Public Meeting of the

President’s Council of Advisors on Science and Technology (PCAST)

July 28, 2022

# Meeting Minutes

## Meeting Participants

### PCAST Members

1. Frances Arnold, Co-Chair
2. Francis Collins, Co-Chair
3. Maria T. Zuber, Co-Chair
4. Dan E. Arvizu
5. Dennis Assanis
6. John Banovetz
7. Ash Carter
8. Frances Colón
9. Lisa A. Cooper
10. John O. Dabiri
11. William Dally
12. Sue Desmond-Hellmann
13. Inez Fung
14. Andrea Goldsmith
15. Laura H. Greene
16. Paula Hammond
17. Eric Horvitz
18. Joe Kiani
19. Jon Levin
20. Steve Pacala
21. Saul Perlmutter
22. William Press
23. Penny Pritzker
24. Jennifer Richeson
25. Vicki Sato
26. Lisa Su
27. Kathryn Sullivan
28. Terence Tao
29. Phil Venables
30. Catherine Woteki

### PCAST Staff

1. Sarah Domnitz, Acting Executive Director and PCAST Designated Federal Officer
2. Reba Bandyopadhyay, Deputy Executive Director
3. Kevin Johnstun, Research Analyst

### Invited Speaker

1. Geri Richmond, Undersecretary of Science and Innovation, Department of Energy

**Start Date and Time:** Thursday, July 28, 2022, 1:30 PM Eastern Time

**LOCATION:** Eisenhower Executive Office Building, 1650 Pennsylvania Ave. NW, Washington DC

## WELCOME

**PCAST Co-chairs: Frances Arnold, Francis Collins, Maria Zuber**

The PCAST Co-Chairs called the meeting to order – Frances Arnold, Francis Collins, and Maria Zuber. After noting that the agenda had changed so that PCAST could meet with President Biden later that day, Arnold stated that innovations related to energy are critical to both economic competitiveness and reducing emissions to slow the effects of climate change.

## SESSION: SCIENCE AND INNOVATION AT THE DEPARTMENT OF ENERGY

**Geri Richmond, Department of Energy (DOE)**

Geri Richmond began her remarks by noting that time is running out to deal with climate change and that there is an urgent need for science and innovation to save the planet from further warming. In her years working in the U.S. science and engineering enterprise, she has had the opportunity to see the effects of climate change in places around the globe, from the changes affecting the African savanna and the rice fields of Vietnam to the unpredictable rains in India. In fact, climate change is already affecting countries that cannot ignore the ongoing changes and buy their way out of the consequences of climate change because they do not have the resources to do so.

Richmond recounted a visit she made five years or so ago to a school in rural Cambodia, where a student asked her what the United States was doing to combat climate change. This young man then accused the United States of coming to countries such as Cambodia and asking them to not take advantage of the technological opportunities that the United States itself had, but which have damaged the climate. "This is in rural Cambodia, and that hit hard," said Richmond. She added that one reason she took her current position in the Biden administration is because she was tired of having her son ask her what she was going to do about climate change.

The Biden administration, explained Richmond, has clear climate and energy goals that include reducing net greenhouse gases by 50 to 52 percent by 2039, have 100 percent of the nation's electricity be carbon-free, and to reach net-zero carbon emissions by 2050. Achieving these goals will require major technological breakthroughs and an all-hands-on-deck call for innovation, collaboration, and acceleration of the U.S. clean energy economy by tackling the toughest remaining barriers to quickly demonstrate and deploy emerging clean energy technologies at scale. This effort must also create a workforce that looks like America and reaches all segments of the nation and also the world.

In her current position, Richmond oversees the DOE Office of Science. Since assuming her role in November 2021, she has worked to ensure that DOE was doing the fundamental discovery science needed to solve the nation's energy problems. At the same time, she has been working to break down the barriers and siloes that have kept basic science, applied energy science, biological and environmental sciences, and advanced scientific computational research—all of which fall under her office's purview—from connecting with one another.

