Public Meeting of the

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

January 20-21, 2022

Meeting Minutes

Meeting Participants

PCAST Members

1. Frances Arnold, Co-Chair
2. Eric Lander, Co-Chair
3. Maria T. Zuber, Co-Chair
4. Marvin Adams
5. Dan E. Arvizu
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. Anne-Marie Mazza, Executive Director
2. Sarah Domnitz, Deputy Executive Director and PCAST Designated Federal Officer

Invited Speakers (in order of presentation)

1. David Crisp, NASA Jet Propulsion Laboratory (ret.)
2. Yasjka Meijer, European Space Agency
3. Steve Hamburg, Environmental Defense Fund
4. Lori Bruhwiler, National Oceanic and Atmospheric Administration
5. Kevin Gurney, Northern Arizona University

6. Harry Atwater, California Institute of Technology
7. Andrew Holland, Fusion Industry Association
8. Katie Rae, The Engine
9. Armond Cohen, Clean Air Task Force
10. Jigar Shah, Department of Energy
11. Gina McCarthy, National Climate Advisor, The White House

START DATE AND TIME: Thursday, January 20, 2022, 12:05 P.M.

LOCATION: Virtual Meeting via Zoom.gov

WELCOME

PCAST Co-chairs: Frances Arnold, Eric Lander, Maria Zuber

The PCAST co-chairs—Frances Arnold, Eric Lander, and Maria Zuber—called the meeting to order. Zuber provided introductory remarks, noting that during the October 2021 UN Climate Change Conference (COP26) in Glasgow, Scotland, participating countries updated their greenhouse gas reduction commitments, pledging to reduce methane emissions by 30 percent. She said it is important to monitor the results in each country—measurements for carbon dioxide and methane must be made at global and regional scales and at local point sources.

SESSION: MEASURING AND MONITORING GREENHOUSE GASES & ACCELERATING ENERGY TECHNOLOGY INNOVATION

IMPROVING EFFORTS TO MEASURE AND MONITOR GREENHOUSE GAS EMISSIONS

David Crisp, NASA Jet Propulsion Laboratory (ret.)

David Crisp began his presentation by noting the work of the Committee on Earth Observation Satellites (CEOS), which has been looking at atmospheric greenhouse gas emissions over the last several years. Human activities, including fossil fuel combustion and land use, add approximately 40 billion tons of carbon dioxide to the atmosphere every year. The amount would be much higher if there were not natural "sinks" (plants, ocean, soil, etc.) that have absorbed about half of the carbon dioxide emitted since the beginning of the industrial age. At present, these sinks are not well understood in terms of exactly where they are located, how they work, and how long they will continue to absorb carbon dioxide.

Crisp also noted that human activities have more than doubled the amount of methane in the atmosphere, also through fossil fuel combustion and agricultural land use. Together, methane and carbon dioxide cause about 90 percent of global warming and are the only two gas emissions that can be measured with the accuracy necessary to reliably quantify them. There is a ground-based network (begun in 1958 in Mauna Loa and expanding ever since such that it is now global) that measures carbon dioxide, including continuous measurements from towers, buoys, specially equipped commercial aircraft, and satellites. In addition to carbon dioxide and methane, the equipment measures several other greenhouse gases monitored by the United Nations Framework Convention on Climate Change (UNFCCC) by using remote sensing methods that cover the entire atmosphere.

Crisp briefly described the process of measuring carbon dioxide and methane fluxes, noting that measurements of emissions cannot be made directly from space. Instead, spectra are measured. More specifically, as sunlight shines through the atmosphere and bounces off the Earth's surface and goes back into space, it runs into carbon dioxide, methane, and oxygen molecules, so the absorption of reflected sunlight can be measured. The ground-based measurements, which come from up to 200 sites around the world and have excellent accuracy, are integrated with the space-based measurements, which have far greater coverage. Crisp said that the coverage still needs to be significantly expanded, noting that NASA's Orbiting Carbon Observatory-2 satellite, which collects three million measurements a month, only covers about one percent of Earth's surface area.

