Intermountain West Energy Sustainability & Transitions

On the road to carbon neutrality in the Intermountain West

Phase One Final Report

December 2022

Version 1.2

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Welcome

Dear Stakeholders,

John Sarrao

Deputy Lab Director
Science, Technology & Engineering
Los Alamos National Laboratory

I am pleased to share the final report from the first phase of the *Intermountain West Energy & Sustainability Transition* (I-WEST) initiative. This report represents a partnership between the U.S. Department of Energy (DOE) and affected communities in the Intermountain West to address the risks associated with an evolving climate. We could not have reached this point without your engagement and support. I-WEST exemplifies how states, sovereign nations, cities, counties, and small rural towns within our region are coming together to address what may be one of the biggest and most difficult challenges of our time: transforming our energy ecosystem while simultaneously creating an environment that is more just and more equitable.

Through our role in I-WEST, Los Alamos National Laboratory demonstrates our commitment to being a trusted advisor to decision-makers regarding science-based, sustainable energy solutions—targeting the best technologies to meet our region's needs. This work is part of our mission, but more importantly, applying our skills to drive these crucial changes is the best way we can partner with communities locally and regionally to build a sustainable future.

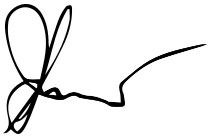
It has been a privilege to work hand-in-hand with our partners at Arizona State University, the Colorado School of Mines, Montana State University, the National Energy Technology Laboratory, the New Mexico Institute of Mining and Technology, Resources for the Future, San Juan College, the University of New Mexico, the University of Utah, and the University of Wyoming. Together we have laid the groundwork for a science-based and community-supported roadmap to carbon neutrality for our region.

I want to thank our sponsors at the DOE Office of Fossil Energy and Carbon Management and the DOE Bioenergy Technologies Office for placing their confidence in us to carry out this important initiative. This was, in many ways, an exploration of place-based energy transition planning, and what we have learned will have far-reaching benefits.

Finally, I wish to express my heartfelt gratitude to the many stakeholders from across the region who partnered with us on numerous workshops, seminars, and listening sessions. Hundreds of residents in the Intermountain West provided valuable insights into local energy systems and economies, as did individuals from outside the region on a wide range of related topics. We honor the trust you placed in us and commit to earning your ongoing collaboration.

Looking forward, I-WEST will be foundational to future community-engaged energy transition efforts in the Intermountain West. There is still a great deal of work to be done, but I-WEST has put us on the road to carbon neutrality, and through our partnerships, we are closer to a clean energy future.

Sincerely,



"The Department of Energy is committed to ensuring equity and energy justice are key elements of our broader energy transition strategy. This can only be achieved through place-based partnerships like I-WEST. DOE and our interagency partners are committed to assisting energy communities facing industry transformation, including the Intermountain West. I-WEST is making significant progress in helping us uphold that commitment through key partnerships with academic institutions and regional organizations, community engagement, and long-term sustainability planning."

—Kate Gordon, Senior Advisor to Secretary of Energy Granholm

"As we continue to build a clean energy and industrial economy, we need to work with community and regional stakeholders and help them take full advantage of their resources and capabilities to help our nation achieve net-zero emissions and meet our shared climate goals. The I-WEST initiative offers a roadmap for doing that in the Intermountain West, and it can be a template for working with other regions. I am proud of the Office of Fossil Energy and Carbon Management's contributions to this report, and I applaud everyone who contributed to this groundbreaking effort."

—Brad Crabtree, Assistant Secretary, DOE Office of Fossil Energy and Carbon Management

"As our economy transitions towards lower carbon solutions, it will require working in tandem with communities to define the most pressing problems and priorities. I-WEST represents an interdisciplinary approach towards this community-centered solution development as a decarbonized economy will require a multitude of approaches including renewable hydrogen, bioenergy, and carbon capture in addition to renewable power sources."