Richmond noted that she is excited about the fact that the program officers and directors on both the basic and applied science sides are now coalescing and working together to make sure that DOE has a seamless transition from one to the other. She stressed that the connection between basic and applied research is not like a relay race where basic science has a baton, passes it on to the applied sciences, and then runs off to the side, but instead is a back-and-forth exchange and an ongoing, circular connection.

Richmond noted that her office works with the National Nuclear Security Administration (NNSA), headed by Undersecretary for Nuclear Security Jill Hruby, on issues of security, uranium supply, and nuclear isotopes, as well as with the deployment and infrastructure side of DOE that Principal Deputy Undersecretary for Infrastructure Kathleen Hogan oversees. The Office of Science is also responsible for the 14 of the 17 DOE National Laboratories—the other three operate as part of NNSA. These powerhouses of energy solutions, as Richmond called them, have taken on the net-zero carbon challenge as their mission and are aiming to serve as models for the rest of the nation. The National Laboratories employ over 70,000 scientists, engineers, and support staff and operate 28 user facilities that host over 30,000 users annually. These include the six national laboratory light and neutron sources; five energy nanoscience centers; several fusion research and environmental system science laboratories; and multiple supercomputing centers, including the exascale supercomputer at Oak Ridge National Laboratory.

Richmond then discussed the Energy Earthshots initiative that targets the major research, development, and deployment breakthroughs needed in the next decade to reach the 2050 net-zero carbon emissions goal. Energy Earthshots will advance the reduction of greenhouse gas emissions, overcome difficult-to-solve remaining technology barriers, demonstrate global leadership on climate change, and engage stakeholder groups. To date, DOE has announced three Energy Earthshots.

Richmond said that DOE announced the first Energy Earthshot—the Hydrogen Shot—on June 7, 2021. This project aims to accelerate innovations and spur demand for clean hydrogen by setting an ambitious yet achievable goal of reducing the cost of producing clean hydrogen by 80 percent within one decade. With an 80 percent reduction, clean hydrogen would cost $1 per kilogram.

Today, said Richmond, thermal conversion of natural gas is the main pathway to clean hydrogen, but since emissions from this process are high, research is needed to improve system efficiency and integrate carbon capture and storage technologies. Electrolysis offers a cleaner route to hydrogen, but it is currently too expensive, in part because it uses precious metals. Reducing that cost requires innovations in materials, system design, and manufacturing. Advanced pathways such as biological and microbial conversion processes or thermal and photoelectric water splitting are in the early stages of research and development and face scale-up challenges. All of these pathways are important to pursue, said Richmond, because the source of clean hydrogen is going to vary by application and location. As a result, she stressed that DOE will need to develop many partners to work together on both research and scale-up challenges.

Richmond said the second Energy Earthshot, which DOE launched on July 14, 2021, is the Long-Duration Storage Shot. This program aims to reduce the cost of long-duration energy storage (systems that can deliver 10 or more hours of storage) by 90 percent within a decade. The nation needs cost-effective long-duration storage so that the energy grid can accommodate more intermittent clean power sources to achieve a clean energy future. This effort will consider all types of technologies, such as electrochemical, mechanical, thermal, and chemical, that might have the potential to meet the necessary duration and cost targets. Improving electrochemical storage, for example, will require addressing the availability of key materials, finding alternative materials, reducing systems cost, and improving manufacturing processes for new chemistries and new battery designs. Electromechanical storage, which would be capable of storing energy beyond the 10 hour mark, needs more demonstration and integration work, while thermal and chemical storage needs further research and development targeted at materials, components, and system designs.

DOE launched the Carbon Negative Shot on November 5, 2021, said Richmond, to tackle the challenge of removing ambient carbon that climate models show must be removed in order to compensate for the processes that will be hard to decarbonize. The goal here is to develop innovative technologies and approaches that will remove carbon dioxide from the atmosphere and durably store it at meaningful scales for less than $100 per metric ton of carbon dioxide. Achieving that goal requires developing enhanced capture materials, new system designs, and demonstrations that address the major cost barriers to capturing and storing carbon. Enhanced biological and natural solutions, such as soil capture and sequestration, must also play a role. One major challenge for enhanced biological and natural solutions is verifying that the captured carbon is stored durably, which will require new monitoring, verification, and reporting techniques and protocols.

