Creating a Model for Global Decarbonization through Washington State Science, Engineering, and Technology

A Summary of the Proceedings of the 13th Annual Symposium

Washington State Academy of Sciences
September 17, 2020

December 2020

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About WSAS

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The Washington State Academy of Sciences (WSAS) is a not-for-profit organization of more than 300 elected members who are nationally recognized for their scientific and technical expertise. All members of the National Academies of Sciences, Engineering and Medicine who reside in Washington State are invited to join; others are elected in recognition of their scientific and technical contributions to our nation and their desire to contribute their expertise to inform issues in Washington State.

Our Mission
WSAS provides expert scientific and engineering assessments to inform public policy making and works to increase the impact of research in Washington State.

Our Value to Washington
WSAS mobilizes the expertise of our members, plus our network of partners, to provide independent, non-advocate scientific and engineering assessments of issues that impact the citizens, government and businesses of Washington State.

Our Approach
We accomplish our mission by drawing on our statewide pool of distinguished members, state government officials, and other key stakeholders and experts to address critical issues facing Washington State. We organize and conduct multi-disciplinary roundtable discussions, workshops, and symposia to assess risks, identify technological opportunities, and define critical research gaps. Our use of peer review ensures the studies we conduct, programs and projects we evaluate, and reports we provide are scientifically and technically sound and unbiased resources for informing the development of Washington State policy.

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Foreword

A few days before the 13th annual symposium of the Washington State Academy of Sciences on September 17, 2020, Washington State had the worst air quality in the world because of wildfires burning uncontrolled up and down the West Coast. Nothing could better demonstrate the importance of the theme chosen for the 2020 symposium, "Creating a Model for Global Decarbonization through Washington State Science, Engineering, and Technology." Anyone in the Pacific Northwest who needed a reminder of the threat that climate change could pose to our state need only look out his or her window at that week's smoke-filled skies.

Fittingly, the theme of the previous Washington State Academy of Sciences symposium was "Wildfire in Washington State," which highlights a critical aspect of the Academy's work—its ability to highlight issues of major importance to the state and its citizens. Among the goals of the Washington State Academy of Sciences are identifying emerging trends and needs that will have significant impact on our citizens' future and organizing in-depth discussions about major issues confronting Washington State. It does this by identifying and recruiting as members the state's most distinguished scientific and technical experts, convening panels of experts to advise the state on scientific and engineering issues, and developing and sustaining a culture of scientific and technical excellence in Washington State through annual scientific symposia and support for students in science and engineering. Most recently, the Academy has been working on studies and reviews of the Skagit River Basin water supply, threats to southern resident killer whales, and assessments of PFAS alternatives, among other topics. The Academy is a resource that the governor, legislators, private industry, and citizens can use to explore and address some of the most critical issues we will face in the years and decades to come.

There was one major difference between the 2019 and 2020 symposia. The COVID-19 pandemic forced the most recent symposium to be held remotely rather than in person. The event came off without a hitch thanks to the careful planning and technological wizardry of Program Operations Manager Devon Emily Thorsell and Program Officer Yasmeen Hussain. In addition, we tapped into the talents of the Torrance Fellows—graduate students in University of Washington's Clean Energy Institute—to prepare pre-read materials for the symposium. In these and other ways, the 2020 symposium demonstrated the potential of new arrangements to complement and even augment in-person meetings. Participants were able to read background materials in advance of the symposium and then engage in discussions with people who might not otherwise have been able to attend the meeting. While we all look forward to meeting in person again soon, the pandemic has taught us lessons that undoubtedly will prove valuable in future years.

Roger Myers, President

Ronald Thom, Past President

Donna Gerardi Riordan, Executive Director

Preface

Decarbonizing the global economy is the greatest single challenge the world will face in the next few decades, and Washington State is at the forefront of responding to that challenge. New state laws are accelerating electricity decarbonization. Enhanced building standards are further reducing Washington State's greenhouse gas emissions. But much more will need to be done to decarbonize the state's economy, much less the global economy. For that reason, the Washington State Academy of Sciences, as part of its mandate to inform public policy making and increase the impact of research carried out in the state, decided to devote its 2020 annual symposium to how Washington could create a global model for decarbonization through science, engineering, and technology.

We decided to focus on three sectors—aerospace, information and communications technology, and land use—because they have the greatest potential for advances made in Washington State to have a global impact. Many of the jets in the global aircraft fleet, which is responsible for about 2 percent of world's greenhouse gas emissions, have been and will continue to be made here in Washington State. The information and communications technology sector has transformed the state's economy and workforce even as it has reshaped lives around the world. Washington's forests contain more carbon than the amount emitted by the entire United States annually. Few other places are as well positioned as our state to lead the way toward a decarbonized future.

By investigating how aviation, infotech, and land use can decarbonize while helping to secure our citizens' prosperity and employment prospects, the 2020 symposium of the Washington State Academy of Sciences has lessons for people everywhere. In improving the lives of Washingtonians, we could help the entire planet.

Daniel Schwartz, WSAS Member and Symposium Chair and Organizer, University of Washington

Welcome from Governor Jay Inslee

I would like to welcome the Washington State Academy of Sciences' 13th annual symposium. This year's symposium is obviously taking place during a time when our society is grappling with a number of unprecedented challenges, all of which involve science. As we work together to respond to and recover from the COVID-19 pandemic and address the immediate needs for communities affected by the climate fires that have ravaged the West Coast states, the need for objective scientific and technological information has never been more apparent. I am pleased that this year's symposium will focus on one of the most urgent issues facing our society—the need to decarbonize our global economy to combat climate change.

We know we are already seeing the devastating impacts of climate change in our state. It took only five days for 2020 to become our state's second worst fire season on record, with more than 600,000 acres burned, eclipsed only by the 1.1 million acres in 2015. As a result, we're also experiencing the worst air quality in the world. The cleanest air in the state is very unhealthy right now, with many communities experiencing hazardous air quality. In addition, climate change is already having devastating impacts on the natural resources in our economy. West Coast marine waters are acidifying at twice the global rate. Our streams are becoming too warm to support salmon, and our agricultural productivity is falling as a result of record heat.

"As we work together to respond to and recover from the COVID-19 pandemic and address the immediate needs for communities affected by the climate fires that have ravaged the West Coast states, the need for objective scientific and technological information has never been more apparent."

-Governor Jay Inslee

This is an issue of people in our state, people who like to go fishing, people who are farmers. This affects people in our state. It is not just an issue of polar bears. Further, climate scientists tell us that if greenhouse gas emissions continue on their current pathway, the average year in Washington will be hotter than the hottest year of the 20th century.

The message from the scientific community is loud and clear. We have no more time to waste. We have to do everything in our power to reduce global greenhouse gas emissions as quickly as humanly possible if we hope to avoid the worst impacts of climate change.

This year, I signed a bill to update the state's greenhouse gas limits to reflect the most current science based on national and international climate assessments. The new statewide limit calls for aggressively reducing greenhouse gas emissions in the near term in order to achieve carbon neutrality by mid-century.

While Washington is in good company in adopting aggressive science-based goals, we recognize that the pathway to meeting these goals will require a dramatic transformation in our economy, both here at home and globally, all of which can involve robust job creation, which we want in our state. I believe, and the evidence shows, that we can achieve this transformation in a way that supports our other public policy goals for economic development, reliable and affordable energy supply, good-paying jobs, social equity, and environmental justice. And we can make this transition in a way that both cleans up our air and jumpstarts our economy. We know it's possible, because it's happening right now all over our state. Washington's culture of innovation, our skilled workforce, and competitive advantage are our greatest assets, and they're the reasons we are a global leader in clean energy transition.

We're building clean infrastructure. In Seattle, the Kraken and the Storm will play in the world's first net zero carbon arena. With innovative building technologies, it avoids the need for fossil fuels.

We're creating clean energy jobs. In Moses Lake, the only advanced solar panel and cell manufacturing plant in the United States will open next year, making that community a critical hub in the U.S. solar supply chain.

We are leading in clean tech innovation. In Redmond, magniX developed the engine for an electric seaplane that took its first test flight with British Columbia's Harbour Air last year. In Richland, Pacific Northwest National Laboratory will host a new national grid energy storage research facility that is going to help develop energy storage technologies to support our transition to a 100 percent clean electrical grid. In the Spokane Valley, Katerra opened the largest factory producing cross-laminated timber, a renewable structural building material that sequesters carbon for the lifetime of a

building.

I've seen it firsthand when I saw the town that had burned down, Malden, Washington. Just a few miles from there, the ridges are replete with wind turbines. They're spinning up clean energy and jobs for that community. What a great vision for our state.

Since 2013, our Clean Energy Fund has invested over $150 million in strategic research development for clean technology, demonstration projects to modernize our electrical grid, and deployment of clean energy technologies. I'd like to thank Dan Schwartz for his work at the UW Clean Energy Institute. It helps us to use these funds to support the next generation of clean energy technology leaders.

We know these successes are due in large part to the critical work of our research institutions in developing the scientific basis for technological solutions, educating policymakers and the public, and cultivating the incredible talent of Washingtonians toward meeting these challenges.

Going forward, we will need to significantly scale up our efforts. Today you're going to hear about outstanding research and partnerships happening in Washington State to find climate solutions for some of our most critical economic sectors, including aerospace, information and communications technologies, and agriculture and forestry.

WSU material science professor Mike Wolcott's leadership at the aviation sustainability center is an extraordinary example of how we're pulling together our aviation industry, academic institutions, and government agencies to reduce climate impacts, to improve air quality, and to produce sustainable aviation fuels at a commercial scale.

Through her leadership on the U.S. National Committee for Soils, soil microbiologist Janet Jansson from PNNL is leading a collaborative research effort to better understand how soil microbiomes respond to and affect climate change. This work is going to inform the development of agricultural solutions to climate change and create opportunities for rural communities where farmers have a revenue source by sequestering carbon.

Through his participation in the Advanced Energy Lab, a partnership between Microsoft, McKinstry, and Cummins, UW chemical engineering professor Stuart Adler is leading efforts to decarbonize data centers using advanced fuel cell technologies and help from our state's Clean Energy Fund. This collaboration is going to help Washington technology companies meet their climate goals and also positions us as a leader in a global market for this technology. These are just a few examples of how Washington is having significant impacts on global carbon emissions by innovating right here at home.

I'd like to leave you all with a small silver lining from our recent experience. The COVID-19 pandemic has forced us to reduce carbon emissions, giving us a glimpse of what's possible and what's needed to secure a healthy climate. And the pandemic has sharply reminded us that we are all still connected on a global scale. We are certainly all in this together. Increasingly, our future depends on our ability to better prevent and respond to global crises like the pandemic and like climate change.

That's why I'm so grateful you are all here today. We need your expertise, innovation, and talent now more than ever. I'd like to thank the Washington State Academy of Sciences for convening this symposium and for recognizing the importance of developing and proving up the tools we need to secure a clean energy future in our state.

I'm confident that we can and will do our part to build that future, and that Washington will lead the world with proven technology developed right here at home. I encourage you to be vocal about your technology, about your research, and about your understanding of science. Science is going to be a leading light for us.

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1. Decarbonizing the Economy

The state that leads in decarbonizing its economy will lead in job growth, infrastructure development, and economic prosperity, said Dan Schwartz, Boeing-Sutter Professor of Chemical Engineering and director of the Clean Energy Institute at the University of Washington, in introducing the themes and speakers of the 2020 symposium of the Washington State Academy of Sciences. Airplanes made in Washington fly all over the world. Washington's information and communications technology cluster trails that of only the San Francisco Bay Area. Washington's agriculture and forestry sectors are the number one or number two producers of many high-value products.

Though Washington's emissions of greenhouse gas emissions are small on a global scale, activities carried out in the state have far broader consequences, said Schwartz. "Everything we do within the state of Washington—driving to work in Seattle, growing onions in Walla Walla, running a sawmill on the Yakima reservation, building Boeing aircraft in Everett, or operating a data center in Quincy—adds up to about one-quarter of one percent of the world's total global greenhouse gas emissions." But jets produce ten times more greenhouse gas emissions than do all the activities in Washington State. Information technology and communications contribute five times as much greenhouse gases as does all of Washington State. And the carbon stored in Washington's forests equals more than 70 years of the state's current annual emissions. Our state's outsized effects on energy and climate ecosystems give Washingtonians tremendous potential to change not only the nation but the world, Schwartz said.

Schwartz proposed four ideas for cultivating this ecosystem. First, strong and coordinated research, development, and demonstration partnerships will enable the state to shape an efficient carbon innovation ecosystem. Second, a shared R&D infrastructure will allow all sectors to progress faster together. Third, a robust workforce development strategy will allow successes to multiply. Fourth, sector-specific technical services like carbon measuring and certification processes will enable faster progress.

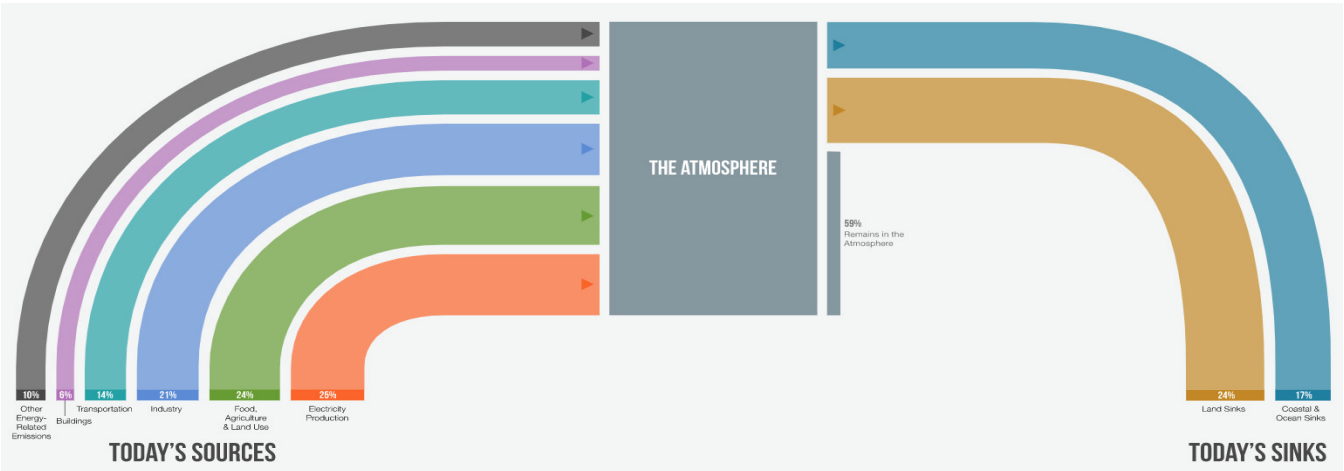
REACHING THE DRAWDOWN POINT

Drawdown is the point in time when the atmospheric concentration of greenhouse gases begins to decline on a year to year basis. "Through drawdown, we can stop and begin to reverse global warming," said Chad Frischmann, vice president and research director of Project Drawdown.

Discussions of climate change typically have been oriented around problems, fear, and conflict, but that is a recipe for apathy and indifference, said Frischmann. A new paradigm of solutions, possibility, and collaboration is needed, because such a recipe could serve as the basis "for something entirely different."

Changes in the levels of greenhouse gases in the atmosphere depend on the sources and sinks for those gases (Figure 1-1). Electricity production, food production and land use, industry, transportation, and buildings all produce greenhouse gases. Terrestrial

FIGURE 1-1. Approximately 59 percent of the greenhouse gases being emitted by humans remains in the atmosphere, with the remainder being absorbed and retained in natural sinks.



sinks and coastal and oceanic sinks pull carbon dioxide out of the atmosphere and store it in non-atmospheric reservoirs.