Crisp said carbon dioxide and methane pose specific challenges for both space-based and atmospheric measurements. There is so much carbon dioxide in the atmosphere that even a strong source rarely emits enough carbon dioxide to change the local atmospheric column of carbon dioxide by as much as one part per million, thus making changes hard to detect. And methane emissions come from varied sources, from concentrated plumes from pipeline leaks to weak emissions from wetlands and agricultural sources, thus requiring measurements with high accuracy and extensive coverage. Scientists are developing inventories of carbon dioxide, methane, and other greenhouse gases, some of which are very accurate (such as fossil fuel emissions) and some of which are more difficult to pin down (such as land use changes). By identifying and integrating national greenhouse gas budgets and greenhouse gas inventories, greenhouse gas emissions for the entire globe can be quantified.

Crisp said that NASA's Orbiting Carbon Observatory-2 satellite measurements have returned very useful information, but the satellite has been working well past its expected two-year lifetime and could fail at any moment. Meanwhile, NASA's Orbiting Carbon Observatory-3 satellite has been on the International Space Station since 2019 but is scheduled to be removed within one year. Consequently, the United States could end up without any carbon dioxide monitoring capability; there are no U.S. plans or resources allocated to maintain or advance future space- or ground-based carbon dioxide monitoring capabilities to meet future needs. Japan's and Europe's satellites will be making revolutionary new measurements of carbon dioxide and methane and will maintain global coverage, but those satellites have a very thin line of operational missions with little redundancy in the system, so any loss of functionality could leave a big gap in monitoring going forward. Crisp said the ground-based network also needs to be expanded, especially in the tropics and at high latitudes to meet the emerging needs as these regions are changing faster than anywhere else on the planet.

Yasjka Meijer, European Space Agency

Yasjka Meijer discussed the Copernicus Carbon Dioxide Monitoring (CO2M) mission, a program co-funded by the European Space Agency and the European Commission. Copernicus CO2M will be an operational anthropogenic (that is, human-use) carbon dioxide and methane emissions monitoring and verification support capability. The objective is to provide an information support system for decision makers. The monitoring and verification support includes detection of emissions hot spots (such as large cities and power plants) and continuous monitoring to assess increases and decreases in local and national emissions.

Meijer said prototyping activities have already begun, with a global stocktake (that is, the process of taking stock of the implementation of the Paris Climate Agreement) in 2022. Ultimately, there will be a constellation of satellites. The first two satellites will be delivered near the end of 2025, with launch shortly thereafter. Copernicus CO2M will be fully operational by 2026 with the next global stocktake in 2028. The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) will be responsible for data processing. The Copernicus CO2M program data are free and available for anyone to access. Each satellite will orbit the earth approximately 14 times per day and produce more than a million measurements. It is expected that 200,000 of the measurements will be from clear sky (measurements through clouds cannot be processed).

Steven Hamburg, Environmental Defense Fund

Steven Hamburg said that assessing the potential for reducing emissions relies on knowing what and how much is being emitted from what sources, and how they change over time. The measurements must include all sources of emissions, from major sources like dense urban centers, to middling sources like agriculture and changing land use, to point sources like individual factories. This requires a fine grain approach and collection of data from spatial and temporal scale satellite remote sensing systems. An example is the use of the European Space Agency Sentinel 5P TROPOMI instrument launched in late 2017, which provided 11 months of surveillance data for the Permian basin and showed an enhancement of methane concentration in that time period. Hamburg stated that it is important to understand the underlying structure of the data, that is, identification of not only the ultra-emitters, which are ubiquitous in greenhouse gas emissions datasets, but also the smaller sources, which can add up to be significant and must be mitigated as well.

Concerning the accuracy of data, Hamburg said that a study of methane emissions in Alberta, Canada found large differences between what industry was reporting, what the inventory stated, and what was measured in the field. The study found that the methane emissions measured in the field were five times higher than what the industry reported and also multiple times higher than what the inventory stated. This kind of mismatch is typical across the globe; usually the field measurement is higher, but sometimes it is lower. To provide more accuracy, the MethaneSAT project was initiated and will be launched in 2023. It involves multiple precision satellite measuring systems that will regularly monitor over 80 percent of methane emissions from global oil- and gas-producing regions. The system is designed to detect, quantify, and track area emission rates as well as those from point sources. The data will be rapidly produced and available free of charge. The International Methane Emissions Observatory (IMEO) will collect self-reported data from companies through the Oil & Gas Methane Partnership (OGMP), which represents more than 40 percent of global methane production. (IMEO and OGMP are both part of the UN Environment Programme.)