Richmond noted that DOE will be announcing several more Earthshots in coming months. One new Earthshot will focus on critical minerals and materials, and in particular, identifying U.S. sources for these materials and developing the ability to process them in the United States. Currently, work on extracting and processing rare earth elements, along with recycling and purifying the water needed for these activities, is occurring at the Mountain Pass rare earth mine outside of Las Vegas. Other Earthshots will address grid modernization, including the development of better transformers and modular systems, fusion energy, clean energy technology manufacturing, industrial decarbonization, and subsurface energy innovation, including making more extensive use of geothermal energy. The 2015 DOE Quadrennial Technology Review discusses the details of the innovations needed in each of these areas.

DOE has a significant effort underway, said Richmond, to identify and protect critical emerging research and technologies from designated countries of risk—Russia, China, North Korea, and Iran—in the early stages of their development rather than addressing security in the latter stages. Toward that end, DOE has developed a science and technology risk matrix and guidelines pertaining to foreign government-sponsored or affiliated activities, including talent recruitment programs and research support. DOE has also issued guidelines for granting foreign nationals access to DOE sites, technology, or information, as well as for contractual arrangements that the National Laboratories engage in with foreign entities.

Richmond pointed out that the Bipartisan Infrastructure Law provides $62 billion for DOE to deliver a more equitable clean energy future by investing in U.S. manufacturing and workers; expanding access to energy efficiency and clean energy for families, communities, and businesses; delivering reliable, clean, and affordable power to more Americans, and building the technologies of tomorrow through clean energy demonstrations. DOE has already released $10 billion in funding opportunity announcements (FOAs), including $3.1 billion to lower utility bills for millions of Americans through DOE's weatherization assistance program; $3.1 billion to boost U.S. battery manufacturing and supply chains; and $2.4 billion to support commercial-scale demonstrations of advanced nuclear reactors. In the coming months, DOE will release additional FOAs, including $3.5 billion for direct air capture of carbon dioxide hubs; $8 billion for regional clean hydrogen hubs; $500 million for clean hydrogen manufacturing, recycling, and research and development programs; $355 million for energy storage demonstration projects; and $150 million for long-duration storage demonstration projects.

Richmond applauded her team for all the work it has put in to move these programs forward. She also noted how important it is to remember that these efforts cannot leave anyone or any community behind. She recalled how she had recently gone to Noatak in a remote part of Alaska, where diesel fuel costs $18 per gallon and noisy diesel generators run 24 hours a day to power the community. In contrast, nearby Shungnak has DOE-installed solar panels and storage batteries that enable the community to turn off its generators for 10 hours a day. Noatak will be getting a similar system, an exciting development for the community. Richmond noted that DOE has numerous activities involving Tribal and Arctic communities.

Growing up in remote Kansas, Richmond said she knows what it means to live in remote area and the economics that go along with that. Every morning when she was growing up, her father would shovel coal into the farmhouse furnace so that the house would have heat. Today, 800,000 people in Kansas get their electricity from a nuclear power plant and no longer use coal.

Richmond said the Justice40 initiative is a key element of every one of DOE's activities, and an important part of that is leaving no one behind in building and sustaining the nation's energy workforce. She stated that the best science is done when people that have different perspectives, different ways of doing things, and different science and engineering backgrounds work together. Workforce, in fact, is a critical issue for DOE given that the National Laboratories are struggling with retention. This struggle, said Richmond, is just one indication of why the nation needs to build its energy workforce at an accelerated rate.