Today, approximately 41 percent of the greenhouse gases emitted into the atmosphere by humans is sequestered in natural sinks, with the remainder staying in the atmosphere. Three mechanisms can change this balance. People can change their consumption patterns and thereby reduce emissions of greenhouse gases. They can replace technologies and practices that are emitting greenhouse gases with clean and renewable alternatives. And they can enhance the sinks that capture and sequester carbon away from the atmosphere.

Project Drawdown, a nonprofit organization that has the goal of helping the world reach drawdown, has been creating a new framework to achieve solutions to the climate crisis. By mapping, measuring, and modeling technologies and practices that exist today, it has identified a system of solutions that can not only produce drawdown but provide many ancillary benefits to human and planetary well-being. Over a 30-year period, based on peer-reviewed data from widely cited sources, solutions could be marshaled to ensure that the world does not exceed either a 2-degree Celsius warming target or an even more stringent 1.5-degree Celsius target (Table 1-1).

The decarbonization of electricity generation is an important part of the solution, Frischmann observed, but electricity accounts for only about 25 percent of global greenhouse gases. Other major sources include carbon emissions from buildings, from industry, and from transportation, all of which consume energy from the grid and also from on-site combustion. In addition, humans produce materials like refrigerants that are powerful greenhouse gases when they are released into the atmosphere. Capturing those refrigerants and destroying them or replacing them with refrigerants that do not harm the atmosphere are ways to reduce sources.

The single most important set of decisions that people make every day with regard to greenhouse

TABLE 1-1. Solutions to Draw Down Atmospheric Greenhouse Gases

Note: Scenario 1 is roughly in-line with 2˚C temperature rise by 2100, while scenario 2 is roughly in-line with 1.5˚C temperature rise at century's end.

SOLUTIONS	SECTOR(S)	SCENARIO 1	SCENARIO 2
Onshore Wind Turbines	Electricity	47.21	147.72
Utility-Scale Solar Photovoltaics	Electricity	42.32	119.13
Reduced Food Waste	Food/Land Sinks	87.45	94.56
Plant-Rich Diets	Food/Land Sinks	65.01	91.72
Health and Education	Health and Education	85.42	85.42
Tropical Forest Restoration	Land Sinks	54.45	85.14
Improved Clean Cookstoves	Buildings	31.34	72.65
Distributed Solar Photovoltaics	Electricity	27.98	68.84
Refrigerant Management	Industry/Buildings	57.75	57.75
Alternative Refrigerants	Industry/Buildings	43.53	50.53
Silvopasture	Land Sinks	26.58	42.31
Peatland Protection and Rewetting	Food/Land Sinks	26.03	41.93
Tree Plantations on Degraded Land	Land Sinks	22.24	35.94
Perennial Staple Crops	Land Sinks	15.45	31.26
Temperate Fores Restoration	Land Sinks	19.42	27.85
Managed Grazing	Land Sinks	16.42	26.01
Tree Intercropping	Land Sinks	15.03	24.40
Concentrated Solar Power	Electricity	18.60	23.96
Public Transit	Transportation	7.51	23.36
Regenerative Annual Cropping	Food/Land Sinks	14.52	22.27

gases involves food, said Frischmann. The production, processing, packaging, transportation, storage, and preparation of food all produce emissions. Furthermore, an estimated 30 to 40 percent of the food that is produced is lost or wasted rather than being consumed.

Protecting, restoring, and expanding natural sinks can draw carbon out of the atmosphere. For example, forests store carbon away from the atmosphere while also protecting biodiversity. Protecting and restoring land is among the most impactful solutions that can be implemented from the local to the international scales to tip the carbon balance toward drawdown.

Finally, health and education have compounding impacts across all sectors by providing access to voluntary reproductive health resources and a quality education. Even in the United States, many people are being denied these basic human rights, said Frischmann. "This needs to change in our country and all over the world because these are solutions to the climate emergency."

The solutions identified by Project Drawdown are not independent but form an integrated system of systems, Frischmann said. As a result, they can be implemented in parallel and holistically. Also, although the solutions cost money to implement, they produce a large financial return to the economy. Project Drawdown has calculated that the implementation costs of its solutions would range from $22 trillion to $28 trillion over 30 years, but the net operational savings may be $95 trillion to $145 trillion over that same period.

Frischmann concluded by pointing to the many opportunities that Washington State has to contribute to drawdown. "The great work you're doing as a state can be internalized, expanded, and exported to the rest of the country," he said, "because you are a leader in creating these opportunities to build the future that we want." Achieving drawdown would convert an economy that is exploitative and extractive to one that is regenerative and restorative. "This is the generation to do it, because the decisions we make today have more meaning than perhaps at any other time in human history. I ask all of you watching today to join us and link arms to create and build a regenerative future that we all need and want."

IMPLEMENTING CLEAN ENERGY IN WASHINGTON STATE

In 2006, by ballot measure, Washington State adopted a renewable energy portfolio standard, well before most states were considering how to increase their reliance on renewable energy. A decade later, Washington State Representative Gael Tarleton and her colleagues in the legislature had the task of devising legislation that would meet the goal.

The result was the Clean Energy Transformation Act, which was signed by Governor Jay Inslee in 2019. As David Roberts of Vox pointed out, the legislation is the "best of the bunch" among state laws.[1] Many other states and cities have passed renewable energy standards, but Washington's legislation is distinguished by its commitment to have 100 percent fully renewable energy on the grid by 2045.

"It wasn't just a statement of intent," Tarleton told the symposium participants. "We needed milestones, we needed checkpoints, we needed to know that we were making progress toward the goal." The legislation, which was developed through extensive coordination with the governor's energy policy staff and with the Washington Utilities and Transportation Commission, seeks to capitalize on a unique advantage Washington has—its supply of hydroelectric power. It also includes critical milestones that affect not just electrification but the entire energy sector. In particular, the transportation sector is critical in Washington, Tarleton pointed out, because of the state's heavy dependence on trade, whether by train, truck, plane, automobile, or ship. But electric batteries for small aircraft, for the maritime sector, and for cars and trucks would all benefit from a renewable energy infrastructure in the state.

Washington State's legislation has established three goals for the decarbonization of the electrical sector. Coal-fired electricity should be eliminated by 2025. The electricity supply in the state should be carbon neutral by 2030. And the electricity supply should be carbon free by 2045. That gives the state just a quarter of a century to achieve decarbonization, Tarleton noted.

To achieve these ambitious goals, the Clean Energy Transformation Act prioritized several principles. It sought to maximize the creation of jobs that pay a living wage. It prioritized ensuring that all customers in the state benefit from the transition to clean energy. And it provided safeguards to ensure that the transition to clean energy solutions would not jeopardize the grid so that it would remain efficient, resilient, and reliable.

A key breakthrough in developing the legislation was changing the authority of the state Utilities and Transportation Commission away from a least-cost model

1. The article is available at https://www.vox.com/energy-and-environment/2019/4/18/18363292/washington-clean-energy-bill

to a performance-based model, said Tarleton. This shift gives the commission the flexibility it needs to work with utilities on planning.

A second key breakthrough was changing the definition of the public interest. The goal was not to increase the burden on vulnerable people and communities, which have already been disproportionately impacted by climate change and environmental pollution. This, too, required a shift away from least-cost investments.

A third breakthrough was to work with the 63 utilities in Washington State and with the federal government to support the bill.

At the time of the symposium, rulemaking was under way to implement the goals and milestones of the legislation The framework for the rulemaking is equitable decarbonization, said Tarleton, which defines the metrics that the Utilities and Transportation Commission, utilities, the environmental community, and the labor community will use to measure progress. "This is a transformation in the way policy not only will be made but will be implemented."

"The key to the legislation's success is that every voice was heard in the negotations."

-Representative Gael Tarleton

The key to the legislation's success, said Tarleton, is that every voice was heard in the negotiations. She and her colleagues in the legislature worked with utilities, environmental advocates, labor organizers, communities of color, and others who have been disproportionately affected by the energy infrastructure. "When we allow diverse voices to be heard, it's an astonishing thing. As my mom used to say, 'Ordinary people have the ability to accomplish extraordinary change.'"

PARTNERSHIPS FOR CHANGE

The week before the symposium, Mary Collins, energy and environment policy advisor within the United Kingdom Foreign and Commonwealth Office, was camping with her family in California and woke one morning to find that it was raining ash. Getting in their car, they tried to drive away from the smoke but instead drove toward an active fire. "It felt like we were driving into the belly of the Earth," she said. "The sky was glowing, pulsating an orange and purple color. It was something I've never seen before in my life." It was the first time she had felt a flight-or-fight response due an event related to climate change. "It gave me a sense of urgency that I hadn't felt before. You may not be personally impacted by the fires or floods right now, or your business maybe isn't impacted by climate risk. But we're getting a wakeup call in 2020 on how we want to live and move forward as a society."

Collins has been leading the engagement with stakeholders in the western United States in preparation for the 26th UN Climate Change Conference of the Parties (COP26), which is scheduled to be held in Glasgow in November 2021. COP26 has five campaign areas—energy, nature, transport, finance, and adaptation and resilience—that are designed to lay the groundwork for stronger and sustained international cooperation. For example, it is working to achieve greater transparency in the banking and financial system, with financial institutions publicly disclosing how much their investments contribute to climate change. In transportation, it is working to double the pace of the transition to zero emission vehicles. For example, the United Kingdom aviation industry has a 2050 net zero target, and it could work with Washington State's world-leading aerospace industrial cluster to create a linked industry and innovation ecosystem, Collins said.

New coal power in the pipeline needs to be eliminated while investments in clean power are doubled, Collins observed. Two of the fastest growing jobs in the United States are wind turbine technician and solar installers, and these kinds of industries could create jobs and put dollars into people's pockets. "These are the jobs of the future, and once people are working and connected to this sector they will be glad to continue to support it." Similarly, as a global innovator in such areas as cross laminated timber and sequestering carbon in the soil, Washington State could link its efforts to others across regions and countries.

Adaptation and resilience planning need to be accessible at all levels, especially at the local level. Climate change threatens to push an additional hundred million people into extreme poverty by 2030, which is why the United Kingdom is doubling its climate finance investments to 11.6 billion pounds toward developing countries. "We can respond to the needs of these most vulnerable countries and communities around the world."

Meeting the Paris Agreement will require solutions that affect many fundamental aspects of life, like food, farming, and land use, Collins said. But Britain has shown some of what can be achieved by acting with a sense of urgency. Since 1990, the United Kingdom has reduced emissions of carbon dioxide by 42 percent while growing the economy by 70 percent. It has a 2050

net zero target that is formalized in legislation. It has a phase-out date of 2040 for internal combustion engine vehicles in light duty vehicles and is working to move that date up. It is constantly assessing and refining how to reach its emission goal.

Despite such progress, the planet needs to decarbonize the global economy three to five times faster over the next decade than it has done over the past two decades, Collins insisted. "It matters what your business is doing. It matters how your research is contributing to drawdown. It matters what your state, local, or tribal governments are doing. . . . Does your city, does your company, does your university have a net zero target and a plan to get there?"

When places like Britain or Washington move toward solutions, they are not acting alone, said Collins. Nor do they need to have every detail finalized to instill ambition and act with a sense of urgency. Solutions at hand from organizations like Project Drawdown or the U.S. Climate Alliance can have immediate impact.

"We're not short on solutions," Collins concluded. "But we need to go forward with ambition and take that sense of urgency into our work." She advocated a solutions-oriented mindset, because capital and creativity are available if the will to change exists. Change also needs to be widespread. Everyone needs to ask how their organization can have a target and a plan to get there, how research can have more of an effect, and how to collaborate with others to achieve solutions. "This year is an inflection point," she concluded. "We're going to move from a point of confusion to one of clarity."

"We're going to move from a point of confusion to one of clarity."

- Mary Collins

2. Decarbonizing Land Use

Land use is a big piece of the puzzle of how to reduce carbon emissions, said Chad Kruger, director of the Center for Sustaining Agriculture and Natural Resources, who organized the session on decarbonizing land use at the symposium. Two speakers addressed the issue and the role that soil carbon storage in particular might play in decarbonizing the Washington State economy.

CARBON AND THE SOIL MICROBIOME

One tablespoon of soil contains billions of microbial cells, most of which have never been cultivated and have properties that are largely unknown, observed Janet Jansson, chief scientist and laboratory fellow at the Pacific Northwest National Laboratory. Yet these microorganisms are responsible for the vital tasks of cycling soil carbon and other nutrients. They therefore are critical for the storage of carbon in the soil and fluxes of greenhouse gases to the atmosphere.

> "[Soil microorganisms] are critical for the storage of carbon in the soil and fluxes of greenhouse gases to the atmosphere."
>
> - Janet Jansson

Carbon enters the soil through the process of photosynthesis and deposition of organic matter. Microbial communities process the carbon that enters the soil, with some of it being returned to the atmosphere and some being retained belowground (Figure 2-1). For example, some bacteria in the soil produce polymers known as extracellular polymeric substances (EPS) that help retain water and organic matter in soils. Carbon in soils can also be in the form of partly decomposed plant material, metabolites, or dead microbial cells, known as necromass. In these and other ways, carbon in the soil is kept in a state where it is retained and not rapidly emitted back into the atmosphere.

Increased carbon dioxide in the atmosphere is predicted to have major consequences in Washington State, Jansson said, including increases in temperature, earlier annual snow melt, sea level rise, saltwater intrusion into coastal soils, increased drought, and greater fire frequency and intensity. These and other consequences of higher atmospheric carbon dioxide levels will also impact ecosystems, including the microorganisms that carry out key steps in the carbon cycle. However, the effects on ecosystems are still not well understood. In the short term, increased atmospheric carbon dioxide would be expected to increase plant productivity and the deposition of carbon in the soil. But faster growth of plants and increases in soil organic matter that stimulate microorganisms could cause them to respire more carbon dioxide into the atmosphere, which could deplete carbon currently stored in soils. "We need to gain an understanding of the fundamental processes that microorganisms carry out in the soil system if we're going to be able to address and predict how those processes will be impacted by future climate change," said Jansson.

The Pacific Northwest National Laboratory is conducting a variety of research projects to understand the impacts of climate change on the soil microbiome and carbon cycle. These projects range from the landscape scale, where hydrology, soil type, and climate are critical factors, to the molecular scale, where the genomes of organisms are being studied to learn how carbon moves through the system. At an intermediate scale, for example, researchers are performing gas flux measurements on soil cores to develop soil carbon models. At the microscopic scale, advanced imaging capabilities are being used to understand how microorganisms interact to break down carbon compounds.

At a Washington State University field station in Prosser, researchers are studying the potential for the arid and marginal soils of eastern Washington to grow biofuel crops and store carbon in the soil. Using four levels of irrigation, studies have looked at two varieties of perennial tall wheatgrass, which grows naturally in the Pacific Northwest and is a potential biofuel feedstock. It grows to be about ten feet tall and has roots that extend as much as six feet underground, twice as far as conventional wheat. The greater depth and surface area of tall wheatgrass roots create the potential to deposit carbon from the atmosphere into soil microorganisms deep underground.