Hamburg concluded with recommendations that diverse types of satellites are needed to catalyze greenhouse gas emissions reductions. The satellites need to be equipped with high precision detectors, including flux rate data capability, which is not the norm currently. And because of the urgency, there must be rapid development and deployment, including the use of commercial space instruments. Measurements, which should be taken multiple times per day, must cover both large and small sources, like landfills, small wells, and rice fields.

Lori Bruhwiler, National Oceanographic and Atmospheric Administration (NOAA)

Lori Bruhwiler said NOAA has been collecting *in situ* measurements of the carbon cycle and methane balance for more than 50 years. Carbon dioxide is steadily increasing in the atmosphere because of the use of fossil fuels that produce carbon dioxide emissions. Methane is more complicated, however. It has a chemical loss that is about as large as total emissions, and its increase in the atmosphere reflects the balance between losses and emissions. The reasons underlying the recent increase in methane levels are not well understood, but measurements of isotopes of atmospheric methane imply that microbial sources, probably a combination of natural and anthropogenic, are driving most of the increase. NOAA collects samples from all over the world, relying on surface observations, aircraft, and tall communications towers. Flux samples are collected every other week to characterize the diurnal profile of local carbon fluxes. A recently-established profile site in Uganda, for example, provides measurements at different altitudes, which is not possible with satellites, which gather an average measurement in a column. Using instruments attached to balloons that can reach into the stratosphere enables collection of more detailed information than a satellite can see.

Bruhwiler stated that atmospheric monitoring of greenhouse gases can provide data on radiative forcing, which quantifies the human impact on the earth's energy budget (that is, the balance between the energy coming from the sun and the energy radiated back to space) since pre-industrial times (units are Watts/meter^2). Radiative forcing is calculated using observations from the NOAA Global Greenhouse Gas Reference Network. The data show that the majority of radiative forcing is derived from the significant and steady increase in atmospheric carbon dioxide. Methane is increasing more slowly and does not contribute nearly as much to radiative forcing. Carbon dioxide increases have contributed to approximately three-quarters of a degree of global warming, and methane has caused a significant half degree increase in global warming, even though its contribution to radiative forcing is much lower than the contribution from carbon dioxide. Improving model accuracy is important because if methane level rise results in a temperature increase that is disproportionately high relative to its contribution to radiative forcing, large climate benefits would result from focusing on decreasing methane emissions. Currently, the oceans and the biosphere absorb about half of emissions. More accurate long-term models of these natural sinks would provide a clue to whether that absorption will continue. Bruhwiler concluded by reiterating the importance of high-quality, long-term measurements and continued efforts to improve the science to make better climate projections.

Kevin Gurney, Northern Arizona University

Kevin Gurney focused his presentation on the design of a "greenhouse gas information system" emphasizing near-term operational decision support. The program would help to increase the number and range of decisionmakers served and ensure that the information delivered is truly actionable. He commented that the policy literature and available stakeholder surveys suggest that the greenhouse gas information needed falls into three categories: 1) planning that defines missions and sets priorities; 2) tracking to monitor results and keep an eye on objectives; and 3) assessment to determine how well the job was done. Most decision makers are currently in the first phase—planning. Gurney suggested that the operational structure might resemble the governance hierarchy of international, national, state, and local interests, but there are other decisionmakers in this space, such as business interests, financial institutions, activists, and the media, which supports communicating the information developed. Mitigation—the overarching goal—typically occurs at the local level.

Gurney said determining greenhouse gas information specifications relies on identifying and assessing fluxes and then defining the sector that is affected, the specific emissions (quantitative and qualitative), the sources, and the technology being used. The information must be accurate, data-driven, and available without charge. Finally, the information must be actionable so that proactive mitigation occurs.

