RFF | *Published since 1959 by Resources for the Future* | NO. 212 | SPRING 2023

Resources

A New Dawn for Climate Legislation

Unpacking the Inflation Reduction Act

ENVIRONMENT
The Economics of Biodiversity

DISCUSSION
The Future of Nuclear Energy

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Seeking Solutions with Satellite Data

Illustration by Nils-Petter Ekwall

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A Note from RFF's President

Historic Climate Legislation

The Inflation Reduction Act (IRA)—passed and signed into law in 2022—creates an enormous set of incentives that stand to reshape the US energy and manufacturing sectors and reduce emissions. Looking toward the future, the implementation of the IRA, the Infrastructure Investment and Jobs Act, and the Creating Helpful Incentives to Produce Semiconductors and Science Act will unfold over several years and will be critical areas of focus for researchers at Resources for the Future (RFF). Given that the IRA is a mix of incentive-based strategies, many of its components must be evaluated on an ongoing basis to assess their effectiveness in reducing emissions—and RFF will help in this analysis by identifying ways to improve and complement the strategies that these policies have put in place.

We began these efforts in earnest even before the bill passed. And since the passage of the IRA last August, RFF has contributed to the implementation process with related reports, blog posts, public comments, podcast episodes, collaborations on state implementation, and more. Take a look through these pages: This issue of *Resources* features analysis of provisions in the IRA that are related to tax credits for medium- and heavy-duty vehicles, subsidies for clean hydrogen, and financial incentives for clean energy projects in "energy communities." An article reviews how the IRA will enable states to increase their climate ambitions in the electricity sector and the associated challenges that remain. A podcast episode reproduced here explores how IRA funding will impact the deployment of nuclear energy.

Alongside these historic developments, RFF continues to tackle our other important ongoing work. Read this magazine, and you'll get updates on our collaboration with NASA and how we've been advancing socioeconomic research through satellite data and Earth observations. You'll catch up on major events that we hosted in the fall to celebrate our 70th anniversary and to convert innovative ideas into action. You'll also get important insights about the economics of biodiversity and hear from an RFF alumna and philanthropic supporter about RFF's work on carbon removal and other fronts.

RFF's concerted efforts account for multiple aspects of progress on energy, the environment, and the economy, particularly in the context of the historic climate actions that are now underway. Just by picking up this magazine, you've joined us in a journey toward climate solutions that we're hoping to navigate with the broadest community possible. Thank you for sharing in our mission.

With thanks and best wishes,

Richard G. Newell
President and CEO, Resources for the Future

Resources

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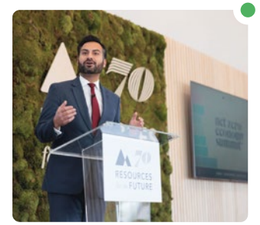

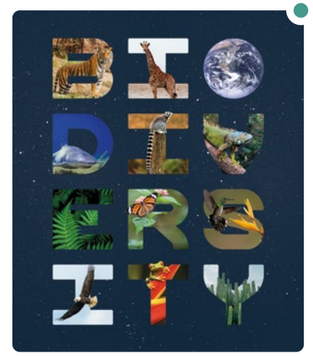

Common Resources

Common Resources is a blog produced by the *Resources* editorial team, offering timely analysis and commentary from expert scholars. New blog posts pop up frequently, especially at notable times when crucial new decisions are under discussion.

News and Views from the RFF Blog: Unpacking the Inflation Reduction Act

The Inflation Reduction Act represents a leap forward for US climate policy; the next steps will involve implementation of the law. Since the Inflation Reduction Act passed in August 2022, RFF scholars have offered insights about the law's provisions on the *Common Resources* blog. Here are some excerpts from their recent blog posts, which collectively have attracted more than 40,000 views.

TEXT Matt Fleck

Matt Fleck is a staff writer and reporter at Resources for the Future.

The Inflation Reduction Act (IRA) marks a turning point for US climate policy. To accelerate US decarbonization, the IRA uses the carrots of incentives, rather than the sticks of climate regulations.

Rather than putting a tax on greenhouse gas emissions, which many economists have long favored as an emissions-reduction policy, the law provides $370 billion for programs that facilitate mitigation and adaptation to climate change, plus tax incentives for qualifying technologies that reduce emissions.

Since the passage of the IRA in August 2022, scholars at Resources for the Future (RFF) have shared related insights on the *Common Resources* blog, RFF's platform for commentary and analysis about pressing environmental and energy issues. In this article, we highlight the analysis from our experts, who offer thoughts on how decisionmakers can implement the IRA efficiently, effectively, and equitably.

CO_2 Much Support for Fossil Fuels?

In a *Common Resources* blog post published in August, RFF Fellow Brian C. Prest looks at the provisions in the IRA that affect federal oil and gas leasing.

"A key compromise that secured the vote of Senator Joe Manchin (D-WV) is the mandate of new oil and gas lease sales on federal lands and waters, including a commitment to tie future renewable energy development on federal lands and waters to analogous onshore and offshore oil and gas leasing," says Prest. "At the same time, the bill imposes higher costs on companies that drill on federal lands—most importantly through higher minimum royalty rates, but also through higher rental rates, minimum bids, and the elimination of noncompetitive leasing."

Prest notes the importance of placing the law's oil and gas provisions in context: "My work to date suggests that the emissions reductions triggered by other provisions in the IRA would far outweigh the potential impacts of the oil and gas leasing provisions."

IMAGE
RFF research shows that emissions reductions can be achieved, even with the new oil and gas provisions contained in the Inflation Reduction Act.

Jeremy Poland / Getty Images

Sparks Fly in the Electric Vehicle Market

The IRA contains provisions that aim to boost the adoption of electric vehicles (EVs) (Figure 1). In a pair of articles on *Common Resources*, RFF Fellow Beia Spiller examines the EV tax credits in the IRA and the requirements that EV manufacturers and buyers must meet to collect the credits.

Spiller, who also serves as the director of RFF's Transportation Program, analyzes the credits for medium- and heavy-duty EVs (MHD EVs) in one of her blog posts. "The IRA inherently incentivizes adoption of the smaller MHD EVs," says Spiller. "Why does it look as though the credits favor relatively smaller vehicles? Smaller MHD vehicles, such as cargo vans or box trucks used for short-haul package delivery in urban areas, are cheaper and have more similar price points relative to their electric versions than larger MHD vehicles, such as long-haul tractor trailers.

"Why, then, are we still seeing so little adoption of these other types of small MHD EVs?" Spiller continues. "The reluctance to electrify may be due to range limitations, range anxiety, uncertainties about new technologies, misinformation, electric grid challenges, and other factors. It's possible that the subsidies in the IRA will provide the necessary compensation to offset the negative aspects of fleet electrification—whether those negative factors are real or perceived."

While the IRA doesn't reinvent the $7,500 passenger EV tax credit, which has been in place for over a decade, the law does include significant changes to the existing credit. Spiller examines these changes in her other *Common Resources* blog post on the topic.

"The IRA … benefits lower-income individuals who previously didn't have enough tax liability to take advantage of the full $7,500, as well as those who don't want to wait until [tax season in] April to get the refund, by allowing these buyers to take advantage of the tax credit at the point of sale," says Spiller.

Requirements for vehicle manufacturers, however, could limit the selection of vehicles that are eligible for tax credits. "The legislation disallows tax credits for vehicles with a majority of battery components and bodies that are imported (or, crucially, imported from 'foreign entities of concern,' such as China), but most battery manufacturing happens overseas … Specifically, the bill requires a percentage of the battery's minerals and manufactured parts to be produced domestically (or by countries with fair-trade agreements, such as Chile and Australia), and increases that percentage every year—starting at 40 percent in 2023 and quickly ramping up to 80 percent in 2026," says Spiller.

"Until auto manufacturers in the private sector make significant changes to their manufacturing processes and resulting vehicle price points, you—and most other car buyers in the market for EVs—may need to forgo the tax credit if you want to go electric," Spiller concludes.

Figure 1. **Number of Electric Vehicles Projected to Claim Tax Credit under the Inflation Reduction Act**

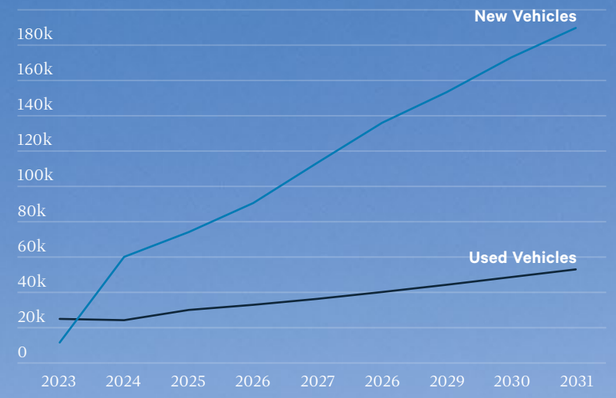

IMAGE
Tightening fuel economy standards will be important for reducing emissions among the remaining gasoline-powered vehicles in the on-road fleet during a transition to electric vehicles.

Thomas Winz / Getty Images

ABOVE (FIGURE 1)
Data come from an August 3, 2022, report from the Congressional Budget Office on yearly expenditures, assuming each new vehicle receives a $7,500 credit and each used vehicle receives a $4,000 credit under the Inflation Reduction Act.

Ensuring that Inflation Reduction Act Subsidies Reach Their Equity Targets

In a blog post published on *Common Resources* in Septtember, RFF scholars Daniel Raimi and Sophie Pesek look at a tricky provision in the IRA: the law's financial incentives for clean energy projects that are located in so-called "energy communities."

Ideally, say Raimi and Pesek, these incentives would support "energy-producing communities that may be most hard hit by changes in the energy landscape." The authors investigate how the law's definition of an energy community measures up to this ideal.

"Do these definitions in the IRA target the energy communities that are likely to be hardest hit by a transition to a net-zero energy system? Because of the imprecision of the selected geographies, and the overly expansive definition of 'energy communities' … the answer appears to be no."

> **"Ideally … these incentives would support 'energy-producing communities that may be most hard hit by changes in the energy landscape.'"**

IMAGE
The tax credit for energy communities requires tens of billions of dollars in government spending—some of which will actually benefit the intended recipients.

Nicholas Doherty / Unsplash

Big Incentives for the Smallest Molecule

The IRA builds upon measures in previous pieces of legislation. For example, the Infrastructure Investment and Jobs Act, which Congress passed in 2021, allocates $9.5 billion for clean hydrogen initiatives in the United States. In a blog post published a few weeks after the IRA became law, RFF scholars Aaron Bergman and Alan Krupnick discuss how the IRA augments the provisions for hydrogen that the Infrastructure Investment and Jobs Act originally put forward.

The tax credit for hydrogen production, known as the "45V" tax credit, subsidizes either investment in clean hydrogen production or hydrogen production itself. The value of the 45V credit increases as the life-cycle emissions associated with hydrogen production decrease (Table 1).

In the short term, the increased tax credit for carbon capture and sequestration, a credit known as "45Q," also could have a large effect on reducing emissions associated with hydrogen production. "Our analysis suggests that the tax credits in the IRA already are sufficient to make hydrogen production from natural gas with [carbon capture and sequestration] competitive with current hydrogen production without [carbon capture and sequestration]," say Bergman and Krupnick.

Bergman and Krupnick also note that these tax credits, along with other provisions in the IRA, could be key to the success of the Regional Clean Hydrogen Hubs (H2Hubs) program, which is funded by the Infrastructure Investment and Jobs Act and has emerged as the largest hydrogen initiative to date. "While the Infrastructure Investment and Jobs Act alone had potential to leave the H2Hubs stranded without a path to sustainability, the incentives provided in the IRA can put the H2Hubs on a wider path to success," they say.

On the other hand, RFF researchers have pointed out potential complications in disbursing the 45V tax credit, depending on how the life-cycle emissions are calculated for clean hydrogen production. Life-cycle emissions include not only what is emitted while producing hydrogen, but also all emissions up until the hydrogen leaves the production facility. For example, if hydrogen production is powered by a natural gas–fired power plant, the life-cycle emissions would be higher than a case in which clean energy drives production. In fact, hydrogen that is produced using electrolysis that is powered by electricity at the grid's average carbon intensity is more carbon intensive than hydrogen that is produced by natural gas without carbon capture (through a process called steam methane reforming).

The US Department of the Treasury is responsible for determining how hydrogen producers can demonstrate that they satisfy the eligibility criteria for the 45V subsidy, which requires the calculation of their hydrogen's life-cycle emissions intensity. In a *Common Resources* blog post published in October, Bergman worked with RFF scholars Brian C. Prest and Karen Palmer to examine the agency's responsibilities. "These choices will be of vital importance for the competitiveness of green hydrogen, because the subsidy is available only if the emissions associated with the consumed electricity are extremely clean," say Bergman, Prest, and Palmer. "The electricity consumed must have emissions that fall short of the current grid average by more than 80 percent to receive even the smallest level of subsidy. More recently, Bergman pointed out a potentially important trade-off: More careful emissions accounting may ensure that the 45V tax credit does not increase near-term emissions, though the stringency also may slow electrolysis deployment and cost reductions, limiting the future options and increasing long-term emissions.

"These types of decisions stray far from the usual expertise of the Treasury Department, which likely does not wish to be in the position of adjudicating complicated requirements," the authors conclude. ■

Table 1. **"45V" Tax Credits Available for Hydrogen Production through the Inflation Reduction Act of 2022**

Life-Cycle Emissions (kg CO_2e / kg H_2)	**Investment Tax Credit** (percentage)	**Production Tax Credit Value** (2022$ / kg H_2)
4–2.5	6%	$0.60
2.5–1.5	7.5%	$0.75
1.5–0.45	10%	$1.00
0.45–0	30%	$3.00

kg = kilogram, CO_2e = carbon dioxide equivalent, H_2 = hydrogen

See More …

Stay tuned to the *Common Resources* blog for more insights from RFF experts on how decisionmakers can most effectively implement the emissions-reduction potential of last year's landmark climate legislation.

Supporter Spotlight

In the RFF Supporter Spotlight, our partners share their insights about climate, energy, and environmental issues and how they've made a difference by working with Resources for the Future—all in their own words.

Catalyzing Philanthropic Ambition to Serve People and the Planet

Resources recently spoke with Jan Mazurek, a senior director at ClimateWorks Foundation, and previously an advisor at the California Air Resources Board and US Environmental Protection Agency. Below are excerpts from the conversation, which touched on the role of philanthropy in catalyzing climate action, the importance of durable climate solutions, the magic of Resources for the Future, and more.