—Valerie Sarisky-Reed, Director, DOE Bioenergy Technologies Office

I-WEST Partners

U.S. Department of Energy | Los Alamos National Laboratory | Resources for the Future | UW School of Energy Resources | The University of Utah | UNM

San Juan College | ASU | New Mexico Tech — Science • Engineering • Research University | National Energy Technology Laboratory | Montana State University | Colorado School of Mines

I-WEST

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Preface

The international scientific community has calculated how much greenhouse gas the Earth's atmosphere can handle before severe climate disruptions are seen worldwide, and we are closer than ever to the tipping point. The sixth assessment report of the International Panel on Climate Change (IPCC) Working Group shows we are on course to reach 1.5 C degrees of warming within the next two decades. Whether we limit warming to this level and prevent the most severe climate impacts depends on actions taken this decade.

This urgency is spurring a global shift in energy markets as more leaders in government, industry, and communities demand carbon-neutral energy. Still, the pathway to carbon neutrality is not linear—in addition to developing innovative technological solutions to this energy challenge, there are economic, social, and environmental factors that must be considered to ensure a just and equitable energy transition.

The U.S. has set a target to reach carbon neutrality economy-wide by no later than 2050, which means carbon dioxide emissions must drop at the gigaton-per-year scale. This will require significant changes in how we produce and consume energy. Thoughtful planning for such a transition takes time, but many communities throughout the nation are already facing economic and environmental challenges related to energy transition. This is especially true for coal, oil and gas, and power plant communities that have fueled the nation's prosperity for decades. So how can we act quickly and still ensure that the strategies we put in place today are sustainable and beneficial to all?

The aim of this public report is to present our findings to a broad range of stakeholders with shared interest in planning for energy transition.

In 2021, the U.S. Department of Energy funded the Intermountain West Energy and Sustainability Transitions (I-WEST) initiative as a pilot effort to scale down national energy goals to a regional level to better understand what energy transition means in terms of local economies, natural resources, infrastructure, workforce, and technology acceptance. Using a place-based, technology-neutral approach, I-WEST assessed the most viable pathways to carbon neutrality in the Intermountain West, allowing the region to speak for itself. The I-WEST team relied heavily on input from a broad range of stakeholders including industry, communities, and tribal nations.

Our findings confirm that, while energy transition poses some significant challenges for the region, the Intermountain West is well suited to take advantage of emerging opportunities. Moreover, I-WEST makes a strong case for place-based approaches that examine the diverse motivations for energy transition and develop strategies to address them. Finally, our findings substantiate that multiple technologies will be needed to achieve carbon neutrality in the Intermountain West and developing symbiotic economies is key to a sustainable energy transition.

The aim of this public report is to present our findings to a broad range of stakeholders with shared interest in planning for energy transition. The accessible nature of this report aligns with our place-based approach and integrates regional perspectives with technology development and deployment. Its primary purpose is to present our findings to our stakeholders, who generously contributed their time and knowledge at I-WEST workshops and listening sessions. The content presented here is a distillation of the extensive research and analysis conducted by the I-WEST team on the scientific underpinnings of each technology pathway examined, as well as the economic, workforce, policy, and energy justice factors that were considered. Unabridged versions are available on the **I-WEST website**. ◆

Executive Summary

I-WEST PHASE ONE: FINAL REPORT

Executive Summary

A region in transition

The Intermountain West is composed of states with shared geographical, environmental, and demographic attributes. More notably, the six states included in the I-WEST initiative—Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming—are all characterized by fossil fuel-based economies and have shared challenges related to climate change. As major producers and exporters of fossil-based energy, these states are highly vulnerable to social and economic disruptions as a result of energy transition, but also have many advantages that could position them as emerging leaders in new energy economies.

One of the overarching strategies of I-WEST is to build a regional team to assess the energy landscape, identify pathways to build symbiotic energy economies, and recommend solutions to the challenges energy communities are facing. Each state is represented in this initiative by a local college, university, or national laboratory. Additional partners from beyond the region were selected for their expertise in applicable fields. In the first phase of I-WEST, the team built the foundation for a regional roadmap that models various energy-transition scenarios, including the intersections between technologies, climate, energy policy, and economic development.