Gurney suggested that more remotely sensed column measurements are essential, as well as more ground-based and aircraft measurements, and a greater focus on the science behind the carbon cycle/biosphere exchange. Academia, non-profit organizations, private companies, and governments are conducting a large amount of measuring, estimating, and tracking, but there can be several challenges, such as lack of real standards, limited transparency, and misunderstanding about the methodological options. Furthermore, there are biases, including unequal treatment that is contrary to environmental justice. As a result, mitigation is insufficient.

Gurney offered recommendations to facilitate a wider perspective and more effective delivery of information: The White House Office of Science and Technology Policy could develop a plan to bring the diverse activities into focus and reduce duplicate efforts, and the federal government could facilitate a program to consolidate the huge amount of data that is available in many agencies and in the private sector, making it more available to the scientific community.

Zuber moderated the Q&A and discussion between PCAST Members and Crisp, Meijer, Hamburg, Bruhwiler, and Gurney.

MEETING ADJOURNED: 2:00 P.M. EASTERN TIME

MEETING RESUMED: FRIDAY, JANUARY 21, 2022, 2:45 P.M. EASTERN TIME

LOCATION: Virtual Meeting via Zoom.gov

ACCELERATING INNOVATION IN ENERGY TECHNOLOGIES

Harry Atwater, California Institute of Technology

Harry Atwater discussed accelerating innovation in solar technologies. He explained that the world's electricity generating capacity is about 2.6 terawatts electric. Global installed solar photovoltaic (PV) cells' electricity generating capacity in peak electric watts is nearing 1 terawatt (about 200 gigawatts electric when considering continuously dispatchable electricity), which is about 10 percent of the world's electric needs. As of 2020, solar PV was the dominant fraction of newly installed electricity generating capacity. There is growing consensus that solar PV will become the world's majority energy source by 2050 if decarbonization is prioritized. Solar PV is currently generating about three percent of U.S. electricity. It has become more competitive with other forms of energy in the last few years, going from a niche energy supply to a major energy source.

Atwater said that the existing solar PV has been dominated by silicon technologies that account for about 90 percent of installed capacity. Cadmium telluride PV, a thin film photovoltaic technology developed in the United States, accounts for the other 10 percent, but a new technology called perovskite PV, is also being developed. Perovskite PV has the potential to have low manufacturing costs, but it is too early to tell whether its reliability and performance characteristics are good enough to make this an important part of solar innovation. Atwater recommended building a foundry to evaluate the performance, reliability, and cost of manufacturing perovskite PV.

Looking to the future, Atwater suggested other options where solar could be used to directly create electricity and other products, like hydrogen and hydrocarbon liquid fuel, to decarbonize such sectors as transportation.

Andrew Holland, Fusion Industry Association (FIA)

Andrew Holland observed that fusion energy is a reliable power source that will replace fossil energy, such as coal and gas, while complementing renewable energy sources. He said fusion energy is close to becoming a reality, made possible by the technological advances recently made in materials, computing power, manufacturing capabilities, and new processes to achieve reliable fusion energy and realize net gain energy. The United Kingdom is a leader in preparing for fusion energy with its plan to build a government-run pilot plant, Spherical Tokamak for Energy Production (STEP), by 2040, its commitment to robust outreach to private partners, and a draft approach for the regulation of fusion energy under the leadership of their environmental and occupational safety regulators. Additionally, China is scaling up its fusion work, including moving towards building a demonstration pilot plan in the 2030s.

Holland said that there are 31 private fusion companies in the world—21 of these are American companies and 27 are members of FIA. A survey conducted by FIA in mid-2021 found investments in fusion at that time were $1.87 billion and grew to $4.3 billion by December 2021. While fusion energy could ultimately affect all types of energy uses, the primary market at this time is electricity generation. FIA member organizations are pursuing various approaches—magnetic, inertial, magneto-inertial, electrostatic, and others.