A 2018 report from the National Academies of Sciences, Engineering, and Medicine, *Science Breakthroughs to Advance Food and Agricultural Research by 2030*, made several key recommendations regarding soil science:

- Maintain the depth and health of existing fertile

soils and restore degraded soils through adoption of best agronomic practices

- Create more productive and sustainable crop production systems by identifying and harnessing the soil microbiome
- Improve the transfer of technology and practices to farmers to reduce soil loss through converging research in soil sciences, technology adoption, and community engagement

These recommendations have special relevance in Washington State, Jansson concluded. Changes in the climate will have unknown consequences on microbial functions that are essential for life. Pacific Northwest National Laboratory has strong and growing expertise in soil and microbiome science, and it is eager to apply new knowledge in practice.

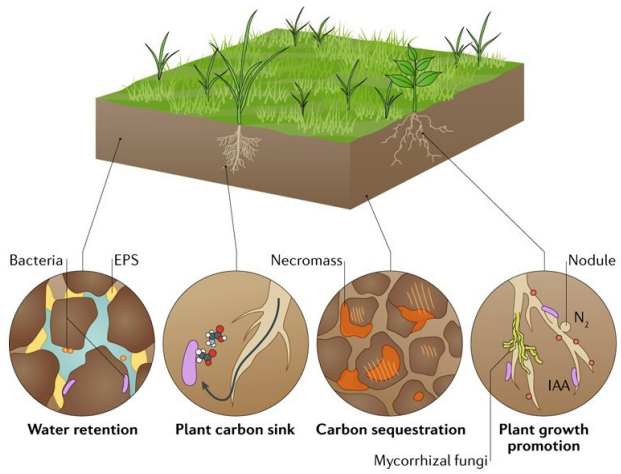


FIGURE 2-1. Microbial communities promote the retention of carbon in the soil through various mechanisms. Source: (Nature Reviews Microbiology, https://doi.org/10.1038/s41579-019-0265-7).

SOIL AND HUMAN CIVILIZATION

According to a 2015 United Nations report, humanity loses 0.3 percent of its global food production capacity each year to soil erosion and degradation, said David Montgomery, professor of geomorphology at the University of Washington.[2] At this pace, humanity could lose roughly a third of its food production capacity even as the population is growing. Already, one-quarter to one-third of the world's agricultural land has been moderately to seriously degraded due to soil loss and degradation, Montgomery noted. A study of history provides many examples of civilizations where soil loss and degradation influenced their decline, from Neolithic Europe, to Classical Greece, Rome, the southern United States, and Central America, usually by rendering societies vulnerable to such cataclysms as droughts or war. "There is society after society where you can connect the dots between soil degradation and the longevity or fate of a civilization," said Montgomery.

In describing his book *Dirt: The Erosion of Civilizations*, Montgomery related how the plow has had an especially pervasive effect.[3] By turning over the soil, it renders the land surface vulnerable to erosion by water and wind until something grows back, whether the next crop or the incursion of plants from elsewhere. Plowing also degrades soil organic matter by speeding the microbial decomposition of the organic matter in the soil. The effects of plowing are highly variable, said Montgomery, but the carbon content of many soils in North American is only about half of what it was before they were converted from forests or prairies to farmlands.

> "[T]he carbon content of many soils in North American is only about half of what it was before they were converted from forests or prairies to farmlands."
>
> - David Montgomery

Based on a compilation of global rates of soil erosion, Montgomery has estimated that soil is eroding from conventionally tilled farms at a rate of 1.5 millimeters per year, meaning that it takes less than two decades to erode an inch of soil.[4] However, nature produces soil at a rate of just a fraction of a millimeter per year, such that it takes centuries to millennia to make an inch of soil. The net loss means that erosion of a typical 0.5- to 1-meter-thick hillslope soil could occur in roughly 500 to 1,000 years, which is approximately the lifespan of most major civilizations outside of major river floodplains, where soils are regularly replenished by sediment-laden floods. However, only 1 to 2 percent of most landscapes are composed of floodplains and deltas, Montgomery pointed out. "Most of the lands are hills and uplands, for which, once tillage starts, the clock starts ticking on soil degradation."

2. FAO and ITPS. 2015. *Status of the World's Soil Resources.* Rome: Food and Agricultural Organization of the United Nations and Intergovernmental Technical Panel on Soils.

3. David R. Montgomery. 2007. *Dirt: The Erosion of Civilizations*. Oakland, CA: University of California Press.

4. David R. Montgomery. 2007. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences* 104(33):13268–13272.

RESTORING SOILS

When Montgomery and his wife bought a house in Seattle, they pulled up their lawn and found that their property consisted of glacial till that had been compressed by the wall of ice that overran Seattle during the last Ice Age. "There wasn't a single worm in the soil. We essentially had dirt." By adding compost, mulch, woodchips, and other organic matter to the soil, they were able to transform the soil from an organic content of 2 percent to 10 percent across most of the yard over the course of about a decade—an increase of not quite 1 percent per year. Soil can be rebuilt, he said, if time, effort, and organic matter are put into it.[5]

In studying the process, he and his wife realized that microbial communities in their soil were doing much of the hard work of bringing the soil back to life. Symbiotic relationships between fungi and plants were benefiting both partners and the soil. Microorganisms were breaking down organic compounds into simpler compounds. This is the "hidden half of nature," Montgomery said, because it is smaller than can be seen and occurs underground.

In addition, plant roots do not just absorb water and nutrients. They are "two-way streets" that exude into soils a large variety of simple and complex compounds. These compounds attract microbial organisms that help the plants grow and protect them against pathogens. The community interactions and relationships in the hidden half of nature "opened our eyes to the science of microbial ecology and its importance for building soil organic matter," Montgomery said.

This process can be applied to much larger landscapes. As Montgomery described in his book *Growing a Revolution*, farmers around the world have been restoring fertility to their land, building up soil carbon, and bringing profitability to degraded farms used a combination of three principles.[6] The first is minimal disturbance of the ground through techniques such as no till farming. The second is maintaining a permanent ground cover through such practices as the use of cover crops and companion crops. The third is using a diverse rotation of crops. Known collectively as conservation agriculture, practices based on these approaches help cultivate the beneficial life in the soil. They are also "more or less the opposite of what we've tended to teach in agronomy for most of the last century, with reliance on tillage-intensive agrichemical use and functional monocultures," Montgomery said.

The practices of conservation agriculture can not only restore healthy and fertile soils but also generate higher profits. They allow farmers to spend much less on fossil fuels, fertilizers, and pesticides even as they rebuild soil organic matter. Furthermore, returning carbon to the soil helps with water retention and reduces off-site pollution from nitrates and phosphates, since less fertilizer is needed to maintain yields.

The practices of conservation agriculture... can restore fertility and keep carbon in the soil not just in Washington State but around the world.

The challenge for Washington is how to translate these three principles for the contexts present in the state, Montgomery concluded. Practices that work in eastern Washington State will not necessarily work in western Washington State. Approaches vary by crops and by the previous condition of the soil. Ranchers need to apply different approaches than farmers. But a combination of approaches can restore fertility and keep carbon in the soil not just in Washington State but around the world.

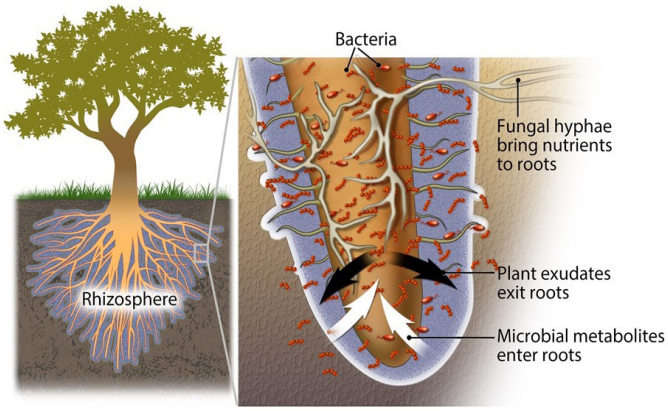


FIGURE 2-2. In the rhizosphere around roots, plants exude compounds that support thriving communities of microorganisms that in turn support plant growth. Source: David R. Montgomery and Anne Biklé. 2016. *The Hidden Half of Nature: The Microbial Roots of Life and Health*. New York: W. W. Norton.

5. David R. Montgomery and Anne Biklé. 2016. *The Hidden Half of Nature: The Microbial Roots of Life and Health*. New York: W. W. Norton.
6. David R. Montgomery. 2017. *Growing a Revolution: Bringing Our Soil Back to Life*. New York: W. W. Norton.

BREAKOUT CONCLUSIONS

In a breakout session on land use issues, Dan Brown, director and professor in the School of Environmental and Forest Sciences at the University of Washington, pointed out that land use occurs in the context of not only environmental capabilities and constraints but also the social context of people, governments, and markets. Thus, land use changes have both ecological impacts and social impacts. He listed five strategies through which science can contribute increased carbon storage and reduced emissions in these systems: better monitoring and inventory of both the natural and the social environment, altered land use management such as increased rotation lengths, reduced forest loss resulting from both natural and social processes, increased forest cover in such areas as low-productivity farmland, and long-term storage of carbon in forest products such as cross-laminated timber.

Kirsten Hofmockel, earth scientist in the Biological Sciences Division of Pacific Northwest National Laboratory, noted that soils are fundamental to food production, clean water, energy independence, and a habitable climate and that soils store three times as much carbon as does the atmosphere. Soil security involves maintaining and improving soil resources to grow food, fuel, and fiber; to filter runoff and provide clean water; and to maintain biodiversity and ecosystem services, all of which contribute to human health and vibrant economies. Washington State could be a leader in developing science and technology priorities through research on issues such as soil carbon cycling and storage, soil ecology, and land management practices, she said. As a particular example, she mentioned the development of real-time sensors of soils, crops, water, and livestock that can be used to model and manage carbon transfer between land and the atmosphere.

Chad Kruger, director of the Center for Sustaining Agriculture and Natural Resources at Washington State University, asked why a farmer might be interested in managing the carbon in soils. Even if a farmer were paid $50 an acre to store more carbon, that might not make much difference in a potato farm generating several thousand dollars an acre or a tree fruit system that generates tens of thousands of dollars per acre. But increasing the amount of carbon in the soil has other benefits that may tip the economic balance—for example, by increasing the water-holding capacity of soil so that crops do better on hot summer days. Better diagnostic tools and tests—which were identified at a 2018 government-university-industry summit as the most important issue in soil health—could help make this case, as could better implementation of scientific research and development of a roadmap for strategic investments.

Finally, William Pan, professor of soil science at Washington State University, described several win-win scenarios for farming and climate change mitigation. Farmers take a very large amount of information into account in developing their farm management plans, but economics is of course a key driver. As such, many long-established ways of getting more carbon into soils now make economic sense. Biosolids from waste treatment plants, manure from dairy farms, lignin-rich wheat straw pulping co-product, and other sources of carbon and nitrogen can all be returned to the land to boost both production and soil carbon. The greatest needs now, said Pan, are for state and federal funding of research on these approaches and a stronger workforce of soil scientists, crop advisors, and others to put these approaches into practice.

Based on these presentations and subsequent discussions during the breakout sessions, Malin Young, associate laboratory director for Earth and biological sciences at Pacific Northwest National Laboratory, identified the important points during the subsequent plenary session:

- Washington State produces 300 different commodities, not just apples and wheat, which means that many crops receive relatively little funding for innovation and the dissemination of best practices. In addition, industry partnerships do not work as well for industries that are composed of many small producers, such as farmers.
- However, the diversity of ecosystems and agricultural systems in Washington also gives the state an advantage in thinking about complicated land use systems.
- Past investments in innovative land use approaches, such as initiatives aimed at sustainable farms and fields and soil health, have not been sufficient to inform how to improve land use practices on a large scale.
- Subsidies can run counter to sustainable farming practices by incentivizing people to grow crops that are not environmentally friendly. A trend in the marketplace toward sustainable products and practices could provide a counterbalance to such subsidies.
- Current production systems can accommodate variable weather and longer term climatic trends, but how many bad years can these systems handle before the need to change becomes compelling?

- Better diagnostic tools and tests are needed that are specific to the ways in which land is used in the state so that land use practices can be informed by the local environment. For example, standard carbon accounting systems do not do a good job of capturing what happens in many parts of the state.
- Balances need to be struck between competing objectives, and these balances may differ from place to place. For example, increasing carbon storage in forests and other ecosystems may increase the associated fire risk.
- More conversations among researchers, policy makers, and producers would help bridge the gap between science and practice, as would more support for professionals such as crop advisors and soil scientists.
- Policies seeking to improve land use practices need to look at the state as a system of interconnected systems, such as forestland use regulation and carbon pricing policies. These policies also need to ameliorate the impact on marginalized communities.
- Diverse stakeholders should come together to establish a common vision and a path forward.

3. Decarbonizing Aviation

Aviation is a difficult part of the transportation sector to decarbonize, observed Michael Wolcott, regents professor and director of the Office of Clean Technology at Washington State University, who organized the symposium session on the aviation industry. Nevertheless, the industry has set ambitious goals. It is planning to cap its carbon emissions at the 2020 level until 2035 and reduce its carbon emissions by 50 percent over the subsequent 15 years. Doing so will require new technologies such as biofuels and electrification, both of which were discussed during the symposium session on aerospace.

THE DECARBONIZATION OF JET FUEL

Jet fuels represent just 3 percent of the energy consumed in the United States, noted Manuel Garcia-Perez, professor and director of the Bioproducts, Sciences, and Engineering Laboratory at Washington State University. But even as more new cars are electrified, the market size for jet fuel is growing. Global consumption of jet fuel is projected to rise from 106 billion gallons a year to 230 billions by 2050, with a current target of having 30 percent of that fuel being in the form of sustainable aviation fuels by 2040. Achieving that goal requires access to an inexpensive source of carbon from biological materials and an inexpensive way of converting that carbon into jet fuel, said Garcia-Perez.

Biomass is an inexpensive source of green carbon, and Washington is rich in diverse and distributed biomass resources. Every year, Washington State produces close to 2.5 million tons of agricultural waste and 5.5 million tons of forest waste that could be used for the production of sustainable fuels (Figure 3-1). The carbon in this biomass is stored in the form of six major biomolecules: sucrose, starch, triglycerides, lignin, cellulose, and hemicellulose. Today, seven approved pathways go from various renewable and waste carbon feedstocks to jet fuels. In general, these pathways rely on cracking or hydrolysis and hydro-deoxygenation to convert biomass into precursor compounds for jet fuels.

Garcia-Perez and his colleagues have studied six specific technologies for the production of alternative jet fuels. For each, they conducted a mass and energy balance and estimated the fuels' minimum selling prices. These prices ranged from $1,150 per metric ton to more than $5,000 per metric ton. However, the cost of the intermediate products in the conversion processes was comparable for all the technologies studied. The difference in cost of the final products is mainly due to the cost of the deoxygenation step.

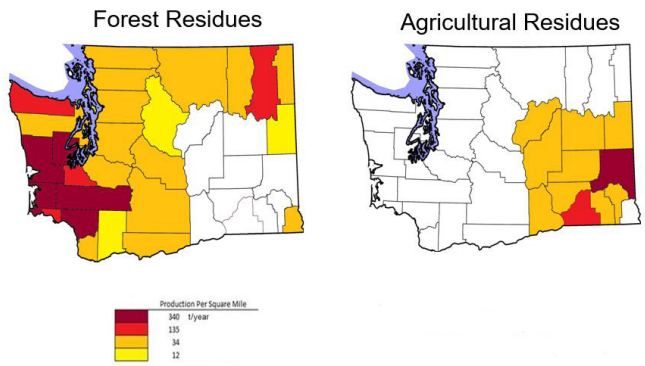


FIGURE 3-1. Forestlands and croplands in Washington States produce residual biomass that could be converted into jet fuels.