Another challenge to developing the energy workforce that Richmond emphasized was the insufficient pay for graduate students and postdoctoral scholars. During the five to seven years it can take to get a PhD, today's graduate students earn somewhere between $10.00 to $11.60 per hour, given that the typical graduate student works 60 hours per week. Richmond noted that some of the smartest people we have in the country are having to put off having children, buying a house, or saving money. She made a point of speaking about this to PCAST to make sure the nation recognizes that to address climate change the United States will need a diverse workforce as much as it needs new technologies and equipment. Richmond stated that the data demonstrate that these salary levels are an impediment for our diversity, for inclusivity of underrepresented groups. She emphasized that if the United States research enterprise doesn't get the stipends up to a good level that's affordable to live on, then the country will continue to disadvantage its underrepresented groups.

To conclude her remarks, Richmond discussed the importance of partnerships. DOE partners with a host of federal programs and agencies, such as the social sciences program at the National Science Foundation (NSF) that is helping DOE understand issues associated with the grid or adoption of solar technologies, for example. Among the many other partnerships are projects with the Bureau of Land Management on mapping subsurface resources, geothermal permitting, and carbon storage; programs with the National Institute of Standards and Technology on materials, manufacturing, semiconductors, and microelectronics; a joint DOE-Department of Transportation office to enable electric vehicle infrastructure and port infrastructure to support offshore wind development; and a project with the U.S. Department of

Agriculture to develop sustainable aviation fuel. In addition, her office and NSF co-chair an Office of Science and Technology Policy-National Oceanic and Atmospheric Administration joint action group on earth system predictability.

Going forward, Richmond said, everyone at DOE, including scientists, need to be ready to work in partnership with others and not worry about staying in their own lane. She concluded by noting that while there are budget issues that some people perceive as an impediment to such partnerships, it is imperative that everyone works together to develop clean energy for all and by all.

**ZUBER MODERATED THE Q&A AND DISCUSSION BETWEEN PCAST MEMBERS AND RICHMOND.**

## SESSION: SEMICONDUCTORS DISCUSSION AND VOTE ON LETTER TO THE PRESIDENT

### MARIA ZUBER, PCAST CO-CHAIR

Zuber explained that PCAST had started a working group on semiconductors earlier in 2022, led by PCAST members Lisa Su and William Dally. This working group explored recommendations that could be helpful in anticipation of Congress passing the Creating Helpful Incentives to Produce Semiconductors (CHIPS) Act (which has become the CHIPS and Science Act since this meeting occurred). Zuber said this is a once-in-a-generation investment, and the PCAST working group has been considering how to maximize use of funds that the Act would appropriate for research and development.

### LISA SU, PCAST MEMBER

Lisa Su said that the CHIPS Act is a phenomenal opportunity to revitalize the U.S. semiconductor ecosystem. Semiconductors are vital to every aspect of our lives, from an economic standpoint as well as from a national security standpoint. While the United States leads the world in semiconductor revenue, the nation's position has been declining over the years as other countries have invested substantially in their own semiconductor industries.

The CHIPS Act, said Su, includes funds for manufacturing as well as for research and development. For the manufacturing component, the Department of Commerce and industry leaders have developed plans to enact as soon as the CHIPS Act passes. However, what to do with the $11 billion the Act earmarks for research and development has received less attention.

Su explained that the working group focused on how to spend that $11 billion. The CHIPS Act includes that the Department of Commerce form a national semiconductor technology center (NSTC) and a national advanced packaging and manufacturing program. The working group's main recommendation is to build a very broad coalition including government, academia, and industry leaders in a public-private partnership to support these efforts. Su noted that the semiconductor ecosystem is much broader than just the companies that make computer chips and includes system and equipment companies as well as the entire U.S. academic infrastructure. Considering the breadth of the ecosystem, the working group is also recommending a broad approach that would include a number of regional centers, distributed around the country, that would work together to build U.S. capabilities in all aspects of the semiconductor ecosystem.

### WILLIAM DALLY, PCAST MEMBER

William Dally said that for the United States to retain its leadership in semiconductors, it will need talented people to invent new processes and materials, develop fabrication equipment, and design innovative chips, but the industry currently has a shortage of skilled semiconductor workers. The CHIPS Act, he noted, is expected to create many thousands of new jobs. To address the expected workforce shortage, the working group recommends establishing a national semiconductor training network. This would involve upgrading laboratory equipment in 50 geographically distributed hub academic institutions. These institutions would create a shared curriculum and establish shared chip prototyping flows that would provide students with hands-on experience designing and fabricating chips. The working group is also recommending that this effort include incentives to hire microelectronics faculty and provide scholarships and research assistantships to attract students to the semiconductor field.

