing climates.

Innovation requires iteration, learning from experience

Effective adaptation, like other innovation processes, requires learning from their experience, experimenting with novel practices and technologies, and participating in a network of people who can share and evaluate new practices that emerge from particular contexts.

Funding is needed to support local solutions to very localized impacts

Critically, what is needed most is funding support to these communities to design local solutions to the very localized impacts of climate change already being experienced. This goes beyond disaster relief funding, but takes a more proactive approach so that farmers, ranchers, and natural resource managers can become more resilient to disasters as the new climate unfold.

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Mitigating the Adverse Climate Impacts on Nutrient Cycling

Intensifying weather patterns affect nutrient cycling

Climate change intensifies weather patterns that affect the cycling of nutrients, such as phosphorus and nitrogen, through the environment. The plants that undergird the food chain mine these nutrients from the soil and deliver them to us through the food chain. The soil obtains them through fertilizers applied by humans and through weather-impacted physical and biological processes that will all be altered by climate change.

Nutrient losses due to runoff lead to pollution of surrounding waters

For example, high temperatures may reduce the ability of farmland soil to capture or ‘fix’ atmospheric nitrogen and may drive more intense rainstorms that erode soil and wash away nutrients, requiring farmers to apply more fertilizer or adopt other practices to compensate. However, increased fertilization may increase the transport of nutrients to surrounding waters and cause severe water pollution issues. In some watersheds, major reductions in nutrient losses from farmland will be required to offset this increased mobilization of nutrients.

Policy considerations

To help effect these changes:

1. **Increase funding for the conservation titles of the farm bill**, with a focus on improving soil health and implementing best management practices for nutrients.
2. **Increase regulation of agricultural animal waste**. We have made impressive reductions in nutrient pollution from human waste. A commensurate reduction is now required of animal waste.
    a. Avenues to improvement include increasing funding for monitoring and enforcement of pollution regulations for National Pollutant Discharge Elimination System (NPDES), EPA-regulated animal feeding operations and eliminating their agricultural stormwater discharges exemption.
3. **Revert to the 2015 Rule defining “waters of the United States”** to protect wetlands and headwaters that buffer nutrient pollution of sensitive watersheds.

4. **Incentivize a shift to plant-based diets**. This reduces the acres we need to farm because we can grow more calories/protein per acre by eating crops directly rather than eating the animals that eat the crops. Restoring acreage to wetlands and forest will further reduce nutrient losses and help sequester carbon.

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Improve efficiency of agricultural water use

Climate change reduces water availability, threatens food security

The Fourth National Climate Assessment completed in 2017 documents that annual precipitation has declined in much of the U. S. West, Southwest, and Southeast. Reduced water availability combined with competing water demand from multiple sectors results in an emerging urgent need to improve the efficiency of agricultural water use, a critical global water adaptation strategy for food security.

Science-backed options for improving water efficiency in agriculture

Crops use more water in dry years. A recent study conducted as part of a NOAA funded project, led by Soe Win Myint, provides several options and implications for climate adaptation with regards to agricultural water conservation for food security:

1. **Double-cropping** practice uses substantially less water than do the same two crops in two different areas as single crops.
2. **Choose less water-intensive crops**. Crop selection is vital in water conservation for future food security.
3. **Choose drought-tolerant crop types**. Some crop types use notably higher amounts of water in dry years even though they may consume much less water than other crop types do overall.
4. **Reduce the proportion of land area planted with water-intensive crops**. Plant more water efficient crops at each site.

It is not necessary to reduce the total land area planted with crops. It may even be possible to sustainably expand agricultural areas if they are planted with less water-intensive, more drought-tolerant crops, and if double- and/or multiple-cropping practices are employed.

Compared to controlling total crop area and limiting crop water use, crop selection and mixing, as well as double- and multiple-cropping practices, are important for water conservation in drought-sensitive regions.

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Coordinate across sectors and scales

Adaptation in agriculture will be enhanced if undertaken as part of efforts in intersectoral (e.g., urban/agriculture/environmental services), watershed-level and inter-urban planning coordinated at multiple levels of governance.

Examples of cross-sectoral collaborations in Arizona

For example, numerous federal agencies and non-governmental organizations in Arizona have built relationships between environmental and agricultural interests to advance regional, economic, and conservation goals. Natural Resources Conservation Service has been an innovator in thinking about land use and ecosystem services related to ranching, helping to serve as a broker and building trust between conservation and agricultural interests. The Bureau of Land Management initiated a collaboration between ranchers, state agencies, and the United States Forest Service to protect a vulnerable and archeologically important ecosystem.

Collaborative planning reduces conflicts over resource allocation

These institutional efforts in coordinated and collaborative planning enhance confidence, build trust and help to ensure greater flexibility in decisions prior to a significant reduction in resource availability, which can create significant conflict between agriculture and other resource users.