> "I, like RFF, have transitioned from a focus on conventional pollutants to the most urgent issue of the day, which is climate change."

Resources magazine: Can you tell us about your priorities for carbon removal and aviation at ClimateWorks? What excites you about the related work that you help support at Resources for the Future (RFF)?

Jan Mazurek: Our mission is to help catalyze philanthropic ambition to, firstly, take emissions to zero. We now find ourselves in the situation of having to obtain negative emissions by midcentury in the amount of 10 gigatons per year. It's an enormous task, and philanthropy is probably one of the best actors to take it on.

I'm interested in questions about durable compliance. Although legislation has led to direct air capture hubs and expanded the 45Q tax credit to bring down costs of carbon dioxide–removal technology, will these approaches be sufficient to incentivize an activity that is a public good? Sure, I'm going to save on my electricity bill if I install a solar roof, or save on gas if I drive an electric vehicle—but no similar private benefits are associated with carbon removal.

What excites me about the carbon-removal work at RFF is that it provides the ability to interact with colleagues who are experts in economic and policy frameworks. A conversation I had earlier this week with the RFF team was one of the most exciting interactions that I've had since standing up this fund in 2015. Everyone is bringing their passions and sharp insights about policy feasibility to bear on these questions.

Your early career included time at RFF as a research associate in the 1990s. How did your work at RFF shape your career? How have you seen the organization evolve over the years?

I can track the arc of my career to RFF, starting with risk assessment and toxins. At RFF, I had the opportunity to work on topics that were

IMAGE *Teresa O'Brien Photography*

of vital interest to the Clinton administration around the use of risk assessment to deploy scarce resource dollars. Twenty years later, I was called upon to deploy those skills to advise then-Administrator-Designate of the US Environmental Protection Agency Lisa Jackson on working with Congress to reauthorize the Toxic Substances Control Act of 1976. That was a major achievement—and a benchmark achievement for me, as well.

I have carried those lessons through the years, even though I, like RFF, have transitioned from a focus on conventional pollutants to the most urgent issue of the day, which is climate change.

You've worked on environmental and energy issues in government, as well as in philanthropy. How would you describe the role of RFF, and organizations like it, in supporting decisionmakers?

Harkening back to the period when we were thinking about carbon-trading systems and carbon taxes, and more recently the great work with implementing green hydrogen hubs—this continues to underscore the effectiveness of RFF, not only in the climate space, but also in the clean energy transition space and so many other areas leading up to where RFF is today. RFF still is uniquely positioned to provide impartial, unbiased, cutting-edge research that informs decisionmakers.

What do you think sets RFF apart from other organizations?

I don't think that there is a brighter assemblage of smart, compassionate, and completely curious environmental and energy thinkers anywhere else in the world. The insights and positive externalities from interactions among the expert staff are unique, owing to this body of learning and adherence to rigor. RFF is still, thankfully, the magical, wonderful place that it's always been and is doing great things for people and the planet. ■

Four Ways You Can Support RFF

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Discover other ways to give at **rff.org/waystogive** or contact Tommy Wrenn at **twrenn@rff.org**

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Energy Insights for Interdisciplinary Scholarship

A two-day interdisciplinary workshop this fall brought together people from universities, the Hill, federal agencies, state houses, industry, and nongovernmental organizations to collaborate on turning novel ideas into action for energy and the climate.

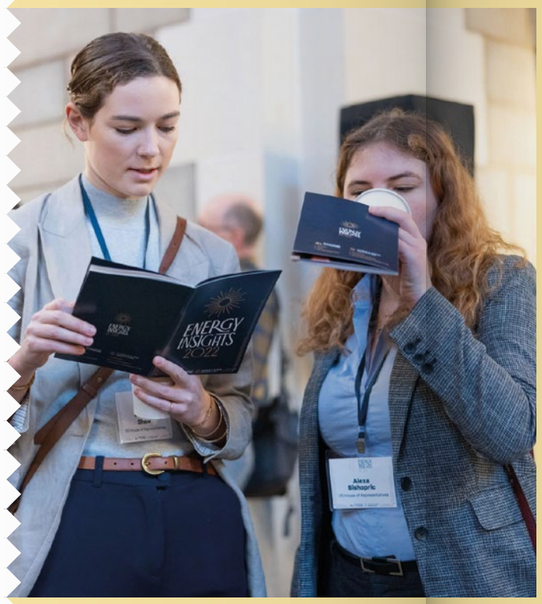
TEXT Kristin Hayes, Evan Michelson, Isabella Gee, and Jessica Klynsma
PHOTOS RFDCphoto

Research is designed to answer hard questions, and the research community thrives on that challenge. We would argue, however, that merely answering hard questions is not sufficient for the kind of impact that we and our research colleagues seek. Instead, to have an impact, research needs to exist not only on the proverbial bookshelf, but also in the hands of those who can put its wisdom to use. The magic really happens in the sharing of research across communities.

That is what the Energy Insights 2022 conference, jointly hosted this past December by Resources for the Future and the Alfred P. Sloan Foundation, was all about. We aimed to bring together a diverse set of scholars and practitioners from across the energy system. The conference was rooted in a commitment by both organizations to advancing interdisciplinary energy and environmental research that informs how decisions are made and how research translates into action.

"Energy Insights 2022 exceeded my expectations and much more," said Pratik Dholabhai, Assistant Professor in the School of Physics and Astronomy at the Rochester Institute of Technology. "I have never had such an amazing experience and learning environment where policymakers, philanthropists, policymakers, scientists, engineers, and environmentalists come together to talk about our future."

During the two-day gathering, we were joined by nearly 200 attendees who not only are dedicated to asking and answering important questions, but also are engaging with those who can benefit from these answers. People who believe that information flows should be multi-directional: not just researcher to decisionmaker, but vice versa, with input from community members, the private sector, and researchers in other disciplines. It takes a true research village to tackle some of the most pressing issues we face as a society related to energy transitions, decarbonization, and energy and environmental justice.



Early on in the planning process, we—the conference organizing team—articulated the following four goals for the time together in Washington, DC:

1. Everyone should learn something new.

2. Everyone should meet someone new, preferably outside of their discipline.

3. Everyone should come away knowing how to better align research with decisions that are being made right now—or at least decisions that will arise in the next few years.

4. Everyone should leave feeling energized about the opportunities ahead and the power of the research community to work with the policy community and broader decisionmaking community to meet the moment.

ILLUSTRATIONS Studio Muti

Who were these 200 attendees? They came from across the country, bringing expertise in economics, public policy, law, engineering, natural sciences, sociology, and more. Many are based at universities, while others joined us from Capitol Hill, federal agencies, state houses, industry, and nongovernmental organizations. Bringing together this blend of disciplines and sectors was a central mission of Energy Insights 2022.

"The conference far exceeded my expectations in terms of the number of different disciplines represented, the quality of the sessions, and the adherence to the conference themes throughout the activities," reflected Ben Gilbert, Assistant Professor in the Department of Economics & Business at Colorado School of Mines.

The energy sector and policy landscape have evolved considerably since our last Energy Insights event in 2018, and the topics we chose to focus on in 2022 reflect those developments. Thematic sessions showcased multidisciplinary work on a range of topics. These issue areas included new technologies and drivers for industrial decarbonization, such as electrification of chemical manufacturing and steelmaking; decarbonizing medium- and heavy-duty vehicles; identifying new ways to improve grid resilience; understanding how extreme weather events and other disruptions might increase grid vulnerability; and exploring the technological, economic, and public engagement dimensions of negative-emissions technologies and pathways.

The conference opened with a plenary session on why research matters for decisionmaking, bringing in both federal and state-level perspectives. This session featured two researcher-policymaker pairs who discussed the role of analysis in informing the development of the Inflation Reduction Act, as well as lessons learned from the governance and design of regional transmission organizations for states and other localities. "The way these organizations have been put together matters: their institutional design makes a difference for how much clean energy is integrated into markets, the prices people pay, and technology innovation," said Stephanie Lenhart of Boise State University and RTOGov, who alongside her RTOGov colleagues had the opportunity to connect with Colorado State Senator Chris Hansen and the Colorado Energy & Water Institute. This engagement gave the research team "an opportunity to share the research we've been doing, identify research gaps through our conversations and engagement with their organization, and think about our research design."

Additional plenary sessions showcased a variety of topics relevant to energy system transitions. Five different philanthropic and government funders shared their complementary views on the needs and priorities for energy research. A multi-sector conversation involving economists, engineers, data scientists, and policymakers explored opportunities to improve energy data and economic models for decisionmaking. New research on equity in the energy transition highlighted place-based research that's occurring in partnership with Tribal communities in the southwestern United States and rural and urban communities across the Midwest and southeastern parts of the country.

Perhaps the most innovative part of Energy Insights 2022 was the inclusion of four small-group roundtable discussions on key thematic areas that span the landscape of energy and environmental research. The topics included new approaches to diversify the energy and environment scholarly community, how to accelerate public-private partnerships for better research outcomes, developing strategies for generating and promoting interdisciplinary knowledge, and sharing best practices for community engagement in research. We were keen to ensure that attendees were in more than just "listening mode" for the two-day event, and instead had opportunities to bring their own experience and ideas to the discussion.

The goal of these sessions was to spark new ideas and collaborations that then can be turned into action. To help facilitate this outcome, the Sloan Foundation's Energy and Environment Program offered to support four seed grants for proposed projects that focus on these cross-cutting themes, building on the conversations fostered and relationships formed at the Energy Insights conference. Conference attendees generated numerous submissions, seeking to bring to life ideas that arose at the conference. Their ideas covered topics like establishing new fellowship programs to diversify energy research; undertaking energy transition research in regions of the United States that scholarship often overlooks; and creating new opportunities for cross-sectoral engagement on critical topics such as the adoption of sustainable transportation strategies, life-cycle analysis of critical mineral mining, and the equity dimensions of power outages and electricity load loss.

The closing session of Energy Insights 2022 brought together four women leaders within the federal government, including Sally Benson from the White House Office of Science and Technology Policy, Julie Cerqueira from the US Department of Energy, Jennifer Gerbi from Advanced Research Projects Agency–Energy, and Jetta Wong from the US General Services Administration. These senior government representatives discussed how the United States is leveraging funding, networks, and tools to drive energy innovation. We were thrilled to hear directly from this all-star panel at this critical moment for US leadership on the development and deployment of clean energy technology.

We hope and believe that Energy Insights 2022 had something to offer every attendee, from the most seasoned researchers to students who are just entering energy and environmental research fields. The conference reminded us of the power of coming together to exchange knowledge and ideas—and we were humbled by the feedback that many attendees shared.

"I am an undergrad passionate about sustainable energy and wanted to hear from the best and brightest minds in the field. This conference surpassed my expectations," noted Isabella Elmore, a student at George Washington University. "It was exceptionally humbling to encounter such open-minded and important leaders; to hear their profound discussion panels; and then talk to them at the mixers, where they answered my questions with open arms. Truly one of the most powerful and influential two days of my life so far." ■

"We hope and believe that Energy Insights 2022 had something to offer every attendee, from the most seasoned researchers to students who are just entering energy and environmental research fields."

Kristin Hayes is the senior director for research and policy engagement at Resources for the Future. **Evan Michelson** is a program director, **Isabella Gee** is a program associate, and **Jessica Klynsma** is a program assistant at the Alfred P. Sloan Foundation.

NO. 212 | SPRING 2023 | *"State engagement in the process will be key."*

Institutional Strategies for State-Level Decarbonization of the Electricity Grid in the Wake of the Inflation Reduction Act

The Inflation Reduction Act has removed many barriers to decarbonizing the electric grid and sets the stage for increased climate ambition by US states. Even so, states will do well to consider how to meet the challenges that remain.

Text Maya Domeshek

The Inflation Reduction Act (IRA) will likely enable states to increase their climate ambitions in the electricity sector. But simply reducing the costs of building out clean electricity generation won't be enough to allow states to decarbonize their electric grids.

The grid is overseen by many institutions that have overlapping authority, including the Federal Energy Regulatory Commission (FERC) and the North American Electric Reliability Corporation at the national level; regional transmission organizations and independent system operators at the regional level; public utility, energy, and environmental agencies at the state level; and utilities, independent generators, and local governments at the sub-state level. States will need to learn to coordinate among these institutions if they want to reach their goals.

In a workshop cohosted this past spring by Resources for the Future (RFF), the University of Virginia, and the National Renewable Energy Laboratory, experts came together to discuss the institutional barriers that states face as they promote clean-generation investment, demand management, and transmission. Many lessons from the workshop have become even more relevant, now that the IRA has removed many cost barriers.

> **"Simply reducing the costs of building out clean electricity generation won't be enough to allow states to decarbonize their electric grids."**

Maya Domeshek is a research associate at Resources for the Future.

Investment in Clean Power Generation

The clean energy tax credits in the IRA are designed to promote investment in clean electricity generation by reducing the cost of building and operating new facilities.

These tax credits complement existing state decarbonization policies such as renewable portfolio standards, clean energy standards, capacity targets, or emissions caps, which also are designed to promote investment in clean generation.

In fact, the IRA likely will allow states to increase the ambition of their current clean-generation policies. But even with increased subsidies and increased ambitions, investment in clean power generation remains subject to some important challenges that states can help resolve.

> **"The longer that proposed generation facilities have to wait to be connected to the grid, the less likely those facilities are to be built."**

Market design that disfavors renewables.

Electricity generation in several eastern regions of the United States is financed partly based on the expected revenue from capacity markets—but renewable energy resources typically do not receive much revenue from capacity markets, because renewables are considered to have low capacity value due to their intermittency. Last spring, RFF hosted an in-depth discussion on the role of capacity markets in the transition to a decarbonized electricity system. This event centered around a book coauthored by RFF University Fellow Todd Aagaard, which offers insights into the design and regulation of capacity markets and their potential role in the clean energy transition. More recently, RFF hosted a workshop titled "Reforming Resource Adequacy Practices and Ensuring Reliability in the Clean Energy Transition," which will generate a forthcoming report. States that are looking to decarbonize may want to consider the lessons learned through this type of research and push the regional transmission organizations in their regions to value renewable capacity in a more nuanced way.

Backed-up interconnection queues.

The longer that proposed generation facilities have to wait to be connected to the grid, the less likely those facilities are to be built. Interconnection queues have been getting longer in recent years, which increases the difficulty of adding large quantities of renewables to the grid. FERC's notice of proposed rulemaking for interconnection in July 2022, which promotes a "first-ready, first-served" process, is a step toward addressing this issue. States can push FERC and regional transmission organizations to improve the interconnection process and work with neighboring states on regional transmission planning that recognizes wider regional benefits.