The research group then asked what would be needed to produce jet fuel at $600 a ton with a feedstock price of $65 a ton and a conversion cost of $300 a ton. They calculated that meeting these milestones would require a conversion efficiency of 61 percent. To achieve this efficiency, almost all the carbon in the feedstock needs to be converted into fuel and the oxygen has to be removed in the form of water. This will require a technology that uses the carbon from the three main macro-components of biomass (cellulose, hemicellulose, and lignin) and does not produce byproducts.

The group has proposed a specific technology that could achieve a selling price close to $600 per ton, though the technology has been criticized due to its use of high volumes of methane. An alternative would be to use biogas obtained from anaerobic digestion, but that would reduce the economic viability of the project. Garcia-Perez said that he would expect a blend of natural gas and biogas to be used to achieve an equilibrium between economic and environmental sustainability.

New concepts are also being studied for the production of jet fuels from biomass, including the use of cheap sources of carbon and energy such as waste plastics and municipal solid wastes. A particularly promising intermediate compound is syngas, which can be readily converted with fermentation and catalytic pathways into jet fuels. Conversion of biomass from both forestlands

and croplands into both jet fuel and char would enable the latter to be used as a soil amendment to sequester carbon. In all these areas, Washington State has a unique opportunity to become a leader in producing sustainable aviation fuels while increasing the carbon content and fertility of agricultural soils and decreasing the intensity of wildfires, said Garcia-Perez.

"Washington State has a unique opportunity to become a leader in producing sustainable aviation fuels while increasing the carbon content and fertility of agricultural soils and decreasing the intensity of wildfires."

-Manuel Garcia-Perez

THE ELECTRIFICATION OF AIRCRAFT

NASA is working on the electrification of aircraft of all sizes, from the large aircraft that are the backbone of the aviation system to small aircraft that might carry passengers or deliver packages (Figure 3-2). Such technologies will take longer to make inroads on larger aircraft, said Jim Heidmann, manager of NASA's Advanced Air Transport Technology Project, since single-aisle and twin-aisle jets represent a mature industry and gas turbine engines are highly developed. However, small vehicles, such as vertical-lift urban air mobility (UAM) vehicles, are drawing considerable interest for electrified aircraft propulsion (EAP), as are small fixed-wing vehicles. For these kinds of vehicles, said Heidmann, "electrification can be a winner even today."

NASA has four programs under which it manages its aeronautics investments: the Advanced Air Vehicles Program, the Airspace Operations and Safety Program, the Integrated Aviation Systems Program, and the Transformative Aeronautics Concepts Program. The final program is the newest and has some of the most ambitious goals, since it is working on technologies that could be big winners two or three decades hence. "We're not doing research just for the sake of research," said Heidmann. "We try to identify with industry and other partners, with universities and other agencies, what are the big technical challenges that need to be overcome to facilitate these new concepts and new approaches."

In the area of urban air mobility and small aircraft, NASA has established several grand challenges:

- Accelerate technology certification and approval
- Develop flight procedure guidelines
- Evaluate communications, navigation, and surveillance options
- Demonstrate an airspace system architecture based on NASA's Unmanned Aircraft System (UAS) Traffic Management (UTM) construct
- Collect initial assessments of passenger and community perspectives on vehicle ground noise, cabin noise, and on-board ride quality

NASA is not developing concept vehicles in this area, Heidmann said. Rather, a variety of companies, from startups to long-established aeronautics firms, are doing that. For its part, NASA has been working on the safety and certification standards and on the tools that the broader industry needs to facilitate concept development. For example, it has developed a UAM proving ground where companies can test prototypes and thereby get technologies to market earlier. It also has worked on airspace management to make sure that flying is safe and does not generate too much noise on the ground when large numbers of vehicles are in an airspace.

As a specific example, Heidmann described the X57 Maxwell Flight Demonstrator, which is a battery-powered fixed-wing aircraft. The aircraft has a high aspect ratio wing that is half the size of a conventional wing and wingtip propellers that counteract wingtip vortices. It is designed to have zero in-flight carbon emissions, better cruise efficiency, and a quieter flight. "We are not promoting it as the solution. We're promoting it as a testbed for looking at some of the challenges that are going to crop up when you get down to the engineering on some of these concepts."

Several revolutionary technologies are being developed for vertical lift aircraft, such as tiltwings and hybrid turboelectric systems. Again, NASA is not developing the aircraft designs, said Heidmann. Rather, it is capturing the key technology needs for the broader industry. Challenges include such issues as interactions among rotors and between rotors and wings, propulsion efficiency, safety, and noise.

Lessons learned with smaller aircraft can be scaled up to transport-scale electrified aircraft propulsion, said Heidmann. For example, hybrid systems use multiple energy sources, such as a combination of a turbo electric and a gas turbine engine, with the power being distributed to propulsors distributed around the aircraft. NASA is also working on technologies that cut across different kinds of aircraft, such as the kinds of insulators needed for high-voltage systems, energy storage, and cryogenic, hydrogen-based vehicles.

NASA is seeking disruptive ideas from universities that can partner with industry to convert those ideas to applications, Heidmann concluded. It also has been identifying technology gaps that need to be filled, "How far do we have to go on energy density? How far do we have to go on efficiency? . . . We all have to work together, small companies, large companies, NASA, universities, to address the range of problems."

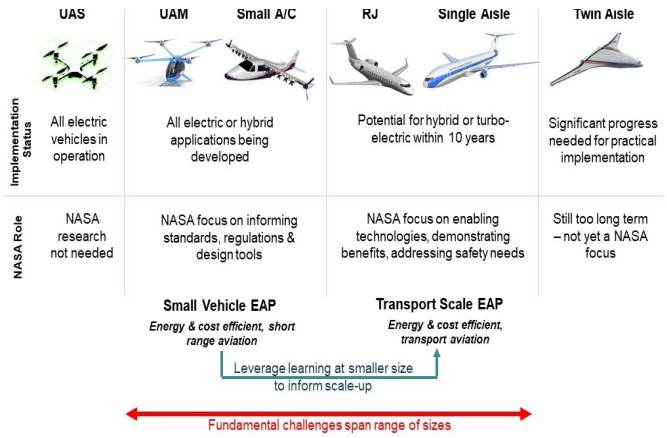


FIGURE 3-2. NASA's work on electrified aircraft propulsion (EAP) spans a range of vehicles and needs, from unmanned aircraft systems (UAS) to urban air mobility (UAM) and other small aircraft, to regional jets (RJ) and large single-aisle jets, to twin-aisle aircraft.

BREAKOUT CONCLUSION

During the breakout session, also organized by Michael Wolcott, several speakers gave brief introductions to important issues affecting the decarbonization of aviation. Roei Ganzarski, the chief executive officer of magniX, pointed out that smaller, more accessible airports focused on shorter trips and fewer passengers may open the door for smaller electric planes to become mainstream. Electrification of the aviation sector will require the development of new infrastructure, the resolution of intellectual property issues that can handicap industry-academia collaborations, and a better prepared workforce with strengths in developing practical solutions to problems.

John Holladay, co-director of the Bioproducts Institute at Pacific Northwest National Laboratory, discussed the potential conversion of waste products into aviation fuels. This process must be able to contend with a wide range of feedstocks, be inherently safe, and be competitive with other ways of producing fuel or higher value chemicals. Successful development of such processes could transform a costly problem of waste disposal into a positive economic resource.

The potential conversion of waste products into aviation fuels...could transform a costly problem of waste disposal into a positive economic resource.

Sean Newsum, director of environmental strategy for Boeing, observed that the ultimate goal of the industry is to decarbonize aviation. However, hydrocarbon jet fuel will remain the major source of energy for aviation until at least 2050 because of the extensive infrastructure that is already in place for such fuels. Sustainable fuels, whatever their route of production, will need to be low cost and will have to meet strict third-party certification requirements.

Marianne Csaky, director of environmental affairs at Alaska Airlines, said that achieving these goals will require "not a silver bullet but silver buckshot." Alaska Airlines has committed to a net zero carbon footprint by 2050, which will be a challenge given the currently low price of jet fuel. The company would prefer not to use carbon offsets to achieve that goal, which will require that research and development focus on reducing the costs of producing sustainable fuels and finding new and inexpensive ways to get fuels "that last mile to the airport."

Mehran Mesbahi, professor of aeronautics and astronautics at the University of Washington and executive director of the Joint Center for Aerospace Technology Innovation, noted that aerospace engineering is currently going through a rebirth, not only in aviation but in space exploration and commercialization, communications, autonomous vehicles, and many other areas. Part of that rebirth is a shift in emphasis from how the environment affects aerospace vehicles to how the use of those vehicles affects the environment. "That has to be reflected in the way that we teach our students in a much more substantial way."

In the plenary session following the breakout session, Wolcott identified several key points that emerged from the discussion:

- Washington State has a robust system of experts and institutions working on the decarbonization of aviation. A current challenge is to coordinate these activities to make as much progress as quickly as possible.
- Research into fundamental problems needs to be combined with translational research to move new technologies into the marketplace.
- The "last mile" problem of getting new energy

systems into aviation requires attention to the aviation infrastructure. Because aircraft go from place to place, the infrastructure needs to change in more than one place for new technologies to have an impact.

- Because aviation is highly regulated by government, new technologies will need to be reliable enough to be certified.
- Government policy has tremendous influence over the speed of deployment of new technologies.
- Considering the effects of aircraft on the environment will require more interdisciplinary work in education, training, and workforce development.
- Engineering education and workforce development should emphasize technology development and the science behind technologies, along with critical thinking and practical applications.

4. Decarbonizing Information and Communications Technologies

Several factors make this the right time to think about decarbonizing information and communications technologies, explained Stuart Adler, associate professor of chemical engineering at the University of Washington, who organized the session on this topic at the symposium. First, personal electronic devices consume just a fraction of the energy consumed by the cloud services that those devices access. The data centers that provide these cloud services currently consume about 2 percent of all the electric power produced in the United States, but their consumption is growing by 12 percent a year. By 2030, they are projected to be consuming 6 percent of U.S. electrical energy, which is about the same amount as the entire iron, steel, and aluminum industries in the United States.

Second, many companies that have leadership roles in cloud services, including Microsoft, Amazon, Google, Facebook, and Apple, have made recent pledges to be carbon neutral by 2030. "This represents a sea change in the environmental leadership away from a regulatory approach where people in government advance an environmental agenda that's imposed on industry," said Adler. Instead, "industry itself is adopting environmental stewardship as a principal goal and leading the way." Furthermore, because the leading cloud services companies are either headquartered or have presences in Washington State, a move toward environmental sustainability creates valuable new opportunities for statewide partnerships and initiatives with national and worldwide impact.

> "[I]ndustry itself is adopting environmental stewardship as a principal goal and leading the way."
>
> -Stuart Adler

Third, technological innovation is reshaping information and communications technologies. To meet the goals they have set, cloud services companies are going to need new and disruptive innovations, said Adler. As a reflection of this need, Amazon recently announced the formation of a $2 billion venture capital fund to support the development of technologies that reduce carbon emissions, while Microsoft has been exploring the commercial use of fuel cells in data centers.

RETHINKING DATA CENTERS AT MICROSOFT

Sean James, director of datacenter research at Microsoft, elaborated on the company's initiatives. Microsoft has made a commitment to be carbon negative by 2030 and to remove all of its historical carbon emissions by 2050 (Figure 4-1). That will require innovation, said James, which is why the company has launched a billion-dollar climate innovation fund to invest in such areas as reforestation, soil carbon sequestration, and bioenergy with carbon capture and storage.

Decarbonization also will require rethinking some of the basic aspects of data centers. Data centers need to have uninterruptable power supplies, which is why they have backup generators. But these generators run very seldomly, James pointed out, which creates an intriguing possibility. Several years ago, Microsoft realized that it could use its data centers to help keep the broader electrical grid stable. If a data center loses power from the grid, batteries take over the load instantaneously and then the standby generators begin operating. These standby generators can also serve the larger grid. In Wyoming, for example, Microsoft has been able to say to the local utility that if it needs extra capacity, it can request that Microsoft start its natural gas generators.

The same logic can be applied to the batteries that serve data centers, James observed. At times during the day, the grid needs quick bursts of energy. Instead of having grid operators install batteries to deliver these energy microbursts, data centers can provide that energy from their batteries. Data centers need the batteries to cover their own needs first, but they can add battery capacity much more cheaply than can utilities.

Battery technology also continues to improve, with considerable progress still possible. The ideal battery would be able to store a lot of energy in a small space, have no self-discharge or degradation over time, and be inexpensive, so that it would be competitive with a diesel generator. Such batteries could store excess renewable electricity for later use, not only for data centers but for other applications.

Data centers have also been working to reduce their

electrical loads. One way to do this is through liquid cooling, which enables heat to be removed efficiently from servers through what are known as dry coolers, thus eliminating the need to air condition the servers. Another is to install fuel cells in the racks holding the servers, which simplifies the delivery of electricity, reduces costs, and eliminates points of failure.

An even more innovative approach is to put servers underwater. In a recent test of underwater servers off the coast of Scotland, the servers had one-eighth the failure rate that they did on land because of the stability of the environment. This experiment had lessons for servers on land as well, James noted, because it demonstrated the benefits of maintaining a very tight operating envelope.

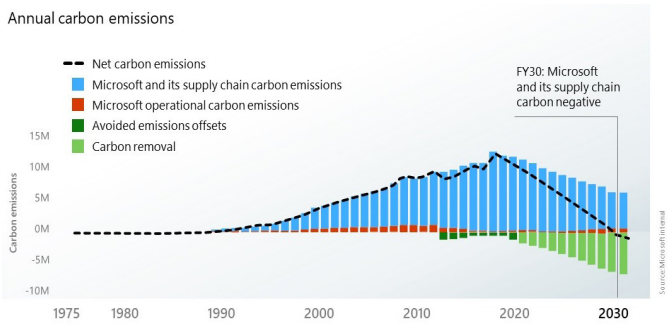


FIGURE 4-1. Microsoft is aiming for its carbon emissions to be net negative by 2030.

INTEGRATING DATA CENTER BATTERY STORAGE WITH THE GRID

Many public and private entities have made aggressive commitments to decarbonization, noted Baosen Zhang, professor at the University of Washington in the electrical engineering and computer science department. New York State, for example, has committed to getting 50 percent of its electrical energy from renewables by 2030 and 100 percent by 2040, even though renewable sources of energy currently account for only about 25 percent of its electrical supply.

Doing so will require integrating major amounts of solar and wind energy into electrical grids, Zhang observed. But these sources vary according to weather conditions, which complicates the provision of a steady supply of electricity. Even today, in states such as California that have had trouble with electrical supply, the problem is not so much handling peak loads as it is dealing with variation in generation and loads.

With variable sources of supply and demand, batteries can "come to the rescue" by storing energy until it is needed, said Zhang. For example, a battery storage capacity of 50 megawatts could serve the electrical energy needs of the San Francisco Bay Area, but this is approximately the amount of storage in a few large data centers. "So the Bay Area, instead of installing 50 megawatts of new batteries, which could cost tens of millions of dollars, could leverage the capacity already in data centers."

Whether batteries can help provide grid services is determined predominantly by the economic benefits of those services. The use of a battery incurs a cost, requiring that the revenue received from the grid cover that cost. For example, batteries are degraded when they are used, just as with the battery in a computer or a phone, so if they are aggressively used for grid services, degradation in the function, or lifetime, of batteries needs to be taken into account. The feasibility of battery backups also depends on the configuration of the batteries. Batteries need to be able to back up the data center as well as serve the grid, adding to the requirements for redundancy already built into data centers.