Continue federal support of FFAR

Continued federal support for the Foundation for Food and Agriculture Research (FFAR) is needed; FFAR provides innovative grants focused on system-level understanding that leverage existing partnerships; such funding is important if we are to continue to support the development of flexible institutions to respond to current and future variability and change in agriculture.

Tap Extension Service to build capacity of irrigation district management

Agricultural adaptation in irrigated regions of the U.S. must involve investment and capacity building with irrigation district management. Greater certainty in the availability of water and land for farming under conditions of market and climatic stress require support for more coordination and collaboration between urban, peri-urban and rural interest groups, a role that the U.S. Cooperative Agriculture Extension Service could potentially effectively play in the future.

Coordinate water allocation over longer time horizons

Research with cotton growers in Central Arizona found that farmers experience climate risk largely through volatility in water prices and the availability of water in their irrigation districts. Irrigation districts can manage water more effectively and flexibly if they are coordinating water availability and allocation over longer-term planning horizons with surrounding urban areas.

Encourage crop and economic diversification

At the farm level, farmers can benefit from federal programs and policy that encourage crop and economic diversification into less climatically sensitive production systems, particularly when such policies are supported through collaborative intersectoral planning and novel partnerships.

Save water, grow hops, sell them locally – an Arizona example

In Arizona, the Nature Conservancy has helped to incentivize shifts to less water intensive crops, like barley, which is then used to make malt that is sold to local craft brewers. Through this innovative mechanism, the Verde River gets more summertime flow, farmers get access to local markets, and breweries get homegrown, high-quality malt for their product.

Innovate new types of agreements or use existing agreements in new ways

Additionally a willingness of agencies and NGOs to generate new forms of agreements, such as the creation of grass-banking systems, or use existing instruments, such as Conservation Resource Management Plans or conservation easements, in novel ways provides the legal frameworks for long-term partnerships.

Agriculture produces diverse benefits

Taxpayers must understand the lesser-known benefits of agriculture

Increasingly, the adaptive capacity of agriculture in the United States -- particularly in relation to farmland near urban areas -- will depend on the willingness of taxpayers to recognize the multiple functions that agriculture has the potential to provide. Economic benefits include commodity production, direct sales of local food, agritourism, local and regional employment and small enterprise development. Local ecosystem benefits include, for example, groundwater recharge, wind breaks, heat island mitigation, agrobiodiversity and pollinator support. Agriculture also benefits our national economic and food system vitality.

Example of phosphorus recycling in Phoenix

An expansion of the dairy industry around the Phoenix metropolitan area led to an increased demand for animal feed, and thus an expansion of alfalfa production. This has provided an opportunity for increased internal recycling of Phosphorus, as phosphorus-rich dairy cow manure is applied to alfalfa fields as fertilizer, and the valuable phosphorus is reclaimed through local recycling of biosolids and wastewater treatment. The proximity of urban populations with dairies and feed production and low runoff in this arid climate have facilitated this serendipitous recycling of Phosphorus in the region.

Optimize multifunctional benefits, build taxpayer support for agriculture

The ‘unintentionality’ of this recycling may mean that current recycling is not maximized and that it is highly vulnerable to future changes in underlying economic and climatic conditions. Evidence suggests U.S. taxpayers invoke such multifunctionality as reasons for being supportive of agricultural protectionist policy. Nevertheless, policy leadership, farm-level incentives and research investment is required to ensure the agricultural sector can deliver food security, ecological services and economic forward and backward linkages effectively under a range of environmental and market conditions.

Water use in agriculture is more flexible than in buildings and industry

Participatory future visioning sessions held in different parts of Arizona found strong support in favor of maintaining agriculture as part of an integrative climate adaptation strategy for the region as a whole. The agriculture sector can serve as a more flexible source of water use when compared to the fixed consumption associated with urban and industrial use; with appropriate institutional arrangements, agriculture can enable flexible movement between groundwater and surface water resources as a regional coping strategy for enhanced climate resilience.

Interest in local food affects agriculture’s economic footprint in Arizona

Interest in local food has also been growing, with consumers stating better quality of produce, support of local community, and knowing where one’s food comes from, as the major reasons for supporting local food. In 2017, agriculture’s economic footprint in Arizona was found to be around $23 billion.

Data is needed for effective planning and decision making

Although governance and institutional design is critical for adaptation in agriculture, appropriate technology also has an important role to play. Climate services play an important role in providing the information and evidence that is needed for effective planning and decision making. The availability and use of satellite imagery for identification of changes in cropping patterns and cropping intensity is an important tool for adaptation during droughts. Cotton growers in Central Arizona emphasized the need for information on water and energy prices, as these play critical roles in the experience of water scarcity in irrigation districts.