Siting opposition.

Local authorities often have the final say on whether a renewable energy facility is built. States can facilitate relationships between developers and local governments by providing up-to-date information, setting clear guidelines for interactions, and making sure all parties can benefit through mechanisms like siting agreements.

Policy uncertainty.

While the passage of the IRA has provided certainty about the tax-credit regime under which clean generation will be built, both state and federal policy around climate and electricity still are subject to change. This unpredictability can make it difficult for renewable energy projects to be planned and built. States that employ multiple complementary policies while maintaining flexibility can help insulate projects from sudden changes—although employing layered policy can decrease economic efficiency.

Tension between local self-sufficiency and cost-effectiveness.

Many state electricity policies focus on decarbonizing the grid entirely within the state itself. Policies with this structure can be attractive to states, because these types of policies may help keep economic development and public health benefits within the state and may offer greater environmental integrity when states have no control over the actions of their neighbors. But go-it-alone policies can be significantly more expensive than policies that involve interstate coordination; policymakers should balance these different priorities.

Demand Management

The IRA promotes electrification of transportation and buildings, both of which are deeply necessary for decarbonizing the entire economy.

Reducing growth in peak demand, even as overall demand increases, is one of the main ways to keep costs low, and demand management—the shifting of demand from peak hours to off-peak hours—is the main strategy for doing so.

States can help coordinate energy efficiency and these demand-management efforts, though challenges remain.

> **Go-it-alone policies can be significantly more expensive than policies that involve interstate coordination.**

Lack of access for low-income households.

Historically, energy-efficiency policies have struggled to reach some demographics, including renters and low-income households. As states switch from promoting energy efficiency to promoting demand management, similar issues may arise. States can address this problem by specifically designing programs to reach low-income households, perhaps by combining new programs with programs that already are accessible to low-income households.

Missing metrics of success.

Most demand-management policies employed by US states focus on reducing overall electricity demand through energy-efficiency targets and associated programs; unfortunately, these policies don't always include an enforcement mechanism. States can use performance-based programs, in which utilities are compensated only if they meet reduction targets—but determining whether the target has been met can be difficult, especially when the demand is being compared to counterfactual demand projections that are themselves uncertain. Enforcing these metrics is an area for future research, including building on work by RFF scholars Brian C. Prest, Karen Palmer, and Casey Wichman that uses machine learning to create counterfactual baseline projections.

Inadequate incentives for electricity customers.

Current electricity rates generally do not reflect the marginal cost of generation, which means that customers don't know the most cost-effective times to scale back their demand for electricity. Innovative time-varying rate structures could communicate this information about marginal costs and encourage customers to reduce demand at times with the greatest potential to reduce costs for themselves and for the grid. Time-varying rates also can reveal opportunities to grow demand at low cost to consumers, and such opportunities often coincide with periods of abundant renewable energy supply. RFF Fellow Beia Spiller has done extensive work on electricity rate design.

Inadequate incentives for utilities and regional transmission organizations.

Demand management often is a more cost-effective way to meet system needs than building additional generation or transmission. As things stand, however, utilities in regulated regions typically are compensated based on capital investment, with utilities in both regulated and deregulated regions compensated based on investment in the distribution grid. Demand resources—that is, managed reductions in electricity demand instead of additional generation of electricity—often are unable to bid into regional electricity and capacity markets in the same way that generators can. States can change the business models of utilities, pushing their utilities toward demand resources. States also can advocate for greater participation of demand resources in regional markets, working with FERC and regional transmission organizations to do so.

Confusing and high-risk rate structures.

Changing customer rates to reflect the marginal cost of electricity may facilitate demand management and produce positive outcomes; on the other hand, time-varying pricing may expose customers to the risk of high prices that those customers may not be equipped to manage. Focusing on simple competitive retail rates (without time-varying costs), incoming RFF Fellow Jenya Kahn-Lang has shown that predatory marketing practices and customer inattention mean that low-income consumers often lose money when they switch to competitive retail electricity providers. This pattern could be worse with the introduction of more complex rate structures. The use of simpler rates or automation for residential customers, and careful evaluation and testing of rate designs before mass application, can protect consumers and prevent harm.

Transmission

The IRA provides tax credits for transmission, because increasing transmission capacity will allow population centers to access the clean energy resources they'll need to cover their demand.

But coordinated transmission planning is difficult, even with subsidies—so, state engagement in the process will be key.

> **States that are looking to promote transmission will need more people with this expertise working in and with state governments.**

Institutional mismatch.

Transmission is inherently a multi-jurisdictional and multi-institutional affair. Transmission requires coordination among FERC, regional transmission organizations, and neighboring states. FERC's April 2022 notice of proposed rulemaking for transmission will provide guidance to states as they move toward proactive planning.

Complex cost allocation.

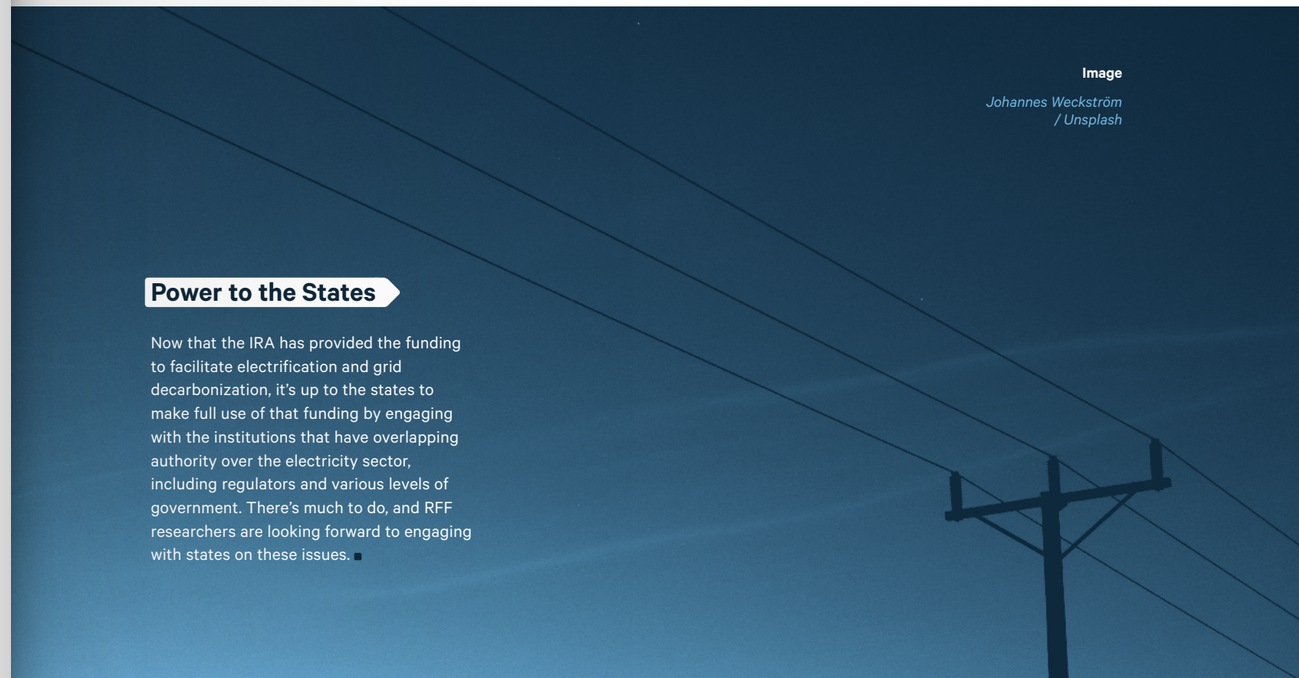
FERC requires that the costs of transmission be allocated among states according to the "beneficiary pays principle"—meaning that all who benefit should pay proportionate to the benefits they receive. But quantifying the benefits and determining where those benefits accrue is a complicated affair. FERC's notice of proposed rulemaking for transmission gives states a more formal role in deciding cost allocation. This is an area in which research and quantitative modeling can be useful.

Limited state government expertise and capacity.

Planning for new transmission infrastructure and engaging in multi-state planning processes take an enormous amount of knowledge and time, and many states do not have capacity for this activity. States that are looking to promote transmission will need more people with this expertise working in and with state governments.

Local opposition to transmission investment.

As with siting considerations for facilities that generate clean power, transmission siting can be either facilitated or blocked by local governments. As part of regional transmission planning processes, states can help regional transmission planning processes identify the transmission pathways that have minimal impact on local communities and can help include local communities from the early stages of the planning process.



Image

Johannes Weckström / Unsplash

Power to the States

Now that the IRA has provided the funding to facilitate electrification and grid decarbonization, it's up to the states to make full use of that funding by engaging with the institutions that have overlapping authority over the electricity sector, including regulators and various levels of government. There's much to do, and RFF researchers are looking forward to engaging with states on these issues. ■

The Economics of Biodiversity

Human beings are connected to nature, which is a major part of our economies and well-being. To date, our global human society has invested so little in nature that we're having trouble preserving important resources for ourselves. One means of pursuing more beneficial outcomes for humans and the environment would be to gauge and preserve the economic value of biodiversity.

TEXT
Partha Dasgupta

> **"The biosphere is not exactly a house of cards, but we humans are now so ingenuous that we would be able to reduce it to one if we put our minds to it."**

That economic policies should be evidence-based is (or perhaps should be) an incontrovertible requirement. But evidence is of no use if it's obtained from a misleading conception of the human condition, for faulty models produce spurious evidence. Systems of thought mislead if they do not acknowledge humanity's embeddedness in nature, when those systems are applied to project the present and future possibilities that are open to us.

Earth scientists see 1950 as when we entered the Anthropocene. Since then, an expansion in our demand for "provisioning goods" from nature (food, water, timber, fibers, pharmaceuticals, and nonliving materials—the ingredients that, with human effort, shape the final products reflected in GDP) has eaten into our ability to derive "maintenance and regulating services" from nature, such as carbon sequestration, nutrient recycling, decomposition of waste, pollination, nitrogen fixing, soil regeneration, purification of water, and maintenance of the biosphere's gaseous composition.

A tension exists between the global demand for the biosphere's provisioning goods and the human need for maintenance and regulating services. That tension is apparent when humans engage in the mining, quarrying, and broader land use changes that accompany expansions of crop agriculture, livestock farming, plantations, and construction. The biosphere is not exactly a house of cards, but we humans are now so ingenuous that we would be able to reduce it to one if we put our minds to it.

For many years, research in environmental and resource economics has demonstrated that the practice of detaching the human economy from the biosphere in contemporary economics can cause harm. Perhaps we can reconstruct contemporary economics to produce more positive outcomes. In that case, we will have to study our embeddedness in nature at all levels: the individual person, households, communities, nations, regions, and the global economy. The latter is where growth and development economics of the long run are fashioned, so a reconstruction also would refashion macroeconomic models of the long run.

Meanwhile, mathematical formulations of the economics of climate change have viewed the climate system in isolation from the biosphere's other systems. The models graft an isolated climate system into contemporary models of growth and distribution, which interpret the human economy as being external to the biosphere—an abiding weakness of the models. This disconnect between humans and the biosphere is the reason that early estimates of the global cost of carbon were so low as to be unbelievable at $10–$20 per ton. Dramatic increases in the estimates of the global cost of carbon in recent years—$185 per ton, based on recent research from Resources for the Future (RFF)—indicate the recognition that, among other impacts, extreme climate events can be expected to occur more frequently with rising carbon dioxide concentrations in the atmosphere.

Biodiversity is a characteristic of ecosystems. Depending on how it gets defined—for example, by emphasizing the functional

diversity of ecosystems as opposed to species diversity—biodiversity has been found to enhance the ability of ecosystems to supply maintenance and regulating services. Biodiversity can facilitate services by, for instance, increasing the resilience of ecosystems to disturbances. This line of thinking is an application of capital theory, such that the biosphere is taken to be an asset in which the human economy is embedded.

Well-intentioned though they are, the United Nations' Sustainable Development Goals were framed with little attention to the economics of biodiversity. We call the gap between the demand by humanity on maintenance and regulating services, and the biosphere's ability to meet that demand on a sustainable basis, the "impact inequality." The aggregate demand for nature's services would be called the "global ecological footprint," the sum total of individual footprints. The impact inequality is a snapshot of the global socio-ecological system. It is an accounting statement on the state of Earth's ecosystems at a moment in time. One estimate of the ratio of our global ecological footprint to the biosphere's capacity for meeting that demand on a sustainable basis, necessarily crude though it is, stands at 1.7, meaning that we need 1.7 Earths to sustain our current aggregate demand.

Other things equal, increases in the efficiency of maintenance and regulating services would reduce the ecological footprint. The received economics of climate change has focused on technological change and pricing carbon emissions as the means for increasing this efficiency. This strategy accompanies the belief that even a moderate annual investment in the transition to clean energy (say, 2 percent of GDP; see also the recap of RFF's recent Net-Zero Economy Summit on page 36 in this magazine) can achieve net-zero emissions by 2050 and enable the global economy to enjoy growth in GDP indefinitely.

But this optimistic view may be a misplaced reading of the biosphere's workings. Because of the complementarities among nature's services, a reliance on energy pricing and the development of clean energy technologies to overcome our ecological overshoot could be expected to backfire; we should be looking for ecological solutions, as well. Raising the biosphere's stock and the net regenerative rate by allowing nature to grow constitutes an investment in nature. Such investment does not so much involve machinery and hardware as it involves simply waiting; that is, waiting for nature to recover.

Accounting for Natural Capital

Inclusive wealth increasingly serves as an appropriate measure of economic well-being. An economy's inclusive wealth reflects the social value of its stocks of produced capital (roads, ports, buildings, machines), human capital (health, education), and natural capital (ecosystems, minerals, and fossil fuels). While GDP is useful for short-run macroeconomics management, we can consider the utility of creating a parallel system of capital accounts, akin to a firm's balance sheet, for judging economic performance.

Inclusive wealth is a good measure with which to conduct both sustainability assessments and policy analysis. Inclusive wealth increases over time if and only if well-being across generations increases over time; inclusive wealth and well-being across generations are two sides of the same coin. A nation's inclusive wealth would increase over a period if aggregate consumption in the period is less than net domestic product (i.e., GDP minus the depreciation of capital assets). Thus, we have a criterion for sustainability that can be based on flow accounts. National statistical offices in an increasing number of countries are creating natural capital accounts—not as a substitute for national income accounts, but rather as a complement (as recently announced in the United States).