The bottom line is that data centers can provide significant flexibilities to electrical grids, Zhang concluded. But better incentives are needed to promote integration, because neither the grid nor data centers have been designed to work together in this way in the past.

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BREAKOUT CONCLUSIONS

During the breakout session, Dustin McLarty, assistant professor in the School of Mechanical and Materials Engineering at Washington State University, briefly described his work on high-temperature fuel cells and asked how academia can best connect with industry and government laboratories. A particular need is for terminal master's programs in clean energy that could help develop the workforce for industry, McLarty said. One-off ideas from industry could provide a focus for master's students, after which they could go to work in that industry.

Jack Brouwer, professor of mechanical and aerospace engineering and associate director of the National Fuel Cell Research Center and Advanced Power Energy Program at the University of California, Irvine, spoke about the research and development being done on electrochemical energy conversion devices and systems, including work with Microsoft on proton exchange membrane, solid oxide fuel cells, and other technologies for making data centers more sustainable. Compared with California and other states, Washington State has been considering the decarbonization of difficult applications like aerospace, he noted. Getting to zero emissions will require innovative technologies like fuel cells and the use of hydrogen as a fuel, which will pose many interesting research questions.

Olga Marina, chief scientist with the Energy and Efficiency Division at Pacific Northwest National Laboratory, pointed out that the laboratory collaborates with industry and universities in any program it develops. The lab also has large-scale infrastructure that academia and industry can use to do both basic and applied research. An example is its work on hydrogen and fuel cells, where the lab is fostering the development of new electrocatalysts and doing research on hydrogen production, liquefaction, storage, and safety.

In the plenary session following the breakouts, session organizer Adler identified several important points that arose during the discussion:

- Decarbonization in information technology and communications has not yet benefited from much planning or road mapping. More interactions among people working on these technologies, including representatives of industry, could engage in strategic planning exercises and develop roadmaps for the future so that better decisions can be made.
- More applied research, along with greater access to research facilities, could create closer connections between academia, government laboratories, and industry while lowering the risk to industry of entering certain business areas. Such interactions could also provide students with stronger connections to industry, enhancing their education and developing their skills and expertise.
- Getting to 100 percent renewable energy will require a broad base of technologies and approaches. Governments at the state and federal level could help reduce the risk of developing and adopting new technologies—for example, by demonstrating technologies at scale in realistic environments.
- Progress will require cooperation across the supply chain, which the state or private groups like the Washington State Academy of Sciences could foster, especially if this work were guided by a roadmap aimed at particular milestones.

5. Cross-Cutting Issues

In a wide-ranging discussion at the end of the symposium, meeting participants talked about the similarities and differences among land use, aviation, and information and communications technologies as candidates for decarbonization. All three rely heavily on use-inspired research that can be quite fundamental but also can be immediately applied to solving problems. All three also demonstrate that the pathway from science to application is not a straight line. For example, an orthogonal dimension can be considered as extending from exploratory research to work that is directly commercial. Research along this dimension can lead not only to research papers but also to intellectual property that enables small companies to be spun off from academic and government research institutions.

This kind of use-inspired fundamental research can especially benefit from partnerships among academia, industry, and government laboratories, each of which brings particular skills and capabilities to the task. Universities can do fundamental research that businesses cannot sustain while also pursuing commercially applied problems in a particular technology area. Government laboratories have research facilities that both universities and industry can access, whether for fundamental or applied problems. Companies can partner with university or government researchers, which enables professors, students, and public sector and private sector researchers to interact in the same space.

The three sectors considered at the symposium also have differences related to decarbonization. As symposium organizer Dan Schwartz pointed out, the aerospace sector and the information and communications sector are dominated by a few huge companies, whereas the land use sector has many more actors, both large and small. However, the three sectors themselves have opportunities to collaborate. Perhaps the monitoring of atmospheric carbon will someday be done by uncrewed autonomous vehicles outfitted with hyperspectral imaging, with the resulting data being analyzed through machine learning to understand more about carbon sources and sinks. Or remote sensing by satellite could reveal more about how carbon moves into and out of changing landscapes.

The Washington State Academy of Sciences, with its multidisciplinary membership, orientation, and projects, is especially well suited to foster this kind of intersectoral collaboration. Furthermore, Washington State is a national and international leader in all three sectors, providing opportunities for progress independently or collectively. Washington State, through its electorate, leadership, and economic stakeholders, has been leading the way toward a carbon-free vision for the future, Stuart said. The Washington State Academy of Sciences could play a crucial catalytic role in realizing this future.

6. Major Conclusions and Potential Actions

The 13th annual symposium of the Washington State Academy of Sciences addressed perhaps the most consequential issue facing the global community today: the need to decarbonize human activities. Unless levels of greenhouse gases in the atmosphere are held below levels that are fast approaching, the nations of the world will face crises greater than any they have experienced in the past.

The symposium was entitled "Creating a Model for Global Decarbonization through Washington State Science, Engineering, and Technology" because of the vast potential for scientific research and technological innovation to reduce the emission of greenhouse gases not just in Washington State but around the world. In particular, the symposium focused on three sectors where science, engineering, and technology in Washington State could have worldwide effects: land use, aviation, and information and communications technologies.

This final chapter of the symposium summary presents the major conclusions and potential actions discussed during the plenary presentations, breakout groups, and symposium discussions.

GENERAL CONCLUSIONS AND POTENTIAL ACTIONS

- States that lead in decarbonizing their economies will lead in job growth, infrastructure development, and economic prosperity.
- Though Washington's emissions of greenhouse gas emissions are small on a global scale, activities carried out in the state have far broader consequences.
- Strong and coordinated research, development, and demonstration partnerships can support an efficient carbon innovation ecosystem.
- A shared R&D infrastructure, a robust workforce development strategy, and sector-specific technical services like carbon measuring and certification processes will enable faster progress.
- Technologies and practices that exist today can not only slow and reverse the accumulation of greenhouse gases in the atmosphere but provide many ancillary benefits to human and planetary well-being.
- Decarbonizing the electrical supply will require working with a wide range of stakeholders, including utilities, environmental advocates, labor organizers, communities of color, and others who have been disproportionately affected by the energy infrastructure.

CONCLUSIONS AND POTENTIAL ACTIONS IN THE LAND USE SECTOR

- Agriculture and forestry practices in Washington State offer ways to increase productivity and reduce greenhouse gas emissions worldwide.
- Loss of soil fertility poses a risk to modern society, just as it has contributed to the decline of past societies.
- Soil microorganisms are critical for the storage of carbon in the soil and fluxes of greenhouse gases to the atmosphere.
- Better understanding of the fundamental processes that microorganisms carry out in the soil will enable predictions of how those processes will be impacted by future climate change.
- The practices of conservation agriculture—minimal disturbance of the ground through techniques such as no till farming, maintaining a permanent ground cover through such practices as the use of cover crops and companion crops—can restore fertility to the land and build up soil carbon.
- Washington State could be a leader in decarbonization through research on issues such as soil carbon cycling and storage, soil ecology, and land management practices.
- Better diagnostic tools and tests are needed that are specific to the ways in which land is used in the state so that land use practices can be informed by the local environment.

CONCLUSIONS AND POTENTIAL ACTIONS IN THE AVIATION SECTOR

- As a global hub of aircraft manufacturing, Washington State will have a major impact on energy use in the aviation sector for decades to come.
- The state has major R&D efforts affecting all three

of the potential pathways to decarbonizing the aviation sector: aviation biofuels, battery-based electrification, and the use of hydrogen as a fuel.

- The development of sustainable aviation fuels requires access to an inexpensive source of carbon and an inexpensive way of converting that carbon into fuels.
- Electrification of small aircraft is already possible, and the lessons learned from developing such aircraft can be scaled up to larger aircraft.
- Electrification of the aviation sector will require the development of new infrastructure, the resolution of intellectual property issues that can handicap industry-academia collaborations, and a better prepared workforce with strengths in developing practical solutions to problems.
- Better coordination of Washington State's robust network of experts and institutions working on the decarbonization of aviation would enable faster progress.
- Solving the "last mile" problem of getting new energy systems into aviation will require changes in the aviation infrastructure.

CONCLUSIONS AND POTENTIAL ACTIONS IN THE INFORMATION AND COMMUNICATIONS TECHNOLOGIES SECTOR

- Because the leading cloud services companies are either headquartered or have presences in Washington State, pledges to move toward environmental sustainability create valuable new opportunities for statewide partnerships and initiatives with national and worldwide impact.
- Decarbonization of data centers, many of which are designed in Washington State, provides an opportunity to consider how such centers could provide services for the broader electrical grid.
- More applied research, along with greater access to research facilities, could create closer connections between academia, government laboratories, and industry while lowering the risk to industry of entering certain business areas.
- Better incentives are needed to promote integration of data centers and the electrical grid because neither has system has been designed to work together in the past.
- Getting to zero emissions in many sectors will require the development and application of innovative technologies, which will pose many important and challenging research questions.

Appendix A

2020 SYMPOSIUM MATERIALS

Creating a Model for Decarbonization through Washington State Science, Engineering, and Technology

Washington State Academy of Sciences'
13TH Annual Symposium

September 17, 2020

Who We Are

The Washington State Academy of Sciences (WSAS) is a not-for-profit organization of more than 300 elected members who are nationally recognized for their scientific and technical expertise. All members of the National Academies of Sciences, Engineering, and Medicine who reside in Washington State are invited to join; others are elected in recognition of their scientific and technical contributions to our nation and their desire to contribute their expertise to inform issues in Washington State.

Our Mission

WSAS provides expert scientific and engineering assessments to inform public policy making and works to increase the impact of research in Washington State.

Our Value to Washington

WSAS mobilizes the expertise of our members, plus our network of partners, to provide independent, non-advocate scientific and engineering assessments of issues that impact the citizens, government, and businesses of Washington State.

Our Approach

We accomplish our mission by drawing on our state-wide pool of distinguished members, state government officials, and other key stakeholders and experts to address critical issues facing Washington State. We organize and conduct multi-disciplinary roundtable discussions, workshops, and symposia to assess risks, identify technological opportunities, and define critical research gaps. Our use of peer review ensures the studies we conduct, programs and projects we evaluate, and reports we provide are scientifically and technically sound and unbiased resources for informing the development of Washington State policy.

Learn more about WSAS on our website: **www.washacad.org**

Washington State Academy of Sciences
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Agenda

9:00—9:05 AM	**Welcome** Roger Myers, WSAS President
9:05—9:15 AM	**Opening Remarks** Jay Inslee, Washington State Governor
9:15—9:20 AM	**Introduction and Framing** Dan Schwartz, Boeing-Sutter Professor of Chemical Engineering and Director, Clean Energy Institute, UW
9:20—9:40 AM	**Keynote** Chad Frischmann, Vice President and Research Director, Project Drawdown *From Drawdown to Regeneration: Creating the Future We Want Today*
9:40—10:00 AM	**Keynote** Representative Gael Tarleton, WA State Legislature, 36th District *How WA State's 100% Clean Electricity Bill Became "the Best of the Bunch"*
	BREAK
10:05—10:50 AM	**Session 1: Decarbonizing Land Use** Chair: Chad Kruger, Director, Center for Sustaining Agriculture & Natural Resources, WSU Janet Jansson, Chief Scientist for Biology and Laboratory Fellow, PNNL *Climate Change Impacts on the Soil Microbiome and Soil Carbon Cycling* David Montgomery, Professor of Geomorphology, UW *Growing a Revolution: Farming to Improve Soil Health*
	BREAK
10:55—11:40 AM	**Session 2: Decarbonizing Aerospace** Chair: Michael Wolcott, Regents Professor and Vice President for Research and Director, Office of Clean Technology, WSU Manuel Garcia-Pérez, Professor and Director, Bioproducts, Sciences and Engineering Laboratory, WSU *Production of Cheap Alternative Bio-Jet Fuels: A Carbon Balance Problem* Jim Heidmann, Manager, Advanced Air Transport Technology Project, NASA Glenn Research Center *The Electrification of Aviation*
	BREAK
11:45 AM—12:30 PM	**Session 3: Decarbonizing Information and Communications Technology (ICT)** Chair: Stuart Adler, Associate Professor of Chemical Engineering, UW Sean James, Director of Datacenter Research, Microsoft Corporation *Decarbonizing Datacenters* Baosen Zhang, Keith and Nancy Endowed Career Development Professor in Electrical and Computer Engineering, UW *Integrating Data Center Battery Storage with the Grid*

Agenda Cont'd

12:30—1:00 PM	*LUNCH*
1:00—1:20 PM	**Keynote** Mary Collins, Policy Advisor, Energy and Environment, UK Foreign and Commonwealth Office *From Local to Global: The Road to COP26 in Glasgow*
	BREAK
1:25 – 2:30 PM	**Parallel Workshops: RD&D for Decarbonizing Leading WA Export Sectors** What is the role of state, federal, and private RD&D to accelerate decarbonization as we look out 10 to 20 years? Panelists will spark conversations about needs in WA related to the research enterprise
Land Use Panel	*Discussion Leader*—Malin Young, Associate Laboratory Director for Earth and Biological Sciences, PNNL *Panelists:* Dan Brown, Director and Professor, School of Environmental and Forest Sciences, UW Kirsten Hofmockel, Earth Scientist, Biological Sciences Division, PNNL and President, Soil Ecology Society Chad Kruger, Director, Center for Sustaining Agriculture & Natural Resources, WSU William Pan, Professor of Soil Science, WSU
Aerospace Panel	*Discussion Leader*—Michael Wolcott, Regents Professor and Vice President for Research and Director, Office of Clean Technology, WSU *Panelists:* Marianne Csaky, Director of Environmental Affairs, Alaska Airlines Roei Ganzarski, CEO, magniX John Holladay, Co-Director, Bioproducts Institute, PNNL Mehran Mesbahi, Professor, Department of Aeronautics and Astronautics, UW Sean Newsum, Director of Environmental Strategy, Boeing
ICT Panel	*Discussion Leader*—Stuart Adler, Associate Professor of Chemical Engineering, UW *Panelists:* Jack Brouwer, Professor of Mechanical and Aerospace Engineering and Associate Director of the National Fuel Cell Research Center and Advanced Power and Energy Program, UC Irvine Olga Marina, Chief Scientist, Energy and Efficiency Division, PNNL Dustin McLarty, Assistant Professor, School of Mechanical and Materials Engineering, WSU Baosen Zhang, Keith and Nancy Endowed Career Development Professor in Electrical and Computer Engineering, UW
	BREAK
3:00 – 3:30 PM	**Reporting out from workshops**
3:30 – 4:00 PM	**Roles for WSAS, WA State, and the Private Sector**

SYMPOSIUM SPEAKERS

MARY COLLINS

Energy & Environment Policy Advisor, UK Foreign and Commonwealth Office
Keynote Address

Mary Collins is an Energy & Environment Policy Advisor to the British Embassy Network, where she leads engagement with stakeholders in the Western United States on the COP26 UN Climate Change Conference and oversees the U.S.-wide zero emission vehicle strategy for COP26. Prior to joining the British Foreign and Commonwealth Office, Ms. Collins was a Visiting Scholar at the California Institute for Energy and Environment, where she worked on the U.S.-Mexico Binational Laboratory. She co-founded a clean energy jobs think tank called American Jobs Project, which worked in 24 states on holistic approaches to grow resilient advanced energy industries. Ms. Collins has also worked in international development, sustainable agriculture, and conservation biology. She is a graduate of Virginia Tech and holds a Master of Public Policy with an emphasis on energy policy and economic development from the Goldman School of Public Policy at UC Berkeley.