A place-based approach and why it matters

The amount of federal funding currently available for clean energy research and infrastructure development is unprecedented, but the success of programs funded by these dollars rests on effective planning and implementation at the local level. I-WEST takes a place-based approach that considers the specific circumstances of the region, and engages communities to actively participate in decisions that will affect them in the long term. Additionally, I-WEST takes a technology-neutral approach that prioritizes societal readiness first and technology readiness second. This is a departure from the traditional approach to developing new energy systems, in which regional perspectives are often not factored into the equation until after decisions have been made, and those decisions are based primarily on the maturity of a technology.

Through I-WEST, a collaborative network of tribes, public servants, policy makers, researchers, educators, advocacy groups, and business leaders came together to participate in a series of workshops and listening sessions. These events yielded valuable input that was integrated into the I-WEST roadmap. Perhaps even more importantly, these engagements helped establish communication channels between stakeholders—a critical first step toward building regional coalitions that can work together to implement the I-WEST roadmap.

In a place-based approach to energy transition, plans for technology development and deployment are informed by regional perspectives.

Symbiotic energy economies

Leading experts in climate and energy sciences, such as the Intergovernmental Panel on Climate Change, recognize that achieving carbon neutrality will require multiple pathways. Moreover, they recognize that those pathways must not only result in reduced greenhouse gas emissions, they also have to be sustainable. Putting both of these principles into practice, the I-WEST roadmap considers four symbiotic “economies” that could be exploited to decarbonize critical energy sectors in the Intermountain West, while simultaneously building new industries that leverage the region’s infrastructure, workforce, and natural resources. The analyses conducted in the first phase of I-WEST explore supply-and-demand scenarios for energy based on carbon capture, storage, and utilization; low-carbon hydrogen; bioenergy; and low-carbon electricity. Water usage is also considered a cross-cutting factor, including the potential for leveraging non-traditional water to improve efficiencies.

These four economies are distinct yet symbiotic and highly dependent on one another from a supply and demand perspective—the growth of each depends on the co-development of all the others. As one of many examples, captured carbon dioxide (CO_2) can be used with green hydrogen to produce sustainable, carbon-neutral chemicals and fuels as replacements for petroleum-based products. The symbiotic nature of these economies has the potential to accelerate development, but could also result in competition for infrastructure, natural resources, and workforce, which could slow growth. This emphasizes the need for an I-WEST roadmap as a tool to help communities evaluate the risks and opportunities associated with new energy technologies.

Stakeholder outreach

The I-WEST initiative kicked off with six state-based workshops that were open to the public and geared toward gathering input from a wide range of stakeholders about perceived risks and opportunities related to energy transition. A corresponding workshop was held to gather perspectives from tribes across the region. Subsequently, 10 region-wide workshops were held, focusing primarily on technology pathways—these events were more targeted to technology developers (R&D) and deployers (industry). In response to stakeholder questions and concerns related to water, one of the workshops honed in on how various energy technologies might impact local water resources.

Experts in a wide range of energy-related fields were featured in a virtual seminar series that was free and open to the public. They included researchers, entrepreneurs, federal program managers, and researchers who shared timely information about relevant initiatives within and beyond the Intermountain West region.

The **I-WEST website** has been an important tool for staying connected with stakeholders. Developed for a broad audience with diverse backgrounds and areas of interest, the website is a platform to both inform and hear from stakeholders with a vested interest in energy transition in the Intermountain West. It houses an interactive catalog of energy projects across the region (organized by technology pathway), a newsfeed with articles and blogs, announcements about upcoming events, and a timeline of past events with links to published resources like videos, slides, and reports.

Keeping the lines of communication open, the I-WEST team holds listening sessions with stakeholders on an ad hoc basis to provide one-on-one engagements where questions or concerns can be discussed at a more granular level.