Continue supporting federal provision and dissemination of data

Continued support for the National Oceanic and Atmospheric Organization's work on climate service provisioning and dissemination, through for example, the NOAA RISA program and Climate Resilience Toolkit, is constructive in providing specific decision support for farmers, salient to their cropping strategies and location.

Flexible agricultural financing enables farmer persistence

Agricultural finance oriented towards resource conservation strategies, such as is made available through the EQUIP program of the USDA, plays a role in enabling farmers' persistence in the face of multiple stressors, including those associated with drought and water scarcity. Lack of flexibility in agricultural financing, particularly for those who are leasing land, limits cotton growers' ability to maintain access to land and make capital investments in such technology as drip irrigation. Innovative financial instruments in the form of new types of operational loans, for example, would allow small farmers and farmers that lease all or most of their land flexibility to support necessary changes in production and investments in infrastructure to transform agriculture for the future.

Infrastructure investment can support climate adaptation

Access to appropriate agricultural infrastructure such as cold storage and market facilities also can help with crop diversification as a strategy to cope with changing soil and water conditions.

Many factors affect farmers' adaptation options – examples from Arizona

Farmers do not adapt to climate risk in isolation; their strategies are significantly shaped by multiple sources of risk from changes in the policy environment, changes in input costs, volatility in international markets and shifts in policy priorities in other nations and geographic locations that affect farmers' choice sets.

In Arizona, the ability of cotton growers to respond to changing water availability is also a function of the dynamics of the real estate market, as was demonstrated in the 2007/2008 recession. More recently, changes in Middle Eastern water conservation policies and increased preferences for dairy products have led to a shift of alfalfa production to export to this market, and even purchasing of numerous farms by United Arab Emirates firms to control production in Arizona. Changing policies related to the hydrology in foreign locations tele-couples with land and water use in Arizona.

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8. Land Management for Adaptation and Mitigation of Climate Change

Question: *How should Congress update the laws governing management of federal lands, forests, and oceans to accelerate climate adaptation, reduce greenhouse gas emissions and maximize carbon storage?*

Laws impact resource management

Identify which existing laws are relevant

Many domestic laws govern management of federal lands, forests and rangelands, whereas a combination of domestic and international laws govern oceans. First, Congress should direct committee staff and the Congressional Research Service to clarify precisely which laws are applicable and the degree of discretion the U.S. possesses. Presently, a wide variety of laws apply to the management of these resources, in the U.S. and globally, with implication for climate adaptation, greenhouse gases, and carbon storage planning.

Direct departments to update and coordinate their adaptation plans

Regarding climate adaption, Congress should use the appropriations process to direct the Departments of the Interior, Agriculture (Forest Service) and Commerce (NOAA) to update and coordinate the most recent adaptation plans on record. Most federal departments have long-standing climate adaptation and action plans. Refining and integrating these plans with specific coordination goals should be doable in a period of time, set by Congress on an accelerated timetable.

Require agency activities to meet or exceed industry regulations

Congress could use its appropriations authority to require federal natural resource management agencies to develop updated orders. Congress could pass new legislation superseding executive action (which is voluntary and subject to administrative discretion) to require decarbonization performance outcomes from federal activities equivalent to or greater than those required of industry.

Integrated and coordinated assessments are needed

Meet carbon management goals without damaging natural systems

An integrated carbon management assessment plan to maximize carbon storage should promote the maximum integrity of natural systems. Assessing how to meet both goals requires substantial coordination within federal agencies and with external experts to account for evolving climate-change related risks, which affect ecological status and the carbon storage potential of forests, oceans, pastures, cropland, and mineral deposits.

Coordinate between research and policy domains

This dual-goal planning requires strong and time-sensitive coordination, assessment and translation between research and policy domains. It should include government entities (such as the U.S. Geological Survey at Interior, the Natural Resources Conservation Service at USDA, and the Climate Office at NOAA), universities, and non-governmental organizations.

The plan should examine a range of evolving technology developments, ecosystem status and trends, and social implications. It should develop reliable mechanisms for dynamic assessment involving stakeholders, researchers and decision makers about the potentials, options, and tradeoffs among land, ocean and biologically based sequestration strategies.

Knowledge gaps are a critical national policy concern

Research in these spaces narrowly focuses on specific resources or geographic locations, with remaining gaps in knowledge about those and almost no focus devoted to cross-compartmental implications. That is a critical national policy concern. While many have called for this capacity to be created, including the National Academies of Science, it does not exist.

Coordinated assessment and translation capacity shows no prospect of occurring without explicit Congressional direction and support. Congress should direct the Governmental Accounting Office (GAO) to mount a study to establish the state of knowledge on this issue and include an ongoing line item to support this capacity. This topic should be high priority in current discussions to enhance Science and Technology Assessment capacity in Congress, which is currently receiving substantial attention and is part of bills aimed at modernizing Congress.