CHAD FRISCHMANN

Vice President and Research Director, Project Drawdown
Keynote Address

Chad Frischmann is a co-author and the lead researcher of the New York Times best-seller Drawdown: The Most Comprehensive Plan Ever Proposed to Reverse Global Warming (Penguin, 2017) and the Drawdown Review (February, 2020). In collaboration with a global team of researchers, Mr. Frischmann designed integrated global models to assess the world's most effective climate solutions and determine if, when, and how the world can reach "drawdown," the point in time when the concentration of atmospheric greenhouse gases begins to decline on a year-to-year basis. With an interdisciplinary background in public policy, human rights, sustainable development, and environmental conservation, he works as a systems strategist to build a new, regenerative future with cascading benefits to the environment and to human well-being. As head of research and technology since Project Drawdown's inception, Mr. Frischmann is a key spokesperson and coalition-builder dedicated to sharing the message and model of Drawdown with the world. He has a systems-based, action-oriented approach to research and strategic leadership. He taught at the University of Oxford and the University of California at Berkeley; and worked as a consultant and researcher for numerous organizations, from small grassroots non-profits to international agencies such as UNESCO, the International Work Group on Indigenous Affairs, and the International Fund for Agricultural Development.

REPRESENTATIVE GAEL TARLETON

WA State Legislature, 36th District
Keynote Address

Gael Tarleton has served in the WA State House since 2013. She is currently House Finance Chair and served as House Majority Floor Leader from 2016-2018. In 2014, she led the effort to designate liquid biomass as a clean, renewable fuel under Washington's Clean Energy Act. In 2019, she prime-sponsored legislation to mandate a 100% clean electricity policy in Washington by 2045. During her 12 years as a state representative and Port of Seattle Commissioner, Rep. Tarleton has fought to build a diverse and sustainable economy where we support living wage jobs and protect our Northwest lands and waters for all of us and for future generations. She was named Washington Conservation Voters' Legislative Champion of the Year in 2018. Since 2018, she has co-chaired the Governor's Maritime Task Force for a sustainable maritime economy. Rep. Tarleton holds a B.S. in Foreign Service and M.A. in Government and National Security from Georgetown University.

DANIEL T. SCHWARTZ

Boeing-Sutter Professor of Chemical Engineering and Director, Clean Energy Institute, University of Washington
Symposium Organizer

Daniel T. Schwartz is Boeing-Sutter Professor of Chemical Engineering and Director of the Clean Energy Institute at the University of Washington. He joined the UW in 1991, following a postdoctoral fellowship at Lawrence Berkeley National Lab and a PhD at UC Davis. An electrochemical engineer by training, Dr. Schwartz is especially proud to have been recognized by the White House with a 2016 Presidential Award for Excellence in Science, Math, and Engineering Mentoring. He is civic-minded, serving on the Executive Committee and Board of the CleanTech Alliance, the Energy and Climate Policy Advisory Committee for Washington State's Department of Commerce, and as co-chair of the Washington State Academy of Sciences Topical Working Group on Jobs, Infrastructure, and Economic Environment.

ROGER MYERS

R Myers Consulting, LLC and Executive Director, In-Space Programs Aerojet Rocketdyne (retired)
WSAS President

Roger Myers has worked on in-space transportation and propulsion for over 30 years. After 9 years at NASA's Glenn Research Center, he joined Aerojet Rocketdyne's Redmond Operations, the world's leading developer of spacecraft propulsion systems, where he held several executive positions before serving as General Manager and as Executive Director of Advanced In-Space Programs until 2016, when he retired to consult. He has worked on dozens of successful commercial, civil, and defense space missions and R&D programs. Dr. Myers was elected a Fellow of the American Institute of Aeronautics and Astronautics in 2010 and to the Washington State Academy of Sciences in 2012. He was awarded the AIAA Wyld Propulsion Award in 2014 and the Electric Rocket Propulsion Society Stuhlinger Medal for Outstanding Achievement in Electric Propulsion in 2017. He is Board Chair for Washington State's Joint Center for Aerospace Technology Innovation (JCATI), Past-President of the ERPS, President of the WSAS, and a Trustee at Seattle's Museum of Flight. Dr. Myers earned his PhD from Princeton University and a BSAE from the University of Michigan.

STUART ADLER

Associate Professor of Chemical Engineering, University of Washington
Moderator – Information and Communications Technology (ICT)

Stuart B. Adler is Professor of Chemical Engineering at the University of Washington, Seattle. His research over the last 30 years has focused on energy-related materials and electrochemical energy conversion. His recent work includes developing diagnostics for failure detection in fuel cells and other holistic systems, and process approaches to water recovery and cooling in data centers. Dr. Adler received his PhD from the University of California, Berkeley. After a postdoc at Imperial College, he was a staff scientist at Ceramatec, Inc. before rejoining academia in 1999. Professor Adler's awards include an NSF-NATO postdoctoral Fellowship (1993), NSF Career Award (2001), Charles W. Tobias Young Investigator Award of the Electrochemical Society (2004), and UW Junior Faculty Innovator Award (2007).

JACK BROUWER

Professor of Mechanical and Aerospace Engineering and Associate Director of the National Fuel Cell Research Center and Advanced Power and Energy Program, UC Irvine
Panelist – Information and Communications Technology (ICT)

Jack Brouwer is Professor of Mechanical and Aerospace Engineering and Director of the National Fuel Cell Research Center (NFCRC) and Advanced Power and Energy Program (APEP) at the University of California, Irvine (UCI). Under his leadership, NFCRC and APEP are focusing research, education, beta testing, and outreach on high-efficiency, environmentally preferred energy conversion and power generation technology advancement with fuel cell and gas turbine systems as the principal targets. His current research projects address ultra-high efficiency and ultra-low emissions high temperature fuel cell systems, integrated hybrid fuel cell gas turbine systems, high temperature electrolysis, fuel cells and hydrogen for data centers, hydrogen for green steel manufacturing, renewable power intermittency and integration, fuel cell and battery electric and plug-in hybrid electric vehicle fueling infrastructure development, and power electronics and energy conversion devices for the smart grid. Prior to joining UCI, Dr. Brouwer was on the faculty at the University of Utah, a senior engineer at Reaction Engineering International, and a staff scientist at Sandia National Laboratories.

DAN BROWN

Director and Professor, School of Environmental and Forest Sciences, University of Washington
Panelist – Land Use

Daniel G. Brown is the Corkery Family Director of and Professor in the School of Environmental and Forest Sciences at the University of Washington. His research is aimed at understanding human-environment interactions through a focus on land-use and land-cover changes, through modeling these changes, and through spatial analysis and remote sensing methods for characterizing landscape patterns. His recent work has used agent-based and other spatial simulation models to understand and forecast landscape changes that have impacts on carbon storage and other ecosystem services, and on human health and well-being. Dr. Brown has conducted field work on three different continents: North America, Asia, and Africa. He has chaired the Land Use Steering Group and Carbon Cycle Steering Group and was a lead coordinating author for the third National Climate Assessment, all under the auspices of the U.S. Climate Change Science Program. In 2009, he was elected fellow of the American Association for the Advancement of Science.

MARIANNE CSAKY

Director of Environmental Affairs, Alaska Airlines
Panelist – Aerospace

Marianne Csaky is currently the Director of Environmental Affairs at Alaska Airlines and leads a small but powerful team of environmental professionals (Jason Brown, Janet Baad, and Graham Gadzia) to ensure both Alaska and Horizon are in compliance with environmental regulations, policies, and commitments. Prior to her role at Alaska, she has worked for other major airlines, the airline industry trade association Airlines for America, and started her environmental career in the energy industry. In her various roles over the last 25 years, Ms. Csaky has worked on and implemented policy related to environmental regulations and sustainability initiatives at international, federal, state, and local levels. She is part of the Sustainable Aviation Fuel MOU committee at both Seattle and San Francisco airports and sits on the Sustainable Aviation Biofuel Working Group. Additionally, at the request of the U.S. Secretary of Transportation, she is one of two airline representatives that sits on the National Academies of Sciences Airport Cooperative Research Program's Aviation Oversight Committee. She has a Bachelor of Science in Marine Biology from Texas A&M University and resides in Seattle, WA.

ROEI GANZARSKI

CEO, magniX
Panelist – Aerospace

Roei Ganzarski is CEO of magniX, an electric aviation propulsion company. With a vision of connecting communities with low-cost, clean air transportation. He is also chairman of Eviation, the electric aircraft original equipment manufacturer (OEM). Prior to magniX, Mr. Ganzarski was CEO of BoldIQ – a provider of dynamic real-time scheduling optimization software. Under his leadership, BoldIQ grew from seed software startup to multi-million-dollar profitable SaaS company. Before BoldIQ, Mr. Ganzarski was with the Boeing family of companies in continuously increasing roles of responsibility. His last role was Chief Customer Officer for Boeing's Flight Services division, where he led worldwide customer and market-facing organizations and was responsible for revenue growth and customer service. Other experiences prior to Boeing include investment banking, corporate finance, advertising, and the military. He is a graduate of Wharton's Advanced Management Program and earned an MBA from the University of Washington and a BA in Economics from The University of Haifa. Mr. Ganzarski sits on the board of the Washington Technology Industry Association and lives with his family in Redmond, Washington, USA.

MANUEL GARCIA-PÉREZ

Professor and Director, Bioproducts, Sciences and Engineering Laboratory, Washington State University
Speaker – Aerospace

Manuel Garcia-Pérez is a Professor in biomass thermochemical conversion at Washington State University and Director of the Bioproducts Sciences and Engineering Laboratory (BSEL). He is co-author of more than 160 scientific publications and holds several patents on biomass and coal thermochemical conversion technology. He received his PhD in Chemical Engineering from the University of Laval in Quebec, Canada, and did post-doctoral assignments at the University of Georgia (in the United States) and Monash University (in Australia). His research interests include torrefaction, pyrolysis, gasification, combustion, and hydrothermal conversion for the production of bio-crudes that can then be refined for fuel and chemical production. Dr. Garcia-Pérez also works in the chemistry of bio-oils and carbons as well as in alternative oils hydrotreating for fuels production. He is currently a member of the DOE/USDA Biomass Research and Development Initiative, associate editor of the journal Biomass and Bioenergy and revision editor of the Journal of Analytical and Applied Pyrolysis.

JIM HEIDMANN

Manager, Advanced Air Transport Technology Project, NASA Glenn Research Center
Speaker – Aerospace

Jim Heidmann currently serves as Manager of NASA's Advanced Air Transport Technology Project. In this capacity, he leads NASA's technology development for subsonic transport aircraft. Prior to this role, he served as Acting Deputy Director of NASA's Advanced Air Vehicles Program, managed NASA's Transformational Tools & Technologies Project, and served as Chief of the Turbomachinery and Heat Transfer Branch. In addition to these management roles, Dr. Heidmann spent 20 years as an Aerospace Research Engineer, publishing over 20 papers and journal articles in turbomachinery aerodynamics and heat transfer. He was elected Fellow of the American Society of Mechanical Engineers (ASME) in 2007, Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA) in 2015, and received the Outstanding Mechanical Engineer (OME) Award from Purdue University School of Mechanical Engineering in 2017. Dr. Heidmann received a Bachelor of Science in Mechanical Engineering from the University of Toledo, Master of Science in Mechanical Engineering from Purdue University, and Doctorate in Mechanical and Aerospace Engineering from Case Western Reserve University.

KRISTEN HOFMOCKEL

Earth Scientist, Biological Sciences Division, Pacific Northwest National Laboratory and President, Soil Ecology Society

Panelist – Land Use

Kirsten Hofmockel is the President of the Soil Ecology Society, an international organization focused on furthering the science, education, and awareness of the importance of soils for human and environmental well-being. Dr. Hofmockel is a member of the U.S. National Committee for Soil Sciences, which advises the National Academies and represents the interests of the U.S. soil science community in the International Union of Soil Sciences. Dr. Hofmockel is a Department of Energy Early Career Award recipient for research focused on how plants, microbes, and soils interact to influence carbon storage. She is the Microbiome Science team lead in the Biological Sciences Division at PNNL. She co-leads the Soil Microbiome research program that investigates the basic biology underpinning how soil microbial community members interact to generate beneficial ecosystem functions. Dr. Hofmockel also leads a National Science Foundation-funded project to study how nutrient availability influences carbon storage in grasslands. She holds a joint appointment in the Department of Ecology, Evolution, and Organismal Biology at Iowa State University.

JOHN HOLLADAY

Co-Director, Bioproducts Institute, Washington State University

Panelist – Aerospace

John Holladay is the Co-Director of the Bioproducts Institute, a joint venture between Pacific Northwest National Laboratory (PNNL) and Washington State University, focused on processing waste carbon—wastewater sludges, industrial waste gasses, and municipal solids—into sustainable materials, products, and fuels with an emphasis on aviation, for which electrification is challenging. Dr. Holladay has been helping the Department of Energy's Bioenergy Technology Office understand the technical requirements for sustainable aviation fuels (SAF) and has been a key player in PNNL's work with LanzaTech leading to the commercialization of a new route to SAF originating from industrial waste gas. Dr. Holladay is an associate director of the PNNL Institute for Integrated Catalysis, which is part of PNNL's lab strategy for reinventing chemical catalysis and includes designing and synthesizing catalysts to efficiently turn waste into feedstocks for fuels, materials, and energy storage. Dr. Holladay holds a B.Sc. in Chemistry from Brigham Young University and a PhD in Organic Chemistry from the University of Wisconsin-Madison.

SEAN JAMES

Director of Datacenter Research, Microsoft Corporation
Speaker – Information and Communications Technology (ICT)

Sean James runs Microsoft's data-center research and development program within the Cloud Operations + Innovation group. CO+I provides the foundational cloud infrastructure for over 1,000,000,000 customers, 20,000,000 businesses, 200+ Microsoft online services, in 90 markets. Mr. James drives new data-center technology for Microsoft's next generation data-centers, including evaluation, development, and testing. He joined Microsoft in 2006 to manage operations at one of Microsoft's data-centers. Later, he joined the construction team and oversaw the design and building of new Microsoft data-centers. Prior to joining Microsoft, Mr. James worked in data-center management overseeing the day-to-day maintenance and repair operations for both IT hardware and critical infrastructure, such as electrical infrastructure and cooling equipment. Prior to joining Microsoft, Mr. James served in the U.S. Navy Submarine Fleet as an electrician. He holds many patents related to data-centers and energy, a degree in Information Technology, and is a certified Project Management Professional from the Project Management Institute. He enjoys spending time with his family, guitar, and technology.

JANET JANSSON

Chief Scientist for Biology and Laboratory Fellow, Pacific Northwest National Laboratory
Speaker – Land Use

Janet Jansson is a Chief Scientist and a Laboratory Fellow at the Pacific Northwest National Laboratory (PNNL). She obtained her PhD at Michigan State University and established a science career in Sweden from 1988-2007. She was a senior scientist at Lawrence Berkeley National Laboratory from 2007-2014 and moved to PNNL in 2014. Her latest research involves application of multi-omics (molecular approaches to characterize the functionality of genes, proteins, and metabolites) to determine how climate change impacts the soil microbiome and metaphenome (combined functions carried out by soil microbial communities). Dr. Jansson is Past President of the International Society for Microbial Ecology (ISME) and a member of the Washington State Academy of Sciences and a Fellow the American Academy of Microbiology, and she serves on numerous national and international advisory panels. She was one of the highest-cited researchers in 2016, 2018, and 2019 with more than 200 publications.