However, accounting prices of natural capital are often deeply contentious, and the stocks frequently are hard to measure. Often, the best we can do is create natural capital accounts that offer qualitative descriptions of their state; for example, whether the health of an ecosystem has improved or deteriorated over the previous year (Figure 1).

Some forms of natural capital are not owned by anyone, such as the atmosphere and the open oceans. But if agents in an economy have free access to these assets, then the assets should be noted in inclusive wealth. For example, the accounting price of a global public good such as the atmosphere as a sink for our carbon emissions (e.g., the subtraction of $185 per ton of carbon emitted) is the sum of the accounting prices of the asset enjoyed by each nation.

Managing Ecosystem Risks and Investments

Imagine a chain of supermarkets that's so inefficient at their check-out counters that customers take home most of the goods they want without paying for them. Pilfering enables people to enjoy a high standard of living, but the benefits are bound to be short-lived, as the supermarket chain is guaranteed to go bankrupt. Globally, we don't pay for the vast quantities of maintenance and regulating services that we use, which means that the current high standard of living in rich countries comes at the expense of future living standards. We can outline three examples of why our use of the biosphere amounts to pilfering from nature.

1. Environmental Subsidies

The aggregate subsidy that humanity pays itself to "mine" nature (e.g., energy subsidies) is on the order of $4 trillion–$6 trillion annually, or some 5–7 percent of global GDP. That value amounts to a negative price for nature and creates an enormous pressure on the world's ecosystems. The subsidies provide us with a strong incentive to plunder the biosphere, rather than preserve it.

2. Global Commons

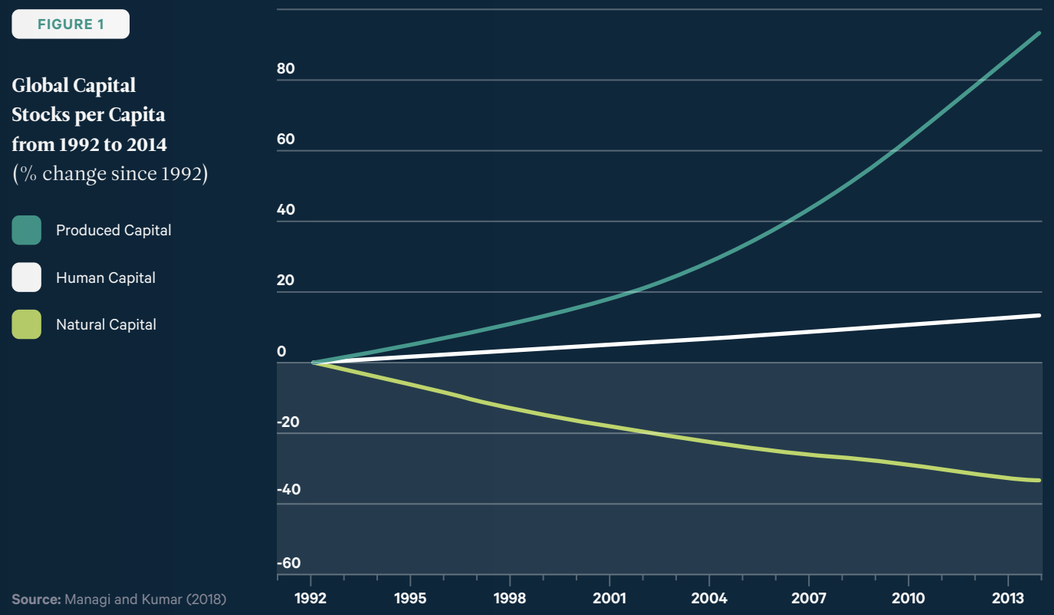
We don't pay for such global public goods as the open seas and tropical rainforests. The oceans represent an open-access resource (beyond exclusive economic zones) and suffer from the "tragedy of the commons." Rainforests are located within national jurisdictions; hence, national incentives to conserve them are less than the global incentive.

3. Trade and Wealth Transfers

It is not an accident that the bulk of the world's biodiversity is in the tropics and that most of the world's poorest people live there. Principal exports from those regions are primary products, and their extraction from mines, plantations, wetlands, coastal waters, or forests inflicts adverse externalities on local inhabitants.

FIGURE 1

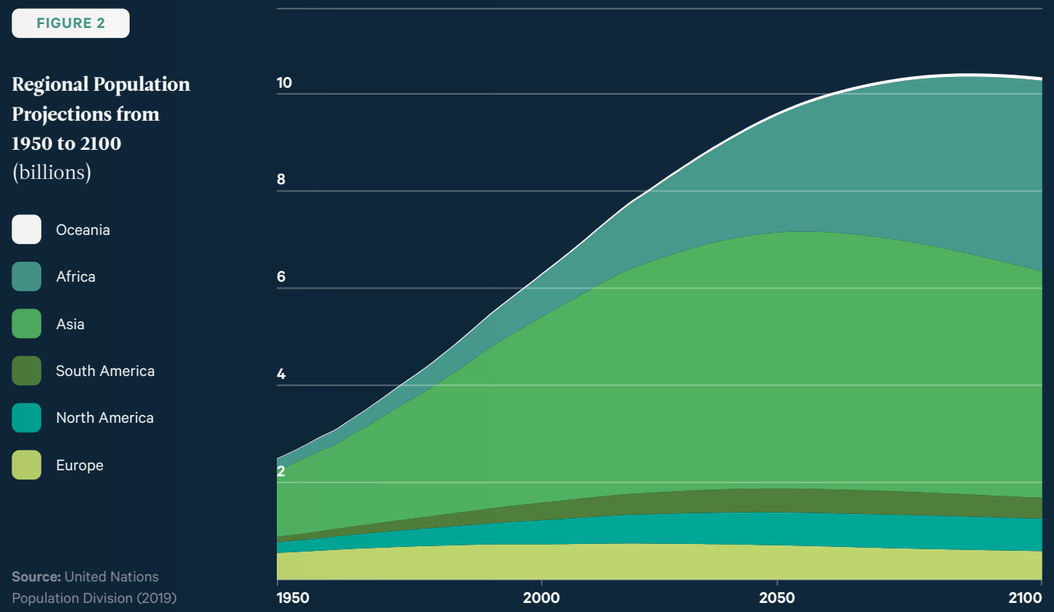
Global Capital Stocks per Capita from 1992 to 2014
(% change since 1992)



Source: Managi and Kumar (2018)

FIGURE 2

Regional Population Projections from 1950 to 2100
(billions)



Source: United Nations Population Division (2019)

The externalities are not reflected in export prices. Thus, local ecosystems are overexploited, which amounts to a transfer of wealth from the exporting country to the importing country—that is, from a poor country to a rich country.

Policy implications arise from these three examples that are drawn from the contemporary economic world. Few attempts have been made to assess quantitatively the effect on our consumption patterns if the subsidies were removed, perhaps because the implications of the first example are obvious enough. On the one hand, an immediate effect would be an increase in commodity prices and therefore lower disposable incomes; on the other hand, reduced taxation would mean an increase in our disposable incomes. The key point is that removing the subsidies would lead to consumption moving away from nature-intensive goods.

The oceans have received far less attention among national and international decisionmakers than the atmosphere as a sink for our carbon emissions. But the seas are vital for our existence. The second example points to the need for an institutional mechanism that incentivizes a reduction in the stress that we inflict on the oceans by commodity transportation, cruises, fishing, and pollutants from land. The standard tools of public economics are regulations (e.g., quantity restrictions) and taxes. The former are enshrined in such policies as protected zones. A benefit of such regulatory policies is that they can be reached by international agreements without the need for an agency to implement them. But such policies have downsides; for example, the benefits from rents imposed for the use of oceans would be enjoyed by users, rather than by the public.

Taxation of public goods has the merit that the rents themselves would, in principle, accrue to us all, though implementing this kind of a tax would require an international agency. The establishment of an agency with the remit to monitor and charge for the use of the high seas by, for example, taxing ocean transportation, deep-sea fishing, or the refuse that is deposited into them by nations, could be possible. Such a solution could raise billions of dollars annually, given that $1 trillion or more of merchandise is shipped across the oceans each year.

Another benefit of taxation is that the rents so collected could be used in part to pay nations to conserve the oceans or tropical rainforests in their jurisdiction. Currently, the rest of the world complains about the continual destruction of what remains of the world's rainforests, but little is done about it. Payment for ecosystem services is becoming familiar within nations, and such a payment system could be extended internationally.

The third example of trade and wealth transfers tells us that the global South *collectively* should impose export taxes on primary products. This strategy would ease pressure on local ecosystems and could serve as a source of income for the exporting nations. Individually, exporting nations would not impose taxes for fear of losing markets, and the global South faces this familiar prisoner's dilemma over the export of primary products. If climate negotiations are taken as illustrative, African nations would find it hard to reach collective agreements.

Although exports of primary products involve wealth transfers from exporting to importing countries, the influx of wealth is not an unalloyed benefit for importing countries. That's because the transfers carry risks for importing companies. Directors of investment companies and financial institutions consistently raise concerns over the financial risks for investors due to ecological overshoot. Formal models connect risks for importing firms to the risks of ecological collapse in the countries that export primary products. Insuring against such risks in the marketplace is not a viable option: Not only must we contend with the moral hazard along extensive supply chains, but the risks also are positively correlated (e.g., if a wetland is damaged, pollination suffers in neighboring farms).

Incentives are necessary to motivate importing firms to protect ecosystems that are upstream in their supply chains—not insurance against the collapse of these ecosystems. Investment in nature would be a highly effective form of insurance. Investment in the sources of primary products makes business sense, if for no other reason than that firms would enhance their reputation among investors. Maintaining the integrity of ecosystems in supply chains is sound business practice for companies.

“Incentives are necessary to motivate importing firms to protect ecosystems that are upstream in their supply chains—not insurance against the collapse of these ecosystems.”

“Human beings are connected to nature, which is a major part of our economies and well-being, now and in the future. Economists would do well to acknowledge this fact officially and explicitly.”

Sir Partha Dasgupta is the Frank Ramsey Professor Emeritus of Economics at the University of Cambridge.

This article was adapted from an essay that was written for a symposium on The Economics of Biodiversity: The Dasgupta Review *in the journal* Environmental and Resource Economics.

How does the risk of ecosystem collapse at the top end of the supply chain of a company translate into the company's risks? We've studied that, by deriving the adjustment that firms should make to the value they attribute to ecosystem services. Suppose a supply source (e.g., a wetland) yields a benefit to a firm. Because ecosystems are being degraded everywhere, the firm fears that the source will collapse at an uncertain, or random, date. This example, albeit stylized, has a general message: the risk of ecological collapse translates into a risk factor on an ecosystem's value.

An extension of the model that's worth considering involves abandoning the assumption that the benefits provided by the supply source are constant. With the world's rainforests being razed to the ground to make way for cattle ranches, plantations, and mines, we would expect the benefits to increase over time relative to our assumed income.

But a company that makes a unilateral move toward ecological stewardship faces risks if consumers are not ecologically minded: first movers don't necessarily have an advantage. How strongly investors and consumers feel about ethical practices matters. One option could be for companies to collectively disclose conditions in their supply chains. A way to do that could be to lobby the government to make disclosure mandatory. Decisionmakers could estimate the accounting price of an asset that is expected to suffer collapse at an unknown date in the future. This estimation would be the first step in translating ecological risks into business risks.

Demographic Pressure on Natural Capital

A nation's demographic structure once was taken to be an essential factor in development options for the United Nations. But demography considerations tend to be absent from environmental and development thinking, in what seems to be a recent phenomenon. For instance, demography has been left out of sustainable development strategies, as reflected in the practice of major global economic players allocating less than 1 percent of their aid budget to family planning and reproductive health. In its budget for 2021, the UK government reduced its already meager allocation to family planning by 85 percent.

The world population in 1950 was 2.5 billion. Today, 8 billion people live on the planet. Population projections by the United Nations Population Division predict that global population in 2100 will be 10.2 billion (Figure 2).

Is that population size likely to be supportable at a comfortable standard of living on a sustainable basis? Work that I published this year with Aisha Dasgupta and Scott Barett showed that a sustainable global population is approximately 3.2 billion, which was the global population in the early 1960s. Hence, the current impact inequality is substantial.

Reducing population size can reduce the pressure that a population inflicts on its local ecosystems. However, a common assertion is that the source of humanity's overreach is not the size of global population, but rather consumption in the global North. The truth is that both high consumption in rich countries and human population size are important parts of the reason for our ecological overshoot. Global population numbers, regional population numbers, and family planning services all have salience in addressing the problems of climate change and biodiversity loss.

Conclusions

Human beings are connected to nature, which is a major part of our economies and well-being, now and in the future. Economists would do well to acknowledge this fact officially and explicitly. To date, models of economic growth have the shortcoming of interpreting the human economy as Septarate from global ecology—but we have the means to assess services from nature, our consumption of those services, and the regeneration of those resources. By acknowledging these interconnections explicitly, stakeholders can better assess and manage risk, policymakers can govern and distribute resources, societies can sustain their needs, and humans can cultivate the type of biodiversity and healthy ecosystems that are necessary for a healthy planet. ■

Windows *on the* World

NO. 212 | SPRING 2023 | *"Measuring the societal value of scientific information."*

The Value of Satellite Information for Decisionmaking

TEXT Sarah Beam Aldy

A collaboration between Resources for the Future and NASA is winding down after six years of productive work to quantify the benefits of satellite information when the information is used to make decisions. This unique collaboration, called the VALUABLES Consortium, supported three major projects by interdisciplinary teams of Earth scientists and social scientists as part of its broader portfolio of research and community and capacity-building initiatives. The results from these teams in the Brazilian Amazon, California recreation areas, and rural communities in Bangladesh demonstrate that satellite data can go a long way toward benefiting people and the planet.

IMAGES *NASA Earth Observatory*

Decisionmakers on three different continents, facing three disparate problems—deforestation in the Amazon, harmful algal blooms in California lakes, and cholera in Bangladesh—can all look to the same place for help: the sky. Information from Earth-observing satellites can help us understand air and water quality, land use, ecosystem functioning, and many other processes on Earth, and this improved understanding can help governments, businesses, and individuals make better decisions.

For example, in Brazil, the satellite-based Real-Time System for Detection of Deforestation (DETER) enables forest managers to enforce laws that protect against illegal forest clearing. And in California and Bangladesh, early-warning systems based on remote-sensing data can help people avoid exposure to harmful algal blooms and cholera.