Holland described the fusion energy development timeline that began in the middle of the last century with research that has spanned 60 years such that we are now arriving at a fusion plant proof-of-concept in the mid-2020s, and a projected plan for pilot plants in the late 2020s that would be put into operation at scale by 2030. Achieving this timeline at an accelerated rate will require private investment, which has begun, and federal government participation and funding support. Holland suggested that the Department of Energy become a partner in fusion energy commercialization, with special support for companies that are demonstrating the ability to contribute, perhaps by encouraging public-private partnerships. He added that federal regulations should not obstruct the rollout of fusion.

Holland said the U.S. National Academies of Sciences, Engineering, and Medicine released a report in 2019 laying out a plan for a U.S. fusion program, but little activity has resulted from this report. The report recommended establishing national teams, including public-private partnerships, to develop pilot plant designs and technology roadmaps. The report also recommended that the Department of Energy strengthen fusion research programs in under-invested areas like accelerators, development of inertial fusion energy, and alternate concepts. The report also recommended that the federal government build a robust cost-sharing program with private industry. In early 2020, the Department of Energy issued a request for information about how to establish a cost-share program and the program was authorized by Congress in the Energy Act of 2020.

Katie Rae, The Engine

Katie Rae discussed how to transition breakthrough technology to a commercial level. Energy technologies, such as fusion, decarbonizing industries, and creating carbon-free cement, are very cost-intensive at the beginning of the development process. The Engine was created at MIT as a for-profit venture to support entrepreneurs navigating the early phase of developing a company and surviving the well-known "valleys of death"—early translation, product development, pilot programs, and deployment—until the company reaches some stability and can be considered a scaled, global company.

Rae said that The Engine recognizes three areas of critical support needed in the early phases. First, the business plan must accommodate the estimated lead time allowed by most venture capital firms, usually no more than 10 years. Second, there must be sufficient, stable infrastructure to support the enterprise, such as labs, fabrication space, and other needs of a new tech company. Third, entrepreneurs need a support network that includes government know-how, commercial know-how, access to capital, and usually a connection with a research university. Many ventures have failed because the founders did not have the triad of private capital, public capital, and academic know-how. Rae noted that if investment falls short, other groups, including other countries, may step in and take control.

Rae suggested three actions that should be taken to strengthen the process. First, the United States should continue to invest in entrepreneurial programs for PhD students. Second, the United States should continue to match venture funds in Small Business Innovation Research (SBIR) programs to enable companies to develop and deploy their products. Third, funding should be provided for pilot programs and clean energy demonstration projects.

Armond Cohen, Clean Air Task Force

Armond Cohen focused his talk on gaps in decarbonization. One gap that needs to be filled is to develop technologies that can deliver reliable electricity without interruption to complement seasonally variable renewable energy sources like solar and wind. For example, solar can be seasonally variable by a factor of as much as two. A second gap that needs to be filled is to develop a zero-carbon fuel substitute for oil and gas.

Cohen offered multiple options that could fill these two gaps. Possibilities include carbon capture and storage for industry and the development of zero carbon gas power. The technology for these has moved from the laboratory and currently exists in commercialization, although it is far from mature. Other options include the development of advanced, rapid deployment manufacturable nuclear fission; harvesting steam from deep, superhot geothermal energy; and development of hydrogen and ammonia as a basis for a zero-carbon liquid fuel solution.

Cohen said there should be emphasis on addressing the following factors to achieve success: reducing cost, rapid project development, easy access to capital, and "ecosystem challenges." There are a variety of policy design principles that can be used to address these factors. Funding for commercial demonstration projects must be consistent and fund more than just the first-of-a-kind technology to get the scale and knowledge that would develop over time, and policies must be simple and provide for wide-scale deployment. The supporting infrastructure—generation plants, transmission capabilities, pipelines, and storage sites—must be built, and the regulatory framework must facilitate getting the product to market efficiently. The Build Back Better Act has some policies that would benefit carbon storage. Finally, dedicated investment in carbon dioxide transport and storage is needed, including consideration of a strategic plan for offshore storage. Cohen recommended priorities for superhot geothermal energy, including a national lab focused on superhot rock geothermal research and development. Also, advanced nuclear fission needs a fundamental focus shift that dramatically reduces costs and significantly increases the volume of global gigawatt production from the current 10 gigawatts per year to more than 100. The Nuclear Regulatory Commission should be supported in its commitment to improve regulation for the coming advanced designs and a reconsideration of how nuclear waste is handled.