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9. Non-CO_2 Greenhouse Gases

***Question:** What policies should Congress adopt to reduce emissions of non-CO_2 greenhouse gases, including methane, nitrous oxide, and fluorinated gases?*

Arizona State University's answers to this question may be found in other sections, including 5a (Innovation) and 6 (Agriculture).

10. Carbon Removal Technology

How can Congress accelerate development and deployment of carbon removal technology to help achieve negative emissions?

Cross-Cutting Policies

Put a price on carbon

Put a price on carbon by demanding carbon removal. One might think of this as a tipping fee.

Carbon Removal Technology

Support research and development

To stabilize climate at a safe level, removing substantial amounts of carbon from the atmosphere is by now unavoidable. Yet, carbon removal technologies are still too costly (especially direct air capture), are not well developed, are in competition with other land uses, or have their own environmental footprint. Therefore, support for research and development on a scale at least comparable to point-source carbon capture is critical.

Accelerate introduction of carbon removal technology

Congress can accelerate the introduction of carbon removal technologies in several ways.

1. **Natural sequestration should be developed** because it can deliver at low cost, direct air capture combined with carbon storage; it should be supported because it is likely necessary to operate at the requisite scale.
2. Carbon removal must be **verifiable and accountable**. This can be done through the development of a credible **certificate of sequestration** backed by the necessary institutional support to link certificates to the emerging carbon price. For example, one could credit any carbon tax back to carbon removal, or demand that a growing fraction of fossil carbon extraction is matched by carbon removal. It is possible to combine the two ideas by only taxing the decreasing fraction of carbon extraction that is not canceled out by mandatory carbon removal, but allow a **tax credit for additional carbon removal**.
3. Since learning by doing is the most powerful way of reducing cost, Congress could facilitate and fund the use of **purchase agreements to accelerate the buy down in cost** for direct air capture technology. This approach has proven very powerful in buying down the cost of renewable energy. While wind and solar had to reduce costs one-hundredfold, direct air capture is currently about five times too expensive. Therefore the need for support is likely much smaller than it has been for renewable energy.

***Klaus Lackner**, Director, Center for Negative Carbon Emissions*
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11. Resilience and Adaptation

Question: *What policies should Congress adopt to help communities become more resilient in response to climate change?*

Improve and enhance access to environmental and health data

Publicly available environmental data helps communities prepare
Current environmental data are difficult to come by, sparse, or are being taken over by large corporations (IBM, Weather Network). Accurate data that are more openly available are generally collected by federal or state governments yet are not fully accessible or well-understood by the public.

When data are open and made available for the public, they become actionable and are a public good. Such data help communities prepare for hazards, improve environmental literacy at a local scale, empower individuals and communities, and lead to healthier lives, all of which increase resilience. Investing in improved data sources, monitoring, and sharing (climate/weather data, pollution, and other environmental) can help communities improve their environments and resilience.

Finer-scale human health data improves tracking of environmental exposures
Improved human health data at finer scales improve our ability to connect environmental exposures to health at higher spatial and temporal resolutions. These data are needed at the scale at which policy decisions are made to support more appropriate actions and track vulnerable communities.

Sometimes only statewide information on specific health outcomes is available, which is often too coarse to help U.S. understand health impacts of environmental changes at the community level. Investing in higher resolution health data for improved tracking, such as the direction taken by the Centers for Disease Control and Prevention (CDC) Environmental Public Health Tracking Program, can help communities improve their resilience to climate change.

Acknowledge inequity

Address systematic vulnerabilities to a changing climate
We need to ensure that solutions-focused activities to address impacts due to climate change are implemented equitably. Many of the climate impacts we are most worried about (heat waves, precipitation variability, pollution) are already large issues that are poorly dealt with. With climate change, these issues are expected to become worse; thus, the current risks to vulnerable communities will increase without society having a chance to focus on environmental justice. We need to focus on building adaptive capacity and resilience in the populations that need it most, through means like education, infrastructure, and improved data sources, to help us solve problems now and in the long term.

Recognize and learn from adaptation successes

Successful adaptation is key to protecting lives

We can slow down the changing climate through mitigation, but adaptation will be the key to protecting lives. In the U.S., many climate change related impacts have decreased due to adaptation. For example, heat-related mortality is decreasing, even though temperatures are rising because of adaptive mechanisms to protect the most vulnerable populations (social, infrastructure, technological, behavioral).

Examples of successful adaptations

We need to learn from examples of what we are doing well. Such examples might include improved communications systems in cities amongst emergency responders, police, fire fighters, and power and water companies during hazards. Another example encourages improved messaging techniques by the National Weather Service via social media and other alerts. A third example includes infrastructural adaptation to houses built along coastlines.