For the past few years, three interdisciplinary research teams at 14 different institutions have been working with the decisionmakers in these locations to investigate whether potentially costly investments in remote-sensing technology pay off—by quantifying the societal benefits of using data from satellites. Each team received a $100,000 Grant for Assessing the Benefits of Satellites (GABS) to conduct this research, awarded by the Consortium for the Valuation of Applications Benefits Linked with Earth Science (VALUABLES). VALUABLES is a partnership between Resources for the Future (RFF) and NASA that brings together Earth scientists and social scientists to measure and communicate how satellite information benefits people and the environment when it's used to make decisions. As the six-year initiative winds down (see Box 1), the GABS teams exemplify the community that VALUABLES has built, which continues to grow and innovate methods for quantifying the benefits of satellite data.

The teams have been among the first to put into action the VALUABLES impact assessment framework, a rigorous tool to investigate how new data influence decisions and quantify how these decisions improve societal outcomes; for example, in terms of lives or dollars saved. The results are a powerful expression of the value of a critical resource: scientific information.

Eyes in the Sky

Space agencies began launching satellites to monitor environmental conditions in the 1960s, with explosive growth beginning in the 1990s. Today, satellites continue to be launched every year, and new applications are being developed nearly daily. When VALUABLES began in 2016, "we had a lot of anecdotes on how these data were being used, but the next step for the consortium and the broader community was quantifying the value of the data in the decisionmaking process," says Yusuke Kuwayama, director of the VALUABLES Consortium and an RFF fellow. "RFF has historically played an important role in establishing an economics literature that helps policymakers understand the value of nonmarket resources, like clean water and air. And now, a few decades later, RFF has worked with NASA on an initiative to value information, which is a resource in and of itself."

The GABS teams have provided important case studies across different applications and different types of decisions to demonstrate the value of Earth observations from satellites. VALUABLES supported these projects as part of the consortium's work to foster an interdisciplinary community of practice in which researchers are empowered to undertake these important evaluations.

The Value of Information to Reduce Deforestation in the Amazon

One group of GABS awardees includes natural scientists and social scientists who have been collaborating on work in the Brazilian Amazon for much of the past two decades. Team leader Jill Caviglia-Harris of Salisbury University explains, "As an environmental economist, I need the work of Earth scientists to do the work I do. You can think of it along a disciplinary-specific path: Earth scientists identify a problem, social scientists design policy interventions, and then policymakers act. But an interdisciplinary approach means that the Earth scientists and policymakers are working hand in hand with economists and other social scientists to not only define problems, but also to figure out how to solve them."

Above Brazil has prioritized the regulation of certain municipalities in the Amazon which contain areas that have been illegally deforested.

Rich Carey / Shutterstock

> **"Facing international pressure to halt deforestation after two decades of rapid settlement of the Amazon, the Brazilian government began using Landsat satellite data in 1988 to calculate annual deforestation rates."**

In this case, the group came together to produce the first estimate of the amount of avoided deforestation that's resulted from the use of satellite data.

Facing international pressure to halt deforestation after two decades of rapid settlement of the Amazon, the Brazilian government began using Landsat satellite data in 1988 to calculate annual deforestation rates. But these rates remained relatively high through the following decade, partly because of a month-long lag before the satellite information was available to the government and other environmental enforcement agencies. As a response in 2004, Brazil's National Institute for Space Research launched a new monitoring system, DETER, based on near-real-time images for the rapid detection of deforestation. The period 2004–2012 saw more than a 70 percent reduction in deforestation, with evidence that the DETER system has played an important role in supporting the country's Forest Code and other policy objectives.

To quantify the outcomes of using the DETER system, the researchers conducted an impact assessment that compared the amount of deforestation in three different potential states of the world: one in which the DETER system was available to decisionmakers and two "counterfactuals" in which the DETER system was not available. The first counterfactual assumed that the DETER system is not available, but that other actions taken by the government and private sector during the study period are fully effective. The second counterfactual imagined that DETER is not available and, as a result, the other actions would have zero effectiveness—because those actions either would not have existed or could not be enforced successfully.

The difference in outcomes among these states represents the value of the DETER satellite data. The researchers found that using the DETER system avoided approximately 467,000–471,000 square kilometers of deforestation between 2001 and 2015—an area larger than California and more than double the recorded deforestation during that period. That translates into about 12 billion tons of carbon dioxide emissions avoided, as well.

The team used the results of the impact assessment to monetize the net benefits of the DETER system in two ways. First, they used avoided deforestation in combination with people's willingness to pay for ecosystem services (such as clean water, carbon sequestration, and ecotourism) to arrive at a range of $1 billion–$5.4 billion in benefits per year. Second, they looked to the social cost of carbon, a figure that helps estimate the cost to society of each additional ton of carbon dioxide emitted into the atmosphere and ranges from $51 to $185 per ton, to estimate the net benefits of DETER as $54 billion–$197 billion per year.

Caviglia-Harris notes that their findings highlight the relationship between the value of information and decisionmaking processes. "After our study period, deforestation began to increase at rates that are now at 10-year record highs—and that's because the Bolsonaro administration failed to enforce the laws that were in place," she says. "Thinking that simply putting together satellite data is going to make an impact is naive. We need to have policies that are enforced. And anything we can do to show the value of those policies and the value of the supporting data is going to be relevant to addressing deforestation—and, more broadly, climate change."

The Value of Information to Detect Harmful Algal Blooms

Research led by Stephen Newbold of the University of Wyoming centered on a different type of decisionmaker: individuals who want to enjoy a day on the water. His team's mission was to quantify the value of satellite data for predicting the timing and location of algal blooms in California lakes, so that visitors could choose unaffected sites for

boating, fishing, swimming, and other water-based recreation.

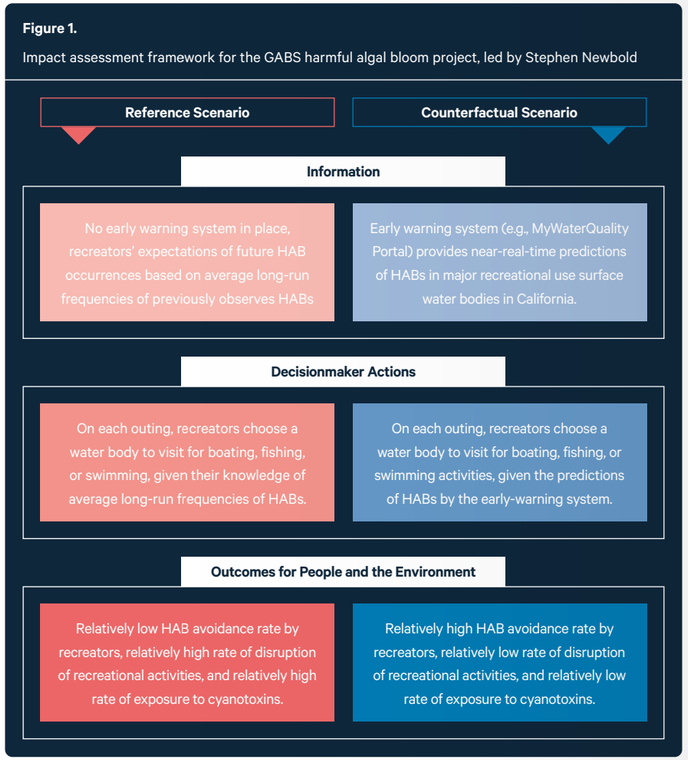
Despite their innocuous name, algal blooms are dangerous excessive growths of algae in lakes that can choke the water's surface and often contain cyanobacteria that can be toxic to humans and non-human animals. These events are intermittent and vary in their frequency, severity, extent, and duration. Algal blooms are becoming more frequent as waters warm and urban and agricultural runoff dumps nitrogen and phosphorus—two nutrients that spur algal growth—into water bodies.

The GABS research team created a model of recreation demand that describes how lake visitors adjust their plans when harmful algal blooms are announced, based on cell phone mobility data. Then, they applied the model framework to two possible scenarios over the course of April–September 2019: The first scenario involved an early warning system for harmful algal blooms, powered by near-real-time satellite data for 100 lakes in California. The second scenario involved recreators who knew only the historic frequency of algal blooms for this same set of lakes (Figure 1). The first scenario, the researchers believed, is plausible in the near future, while the second better represented the current state of the world.

Their comparison of the two scenarios produced a quantitative estimate of the value of additional information about harmful algal blooms. To calculate this estimate, the researchers asked, What is the maximum amount that recreators would be willing to pay to know whether a harmful algal bloom is present at each lake among their options before deciding which site to visit? The researchers found that the total value of a perfect early-warning system was $2.46 million, applied across the 17 million visits to lakes that occurred during the time period.

"Algal blooms can severely disrupt water-based outdoor recreation activities, but they are highly intermittent and likely difficult for casual recreators to anticipate, so near-real-time satellite information on these events could be very useful," says Newbold. "Satellite data also can be used by natural resource agencies to help identify when and where water-contact warnings should be posted. This application would be distinct from the source of value we studied in our project, but it could be an important area for further research by the VALUABLES community."

Figure 1.
Impact assessment framework for the GABS harmful algal bloom project, led by Stephen Newbold



Above (Figure 1) Information, actions, and outcomes for a reference scenario with satellite data and a counterfactual scenario without satellite data, involving the influence of harmful algal blooms (HABs) on outdoor recreation activities in California.

The reference scenario represents current conditions, and the counterfactual scenario represents a possible near-term future, when highly accurate real-time forecasts of harmful algal blooms would be widely available.

The Value of Information to Reduce Cholera Risk

Investigating the value of information provided by another type of early-warning system—one that alerts Bangladeshi households of potential cholera outbreaks—was one of two goals of the third GABS-funded research project. "The second touchpoint we had in our team," remarks Sonia Aziz of Moravian College, "was the concept of radical empathy."

Cholera poses a significant health risk in Bangladesh, where disease outbreaks lead to at least 100,000 cases and 4,500 deaths every year—numbers that are almost certainly underreported. While information is available on the seasonality and peaks of cholera risk, this information often isn't accessible to those who are most vulnerable to the transmission of the disease. The research team set out to address this problem, by making information more accessible. Putting empathy into practice, they worked in depth with local scientists and residents in what Aziz describes as a "truly collaborative experience," in which all participants had a voice. "We were working with one of the poorest countries in the world and needed to make sure that we understood where our Bangladeshi partners are coming from."

> **"Algal blooms can severely disrupt water-based outdoor recreation activities, but they are highly intermittent and likely difficult for casual recreators to anticipate, so near-real-time satellite information on these events could be very useful."**

The researchers developed a cell phone app that uses remote-sensing data to provide households with a monthly prediction of cholera risk that's unique to their location, which may be categorized as low, moderate, or high. The app, called CholeraMap, provided information on how households can reduce risk when the cholera risk is high. The researchers provided the app to households—and most commonly women, who are the primary water procurers—in 40 villages in Matlab, a rural sub-district in Bangladesh. The team compared outcomes among three categories of households: CholeraMap users; households that were given a simpler app called CholeraApp that was identical in terms of design and functionality but provided users with only static, publicly available information on cholera risk; and a control group that received no app.

Over an eight-month study period, the team found that the use of the satellite-based CholeraMap was higher than the use of the

Opposite A prolonged dry season followed by an intense monsoon season in Bangladesh exposes the population to water insecurity and cholera outbreaks.

Courtesy of Sonia Aziz

See More ...

Get to know the people, case studies, tools, and resources that are involved in quantifying the value of satellite data when we use it to make decisions.

Space-time(line)

Exploring Six Years of VALUABLES Work to Quantify and Communicate the Benefits of Satellite Data

1 Dec 12, 2016
NASA and RFF officially launch the Consortium for the Valuation of Applications Benefits Linked with Earth Science.

2 May 23, 2017
VALUABLES is introduced in a webinar, "Understanding the Benefits of Observing Earth from Space."

3 Throughout 2017
VALUABLES appoints a core group of Earth scientists, economists, and advisors from the private and public sectors.

▶▶▶

What's Satellite Data Worth in Dollars?

Using Satellite Data to Help Make Sense of the Planet's Biggest Challenges

Infographic by James Round

Measuring the socioeconomic benefits of Earth observations is an important way for scientists and economists to understand and communicate the value of their research. These tangible benefits are a compelling argument for society to harness satellite data and capture its value.

With this infographic, the VALUABLES Consortium showcases three case studies that demonstrate how researchers can measure the benefits of satellite data. These case studies quantify and explain why the world is a better place, thanks to the decisions that can be made differently—and with better outcomes—in the presence of satellite data.

Better outcomes are possible with Earth observations; these quantitatively better outcomes present a persuasive argument for using satellite data in decisions.

"I'm proud of the collaborations and partnerships we've built through this consortium. We hope that they serve as examples for this kind of work moving forward—to show that it's possible to capture the enormous social value of satellite information."
Yusuke Kuwayama
VALUABLES Consortium Director

4 Oct 23, 2017
VALUABLES colleagues talk about the value of Earth observations at an event for Group on Earth Observations Week.

5 Dec 31, 2017
VALUABLES reflects on its first year, which included 13 workshops and conferences and more than 40 stakeholder meetings.

6 Jan 9, 2018
VALUABLES is the focus of a talk and panel discussion at the winter meeting of the Earth Science Information Partners.

7 Feb 28, 2018
RFF hosts the VALUABLES Consortium annual workshop with economists, NASA experts, Earth scientists, and decisionmakers.

8 Sept 4 and Oct 2, 2018
VALUABLES colleagues present webinars about the socioeconomic value of Earth science data, information, and applications.

9 Sept 12, 2018
RFF publishes a working paper about how plugging gaps in the US air pollution monitoring network can benefit human health.

10 Dec 10–14, 2018
VALUABLES presents new research and hosts a scientific workshop at the fall meeting of the American Geophysical Union.

11 Throughout 2018
VALUABLES presents at eight NASA meetings and two economic conferences throughout the year.

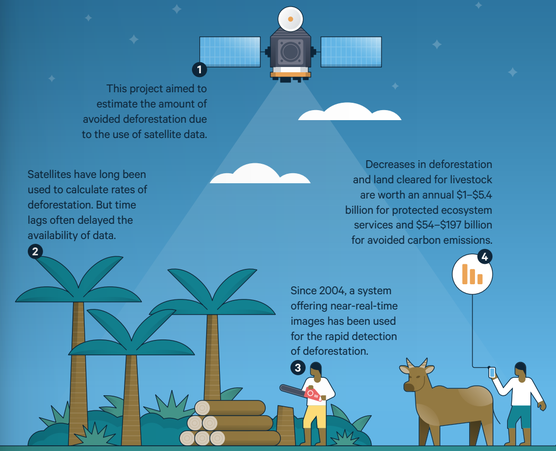
12 Jan 7, 2019
The first of four talks about economic valuation delivered during the year at meetings of the American Meteorological Society.