CHAD KRUGER

Director, Center for Sustaining Agriculture & Natural Resources, Washington State University
Moderator – Land Use

Chad Kruger directs WSU's Center for Sustaining Agriculture & Natural Resources (CSANR). He was the Project Director for WSU's Climate Friendly Farming Project, and co-PI on the USDA funded integrated projects: Regional Approaches to Climate Change in Pacific Northwest Agriculture, Anaerobic Digestion Systems, and BioEarth. He managed the WSU Waste to Fuels Technology Partnership with the Washington Department of Ecology from 2010-2017 and was a convening author of the WSU Applied Bioenergy Research and Washington Oilseed Cropping Systems Programs (est. 2007). Mr. Kruger served on the 2007/2008 Washington State Climate Action Team, co-chairing the Agriculture Sector Carbon Market Workgroup. He currently serves on the Washington State Department of Natural Resources Climate Resilience Advisory Council, the Washington State Department of Agriculture's Dairy Nutrient Advisory Committee, and the Washington Food Policy Forum. He co-chairs the Sustainable Agriculture Committee for the Cascadia Innovation Corridor. He is a convening author of the University-Agency-Industry Washington Soil Health Initiative. He was raised in Washington State and is from generational farm families in both Eastern (wheat and cattle near Spokane) and Western Washington (berries in Whatcom County).

OLGA MARINA

Chief Scientist, Energy and Efficiency Division, Pacific Northwest National Laboratory
Panelist – Information and Communications Technology (ICT)

Olga Marina is widely recognized for her technical contributions relating to the solid oxide fuel cell advanced electrode and interconnect development and understanding of the degradation mechanisms. She joined PNNL in 1999 after holding research positions at Boreskov Institute of Catalysis, Russia, University of Patras, Greece, and Risø National Laboratory, Denmark. Dr. Marina's interdisciplinary research is at the forefront of materials chemistry and electrocatalysis focusing on the development of innovative materials for solid oxide fuel cells, electrochemical sensors, electrolyzers, and ceramic membranes relative to energy generation and storage and CO2 capture and conversion. She has published over 60 peer-reviewed journal articles and conference papers, 2 book chapters, and holds 6 U.S. and foreign patents. Since 2003, she has served as adjunct faculty at Washington State University.

DUSTIN MCLARTY

Assistant Professor, School of Mechanical and Materials Engineering, Washington State University
Panelist – Information and Communications Technology (ICT)

Dustin McLarty is an assistant professor in the School of Mechanical and Materials Engineering at Washington State University. He holds both a Master's and Doctor of Philosophy degree in mechanical engineering from the University of California, Irvine and a Bachelor of Science in aerospace engineering from the University of Florida. Originally from DeLand, Florida, Dr. McLarty studies high temperature fuel cells and the dynamics and controls of advanced micro-grids. This research expands upon previous systems integration experience garnered in Irvine, CA, Boulder, CO, Birmingham, UK, and Morgantown, WV. Involved in research for clean energy systems, Dr. McLarty has worked with industry partners and national labs to develop systems integration solutions and novel electrochemical power concepts. A lifelong competitive swimmer who has represented the US national team at international competitions, Dr. McLarty has also served as a professional surf lifesaver in both Daytona Beach and Huntington Beach.

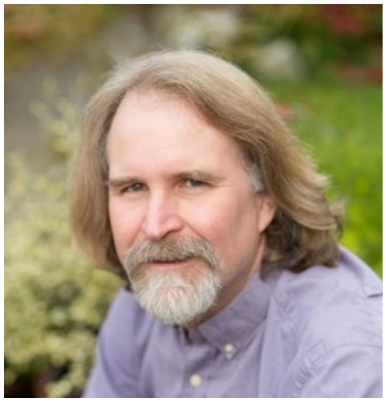
MEHRAN MESBAHI

Professor of Aeronautics & Astronautics, University of Washington
Panelist – Aerospace

Mehran Mesbahi is a Professor of Aeronautics & Astronautics and an Adjunct Professor of Mathematics and Electrical & Computer Engineering at the University of Washington. He is currently the Executive Director of the Joint Center for Aerospace Technology Innovation (JCATI), a center supported by the State of Washington dedicated to promoting collaborations between academia and the aerospace industry in the state. Dr. Mesbahi's research interests are distributed and networked systems, electric and hybrid-electric aircraft control and energy management, and autonomous aerospace and robotic systems. He is the co-author of the book Graph Theoretic Methods in Multiagent Networks (Princeton University Press, 2010) and a Fellow of the Institute of Electrical and Electronics Engineers (IEEE).

DAVID MONTGOMERY

Professor of Geomorphology, University of Washington
Speaker – Land Use



David R. Montgomery is a MacArthur Fellow and Professor of geomorphology at the University of Washington. He studies landscape evolution on Earth and Mars, and the effects of geological processes on ecological systems and human societies. An author of award-winning popular-science books translated into nine languages, he has been featured in documentary films, network and cable news, and on a wide variety of TV and radio programs. Dr. Montgomery has published more than 200 peer-reviewed scientific papers and two textbooks.

SEAN NEWSUM

Director of Environmental Strategy, Boeing
Panelist – Aerospace

Sean Newsum is director of Sustainability Strategy at Boeing Commercial Airplanes. In this role, he leads a team that addresses key industry-wide environmental issues, including aircraft emissions and community noise reduction, sustainable fuel development, and other opportunities to enhance commercial aviation's environmental performance. Mr. Newsum is also responsible for developing an integrated strategy to ensure that products and services are aligned with the company's environmental objectives. He represents Boeing with key industry bodies, including the International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection and as a member of the Air Transport Action Group Board of Directors.

WILLIAM PAN

Professor of Soil Science, Washington State University
Panelist – Land Use

William Pan earned degrees at three land grant universities (Wisconsin, Missouri, and North Carolina State) in preparation for his 36-year career at Washington State University. He established an integrated research, teaching, and outreach program to create, implement, and monitor innovative agronomic and soil management systems. Research and extension have focused on creating win-win scenarios for farm and climate by developing alternative crop rotations and soil management strategies and improving nitrogen use efficiency and farm economics while reducing greenhouse gas emissions and increasing soil health. Dr. Pan served as past chair of the Department of Crop and Soil Sciences, Director of the WA Biofuels (Oilseed) Cropping Systems Program, and as 2019 President of the Soil Science Society of America, which is dedicated to driving soil–plant–water–environment systems solutions for healthy people on a healthy planet in a rapidly changing climate. He engaged in statewide discussions on crop-based biofuel production for ground transportation and jet fuel during the energy crisis, and more recently on the WA Soil Health Initiative to assess the status of WA soils as an essential state resource.

MICHAEL WOLCOTT

Regents Professor and Vice President for Research, and Director, Office of Clean Technology, Washington State University
Moderator – Aerospace

Michael Wolcott, Regents Professor, has been a member of the WSU faculty since 1996 conducting research in the field of biobased materials, chemicals, and fuels. Dr. Wolcott currently serves as the Director of ASCENT, the FAA Center of Excellence for Alternative Jet Fuel and the Environment. He was formerly Project Co-Director for NARA - Northwest Advanced Renewables Alliance, a USDA Agriculture and Food Research Initiative (AFRI) Sustainable Biofuels Coordinated Agricultural Project, which most notably flew the first cellulosic biofuels flight cross-country with partners Gevo and Alaska Airlines. He is the founding Director of the Institute for Sustainable Design and the Integrated Design Experience (IDX). Many of his research projects have featured public-private partnerships with industry, government laboratories, agencies, and communities.

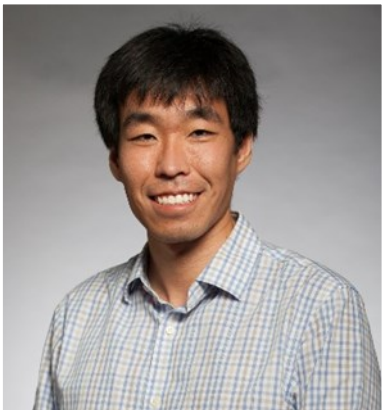
MALIN YOUNG

Associate Laboratory Director for Earth and Biological Sciences, Pacific Northwest National Laboratory
Moderator – Land Use

Malin Young is the Associate Laboratory Director for Earth and Biological Sciences at Pacific Northwest National Laboratory (PNNL). In this role, she sets the vision and strategy for PNNL's research in support of the Department of Energy's Office of Biological and Environmental Research and the National Institutes of Health. Dr. Young was PNNL's Deputy Director for Science and Technology from October 2015 to February 2020. In this role, she was responsible for integrating PNNL's science and technology capabilities to address critical challenges in science, energy, the environment, and national security. Prior to joining PNNL, Dr. Young served as Director of the Biological and Engineering Sciences Center at Sandia National Laboratories in Livermore, California. In that role, she was responsible for leading the performance of exploratory science and the development of technology to address pressing national needs in energy security, homeland security, and national defense. Born in Washington State, Dr. Young earned a Bachelor's degree in Biology and a Master's degree in Genetics from Oregon State University, and a PhD in Pharmaceutical Chemistry from the University of California, San Francisco.

BAOSEN ZHANG

Keith and Nancy Rattie Endowed Career Development Professor in Electrical and Computer Engineering, University of Washington
Speaker, Panelist – Information and Communications Technology (ICT)



Baosen Zhang received his Bachelor of Applied Science from the University of Toronto and his PhD in Electrical Engineering and Computer Sciences from University of California, Berkeley. He is currently the Keith and Nancy Rattie Endowed Career Development Professor in Electrical and Computer Engineering at the University of Washington. Dr. Zhang's research interests are in control, optimization, and learning applied to power systems and other cyberphysical systems. He received the National Science Foundation CAREER award as well as several best paper awards.

SYMPOSIUM PRE-READING

Brittany P. Bishop,[a,c] Martin N. Brischetto,[a,c] Miguel A. Gonzalez,[a,c] Zang T. Le,[a,c] Sarah R. Pristash,[a,c] Parker C. Steichen,[a,c] Jonathan M. Witt,[a,c] Tony Usibelli,[b,c] Yasmeen Hussain[d], Daniel T. Schwartz,[c,†]

Washington's Economy and Global Greenhouse Gas Emissions

The Washington State Academy of Sciences (WSAS) Topical Working Group 2: "Jobs, Infrastructure, and Economic Environment," examines the role of science, engineering, and technology as it relates to the vitality of Washington's economy. The 13th annual WSAS symposium provides a first look at some of the scientific and engineering approaches being taken by three key Washington state economic sectors as they engage with and advance global decarbonization.

Washington's inventory of emissions shows that activities within the state contribute about 0.27% of the global greenhouse gas (GHG) burden [1]. With new 2019 laws accelerating electricity decarbonization, super pollutant reductions, and enhanced building standards, we expect to see these in-state contributions fall.

Washington's impact on global GHG emissions extends well beyond the state boundaries. As the most trade-dependent state in the U.S., our exports contribute to global emissions and are subject to global regulations. Washington is home to the largest aerospace economic cluster in the nation, and one of the two largest commercial aircraft manufacturing clusters in the world. Aviation contributes 2.0-2.5% of global greenhouse gas emissions [2]. By key measures, Washington has the nation's second-largest information and communications technology (ICT) economic cluster and is home to two of the five largest publicly traded ICT companies. The ICT sector contributes almost 2% of global greenhouse gas emissions [3]. And Washington State's high value agricultural and forest products are sought-after global goods. Agriculture, forestry, and other land use contributes about 24% of net emissions globally [4].

We have chosen to focus on aerospace, ICT, and the land-intensive agriculture and forestry sectors because they have great potential for Washington science, engineering, and technology innovations to impact global carbon. Speakers in the 13th annual WSAS symposium will provide a sampling of the outstanding research happening in Washington and nationally in these sectors, providing an appreciation for some of the fundamental knowledge and applied considerations that underpin decarbonizing (or even recarbonizing, in the case of soils) an industrialized economy.

The symposium's breakout sessions will assess Washington's environment for low carbon innovation, guided by the idea that subnational entities like regions and states have a role in shaping an efficient innovation ecosystem through the cultivation of: (i) strong and coordinated research, development, and demonstration (RD&D) partnerships, (ii) shared RD&D infrastructure, (iii) a robust workforce development strategy, and (iv) sector-specific technical services (like third party certification, standards, and trade organizations, intellectual property management, etc.) [5].

This analysis is intended to be a useful starting point for assessing the state-level environment for carbon innovation, recognizing that Washington's products and services should embed technical know-how that underpins sustained economic vitality in a carbon-constrained future.

[a]Torrance Policy Analyst or [b]Torrance Policy Analyst in Residence, [c]University of Washington Clean Energy Institute; [d]Washington State Academy of Sciences; [†]Correspondence to: dts@uw.edu

	Aerospace	Info & Comms Tech	Land – Agriculture / Forestry
Industry RD&D in WA ($M) [A]	$2,279	$14,087	$60
Federal RD&D in WA ($M) [B]	Note (C)	Note (C)	$63 (USDA)
Focus of RD&D on emissions	High	Growing	Growing
Employment [D]	~ 83,000	~ 220,000	~ 200,000
Summary descriptors for public/private RD&D integration, coordination, and infrastructure	Multifaceted corporate, state, federal & trade organization coordination. Substantial specialized RD&D infrastructure, including wind tunnel, open airspace, LightMAT, etc.	Corporate leadership on workforce and RD&D, with major coordination via trade and civic organizations. Substantial new state investment in high demand tertiary education.	Mature academic & industry relations mediated by WA land grant and forestry programs. WSU and UW have research sites across the state. The Soil Health Initiative is a new state supported RD&D effort.

Data: Research, Development, & Demonstration Funding and Sector Jobs in Washington

NOTES

A. Center for Science and Engineering Statistics, National Science Foundation, 2017 data, NSF 20-311, Table 28B (2020). https://ncses.nsf.gov/pubs/nsf20311 The land use category is a compilation of several manufacturing and non-manufacturing agriculture & forestry related categories.

B. Center for Science and Engineering Statistics, National Science Foundation, Survey of Federal Funds for Research and Development for FY 2018-19, Table 91. https://ncsesdata.nsf.gov/fedfunds/2018/html/ffs18-dt-tab091.html The Land number represents USDA R&D funds to WA. USDA is a mission-oriented agriculture and forestry funder. Funding from multi-objective agencies such as NSF, DOE, and other federal agencies cannot be easily disaggregated.

C. It is difficult to disaggregate the most relevant aerospace and ICT support from the total federal R&D funds provided to WA from sources such as DOD ($903M to WA), DOE ($417M to WA), NSF ($126M to WA), and NASA ($60M to WA). These RD&D funding to WA numbers are from the source cited in Note B above.

D. Employment numbers are for the entire sector, as given by the Washington Department of Commerce "Choose Washington" campaign. They do not reflect research personnel or decarbonization specialties.

Decarbonizing Aerospace

Lead contributors: Miguel A. Gonzales, Sarah R. Pristash

(i) Research, development, and demonstration (RD&D)

One of the animating drivers for aviation RD&D is energy efficiency, because fuel is a major operating cost and determinant of profitability in commercial flying. Current approaches widely used to achieve fuel savings include drag reduction strategies, advanced materials to make components and airframes lighter, more efficient turbines, more electric aircraft, and more optimal flight paths. Opportunities for emission reductions in commercial aviation were recently evaluated by the National Academies of Sciences, Engineering, and Medicine (NASEM), with the following priority research areas identified [2]:

- *improvements in gas turbine engines*
- *advances in sustainable alternative jet fuels*
- *development of turboelectric propulsion systems*
- *advances in aircraft-propulsion integration*

Washington State has convened separate working groups on sustainable aviation biofuels and electric aircraft to better understand the opportunities and barriers for these transformational paths to reduced aviation emissions [6, 7].