Dally also said that the nation needs to attract and retain talented individuals from around the world. To do that, the working group recommends that existing statutes be used and for the Department of Homeland Security to grant premium processing of immigration petitions for microelectronic workers to speed up providing those skilled individuals with work permits.

With the nation's semiconductor workforce in place, said Dally, the next step will be to support the growth of startup companies in this field. Historically, startups have been a significant source of innovation in semiconductors, yet the U.S. venture capital enterprise devotes less than 1 percent of its investments to semiconductor startups, compared to 8 percent 20 years ago. Moreover, China has created six times as many semiconductor startups as the United States recently. Dally said that the core problem behind these trends is the very high cost of bringing a semiconductor product to market, typically about $500 million for a state-of-the-art semiconductor product.

The working group, said Dally, has a number of recommendations for lowering that barrier. One recommendation is for NSTC to have a fund that it would use to create financial incentives and prototyping assistance for startups. Another recommendation is that NSTC should create a "chiplet platform."[1] This could greatly reduce the cost of innovation and thus foster the creation of more startups.

Dally said that for the nation to sow the seeds for its future semiconductor ecosystem, it will need to support fundamental research in areas such as processes and materials, packaging, energy-efficient computing, security, and applications for the life sciences. To ensure this research occurs, the working group recommended that NSTC devote 30 to 50 percent of its budget to fundamental research, with a particular focus on several grand challenges, such as creating a zettascale computer that would be 1,000 times more powerful than any computer available today.

### ZUBER MODERATED THE SUBSEQUENT DISCUSSION AMONG PCAST MEMBERS

Before opening the discussion, Zuber noted that Su and Dally only presented high-level recommendations and that the working group will submit a more detailed report for PCAST's consideration in the coming

[1] A chiplet platform is an integrated circuit that is composed of multiple smaller chips where the common, non-innovative parts of a product have been specifically designed so that customizable components ("chiplets") can be added to address particular applications, performance, or functionality.

months. She then asked Su and Dally to talk about the stakeholders the working group consulted with to inform its recommendations.

Su said the working group itself comprised a broad set of stakeholders that included companies with manufacturing capabilities and others with design capabilities, as well as representatives from a range of teaching and research universities. The working group also received input from the Department of Commerce, NSF, DARPA, and many other federal agencies.

Dally noted that early during the working group's activities, it engaged with many representatives from the electronic design automation industry, which is part of the semiconductor field but was not represented in the working group. The working group also had helpful information-gathering meetings with representatives of the Interuniversity Microelectronics Centre, Europe's semiconductor consortium that has similar goals to those of the proposed NSTC, and with a number of startups. In addition, the working group met with representatives of venture capital groups that fund semiconductor startups to take a broad survey not just of the semiconductor industry but also adjacent industries that either supply or consume from the semiconductor ecosystem.

Joe Kiani (PCAST member) asked how the working group's recommendations address supply chain problems, the lack of fabrication facilities in the United States, and the nation's dependence on Asia for chips. Su replied that onshore manufacturing is a major concern and rebuilding U.S. semiconductor manufacturing capacity is a large piece of the CHIPS Act. The group's recommendations were focused on research and development—rather than manufacturing— to help strengthen the pipeline for the next generation of semiconductor manufacturing and design. She noted that the research and development pipeline is as important as manufacturing, but it is a topic that does not get as much attention because of the long lifecycle associated with product development. Su called this an investment for the next decade, along with rebuilding the semiconductor workforce and adding facilities, manufacturing capabilities, and research programs.