Communicate best adaptation practices

We should craft communications around questions such as: What are we doing right? How can we learn from that and replace currently broken systems with proven methods?

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Co-produce research and solutions with communities

Train people to meet with local communities

Congress should invest in the resources needed to train people to meet with local communities to determine their needs to improve their resilience and adaptive capacity. This process should go beyond conventional customer surveys or working to appease complaints.

Congress should focus on determining the strengths and assets that exist in as many communities as possible and use them to help the communities find their own expressions of resilience.

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Take an interdisciplinary approach

By blending humanistic and scientific approaches, interdisciplinary teams can support the development of applied research agendas that address the problems at hand rather than serving individual research agendas.

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Support long-term urban strategic planning

Finance cities to plan for adaptation

Create a federal program that finances cities to strategically plan for climate adaptation, requiring them to draw on the resources of federal agencies, universities, and industries (which could also be financed through research programs). Cities are the major entities at risk from climate change and do not currently have the resources to staff major climate adaptation planning efforts.

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11a. Extreme Weather Risk

***Question:** What adjustments to federal disaster policies should Congress consider to reduce the risks and costs of extreme weather and other effects of climate change that can no longer be avoided?*

Collect actionable data to cope with and adapt to extreme weather

Update FEMA's all-hazards mitigation plan

The all-hazards mitigation plan, mandated by Federal Emergency Management Agency (FEMA) to respond and adapt to extreme weather events, needs additional information that would allow the plan to be effective. To ensure the efficacy of the plan, changes should:

1. Adjust the time scale of information to **coincide with planning and budget cycles**
2. Collect **additional information about weather hazards** including frequency of occurrence, duration, and magnitude.

Give communities better data to prioritize hazard planning

Due to the ambiguity that surrounds the process by which urban planners define hazard risk, we need to understand the type of weather and climate information communities need to better prioritize hazard mitigation planning. For example, knowledge of precipitation under current and projected climate regimes can allow engineers and city planners define flood risk zones and water retention areas.

Require local risk maps for use by emergency responders

Emergency responders benefit from local hazards maps that indicate the places most at risk of a given hazard (e.g. flood plains, high flood areas, hottest areas of cities, areas with poor electrical infrastructure, etc.) and well as information on the most vulnerable populations. Such information can be required at the city government level to ensure timely and hazard-specific responses that protect the most vulnerable populations

Align training protocol with best data

Training involved in mitigation planning processes needs to be improved to develop skill sets that understand risk, vulnerability and impacts of hazards. Without these improvements, the insertion of actionable climate information will not greatly alter the resulting outcomes. For this reason, FEMA may need to reexamine their training protocol.

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Consider extreme temperature in disaster guidelines

Develop federal infrastructure for managing health risks of extreme temperatures

Federal disaster guidelines should be reviewed and revised to ensure that extreme temperature events (both heat and cold) are considered within the purview of disaster management agencies including FEMA. CDC statistics routinely demonstrate that extreme heat and cold pose a greater threat to human health than all other extreme weather events combined. There is almost no federal infrastructure for managing health risks associated with temperature extremes.

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Use reconstruction funds to adapt infrastructure

Enable cities and states to use reconstruction funds to adapt infrastructure (e.g., energy, roads, buildings, bridges) toward more resilient long-term alternatives. For example, federal policies prohibited Puerto Rico from adopting more resilient energy infrastructure strategies when rebuilding after Hurricane Maria.

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Upgrade the adaptive capacity of the public sector

Increase support and funding of public organizations on the front lines

We must increase the adaptive capacity of public organizations to respond to recurrent extreme weather events. As demonstrated by Hurricane Sandy or the fires in Los Angeles, extreme weather can have significant ramifications for the effective functioning of social and economic systems.

While public organizations often have experience coping with weather related disruptions, the more recent increase in the frequency, scope and intensity (as well as the cumulative impacts, such as fires followed by flooding) of weather-related disasters exposes the limitations and weakness in current social and economic systems. By addressing these weaknesses through increased support and funding to the public organizations that are on the front lines, we can mitigate losses to life and infrastructure,

Improve capacity by undertaking fundamental adjustments to standard processes

Furthermore, many public service organizations – transit and transportation, electric power, information and communication, public safety – are at the forefront of extreme weather events. Nevertheless, most cities and counties use professional emergency response routines and formal contingency management structures to coordinate with first responders, rather than undertake fundamental adjustments to improve their capacity in response to extreme events while also anticipating future weather conditions.

Public organizations need long-term adaptive strategies that reduce the risks associated with recurrent extreme weather in a given region and focus on addressing and alleviating local-to-regional scale social and/or infrastructure vulnerabilities based on hazard type.