Brazil

Capturing Real-Time Evidence of Deforestation

This project estimated the amount of deforestation in the Amazon that was avoided and the carbon dioxide emissions that were prevented through the use of satellite data, which helped the Brazilian government detect and report illegal forest clearing.

Satellites Used	Researchers	Scale of Study
1	7	783 Amazon municipalities

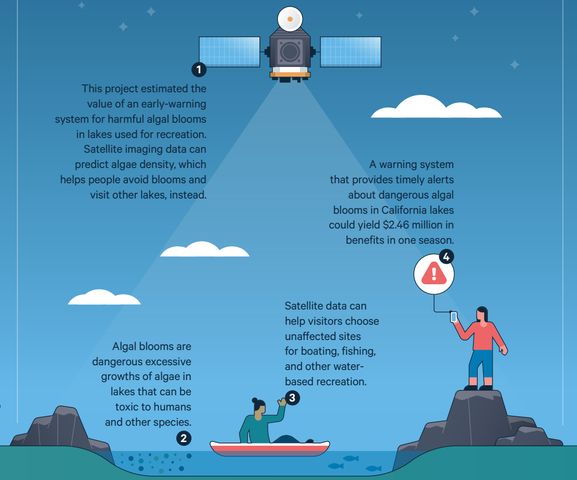


United States

Informing People about Harmful Algal Blooms

This project estimated the value of an early-warning system for harmful algal blooms in recreational lakes, using timely satellite imaging data which could divert visitors away from bloom-infested waters and opt to enjoy unaffected lakes, instead.

Satellites Used	Researchers	Scale of Study
2	6	100 lakes in California

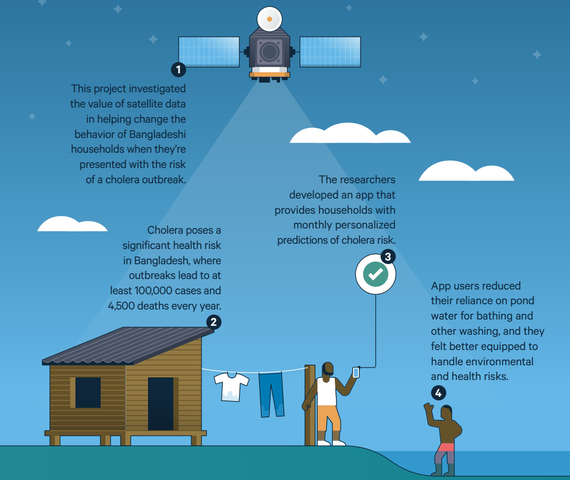


Bangladesh

Reducing Cholera Risks in Local Communities

This project investigated how access to a smartphone app, which contains household-level cholera risk predictions, affects the ability of villagers in Bangladesh to effectively respond to the environmental and health risks that can lead to disease.

Satellites Used	Researchers	Scale of Study
≥3	5	484 square kilometers



13 Mar 5, 2019
VALUABLES launches its explainer series about the tools and methods that can be used to value scientific information.

14 Oct 16, 2019
VALUABLES announces the Grants for Assessing the Benefits of Satellites competition, to fund studies of the value of satellite data.

15 Oct 30, 2019
VALUABLES holds its annual workshop to present new results from case studies and discuss research collaborations.

16 Nov 13, 2019
The academic journal *Environment Systems & Decisions* publishes VALUABLES research about monetizing uncertainty reduction.

17 Jun 11, 2020
RFF reveals the winners of the Grants for Assessing the Benefits of Satellites competition, awarding $300k to three research teams.

18 Jun 18, 2020
The journal *GeoHealth* publishes VALUABLES research about detecting harmful algal blooms in US lakes.

19 Oct 22, 2020
The *International Journal of Wildland Fire* publishes VALUABLES research about wildfire assessment and response.

20 Apr 26, 2021
VALUABLES publishes a working paper about using satellite data to facilitate the cost-effective conservation of blue whales.

21 Aug 11, 2021
VALUABLES hosts an interactive public session on how to design an impact assessment for NASA's Earth Science Applications Week.

Looking to the Sky for Evidence

VALUABLES Impact Assessments

Impact assessments investigate how people use improved information to make decisions and quantify how these decisions improve outcomes such as lives saved or resources conserved.

Protecting Endangered Species

Satellite data can help us estimate where blue whales spend their time, so shipping boats can avoid running into them. Using these data is a cost-effective form of conservation.

Informing Post-Wildfire Response

The fallout from wildfires is dangerous even after the fires go out. This study shows that mapping the continued threat of wildfires with satellite data can save millions of dollars.

Enforcing Air Quality Standards

Satellite data on local air pollution can verify whether the pollution levels meet healthy air quality standards. Basing decisions on these data could save lives and billions of dollars.

Regulating Oil and Gas Emissions

Satellite images help simulate the dispersion of pollution, which provides insights about the origin and direction of airborne particles like wildfire smoke and radioactive materials.

Predicting Corn and Soybean Prices

A satellite system can reduce uncertainties when predicting weather and soil moisture, which can help in managing agricultural production and anticipating crop yields.

Improving Drought and Flooding Forecasts

Soil-moisture forecasts, based on data from satellites that are sensitive to water, can yield societal benefits through better policy responses to drought and flooding.

Halting Disease Transmission

Satellite data can help limit the spread of disease by producing higher-accuracy maps and population estimates, which can support more highly effective vaccination campaigns.

Supporting Elk Migration

Conserving migratory species can be more cost-effective when policymakers use satellite data to help decide which sites in a landscape should be preserved as habitat.

Some Key Stats

VALUABLES in Numbers

$4.1 M Funding from NASA for the VALUABLES cooperative agreement

6 Number of years that the VALUABLES project has been active

17 Members involved in the VALUABLES scientific council

13 Explainers published during the VALUABLES project

9 Journal articles published as part of VALUABLES

11 Working papers and reports published alongside projects

Discover More ...

Digging into the details of any one of these impact assessments is as easy as visiting the VALUABLES website.

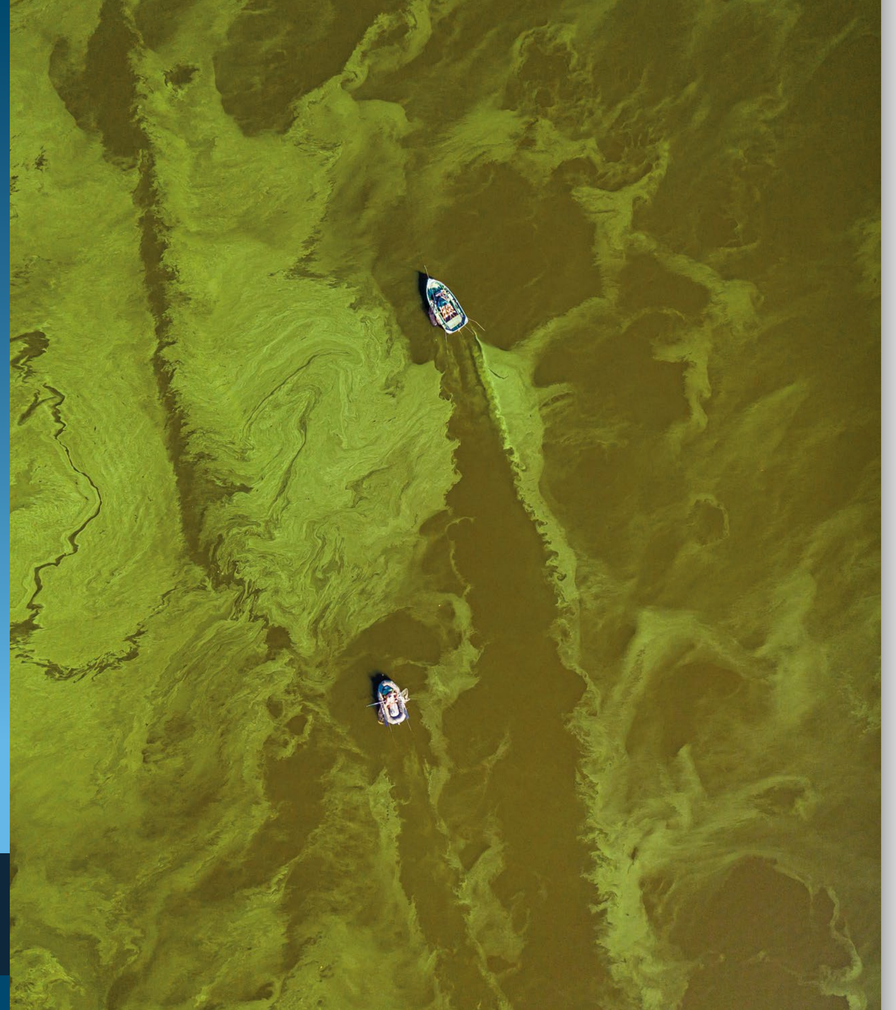
www.rff.org/valuables

22 Oct 2–3, 2021
VALUABLES designs a challenge on socioeconomic benefits for NASA's Space Apps Challenge, an international hackathon.

23 Dec 17, 2021
VALUABLES reflects on a year of quarterly meetings with the consortium's community of practice.

24 Oct 19, 2022
VALUABLES releases five working papers on topics ranging from deforestation to halting polio transmission in Nigeria.

25 Dec 5, 2022
VALUABLES hosts its capstone celebration, marking five years of measuring the benefits of using satellite information in decisions.



simpler CholeraApp, and the satellite-based app led users to decrease their pond-water bathing and other washing. The researchers found no change in other behaviors, such as hand washing and treating drinking water, and no change in self-reported cholera incidence. However, CholeraMap users increased their knowledge and felt better equipped to deal with environmental and health risks: app users reported that they were 8–9 percent more confident in their response than control households and 21 percent less likely to report diarrhea (a symptom of cholera) as a major concern for themselves and their children.

The GABS team plans to incorporate lessons from the experiment into an improved app design and "see tremendous scalability," according to app developer Ali Akanda. And the researchers are grateful for the funding that made the research possible. "I hail from a small liberal arts university," says Aziz. "I've involved students in this work who have never even been on a plane before—so, for them to be able to see how the window from space lets you peer into and improve the lives of people who are more similar to us than different was a really great opportunity for a small research community like ours."

Next Steps

The three GABS projects are among the first of a growing number of studies from the broader VALUABLES community that bring together natural scientists, economists, and decisionmakers to quantify the socioeconomic benefits of satellite data. As this community continues to expand, people across disciplines and roles will learn from each other to strengthen their tools and methods to measure the societal value of scientific information.

Lawrence Friedl is the director of the Applied Sciences Program at NASA and was instrumental in creating the VALUABLES Consortium. He explains, "We can expand on the approach of the value of information and build in other methods to show more and more communities how Earth science information could help them. We're also hoping that our work over the last six years is going to lead to new research questions, especially in Earth sciences."

Many researchers in the VALUABLES network have years of experience working as part of interdisciplinary teams, while others are newly initiated. For some, the experience with interdisciplinary research shapes how they think about impact. "The way that this opportunity has changed my thinking is fairly significant," says Aziz. "I've never been exposed to interdisciplinary work that had the potential for such impact before. If this revolution can advance enough to show the improved and saved lives—and if it can change mindsets in a world that so critically needs change—it's a privilege to be a part of that." ■

> **"Disease outbreaks lead to at least 100,000 cases and 4,500 deaths every year—numbers that are almost certainly underreported."**

Left Researchers answered questions and helped households in Bangladesh install a smartphone app that makes information more accessible about cholera risk and how to reduce the risk of infection.

Courtesy of Sonia Aziz

Far Left Satellite data can help local water quality managers prioritize locations in the field to take water quality samples, so they can decide whether an advisory is warranted.

Sergey Muhlynin / Shutterstock

Sarah Beam Aldy is a freelance writer and a former editor of *Resources* and *Environment* magazines.

NO. 212 | SPRING 2023 | *"What do we do with the rest of this decisive decade?"*

Pursuing a Future of Net-Zero Emissions and Net-Positive Economic Solutions

Leading voices in research, business, government, and the media convened at the Net-Zero Economy Summit, a recent event hosted by Resources for the Future, to discuss the transformative decisionmaking involved in creating a net-zero economy.

TEXT Matt Fleck
PHOTOS RFDCphoto

In kicking off the Net-Zero Economy Summit, White House National Climate Advisor Ali Zaidi laid out the climate challenge facing the United States: "We are in a moment of crisis—and in a moment of tremendous opportunity." The Inflation Reduction Act had passed just a few months earlier, providing $369 billion in public spending for clean energy and climate measures—the most significant climate action in US history.

Zaidi addressed an audience of leaders in government, research, business, and the media in the Skylight Pavilion at the REACH, a spacious expansion of the Kennedy Center alongside the Potomac River in Washington, DC. Zaidi closed his keynote address with a prompt toward implementation: "The question is: What do we do with the rest of this decisive decade?"

The Net-Zero Economy Summit, a conference hosted by Resources for the Future (RFF) in October 2022 to celebrate the organization's 70th anniversary and convene top minds in the energy and environmental space, provided a forum to discuss the decisions we can make moving forward that justly and equitably confront climate risks and build resilience. More than 300 attendees gathered at the REACH to join the discussion.

"Conversations at the summit will examine both the opportunities and the challenges of delivering a net-zero economy," said Richard G. Newell, RFF president and CEO, in his welcome remarks. "We'll tap some of the best thinkers in the United States and internationally to uncover the system-wide transformations that are needed to build a net-zero economy through solutions that are effective, efficient, and equitable."

The result was a composite sketch of the transition to clean energy—the road to a net-zero economy, in which the amount of carbon dioxide emitted by humans into the atmosphere equals the emissions captured from the atmosphere. The summit featured one-on-one conversations with leaders in the energy transition, along with panel discussions that got into the nitty-gritty of decarbonization, such as grid permitting reform, international carbon tariffs, and climate change communication.