I-WEST Seminar Series

Melanie Kenderdine
Gigaton Needs, Gigaton Challenges

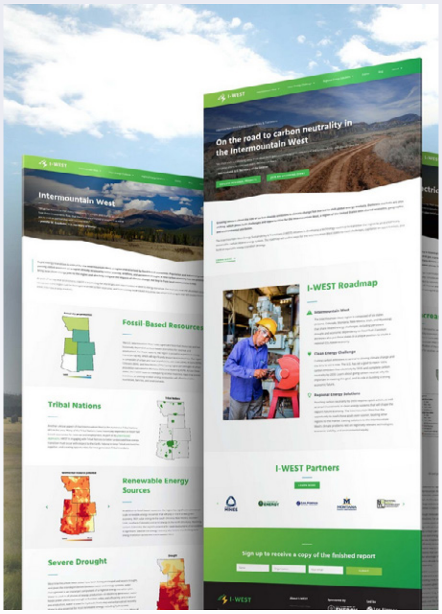
Jason Sandel
Rocky Mountain Natural Gas Production and a New Hydrogen Economy

José Benitez
Deep Decarbonization and Energy Markets Modeling at the DOE Office Fossil Energy and Carbon Management

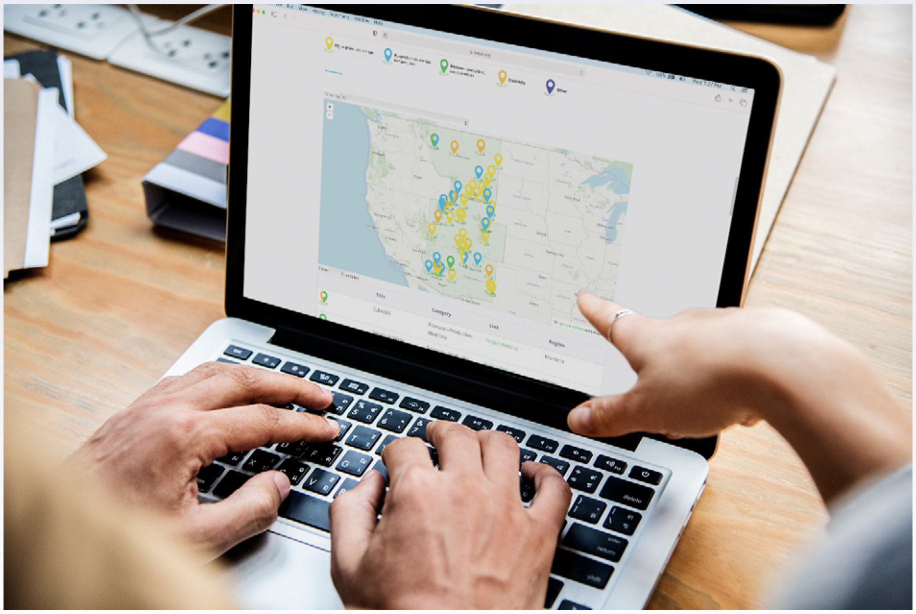
Dr. L. Ruby Leung
Projecting Regional Climate Change and its Impacts in the Western U.S.

Moji Karimi
Synthetic Biology Meets Energy Transition: Reimagining the Heavy Industries for the Net-Zero Economy

Mike Hightower
Emerging Energy Trends and Water Use Innovation in the West



The I-WEST website is a platform for continuous community engagement.



An interactive catalog of energy-related projects in the region is organized by state and technology pathway.

About this report

Each chapter of this report addresses a key component of the I-WEST roadmap. Chapter 1 provides an overview of the unique attributes of the Intermountain West and provides a rationale for why the region was selected for this detailed assessment. Chapters 2-8 focus on technologies within the aforementioned "symbiotic economies," including an overview of the technology or pathway under evaluation, its relevance to the region, key findings, and next steps. Chapters 9-11 focus on key policy and socioeconomic factors critical to a sustainable energy transition, again honing in on issues of particular relevance to the Intermountain West. Finally, Chapter 12 presents a nascent I-WEST roadmap and a discussion of the analytical approaches applied in building the roadmap. Subject matter experts are identified at the end of each chapter. ◆

I-WEST Assessment

CHAPTER 1

Regional Overview

The Intermountain West is an incredibly resource-rich region, particularly in the energy sector where it accounts for nearly 20 percent of the nation's energy production. Historically, nearly all of this production has been fossil-fuel based. Today, demand for decarbonization efforts and cleaner energy alternatives is growing throughout the region and at national and global levels. These external and internal pressures are prompting the Intermountain West to reconsider its fossil fuel production and consumption. Localized and state-based measures will be critical to facilitating an energy transition, but an integrated regional plan will also be key to providing a connected framework for the shift and accounting for the many economic, social, environmental, and political factors involved.