Arnold asked if the working group received pushback from any of the agencies that its recommendations might affect or from the stakeholders they engaged. Dally said there was no pushback from the agencies or stakeholders. There were some people from the manufacturing sector that wanted a larger fraction of the $11 billion research and development budget go to establishing prototyping facilities that they could use to develop their next-generation processes, however. Among the agencies, representatives from NSF mentioned that they had been funding fundamental research for a long time and wanted to work with the Department of Commerce. The working group did in fact recommend that there be better coordination among agencies.

Terence Tao (PCAST member) noted that much of the progress in the semiconductor field came from increasing chip density following Moore's Law and his understanding is that chip density is reaching its limit. He asked if there is a corresponding shift in priorities for semiconductor research. Dally replied that Moore's Law, as Gordon Moore defined it in a 1960s paper, is about semiconductor economics—reducing the cost per transition over time as line width would shrink—even though people have since attributed other properties to Moore's Law. Dally noted that at PCAST's public meeting in May 2022, Pat Gelsinger, CEO of Intel, said that Moore's Law will not be dead as long as there are elements in the periodic table that have yet to be explored for use in semiconductors. However, the working group's observation is that transistors are not getting less expensive with each succeeding generation of chips. This raises the stakes to invest more in research and development because the approach of going to a smaller line width to generate greater capabilities is not going to continue producing advances of the same scope as it has in the past. This means that the semiconductor industry will need to consider approaches such as domain-specific architectures to make computing more energy efficient as important alternatives to generate increased value in terms of more computing per dollar or per watt, which is what many industries depend on for making progress. Dally said the end of Moore's law may create an even bigger need to invest in fundamental research and to create the workforce to do it. Su added that the working group's report discusses some of the topics that will help the field go beyond Moore's Law. These include design, architecture, and packaging, among others.

Dennis Assanis (PCAST member) complimented the working group for taking a balanced view across research and development, manufacturing, workforce development, and access to capital for startups in its recommendations. He asked if there was one critical item that was a prerequisite for everything else in the recommendations. Dally replied that if he were to pick one thing, it would be workforce development because without the needed workers, research and development will not get done and startups will not be able to find employees, for example. Su added that the $11 billion in the CHIPS Act will be a significant injection into the system that would allow for facility and infrastructure development, research and development activities, growing the workforce, and seeding startup funding, which she sees as a balanced view of what the nation needs to accomplish.

Vicki Sato (PCAST member) asked how much work is needed on education to train the future workforce, noting the importance of inspiring students to want to work in the semiconductor field. Dally replied that in the ideal situation, kindergarteners would be doing science experiments, but the working group's focus started after high school. He agreed with Sato that a big part of the challenge will be to motivate students to choose to study microelectronics. Another challenge is to create the appropriate infrastructure of laboratory facilities, curriculum, and chip prototyping flows so that once students do choose to study microelectronics, they will have a positive experience and become skilled workers that can benefit the ecosystem.

Zuber asked the assembled PCAST members if they had any objections to taking a vote on whether to send a letter with these high-level recommendations to President Biden even with a more detailed report to follow in a month or so. Collins clarified that this letter would be from the entire PCAST membership, not the working group. There were no objections and the members voted to send the letter, which Collins noted would be copyedited before being sent to the President.

Collins then pointed out that the timing of this letter and its recommendations for making the best use of the $11 billion for research and development could not be better given that the House of Representatives was planning to vote on the CHIPS and Science Act that the Senate had passed the day before. He also thanked the two working group co-chairs and the members of the working group who put in months of work on the recommendations.

## PUBLIC COMMENT

No public comments were presented.

## CLOSING COMMENTS

Collins closed the meeting by noting that PCAST would be meeting with the President to share what they have been working on, including the semiconductor letter.

**MEETING ADJOURNED:** 2:54 PM Eastern Time

I hereby certify that, to the best of my knowledge, the foregoing minutes are accurate and complete.

Frances Arnold, Ph.D.
Co-Chair
President's Council of Advisors on Science and Technology

Francis Collins, M.D., Ph.D.
Co-Chair
President's Council of Advisors on Science and Technology

Maria Zuber, Ph.D.
Co-Chair
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