Policy considerations

New policies should support public service organizations to undertake deliberate efforts to:

- Invest in **higher funding of public service organizations for preparedness** and responses to climate-sensitive weather extremes.
- Systematically **assess organization-specific vulnerabilities** to local extreme weather events.
- Seek out and **learn from other cities' innovative adaptive strategies** to specific extreme weather events.
- Prioritize investments in physical infrastructure, information and communication systems, human capital and inter-organizational coordination for long-term adaptive response.

While some public organizations have undertaken these activities, most have not due to either a lack of funding, incomplete information for accurate implementation, or lack of initiative. As a result, there is an important opportunity for the Federal Government to upgrade the adaptive capacity of the public sector to respond to extreme weather.

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11b. Front-Line Communities

Question: *How can Congress better identify and reduce climate risks for front-line communities, including ensuring that low and moderate-income populations and communities that suffer from racial discrimination can effectively grapple with climate change?*

Explore neighborhood approaches to sustainable urban development

Poor communities bear the brunt of extreme weather

The effects of climate change and extreme weather will be most acutely experienced in urban areas; poor neighborhoods and communities will bear the brunt of extreme weather. Yet at the neighborhood level, the processes through which urbanization and cities contribute to socioeconomic development are experienced by individuals.

Explore approaches at the intersection of climate change and poverty alleviation

There is an urgent need to explore neighborhood approaches to sustainable urban development, particularly at the intersection of climate change mitigation and poverty alleviation. This need is felt acutely globally as much of the expected increase in urban population will be slums.

Support community-academic partnerships

The Federal Government should support community-academic partnerships and organizations engaged in collecting, mapping, and analyzing community data (e.g., health, infrastructure, environment/weather), and in identifying environmental hazards and extreme weather vulnerabilities so as to strengthen the role of neighborhoods in urban planning and policy. Many such efforts are underway, from Chicago to Cape Town (South Africa) but much more needs to be done in a timely fashion to avoid negative impacts to communities.

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Draw on local knowledge and practices

Include local knowledge and experiences in the innovation process

Creating connections with public, private, NGOs and community organizations is essential. Multi-directional connectivity is important for building greater adaptive capacity. Opportunities for those with local knowledge and experiences need to be provided to enable the creation, sharing and implementation of ideas. Typically, individuals find ways to adapt but do not view their adaptations as innovative.

Provide a platform for idea-sharing

Providing a platform for sharing those ideas is essential to the development of large-scale innovation. One example is “The Ministry of Awesome” in Christchurch, New Zealand, which

has increased community connectedness and social cohesion, both of which are indicators of a more resilient community in the face of extremes.

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Fund the creation of community-based knowledge systems

Fund the creation of community-based knowledge systems for climate resilience and adaptation that enable local policy, business, and community members and leaders to understand risks and take appropriate actions to reduce and respond to them.

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Community resilience is born of local collective action

Local context is incredibly relevant

Innovation that builds resilience in communities that are vulnerable to climate change must come from local collective action. Communities at risk possess local knowledge including the awareness of local structural inequalities, previous adaptation strategies, stresses, etc. This context in incredibly relevant when communities are faced with imminent danger posed by natural disasters.

Integrate climate resilience into traditional welfare and community supports

Our team recommends that Congress integrate climate resilience language and funding into traditional welfare and community support mechanisms including tax, neighborhood planning, anti-discrimination, and employment/wage policy. The most effective way to build resilience for front line communities is by addressing the underlying social and economic conditions that make them uniquely vulnerable to climate change impacts.

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Promote participatory governance

We recommend using a conceptual tool, such as the Community Capitals Framework, to identify and reduce climate risks in a way that promotes participatory governance and identifies and develops tangible and intangible community assets. Using such a tool ensures the process fosters equity, inclusion, and accounting for intangible resources like social and moral capital that makes economic prosperity possible.

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11c. Infrastructure and Building Standards

Question: *What standards and codes should Congress consider for the built environment to ensure federally-supported buildings and infrastructure are built to withstand the current and projected effects of climate change?*

Transform infrastructure policy and practice

Climate change and extreme weather present a fundamental challenge to the ability of infrastructure to protect communities. Beneath the seemingly endless cascade of catastrophes lie consistent, systemic failures in current approaches to infrastructure. One common failure is overconfidence in the ability to tightly control complex social and ecological systems through the management of technological systems. Another is the failure often associated with managing interdependent infrastructure systems. There also are failures in the ability of institutions that manage infrastructure to generate, communicate, and utilize knowledge.

The United States is at an infrastructural crossroads

Climate is changing faster than our infrastructure

First, the climate is changing faster than built infrastructure and the institutions that manage and maintain it. Recent and ongoing extreme weather events highlight the precarious state of the nation's infrastructure and the ability of cities to adapt to climate change.