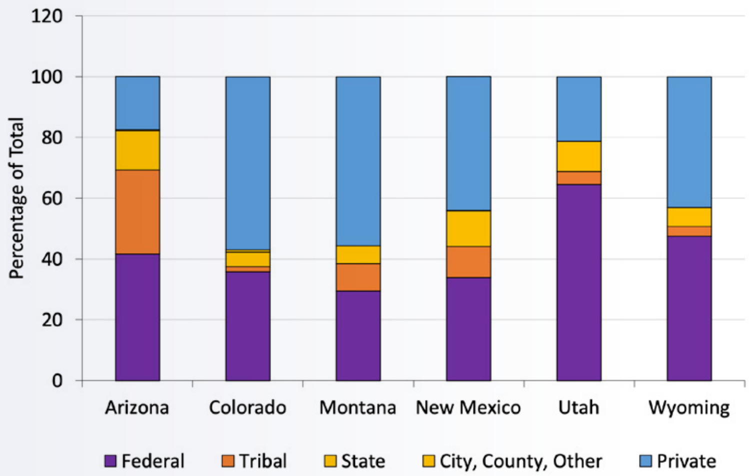
Place-based approach

Such a plan would likely rely on what is called a place-based approach, which has two core tenets: a familiarity with the geographical context of a region, and well-defined interactions and channels between all stakeholders. Place-based approaches rely heavily on the natural resources in a given region and operate under the limits afforded by available human capital. A place-based plan will require input and buy-in from a broad range of stakeholders. Sovereign nations, governmental bodies at every level of government, private entities, non-governmental organizations, educational and research institutions, and local communities and the public will all have a role to play in this type of strategy.

Place-based approaches are successful because they can be used to identify, at a local level, what comparative advantages exist, allowing for the most efficient allocation of resources. They also identify the technologies and industries that are most applicable to a region and what policies could be implemented to develop and deploy them.

Geographical attributes

The first step in developing a place-based approach to energy transition in the Intermountain West is recognizing its geographical advantages and limitations. The region is an incredibly diverse landscape with wide-ranging topographies and climates. Owing to this is the fact that the six states are among the 13 largest in the country, covering over 650,000 square miles. Much of the region faces the threat of drought annually, and the effects of climate change are expected to exacerbate this in the future. The region has already experienced an increase of 2-2.5°F since the start of the 20th century. The Intermountain West's geology also offers some key insights; in addition to abundant fossil fuel



Land ownership in the Intermountain West is complex, with various combinations of federal and state government, tribal government, and private ownership. An increased level of coordination will likely be needed between these groups to support new energy projects in the region.

resources, the region is rich with minerals, natural CO_2 reservoirs, and sedimentary basins that could potentially be used for storing CO_2.

Due to the region's sheer size, along with its semi-arid to arid nature, the Intermountain West is sparsely populated with a significant portion of the population concentrated in four urban areas: Phoenix-Tucson, Arizona; Fort Collins-Denver-Colorado Springs, Colorado; Albuquerque-Santa Fe, New Mexico; and Ogden-Salt Lake City-Provo, Utah. Another unique feature of the region is its high number of sovereign nations, 63 in all including the largest tribe in the U.S., the Navajo Nation. This contributes to unique land-ownership dynamics—some states like Arizona and Utah have nearly 80 percent non-private land-ownership, while other states like Wyoming and Colorado have around 60 percent private ownership.

In the energy sector, all but one (Arizona) of the assessed states rank in the top 15 nationwide for coal, oil, and natural gas production, and all but one (Colorado) are also net exporters of electricity. This could become a pressing issue as most states on the receiving end of energy exports are primarily to the west, including California. Those states are increasingly demanding carbon-neutral electricity, which poses a challenge for the fossil-fuel dependent Intermountain West economies. However, the region is poised to pivot to low-carbon energy by taking advantage of its extensive infrastructure network of fossil fuel extraction plants, processing plants, and transportation methods. These could help reduce the time and costs associated with launching new energy economies.