Highlighting Insights from the Net-Zero Economy Summit

The Justice Forum amphitheater down the hall from the Skylight Pavilion housed the other half of the day's programming. Geraldine Richmond, Under Secretary for Science and Innovation at the US Department of Energy, explained during a panel discussion on industry and fuels why a continual process of innovation is "the seed corn to the decarbonization effort."

"It's not like a relay race, where you do the discovery science, then you pass it on to the application, and then you pass it on to deployment," said Richmond. "There are always going to be problems along that string. If you don't keep a cycle of life going, so that you've got teams on one end that can come back to the beginning, so that you can go even further, it's not going to work."

Another key element of decarbonization, the integration of renewable energy sources and increased transmission capacity into US electricity markets, was a focus of the panel on electric power. "Offshore wind is probably one of the biggest places that the US Northeast really, really needs to benefit from not only cohesive policy, but also leadership by the Federal Energy Regulatory Commission and by the US Department of Energy," said Doreen Harris, president and CEO of the New York State Energy Research and Development Authority, "not only to advance the analysis and market rules to deploy these technologies, but frankly to help our regional transmission organizations come together in interregional planning."

Where Government Fits In

Government decisionmakers at the summit stressed a desire to enable entrepreneurs to help spearhead innovation and collaborate on the broad deployment of nascent, high-potential technologies. In conversation with RFF Board of Directors Chair Susan F. Tierney, entrepreneur Jigar Shah, who directs the Loan Programs Office at the US Department of Energy, said that the federal government can nurture the seeds of innovation by getting capital into the right hands.

"The goal for us is to pay attention where commercial banks are not paying attention," said Shah. "We're supposed to be a bridge to the commercial banks … If [an applicant] makes it through our office, they're more likely to get picked up by a bank for their next project."

State and local governments, though unable to bankroll quite so many projects, often are responsible for implementing federal funding. Coordination among levels of government on the distribution of funding has become especially relevant, following the passage of the Infrastructure Investment and Jobs Act of 2021 and last year's Inflation Reduction Act, noted Samantha Medlock, senior counsel for the Select Committee on the Climate Crisis in the US House of Representatives. "We need to be working with state and local leaders to ensure that their land use decisionmaking and their building codes and standards are steering federal infrastructure money to the right places."

Sea level rise and more frequent extreme weather events, among other climate impacts, additionally could strain the ability of government to prepare and react if clear direction is absent. "There is a need for a national climate adaptation and resilience strategy," said Medlock during the panel discussion on climate risks and resilience. "We see progress at the federal, state, local, and sector level, but what we're lacking is a unity of purpose that a national strategy would provide."

Collaboration among states on regulations for various clean energy technologies also would smooth the road to net zero. David Strickland, a vice president at General Motors, highlighted the importance of harmonious regulation during the panel discussion on transportation.

"It can't be different sets of rules for different agencies, in different states, all at the same time," said Strickland. "Investment [in electric vehicles] has to be distributed effectively and thoughtfully. If you're trying to play in different parts of the world or in the United States, it's more resource intensive to get there."

Community-Level and Private-Sector Engagement

The theme of engagement and buy-in came up in many of the panel discussions. Speakers generally agreed that a top-down approach to decarbonization is more likely to encounter resistance from participants, whether individuals, communities, industries, state governments, or local governments.

In the panel discussion on land use, forestry, and agriculture, American Forest Foundation CEO Rita Hite noted that the nature of forest ownership demands buy-in on a granular scale: "Forests are a huge piece of the current carbon sink, and we have the potential to double that. But we have to focus on inclusion: we have to engage the small forest landowners, who make up a majority of US forests."

The theme of engagement involved a focus on environmental justice. For many communities in the United States, especially lower-income communities and communities of color,

energy policy and local energy industries historically have delivered pollution and negative health outcomes. "There needs to be positive interaction to meet the concerns of the environmental justice community," said RFF Senior Fellow Alan Krupnick about possible opposition to the expansion of hydrogen and carbon dioxide pipeline networks in the United States. The US Department of Energy has begun walking the talk on this front by requiring funding applicants from the agency's hydrogen fuel initiative to include a community engagement plan in their applications, said Krupnick during the panel on industry and fuels.

Many of the speakers accepted that opposition to specific climate policies and programs is inherent to the decarbonization process. Effective communication could soften some of that opposition. During the climate risks and resilience panel, Brookings Institution Fellow Carlos Martín responded to a question from an audience member about how to discuss climate change: "Some of the most effective climate adaptation and resilience communication strategies have focused on health … I think we'll see a lot more of that strategy in [the United States] moving forward."

Concluding the Summit on a High Note

For the full day of the summit, panelists and speakers discussed policies, technologies, and partnerships—the necessary components of achieving net zero. The day's final speaker, poet Harold Green III, was contemplative; he considered the immediate climate challenge in the context of the relationship between humans and nature.

At the day's end, Tierney and Newell toasted RFF's 70th anniversary and the collaboration that took place at and in the lead-up to the summit. For RFF scholars, the toast and the reception that followed the summit were opportunities to both celebrate decades of good work and reflect on continuing with their mission, which Newell summed up in his opening remarks: "We need the economy to work for the climate." ■

Thank You

RFF is grateful to the following supporters who helped make our Net-Zero Economy Summit possible:

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- Barbara Kates-Garnick and Marc B. Garnick
- Kyung-Ah Park
- Susan and John Tierney

Matt Fleck is a staff writer and reporter at Resources for the Future.

Nuclear Energy Innovation and Deployment

Recent advancements in nuclear technologies, along with recent policies—especially the Inflation Reduction Act—are incentivizing nuclear energy deployment. Alex Gilbert catches us up on these developments; he leads regulatory efforts at Zeno Power for applications of nuclear energy systems in space and is a fellow and PhD student at the Payne Institute for Public Policy at the Colorado School of Mines.

Resources Radio, a podcast produced by the *Resources* editorial team and Resources for the Future (RFF), broadcast its 200th episode last fall. New episodes are released weekly, in which one of the hosts—Daniel Raimi, Kristin Hayes, or Margaret Walls—speaks with a special guest about energy, environmental policy, climate impacts, and more.

Transcribed here is one such episode, which was originally released on September 27, 2022. The transcript of the conversation has been edited for length and clarity.

Daniel Raimi: Can you tell us how you started working on energy and environmental topics in the first place?

Alex Gilbert: If you care about environmental issues and climate change, then what you really care about is energy. It's your top concern, because energy has the biggest impact on the environment out of anything that humans do. Conversely, if you care about energy systems, you care about the environment, because the environment is the largest constraint on energy systems. I started focusing on energy systems because of the environmental aspect.

Nuclear energy in the United States and globally is a very large energy source. In the United States, it's the single largest clean power source. Even today, hydro, wind, and solar power combined produce about as much energy as just nuclear. Globally, about 10 percent of all power is from nuclear energy. Next to hydropower, nuclear is the second-largest clean energy source globally.

Your role at Zeno Power involves nuclear energy and related regulatory work—so, you are participating in the nuclear economy. Do you want to say anything about disclosures regarding your work?

Zeno Power is developing radioisotope power sources. We essentially take nuclear waste and use it to create small power sources for outer space and for remote locations on Earth. Historically, this is how people have powered things like the Mars rovers and deep-space probes.

We at Zeno see ourselves as part of this waste-innovation group that is emerging right now.

IN CONVERSATION
Daniel Raimi
and Alex Gilbert

ILLUSTRATION
Estudio Santa Rita

Various companies are starting to say, "We've seen all this innovation happening with nuclear reactors, and it's important for emissions reductions and for the success of the nuclear industry, but we're still going to have a challenge with nuclear waste. What can we do with that waste? What are ways to recycle it or to otherwise address it—to potentially store it, from a commercial perspective, that's longer term?"

As for the nuclear industry more broadly, we definitely are rooting for its success, but our company is Septarate from the innovations that are happening right now with advanced nuclear reactors.

We're going to talk about this bucket of technologies that you've referred to as "advanced nuclear technologies" and what the private and public sectors have been doing to push those technologies forward in recent years. Can you define "advanced nuclear technologies" for us?

It's a very squishy term. If you talk to different nuclear energy professionals, you'll hear different definitions. The best way to think about advanced nuclear technology is it's everything that's not a large light-water reactor, which is what exists right now. The United States is building two AP1000 nuclear plants in the South. Those are the last of the non-advanced reactors. Everything else that we'll build moving forward is considered, more or less, an advanced reactor.

What does that mean from a technology perspective? To start with basics, nuclear fission is based on the fission of atoms to create energy. You take a fissile isotope (an atom), usually uranium-235, and you hit it with a neutron. That neutron causes the atom to split. That split creates what we call "fission products," which are one of the main things in nuclear waste that we're concerned about. But it also creates energy, which we can harness. And it creates more neutrons, usually two or three, that you can then use to create more fissions.

A fission chain reaction can produce energy sustainably. And because we're dealing with atomic bonds here, and not chemical bonds, there's a lot more energy released than, say, burning natural gas or burning coal.

Historically, the way that we've harnessed that large load of energy is with a large light-water reactor. What does that mean? Generally, these are reactors that are a gigawatt or more in capacity. They use the isotope uranium-235 in fuel rods. Uranium-235 actually produces the fission, but this isotope accounts for only about 5 percent of the fuel rods; about 95 percent of the uranium in fuel rods is uranium-238, which doesn't fission much. That enrichment with uranium-235 is a key part of how you run these reactors.

The design philosophy with nuclear is about efficiencies of scale. The larger the reactor is, the more you can get the costs down in terms of engineering, regulatory costs, equipment, and materials.

When you run a nuclear reactor, you're using water for several things. Water transfers heat in either pressurized- or boiling-water reactors. It's like a coal or natural gas plant—you're using steam to turn a turbine. But you're also using the water to cool the fuel itself. The fuel heats up over time; if you don't cool it, it will cause issues like meltdowns and other sorts of accidents.

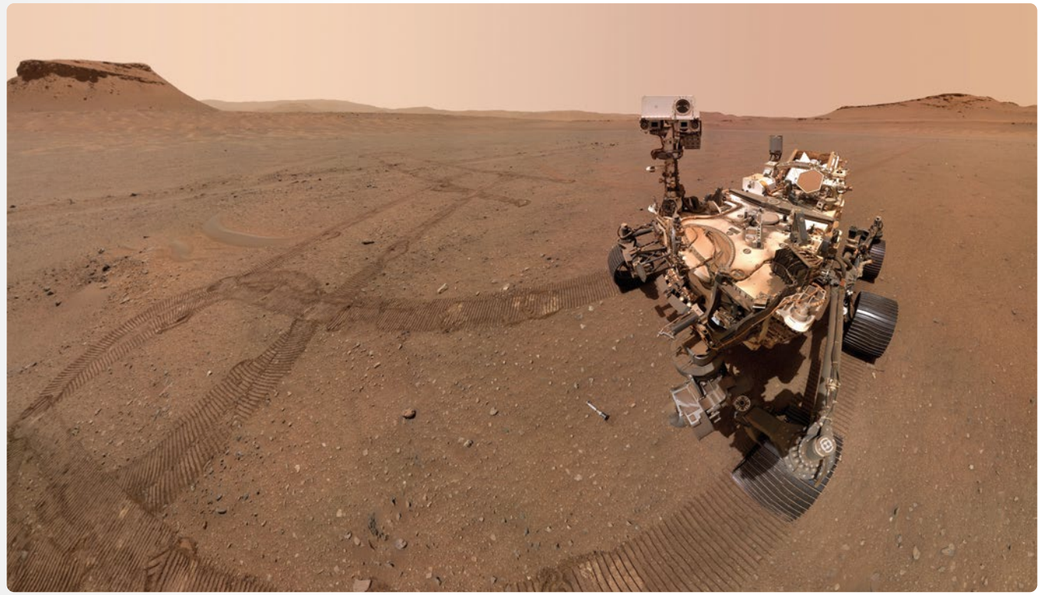
The other important thing with water is that it's a moderator: it slows down neutron speeds. Neutrons have different speeds. If they hit an atom at a certain speed, they'll cause the atom to fission. If they're going too fast or too slow, they might not cause fission.

What does all this mean in terms of advanced nuclear reactors? Advanced reactors essentially are everything that's *not* what I've just described to define large light-water reactors.

One class of advanced reactors is called "small modular reactors." This class is similar to large light-water reactors in that small modular reactors use fuel rods with the same uranium enrichment levels. They use water as the coolant, heat-transfer mechanism, and moderator. But these reactors are smaller: instead of one gigawatt, we're talking anywhere from 50 megawatts to a couple hundred megawatts. With small modular reactors, you're trying to get efficiencies of serial production instead of trying to get efficiencies of scale.

Aside from the small modular reactors, other types of advanced reactors are quite different.

> **"If you care about environmental issues and climate change, then what you really care about is energy. It's your top concern, because energy has the biggest impact on the environment out of anything that humans do."**



Above Nuclear waste can be used to power things in space, such as NASA's *Perseverance* rover shown here.

NASA / JPL-Caltech / MSSS

> **"A fission chain reaction can produce energy sustainably. And because we're dealing with atomic bonds here, and not chemical bonds, there's a lot more energy released than, say, burning natural gas or burning coal."**

They use different fuel forms and different chemical setups for the fuel. They don't use fuel rods. Some of them have different enrichment levels. Instead of 5 percent uranium-235, they go up to 20 percent uranium-235. Some reactors have different coolants. They don't necessarily use water. They might not need moderators, because instead of needing to slow down the neutron speed, they use what's called the "fast spectrum." Their design uses quicker neutrons that fission more efficiently.