We need greater investment just to maintain current service levels

Second, U.S. infrastructure—in such diverse sectors as transportation, energy, and water—needs billions of dollars of investments to merely maintain current service levels, according to the American Society of Civil Engineers.

A 2017 executive order reduces federal requirements to account for climate risks

Finally, over the coming years there may be massive investments in the nation's infrastructure. Cities, states, and regions will continue or ramp up efforts to maintain and retrofit infrastructure to deal with increasing demands, changing populations, and the changing climate. The states and regions affected by recent extreme events will recover and rebuild. Meanwhile, the federal government has proposed to invest up to $1 trillion in infrastructure while at the same time, according to an August 2017 executive order, reducing requirements for federal spending on infrastructure to account for climate risks.

What path will we take?

How cities, states, regions, and the Federal Government navigate these key issues will determine the path taken at this crossroads. Will it be a path that uses the technologies and climate conditions of the twentieth century to design for tomorrow? Or one that rethinks how infrastructure is designed, managed, and maintained for the technologies, societal needs, and hazards of the twenty-first century?

Policy approaches for resilience

Based on these recurrent failures in our infrastructure systems, we present three core organizational and policy approaches to foster resilience:

Move from a risk-based to resilience-based approach

The current strategy is one where failure of infrastructure is not allowed; yet, infrastructure does fail. Infrastructure managers must be trained to consider the possibility of failure, how to manage failure (that is, reduce the consequences), and how to evaluate the costs and benefits of safe-to-fail strategies. Although the current federal administration is not requiring climate change to be considered in infrastructure design, doing so is necessary and unavoidable. It is now an opportune time for professional societies, cities, and states to step up, establish guidelines, and share knowledge.

Require knowledge systems analysis

Assumptions about future conditions are embedded at every level of infrastructure design and maintenance. Yet, rarely are systemic efforts undertaken to analyze how assumptions about future weather and climate may generate vulnerability. Such a position is becoming increasingly untenable. Moody's Investor Services, for example, recently issued a report stating that the credit rating agency will assess a city's climate preparedness when accounting credit risks. Those institutions responsible for managing and maintaining infrastructure must critically evaluate how assumptions about the future of climate and weather are embedded in decision making, policy, codes, and standards.

Enhance institutional integration and coordination

To address the interdependence of infrastructure systems, the institutions that build, manage, and maintain them must explore new models of institutional design. The institutions that now manage infrastructure must continue to do so, with the knowledge and depth they have of the systems. But there remains a need for new forms of organization that are able to manage interdependencies—such as regional governmental entities—and integrate efforts to manage infrastructure and enhance resilience. Pavement engineers and nuts-and-bolts knowledge of hydraulics will remain critical, but so too there will be a need for new competencies that understand complexity and interactions. Most important, we will require people who can work within these interdependent systems and acknowledge their complexities and the growing possibilities that we cannot predict what might happen when things are perturbed. That's a fundamentally new approach.

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Measure structures for their capacity continue to serve populations under extremes

Our team recommends that Congress works with researchers and engineers to ensure that both physical and social climate change risks are considered when civil infrastructure upgrades and hardening projects are planned and implemented. The resilience of civil infrastructure—bridges and roadways, water treatment facilities, electrical generating stations and transmission and distribution systems, and more—to climate change related impacts, should be measured not

only in terms of their total capacity to withstand increasing extreme weather and other climate change related stresses, but also their specific capacity to continue to serve populations uniquely vulnerable to climate change impacts when stressed.

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Assess projects using an integrated life cycle approach

When assessing projects, the Federal Government should move from separate life cycle cost assessments and environmental assessments to formal integrated life cycle sustainability assessments that consider all environmental, social and economic negative impacts and benefits throughout their life cycle.

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12. National Monitoring, Research and Assessment

Question: *Our understanding and response to the climate crisis has relied on U.S. climate observations, monitoring and research, including regular assessment reports such as the National Climate Assessment. What policies should Congress adopt to maintain and expand these efforts in order to support solutions to the climate crisis and provide decision makers – and the American people – with the information they need? Where possible, recommend the scale of investment needed to achieve results.*

Assemble knowledge at a local scale

Invest in local-scale knowledge

The major shortfall of federal investments to date in climate risk assessment and management has been at local, regional, and state scales. Each community, city, tribe, and state requires knowledge for understanding local climate changes, analyzing their implications for local families and businesses, and developing locally appropriate solutions. This requires unique assemblages of knowledge about climate, community, economy, infrastructure, and the environment for each locality.

Build capacity for local-scale knowledge systems

The next step of federal monitoring, research, and assessment should be to build the capacity of the nation's communities, cities, tribes, and states to develop their own unique knowledge systems for informing climate adaptation decision making and using those to shape local decision making.