Key findings

With this general understanding of the geographic factors in place, the second step in the I-WEST place-based approach was to engage with communities across the region to gather a wide range of stakeholder perspectives on energy transition. This was carried out through state-based workshops (hosted by the respective I-WEST partners) open to the public and focused on energy-related concerns at the grass-roots level; technology-focused workshops that focused on technology development, deployment, and implementation; seminars that featured experts on regionally relevant energy topics; and one-on-one listening sessions to have in-depth conversations about energy transition challenges specific to a tribe, county, state, or energy sector.

One of the more important factors that community members say will affect their support of projects is the level of investment made in that community's location. Local stakeholders want to see a level of permanence to a project so that the economic impact is long-lasting and can help sustain the community financially. There are also very different understandings of what an energy transition would look like, with opinions falling along a spectrum. Some see the importance of implementing policies and technologies as a means of diversifying, and in some cases revitalizing, local economies. For others, energy transition is more in line with mitigating the effects of climate change and achieving carbon neutrality. Across the board, there are concerns about a rapid energy transition without a well developed plan to make energy affordable for all and replace jobs and revenues that will be lost in the wake of coal-fired power plant and mine closures.

Balancing these competing views will be a challenge, but ultimately an effective approach will include assessments of economic, environmental, and workforce impacts. If assessments show that a project provides equitable economic opportunities for an entire community, it is more likely to be accepted. While there is some wariness over newer technologies and how they might impact natural resources, local workforces, and the environment, the prevailing belief is that the Intermountain West community doesn't want to get left behind as other regions continue to innovate and adopt newer technologies.

For many stakeholders, technology-specific concerns are related to feasibility of implementation. Technology that can build off of existing infrastructure is favored because of the lower bar of entry that would be required to enter the industry. Additionally, the more complex the technology, the more hesitant communities tend to be. A lack of familiarity and understanding seemed to dissuade stakeholders because it was perceived to have more risks or unknown factors that would have to be learned and accounted for.

The way the transition is implemented is also important to regional stakeholders. Justice initiatives are becoming increasingly important, especially for communities and sovereign nations that historically have been marginalized by the energy industry. I-WEST heard a loud and clear message from these stakeholders that they want a sustained energy, environmental, and social justice (EESJ) effort that occurs throughout the lifetime of an energy project, and they want to be partners in the decision-making process rather than bystanders.

From a policy perspective, stakeholders perceive the need for few alterations to current approaches. There is a belief that policy makers will have to be more proactive due to the rapidly evolving nature of the energy industry and impacts of climate change. If this approach is taken, a balance must be found where, even as decision-making timelines reflect the urgency of the situation, community input is not trivialized and seen as a secondary determinant. There also needs to be more coordination across tribal, state, and local boundaries, as a lack of uniformity makes collaborative efforts difficult and hinders efforts to achieve regional goals or implement large-scale initiatives. Additionally, local and tribal governments will need guidance on how to access funding and technical assistance for deploying projects because many of them lack the necessary bandwidth, resources, or experience.

Preparing the regional workforce for the energy transition is a concern that cuts across energy sectors, technology pathways, and stakeholder groups. Alongside a strategy for replacing jobs that will be lost as fossil-based resources are phased out, plans must also be made for how to train workers with the skills they will need to work in emerging energy industries. Depending on how long it takes to get a training system up and running, a lack of skilled workers could lengthen the deployment period for new energy technologies. It is also imperative that many of the jobs created fall in line with the quality of the well-paying and secure jobs that currently exist in the energy sector. A failure to take care of this aspect could lead to economic decline, which could have devastating impacts on individuals, families, and entire communities.

Next steps

The Intermountain West is a complex region with a wide range of geographic and demographic characteristics that make any sort of transition difficult. Achieving a just and equitable energy transition on an accelerated timeline, and with a heavy technological, economic, and political load, presents an enormous challenge. A place-based approach is key to developing a regional strategy that stakeholders from the entire spectrum of energy-system development can take ownership of and work together in an integrated fashion to implement.