Cohen also recommended a regional clean hydrogen hub program expansion, incentives for broad-based production of zero-carbon fuels, a demonstration of hydrogen extraction using nuclear energy at larger scale, and very low nitrogen oxides (NOx) combustion of hydrogen to reduce local air pollution and reduce global climate change.

Jigar Shah, Department of Energy (DOE)

Jigar Shah said that the DOE Loan Programs Office (LPO), which has been inactive for almost a decade, was revived after the confirmation of Jennifer Granholm as Secretary of Energy in February 2021, and loan applications per month are now for about $7 billion. The LPO's role is to enable applicants with proven lab-scale technologies to get to capital formation and marketplace commercialization. Shah said any substantial change made in climate change will require about a trillion dollars of capital, which is the amount that has been attracted already in solar and wind technologies, and recently in lithium-ion battery storage. The LPO has disbursed about $30 billion to borrowers who have already repaid about $11 billion in cumulative principal payments, and interest generation is about $500 million annually.

Shah described what he called the "Bridge to Bankability," which reflects the LPO's role of taking proven innovative technologies and helping them reach full marketplace acceptance. The first milestone on the bridge is applied engineering, which has been somewhat neglected in recent decades. The second milestone is overcoming construction risks, such as finding ways to reduce risk and decrease costs, mostly through traditional engineering and construction firms, many of which are in the United States. The third milestone is establishing demand. The fourth milestone is gaining Wall Street interest.

Shah described the work LPO is doing in several sectors. He said there has been significant effort to work with utilities on advanced nuclear energy, and the first few nuclear plant constructions will be announced by the second quarter of this year. The goal is to build 10 to justify the supply chain investments anticipated. In the area of transmission, the LPO is working with governors, regional transmission operators, and high-voltage, direct current technology providers. During the past three years, most of the major critical minerals projects have been mapped and identified, as have the private sector sponsors who have filed for mining site permits and are ready to begin mining. In the area of offshore wind, LPO has been filling the communication gaps between states and industry. For hydrogen, the LPO is the lead agency on trying to define the meaning of a hub. Little coordination is occurring, and most hubs are actually just bilateral contracts between a producer and a user. LPO is also working on biofuels. For example, most projects for sustainable aviation fuels are bilateral contracts between a producer and a single airline, which increases credit risk. It might be better for the airlines to belong to a buying pool.

Shah said conditional commitments to guarantee loans will probably be issued in 2022, ranging from advanced technology vehicle manufacturing programs with battery factories, critical materials, electric vehicle manufacturing, several industrial decarbonization projects, support for the offshore wind supply chain, hydropower, and hydrogen projects.

Gina McCarthy, National Climate Advisor, The White House

Gina McCarthy commented that there are many clean energy technologies, but the United States does not have a clearly defined path to net zero emissions by 2050. When finally clarified, that path must be founded in innovation and also in ways that lower costs and that lead to cutting edge technologies that contribute to building the economy. Arriving at zero carbon energy implies clean electricity, clean fuels, clean feedstock, and energy storage technologies that can be relied on. The country must take advantage of the ongoing work in the national labs. McCarthy suggested making plans for speeding commercialization of energy and mitigation of greenhouse gas effects on the climate. She added that climate is not a planetary problem, it is a people problem—a challenge and opportunity for all Americans.

Arnold moderated the Q&A and discussion between PCAST Members and Atwater, Holland, Rae, Cohen, Shah, and McCarthy.

PUBLIC COMMENT

Steven Krivit, New Energy Times

Closing Comments

The co-chairs expressed appreciation to the speakers for their presentations. Lander closed the meeting by emphasizing the commitment expressed by National Climate Advisor McCarthy to support innovation and the deployment of technology necessary to attain net zero emissions.

Meeting Adjourned: 4:30 P.M. 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

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