Washington has mechanisms for public-private research partnerships to address the priority decarbonization areas identified by state and federal studies. The state hosts two Federal Aviation Administration Centers of Excellence, Washington State University (WSU)-led ASCENT (the Aviation Sustainability Center) and the University of Washington (UW)-led AMTAS (Advanced Materials in Transport Aircraft Structures). The LightMAT consortium at Pacific Northwest National Lab (PNNL) also enables industry to access Department of Energy (DOE) expertise and capabilities in lightweight materials. The state-funded Joint Center for Aerospace Technology Innovation (JCATI) is an adaptable research sponsor covering a wide range of areas of interest to Washington industry, including academic-industry research in electric aircraft propulsion and aviation biofuels. Only ASCENT has emission reductions as an explicit goal, though all of these research centers and consortia activities impact aviation energy efficiency.

(ii) Shared RD&D infrastructure

Industrial organizations in Washington have a large base of captive facilities to support RD&D within their organizations. The state also hosts some shared aerospace infrastructure.

Shared infrastructure that is partially or wholly suited to advancing aviation decarbonization RD&D has been anchored, for more than eight decades, by the UW Kirsten Wind Tunnel, a heavily used facility that is available for companies and others as a fee-based service. Mechanical testing and composites manufacturing capabilities are available as a fee-based service at both WSU and UW. The 57,000 square foot Bioproducts Science and Engineering Laboratory on the WSU Tri-Cities campus is a shared research facility co-occupied by WSU and PNNL, with part of the research activities directed toward aviation biofuels. The UW Clean Energy Testbeds is a fee-for-use facility available for power hardware-in-the-loop testing of electrical components at the 40 kW, 400 V scale. Full electric and hybrid electric propulsion system testing requires MW-scale, kilovolt-level power hardware capabilities. To the best of our knowledge, the only publicly supported facility of this nature in the U.S. is located at the NASA Electric Aircraft Testbed in Ohio.

Experimental infrastructure for aviation in Washington State includes open airspace such as the Grant County International Airport, a widely used test flight center with dedicated flight zones for commercial, military, and uncrewed aerial vehicles, as well as a spaceport. Deployment research on novel aviation energy sources also requires specialized airport infrastructure. The Port of Seattle has performed an infrastructure feasibility study for sustainable aviation biofuels [6], with the goal of being able to supply biofuel blends at SeaTac airport. There does not appear to be any hydrogen fueling or electric aircraft charging infrastructure at a Washington airport [7].

(iii) Workforce development

Specific aerospace workforce demand and supply in Washington was comprehensively reported in early 2019 [8]. In the intervening period, COVID-19 has had a profound impact on the landscape of aerospace employment in Washington.

Everett Community College houses the Center of Excellence (COE) in Aerospace and Advanced Manufacturing. The COE helps ensure that the technical and community college system offers industry-relevant training in a wide range of areas, including composites manufacturing, aerospace design, precision machining, and advanced fabrication methods, among other technical skills. Career Connect WA and the Aerospace Joint Apprenticeship Committee are working together to ensure students get advanced on-the-job training.

The UW Aeronautics and Astronautics department offers the state's only ABET accredited B.S degree in aeronautical engineering, though as the aerospace workforce study shows [8], a wide diversity of engineering and other post-secondary technical fields are used in the aerospace sector. Since the launch of the Boeing 787 – designated a "more electric aircraft" because its megawatt-scale electrical system replaced hydraulic and pneumatic systems – the need for expertise in aviation power systems engineering and aircraft energy management (including on-board Li-ion batteries) has grown significantly. The trend of increasing aircraft electrification is expected to continue, potentially requiring new kinds of education and training.

(iv) Sector-specific services

Perhaps the most noteworthy sector-specific characteristic is that any aviation technology innovation is subjected to a national and international regulatory framework that requires coordination between government and industry. Washington's aerospace sector is supported by a large number of FAA Designees, the individuals and organizations in the aviation industry authorized to conduct examinations, perform tests, and issue approvals and certificates on behalf of the FAA. There is also a sophisticated network of trade organizations such as the Aerospace Futures Alliance and Pacific Northwest Aerospace Alliance that help set goals and strategy, as well as coordinate government affairs, for the aerospace industry.

Decarbonizing Information and Communication Technology

Lead contributors: Zang T. Le, Jonathan M. Witt

(i) Research, development, and demonstration (RD&D)

Decarbonization is a growing focus of RD&D in the information and communication technology (ICT) sector. The ICT sector has voluntarily embraced their role in climate change related emissions, with Amazon [9] and Microsoft [10] both announcing aggressive carbon emission goals and timelines. Amazon has provided an initial $2 billion for the Climate Pledge Fund to "invest in companies building products, services, and technologies to decarbonize the economy and protect the planet" while Microsoft has created a $1 billion Climate Innovation Fund to "accelerate the development of carbon reduction and removal technologies".

Properly accounting for net emission contributions of ICT is an area of research in its own right and will not be broached here. Instead, we focus on data centers, an area dominated by regional cloud providers Amazon and Microsoft. Data centers use about 1% of electricity globally [11]. Despite a 12-fold increase in internet traffic and 7.5-fold increase in data center workload over the past decade, total energy consumption across the global sector has only grown modestly over the same period [11]. This sector-wide increase in energy efficiency is largely driven by the replacement of traditional computing infrastructure with increasingly optimized hyper-scale data centers. The efficiency of hyper-scale data centers has involved both hardware and software innovations, from new application-specific integrated circuit designs to more efficient data storage, data networks, thermal management, and compute load optimization [3, 12-15]. RD&D innovations in these areas will continue, but most of the low efficiency traditional computing infrastructure has already been replaced [11].

New challenges are introduced by the fact that the electrical grid load for a modern hyper-scale data center is in the range of 100 MW. To meet energy and climate goals, ICT companies have accounted for half of the global corporate clean energy acquisitions in the past 5 years, with the top four corporate purchasers of renewable energy in 2019 being Google, Apple, Amazon, and Microsoft [11]. However, simply adding renewables to replace data center annual energy usage does not fully address the grid integration challenge of siting a new 100 MW data center, nor does it eliminate fossil energy emissions on a 24x7 basis. RD&D is addressing this system-of-systems integration challenge. Google has demonstrated carbon-intelligent computing, software to forecast clean energy generation and optimally prioritize computing loads to accomplish 24x7 carbon free computing [16]. Likewise, since data centers have appreciable battery storage on-site, a Microsoft and UW collaboration has evaluated use of these assets to support optimal acquisition of low-cost clean energy [17].

Data center operators are experimenting with ways to leave the electrical grid entirely. For nearly a decade, Apple and Ebay have experimented with high efficiency self-generation of data center electricity using large solid oxide fuel cells fed with natural gas or biogas. During the same period, Microsoft has explored and demonstrated distributed electricity production with fuel cell-powered server racks, as well as renewable hydrogen fuel production, enabling a transparent strategy for energy and computing to easily scale together [18, 19].

It does not appear that the state has yet to play a role assessing or coordinating Washington's RD&D capacity to accelerate ICT decarbonization. The Technology Alliance, a statewide non-profit organization, recently reviewed the roles of state governments in tech start-ups and innovative research [20] and found that Washington lacked several innovation-promoting mechanisms offered by states we consider peer technology competitors. Given the context of emerging billion-dollar funds to spur zero- and negative-carbon innovation, there may be new impetus for statewide coordination around carbon innovation. A nascent industry/university research

consortium effort, "The Energy Information Nexus" has been launched in Washington with a National Science Foundation planning grant [21].

(ii) Shared RD&D infrastructure

The State's Clean Energy Fund provided some of the capital funding to launch Microsoft's Advanced Energy Lab (AEL), a partnership with McKinstry and Cummins [22]. Located at the McKinstry Innovation Center in South Seattle, the AEL houses a computing cluster powered by rack-scale solid oxide fuel cells [18]. Microsoft has supported UW researchers in the AEL to help with the evaluation and analysis of fuel cell performance.

Cooperative research and development agreements with the Pacific Northwest National Laboratory (PNNL) enable access to advanced Lab capabilities. PNNL has a leading role in the DOE Solid-state Energy Conversion Alliance fuel cell development and system integration effort, and co-leads the DOE Grid Modernization Lab Consortium, which includes computing and physical infrastructure to tackle grid integration and cybersecurity challenges.

Real time digital simulators and hardware-in-the-loop capabilities are available to support electrical system design as a fee-based service at the Washington Clean Energy Testbeds and through the WSU Energy System Innovation Center.

(iii) Workforce development

The Washington Technology Industry Association (WTIA) maintains a workforce dashboard, cataloging the needs for IT professionals, and has been a critical advocate for expanding computer science and engineering degrees in Washington. WTIA also launched Apprenti, a certified ICT apprenticeship program which includes cloud support specialist and data center technician certifications and apprenticeships. Data center workforce training is also supported by specialized technical education providers such as Cisco data center network technician certificates and Uptime Institute advanced data center certificates.

Bellevue College houses the Community and Technical College's Center of Excellence (COE) in Information and Computing Technology. The COE is a resource and solution-provider for, among other things, dissemination, and instructor professional development in new and emerging technologies. Washington State has provided several budget provisos to expand computer science and engineering degree production in Washington, as well as new STEM facilities at several university campuses.

(iv) Sector-specific services

The ICT sector has a vibrant trade association network, including WTIA and the Technology Alliance, that amplifies the sector's voice in government affairs, workforce development, and cultivating the innovation ecosystem. Seattle has a strong ICT start-up investment environment, and one can anticipate a growing role for carbon innovation within that innovation ecosystem.

Decarbonizing Land-use / Recarbonizing Land

Lead contributors: Brittany P. Bishop, Martin N. Brischetto, Parker C. Steichen

(i) Research, development, and demonstration (RD&D)

Washington's agriculture sector is one of the top-two U.S. producers in a wide array of high value fruit, mint, vegetable, and seafood products, as well as wine and hops. Forestry in Washington provides a wide array of manufactured products, as well as critical ecosystem services, including an estimated 2.7 billion tonnes of sequestered forest carbon stock [23]. As of 2012, the State was 42% forest land, 17% grassland pasture and range, and 18% cropland, which means that 77% of WA is agricultural or forest land [24]. As a state, Washington produces about 2% of the nation's land-use related GHG emissions [24]. Globally, agriculture, forestry, and other land use is responsible for 13% of carbon dioxide, 44% of methane, and 81% of nitrous oxide emissions from human activities [25]. Thus, the terminology used here of "decarbonize" and "recarbonize" refers to the CO_2 equivalents (CO_2-e) of all emission types, which together, represents about 24% of global GHG [4].

Land management practices are critical to net flows of carbon and reliable sequestration in terrestrial and coastal environments [26]. Given the rich mix of coastal, forest, and agricultural lands in Washington, one finds a growing set of State-led RD&D initiatives to decarbonize land-use. In 2019, the Washington State Department of Natural Resources (DNR) launched a Carbon Sequestration Advisory Group (CSAG) composed of researchers and stakeholders to help guide carbon sequestration strategy on natural and working lands in Washington [27]. Critical RD&D areas being evaluated by CSAG include improved methods for obtaining carbon inventories and economic incentive policies to increase sequestration. Improved forest management (IFM) is critical for avoiding catastrophic wildfire seasons like in 2015, where Washington's forests were the state's second biggest carbon emission source [28].

The management and treatment of agricultural lands leads to a complex set of physical and biogeochemical transformations that manifest as "soil health", including the ability to store carbon and nutrients. In 2018, the Washington State Conservation Commission and WSU Center for Sustaining Agriculture and Natural Resources (CSANR) held the Washington State Soil Health Summit, resulting in a prioritized set of soil health issues needing to be addressed through RD&D [29]. The top issue was diagnostic tools and tests. The inherently complex nature of soils means it is difficult to define clear and consistent soil health metrics for different regions and cropping systems. In 2019, the state funded the Soil Health Initiative at CSANR to begin addressing the priority RD&D areas.

Healthy terrestrial/aquatic interfaces store more carbon per unit area than forests [26]. Washington is a coastal state and our tidal zone is the top bivalve producer in the nation, but shellfish suffer from ocean acidification. The State's Blue Ribbon Panel on Ocean Acidification identified co-culturing of seaweed alongside shellfish as a strategy to potentially remove CO_2 from local water, thereby reducing the corrosive effects of ocean acidification on larval shell formation [30]. Washington Sea Grant funding has supported RD&D in kelp co-culturing, and the state subsequently funded the Washington Ocean Acidification Center at UW.

The Pacific region of the U.S. tends to lead the nation in the use of technological approaches to decarbonization, such as precision agriculture, an information-based crop management system that optimally controls water and fertilizer inputs to the field [31]. Likewise, high tech forest products such as cross-laminated timber (CLT) can dramatically improve the embodied carbon performance of commercial construction, while supporting IFM to improve forest health. The WSU Composite Materials and Engineering Center and UW Carbon Leadership Forum are recognized for supporting low carbon advanced construction materials.

Agriculture and forestry RD&D relies heavily on state and local support, in part, because the public laws establishing cooperative agricultural extension services (the Smith-Lever Act) and cooperative forestry research programs (McIntire-Stennis Act) require matching as part of the USDA formula funding. Of course, a great deal of carbon-relevant fundamental work is supported by federal agencies other than USDA. For example, PNNL has a substantial portfolio of DOE-funded basic science in soil microbial ecology and the analysis of terrestrial/aquatic interfaces where it is essential to fully understand coastline carbon flows in detail to ensure they are properly treated in Earth system models. Likewise, Washington universities receive a diversity of support in carbon-relevant fundamental research funding linked to land and coastal ecosystems.

(ii) Shared RD&D infrastructure

Public lands are among the main RD&D assets for agriculture and forestry research. WSU has nine farms and four research and extension facilities, along with green houses. The College of Agriculture, Human, and Natural Resource Sciences (CAHNRS) at WSU also has four shared core facilities in imaging, biotech, genomics and phenomics. The UW School of Environment and Forest Sciences has the UW Center for Sustainable Forestry at the Pack Forest and the Olympic Natural Resource Center. Researchers also have access to state and federal lands for research. The U.S. Forest Service Pacific Northwest Research Station, located in Seattle, has both laboratory research and uses Forest Service lands for research. Likewise, foresters from the DNR carry out research on State forestlands.

(iii) Workforce development

Walla Walla Community College houses the Center of Excellence (COE) in Agriculture and Natural Resources. The COE helps ensure that the technical and community college system offers industry-relevant training in a wide range of areas, including biotechnology of biofuels, environmental service, natural resources, plant science, and forest management.

WSU is the State's land grant university, and CAHNRS offers a wide array of agricultural science, management, and economics degree programs. The UW School of Environment and Forest Sciences offers a wide array of silviculture, ecology, and bioresource degrees.

(iv) Sector-specific services

Non-profit organizations including, but not limited to, The Nature Conservancy in Washington, the Land Institute, and the Soil Carbon Initiative play a major role in large scale natural climate solution demonstration projects in agriculture and forestry, often in partnership with universities and other stakeholders. Similarly, third party non-profits are widely used as trusted certification organizations, for example Oregon Tilth for organic food, Forest Stewardship Council for sustainable wood, and Climate Action Reserve for carbon offsets.

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