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CHAPTER 2

CO_2 Point Source Management

A point source is a stationary facility that produces a significant amount of CO_2 mixed with other gasses—typically with a concentration of 5-15 percent CO_2, compared to roughly 0.04 percent in the atmosphere. Historically, the CO_2 produced at point sources is released into the atmosphere. Point source management refers to a variety of measures that can be taken to reduce emissions at a facility. Point-source capture (PSC) is one method in which a large emissions source, such as a steel mill, cement plant, or coal-fired power plant, is equipped with technology to capture and divert CO_2 before it reaches the atmosphere.

During PSC, the CO_2 is separated from other gasses, purified, and compressed. This involves increasing pressure so that the CO_2 behaves like a liquid that can then be transported to an appropriate storage site. Pipelines are the most common mode of transport for large amounts of CO_2. A variety of PSC technologies are available, ranging in readiness from commercially available to under development. These technologies generally employ one of three main strategies for separating the CO_2 from other gasses: (1) use of a

Highlights

- Point sources account for 65 percent of all CO_2 emissions in the Intermountain West, making point source management a key component of a regional energy transition strategy.
- As a net producer and exporter of fossil-based energy, the predominant point sources in the region are coal- and natural gas-fired power plants.
- Retrofitting existing facilities with proven PSC technologies could be an effective near-term strategy to reduce emissions while the region explores alternatives to fossil energy.

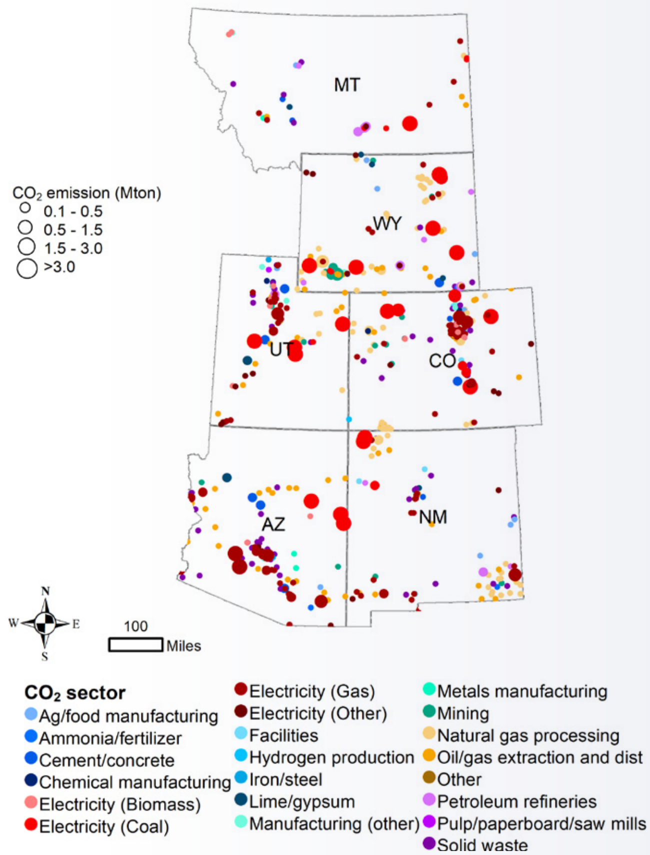
liquid solvent or dry sorbent to bind and then release CO_2, (2) use of a liquid to selectively dissolve and then release CO_2, or (3) use of membranes that selectively allow some gasses to pass through at a higher rate than other gasses.

Commercial at-scale deployment is available today for flue-gas capture from electricity generation and some industrial sources. Liquid solvents in the amine family are the dominant choice for commercial deployment due to economic factors and a track record of at-scale deployment—they have been used at scale for some applications for decades. Additionally, in natural gas processing, CO_2 is separated from the natural gas product as a matter of course. However, PSC technologies have yet to prove economically viable for large-scale deployment in other industrial processes like cement production, which contributes 8 percent of global CO_2 emissions. Experimental technologies are being developed or implemented at pilot scale for many PSC applications. Processes to treat emissions from smaller emitters, which at present are too expensive for wide-scale deployment, are also in various stages of development.