Federal investment will ensure widespread availability of federal data to localities, cross-jurisdictional coordination, and adequate resources for robust investment. Local universities, city, state, and tribal agencies, non-governmental organizations, and business organizations can all act as resources for developing these knowledge systems and should be encouraged to collaborate in urban and regional partnerships to support these efforts.

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13. Leading the Global Response

Question: *The climate crisis requires a global response. U.S. leadership is critical for successful global solutions. What policies should Congress adopt to support international action on the climate crisis?*

Invest in developing countries

Investment in developing countries reduces risks to the United States

Failing to support low-carbon development pathways in developing countries will result in significant climate change, which brings substantial risks to the United States as well as other countries. The following recommendations are supported by substantive field research on climate adaptation of households in rural communities in Mexico and Central America completed by researchers at Arizona State University in collaboration with regional experts and research conducted by others.

We recommend that Congress:

- Continue to **invest in international aid** to support adaptation in developing regions, via the United Nations Adaptation Fund, the Global Environmental Facility, and United States bilateral aid programs.
- **Reinstate Executive Order 13677**, requesting consideration of climate resilience in development assistance.
- See that the U.S. International Development Finance Corporation (USDFC) **make climate resilience and adaptation an investment priority**.
- **Invest in local organizations** that provide community education, agricultural and rural research and development, health and small-scale and social-enterprise support, to enhance rural adaptive capacity in highly vulnerable and climate-sensitive regions.
- Invest substantial international aid in activities that **foster the 2030 Agenda for Sustainable Development** embodied in the Sustainable Development Goals, which enhance adaptive capacities, reduce vulnerabilities, and mediate risk of social conflict.

Climate impacts human migration

Research on human migration in regions sensitive to climate impacts concluded that enhanced investment in in situ livelihood stability, accompanied by strong and resilient public institutions, addresses emergent needs, mediates emigration pressures from climate extremes, and moderates other social and environmental pressures that can lead to migration and social conflict.

Food insecurity increases with climate change

Prioritize food security

Climate change has significantly increased food insecurity in many nations due to the greater frequency and intensity of extreme weather. Insufficient food quality and quantity generate societal unrest and political instability, resulting in downstream impacts such as increasing migration pressure.

Rescue policies that require that the U.S. ship agricultural crop surpluses to high stress environments are becoming insufficient due to large increases in climate induced disasters. The U.S. must support international investment programs to help highly stressed agricultural systems adapt to climate change more rapidly by strengthening the internal capacity of vulnerable countries to confront climate challenges.

U.S. leadership in global food security

Invest in research and innovation systems in developing countries

The U.S. and its allies must invest in research and innovation systems in developing countries to generate capacity that effectively solves local adaptation challenges. Such investment builds the scientific, technological and organizational infrastructure needed for a complete and viable agricultural research system.

Facilitate the spread of biodiverse genetic resources for agriculture

The U.S. must facilitate the spread of genetic resources for agriculture. The global storehouse of agricultural biological diversity is enormous, yet it is declining due to the destruction of natural environments and the underuse of many crop varieties.

Policy considerations for global food security

Agricultural biodiversity is constrained by the complex network of policies and institutions that control access and use. Improving systems that harness agricultural biodiversity is a job for national and global policy, such as governance solutions for the effective exchange of biological materials and organizational systems that facilitate mobilization.

International Treaty on Plant Genetic Resources for Food and Agriculture

Congress can support the International Treaty on Plant Genetic Resources for Food and Agriculture, to which it is a signatory, by pursuing international investments that ensure that locally produced seed stocks are preserved, and that commercial patents of genetic material do not threaten the ability of local populations to harness agrobiodiversity to enhance their domestic food security.

US AID Feed the Future program

Congress should continue to support and enhance the USAID Feed the Future program, with its support for capacity building in research and innovation as its core investment pillars.

Leading by example is impactful

Political leadership in climate change mitigation

The U.S. should reengage in international climate change actions, such as the Paris Agreement and the UNFCCC. The country should direct substantial, sustained financial support through these bodies to support climate mitigation and adaptation internationally, such as to the Green Climate Fund.

To achieve the ambitious goals of the Paris Agreement, the U.S. should support the development and diffusion of low-carbon technology to all countries, including China and India. Given the potential increase in emissions accompanying the growth of the middle class in these countries, such support is central to protecting vulnerable American populations and lessening future domestic climate change costs.

Adequate action in the World Trade Organization is needed to ensure that countries are not penalized for taking strong domestic climate action, or for mandating high environmental standards for domestic or transnational corporations that operate within their borders. Similarly, through the G8 and other multilateral venues (including through its representation in the International Monetary Fund and the World Bank), the U.S. should be leading efforts to eliminate fossil fuel subsidies.

Lead by Example

High profile U.S. action on climate change within its own borders is critical to facilitate climate action in other parts of the world.

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