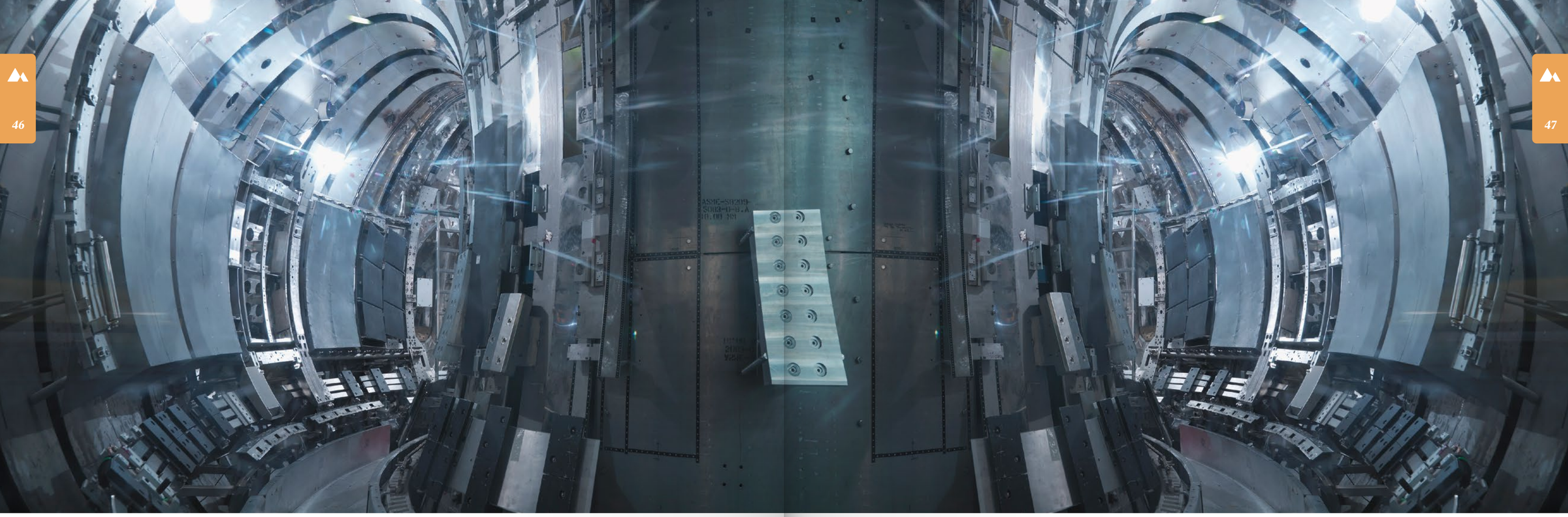
Others include molten-salt reactors. High-temperature gas reactors use a type of fuel that's essentially little billiard balls of uranium instead of fuel rods. We also have liquid-metal cooled reactors. These various advanced reactors can fission in different, more efficient, or more economical ways.

We also have a new category of reactors called "microreactors." These are defined by their size, instead of according to the way they fission atoms, their fuel form, or their enrichment levels. Traditional large light-water reactors are one gigawatt. Small modular reactors are maybe 50 megawatts to 200 megawatts or more per reactor. Other advanced reactors are somewhere on the scale of hundreds of megawatts. Microreactors are much smaller. Commercial reactors can be as small as 1 megawatt, with many in the 5–10 megawatt range, and some up to 20 or 30 megawatts. This is completely different for the nuclear industry. It's distributed nuclear energy on a distributed scale. You could use this type of energy for small towns, on the grid's edge, or for remote operations.

These new advanced reactors are opening up new ways of using nuclear energy.

Can you help us understand some of the differences, with regard to economics, safety of operations, and waste when we think about the large light-water reactors of today versus these next-generation technologies that are being discussed and developed?

Economics is probably the most important difference. That's because, once large light-water reactors are built, they're very cheap to operate, and you can operate them for decades. The problem is building them in the first place. They are megaprojects. They cost billions of dollars.



They can take a decade or more to build. That is a challenge to finance, especially with what we're seeing with electricity markets: increased competition and moving away from rate-basing.

On the economics side, the advanced-reactor companies are trying various methods. First of all, many advanced-reactor companies exist. It's a very different situation to have competition emerging among developers. Instead of trying to get efficiencies of scale by making big reactors, these new companies are trying to go for the economics of series production—essentially, looking at how wind and solar were able to iterate rapidly over multiple generations to drive costs down.

In the United States, we've never had "nth" of a kind of reactor built. Everything that we've done is essentially a first-of-a-kind, bespoke reactor. That leads to significant increases in costs, as well as construction complexity and issues arising.

The biggest motivator for the innovation among these new reactor companies is to get economies of scale and reduce nonrecurring engineering costs, so that it's much cheaper and more affordable to build these reactors than ever before.

On the safety side, we're also seeing major advancements. Advanced reactors all use a different principle to get to what's called "inherent safety." The idea is that you don't need active systems to function to keep the reactors safe. Those active systems are things that we've seen to be problematic in all major accidents. At Fukushima, in particular, the reactor lost off-site power supply. Their basement generators flooded, which prevented them from running water over the reactors to cool them, which eventually led to the accident.

Advanced reactors completely change all elements of the risk equation, which for industrial risk is the consequence of an accident times the probability. The consequences are going to be a lot smaller for advanced reactors because of their design. One, they're smaller; there's less nuclear material at risk. Two, they don't necessarily run at higher pressures and don't need to have consistent cooling. They don't need as many operator interventions. Three, they reduce the likelihood of any accidents happening in the first place by being simpler systems and by requiring less intervention.
No advanced reactor built in the United States will be less safe than the existing fleet, because of regulation. Safety regulation will use standards for conventional light-water reactors as the baseline benchmark. If you run the numbers, next-generation reactors will be at least one to two or more orders of magnitude safer than that.

Above Inside a fusion reactor.
Getty Images / Monty Rakusen

> **"Waste is more of an uncertainty. It's an area that's not driving innovation as much as economics."**

Finally, waste. Waste is more of an uncertainty. It's an area that's not driving innovation as much as economics. As we've scaled down the reactors, we've been losing some of the efficiencies of scale for waste production. We can expect to see more low-level or intermediate waste, which we can handle with the existing waste system—but there's going to be more of it.

The big concern is high-level waste—spent nuclear fuel. We could see some increases in the volume of high-level waste—or it's possible that the volume of waste will be about the same as with the existing large light-water reactors. That's uncertain. It also depends on how the fuel cycle works and seeing if we can find any innovations on that front. Ultimately, though, we do manage nuclear waste responsibly in the commercial sector. We have short-term solutions for the waste problem, but we will need a geological repository for any type of nuclear energy, including advanced reactors. This is still a major policy challenge.

Let's move to what's happening in the real world. Various demonstration projects are in the works for nuclear technologies that are in development. Can you give a few examples of what these projects may look like, or even plants that are operational?

Not quite two years ago, when I was at the Nuclear Innovation Alliance, I worked with

Above Advanced nuclear reactors will function—and look—quite different from traditional nuclear power plants.

Gensler

> **In the United States, we're right at the point where we're starting to license reactor projects commercially.**

some other nongovernmental advanced nuclear organizations—Third Way, Clean Air Task Force, and ClearPath—to ask, "Beyond just ideas, are these projects the real thing? Are they moving forward?" We found that just over 30 advanced reactors around the world are in what we would consider advanced stages of demonstration, several of which are operating.

To start off, the United States built and operated a very small advanced reactor in 2018 called Kilopower. It was a kilowatt-scale reactor that demonstrated the capability of something like this for NASA and space applications. That was important, because it was the first new reactor that was designed, built, and operated in the United States in decades. That project kind of kicked off things here. Its design philosophy has inspired a lot of the companies that are developing reactors in the United States.

Abroad, projects are in operation. Russia has a small modular reactor, a light-water reactor called the *Akademik Lomonosov*, which is derived from some of their nuclear technologies. It's essentially a floating nuclear power plant—a barge that's currently powering a small town in the Russian Arctic. In addition to providing power, it's also providing heat. That's really important if you're trying to look at the decarbonization potential. Earlier this year, China officially opened their high-temperature gas reactor that they've been working on for several decades. They've got that demonstration project running, along with other projects that are in advanced licensing and construction phases.

In the United States, we're right at the point where we're starting to license reactor projects commercially. We have three major demonstration projects: TerraPower and X-energy have funding from the Department of Energy's Advanced Reactor Demonstration Program. They're going to submit their first license applications within a year or so—one, to build a reactor in Wyoming at a retiring coal plant; two, to build a reactor for industrial heat on the Gulf Coast. NuScale Power, which recently went public, is working to build a reactor to power Utah utilities, as well. These three projects are set to be operating by 2030. We also have a number of small-scale projects—Kairos Power, Oklo, and Ultra Safe Nuclear Corporation—that are moving toward developing different types of projects. Some of them will focus more on the research scale. The Kairos Power project, which is undergoing licensing right now, is meant to provide information for a larger version that they'll do down the line, whereas the Ultra Safe project is a research reactor to support research activities at the University of Illinois.

One other big demonstration project that I want to flag is Holtec, a longtime nuclear company. They've just announced applications for over $7 billion in loan guarantees to build a factory for the first four of its reactors and ultimately to produce more reactors.

We're seeing a lot of momentum to get to the first major stage, which is licensing. We would expect that a lot of these initial small reactors will be online by the middle of the decade, with the larger reactors online by the end of the decade.

What about policy here in the United States? A lot of legislation has passed in the last five years or so that has facilitated nuclear energy in different ways. Can you highlight a few ways in which these new pieces of legislation seek to accelerate the deployment of different kinds of advanced nuclear technologies?

It really started off in 2017 or 2018 with work on two precursor bills: the Nuclear Energy Innovation and Modernization Act, which focused on making the Nuclear Regulatory Commission into a modern regulator, and the Nuclear Energy Innovation Capabilities Act, which focused on bringing the Department of Energy up to speed for advanced reactors. These pieces of legislation kick-started innovation at the Nuclear Regulatory Commission and the US Department of Energy.

The idea with the Nuclear Regulatory Commission was that we'll need to reform how we regulate nuclear energy. The way our entire regulatory system is set up is around large light-water reactors. To handle the whole variety of advanced reactors, we need to reform how we make smart, effective regulations so we can reassure the public that we are handling these reactors safely.

The Nuclear Energy Innovation Capabilities Act is the beginning of a lot of related work at the Department of Energy; this legislation ensures that the agency has the capability to support innovation. Since then, almost every major energy bill that we've seen in the last several years has had some nuclear component: the Energy Act of 2020, the Infrastructure Investment and Jobs Act, the Creating Helpful Incentives to Produce Semiconductors Act, and the Inflation Reduction Act. The Inflation Reduction Act has been the keystone that capped off this whole area of very active legislation. Most of these bills have been bipartisan; both parties are supporting nuclear right now. Both parties see nuclear as an area that everyone can work on together because of its clean energy and decarbonization potential.

An important point is that these programs have established the basis for demonstration projects, either through direct funding or, most recently with the Inflation Reduction Act, by setting up the tax credits that will allow us to build many of these reactors in the future. The Inflation Reduction Act levels the playing field for advanced nuclear reactors and other clean energy sources.

You highlight the provisions of the Inflation Reduction Act as particularly important. How is the Inflation Reduction Act likely to benefit not just next-generation reactors, but also the fleet of existing reactors, many of which have retired in recent years or have been in other types of economic straits?

The primary way the Inflation Reduction Act benefits nuclear energy is via tax credits. This is the case for advanced nuclear energy, specifically: the act establishes tax credits that essentially are equal to the credits that exist for other clean energy sources out there.

These tax credits are valuable because advanced nuclear projects are still in the first-of-a-kind development stage. They'll need support from tax credits to get to market, compete, and scale up until they become more self-sufficient. Other small tax credits throughout the Inflation Reduction Act could help: the Advanced Manufacturing Production Credit; some of the support for hydrogen tax credits; and provisions that are more focused on demand or on other opportunities, which could include nuclear.

> **One of the issues with nuclear is that it's on a longer time frame.**

Another big way that the Inflation Reduction Act benefits nuclear is by providing support for the existing nuclear fleet. Over the past 10 years, we've seen a large number of retirements in the existing nuclear fleet—we've had over 10 gigawatts retire. The nuclear fleet is the largest single source of carbon-free power in the United States, which has been a big concern for state and federal policy for years. We've seen a lot of work to try and reverse those retirements. The Inflation Reduction Act, working in conjunction with some provisions in the Infrastructure Investment and Jobs Act, provides funding that targets the nuclear reactors that are most at risk of retirement.

Within several weeks of the Inflation Reduction Act passing, the Diablo Canyon nuclear power plant in California, which was set to close down, completely flipped from having political opposition for any sort of long-term operations, to having significant political support, including from the governor, for long-term operations. The funding from both the Inflation Reduction Act and the Infrastructure Investment and Jobs Act has seemed to change the direction of that facility.

We've also seen that the Palisades Nuclear Generating Station in Michigan, which closed down in May 2022, is looking at restarting and coming back online. Many people, even the nuclear industry, did not expect that to happen. The funding and the Inflation Reduction Act already are having impacts on markets.

How about expectations for the future: If you had to speculate about the future of nuclear energy in the United States, where do you think it'll be in 5 or 10 years?

For a long time, people thought that nuclear production in the United States would decline steadily through the middle of the century as reactors continued to retire. With recent policy developments, it seems right now that nuclear power from existing power plants probably will remain largely flat. We don't expect markets to drive many more retirements in the next 10 years or so.

The big question is, What happens on the advanced nuclear side? One of the issues with nuclear is that it's on a longer time frame. It takes a while to build these projects and get them established, but they'll operate for a very long time once they're built.

Over the next 10 years, I think a couple things will happen. First, we'll see microreactors—the 1- to 30-megawatt reactors—grow and accelerate quickly. The project life cycles on those are really short. In theory, right now, the primary determining factor for the timeline is licensing. Once you have production capabilities, you probably can get a microreactor up and going within 12 months in terms of construction. We could see a large number of microreactors being built in locations throughout the United States, particularly in Alaska.

In terms of the broader energy markets, we're likely to see a large amount of orders for advanced reactors. Especially as these demonstration projects move closer to operation by the end of the decade, I expect that we'll start seeing advanced nuclear considered more in integrated resource plans and utility-level analysis.

When you're looking at the decarbonization potential—and how much this type of energy generation can grow—we won't see a lot in the 2020s. We'll see that more in the 2030s, with rapid acceleration in the 2040s if the industry takes off; that is, if the nuclear industry can solve its economic challenges.

That's one big takeaway from the Inflation Reduction Act. The policy environment now is largely complete. The federal government, working with its regulatory and other entities and with state governments, largely is setting things up for industry to deliver. It's going to be on industry to show that they can build these projects on time, on budget, and economically.

Various recent studies have shown that the potential, if the industry can deliver, is literally hundreds of gigawatts. By the middle of the century, we could see advanced nuclear reactors dwarfing the scale of the existing nuclear fleet—we could see 100 to 400 gigawatts. This progress could decarbonize not just power, but also industrial heat and process heat.

That's the potential—but we're not going to know whether industry has cracked that nut for quite a while. It'll be a big challenge for them to get to that scale, especially in these time frames.

“Various recent studies have shown that the potential, if the industry can deliver, is literally hundreds of gigawatts. By the middle of the century, we could see advanced nuclear reactors dwarfing the scale of the existing nuclear fleet—we could see 100 to 400 gigawatts.”

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