Regional relevance

The Intermountain West region is a net producer and exporter of fossil energy, where most point sources are facilities that generate electricity from coal or natural gas, although regional point sources also include industrial processes like cement production and fossil fuel production. Currently, point sources emit about 250 million metric tons of CO_2 per year, which represents 65 percent of the region's total CO_2 emissions per year (approximately 385 million metric tons). Hence, point-source management will play a pivotal role in a regional energy transition plan.

Most of the region's point-source emissions come from large facilities: 90 percent are generated by 20 percent of facilities, each of which produce more than 250 thousand metric tons of CO_2 per year. Of these, 66 facilities that produce electricity from coal and natural gas account for about 170 million metric tons of CO_2 per year, making capture of emissions from these facilities a significant opportunity for moving to carbon neutrality. The region has sufficient geologic capacity for storing all captured CO_2 below ground. Over 1,200 billion metric tons of storage potential exists across saline reservoirs, coal seams, and oil and gas reservoirs. This is sufficient to store current regional point source emissions for more than 6,000 years.



This map shows point sources in the Intermountain West region. The dominant CO_2 emissions are from facilities that generate electricity from coal or natural gas.

Given the prevalence of drought across the Intermountain West, water use must be considered in deploying PSC technologies, as many require significant water for cooling. With planning, however, water needs can be greatly reduced by using alternative strategies. For example, dry cooling is being deployed at Wyoming's Dry Fork Station Complex. Another regional opportunity under development is the use of nontraditional water for cooling.

Key findings

Recognizing that the long-term goal for energy transition is to shift away from fossil-based resources entirely, point-source management is a pathway for the Intermountain West region to reduce its large-facility CO_2 emissions reductions in the short- to medium-term.

Point-source capture at fossil-based electricity facilities alone could reduce regional emissions by more than 40 percent. While many of these point sources may eventually be retired or transitioned to operations with significantly lower emissions, PSC technology that is commercially available today could be used as part of a near-term transition strategy. Adoption of PSC could lead to a significant new industry, generating jobs that span a wide range of skills from across energy sectors. Capturing CO_2 point sources in the region would involve managing an amount of gas comparable to the region's current natural gas production.

Using current water-cooled technologies, capturing all of the CO_2 from electricity generation would double the current level of water usage for electricity production. However, the water needs for point-source capture could be reduced by 90 percent or more with regionally relevant strategies, such as the use of air cooling technologies and/or the use of nontraditional water resources. One example would be cooling with salty water (also known as non-traditional water) produced during the storage of captured CO_2 or during the production of oil and gas.

For PSC technology to be adopted in a sustainable way, there must be a demand for captured CO_2. In the short- to medium-term, 45Q tax credits can incentivize some facilities to capture CO_2 and ready it for storage. Point sources qualifying for 45Q include facilities that produce more than 18.8 thousand metric tons of emissions per year for electricity generation or more than 12.5 thousand metric tons per year for industrial sources. The financial savings are significant: one carbon capture and sequestration project underway in New Mexico stands to benefit from billions of dollars in 45Q tax credits. The region has many options for developing demand for at least some of the captured CO_2, including those that intersect with green hydrogen and, potentially, bioenergy.

Economics will continue to drive adoption. Because of the large number of existing facilities in the region, retrofitting with carbon capture systems is a sound near-term strategy to significantly reduce emissions while maintaining facility operations and jobs.

Next steps

A detailed assessment of how existing facilities plan to address CO_2 emissions is needed. This would provide a more accurate view of the timing and distribution of PSC technology deployment. Additionally, it would help regional energy transition planners understand the role PSC can play in reducing overall emissions, which is critical to informing how tribes, states, cities, and counties may need to invest in infrastructure to support PSC operations. Moreover, regional planning related to electricity and water needs for CO_2 capture would also benefit from such an assessment.

In addition to existing facilities, plans for anticipated future CO_2-producing facilities must be considered. Point source capture is integral to some hydrogen production operations, and forecasting the number and distribution of those types of facilities should be part of a detailed, facility-scale assessment.

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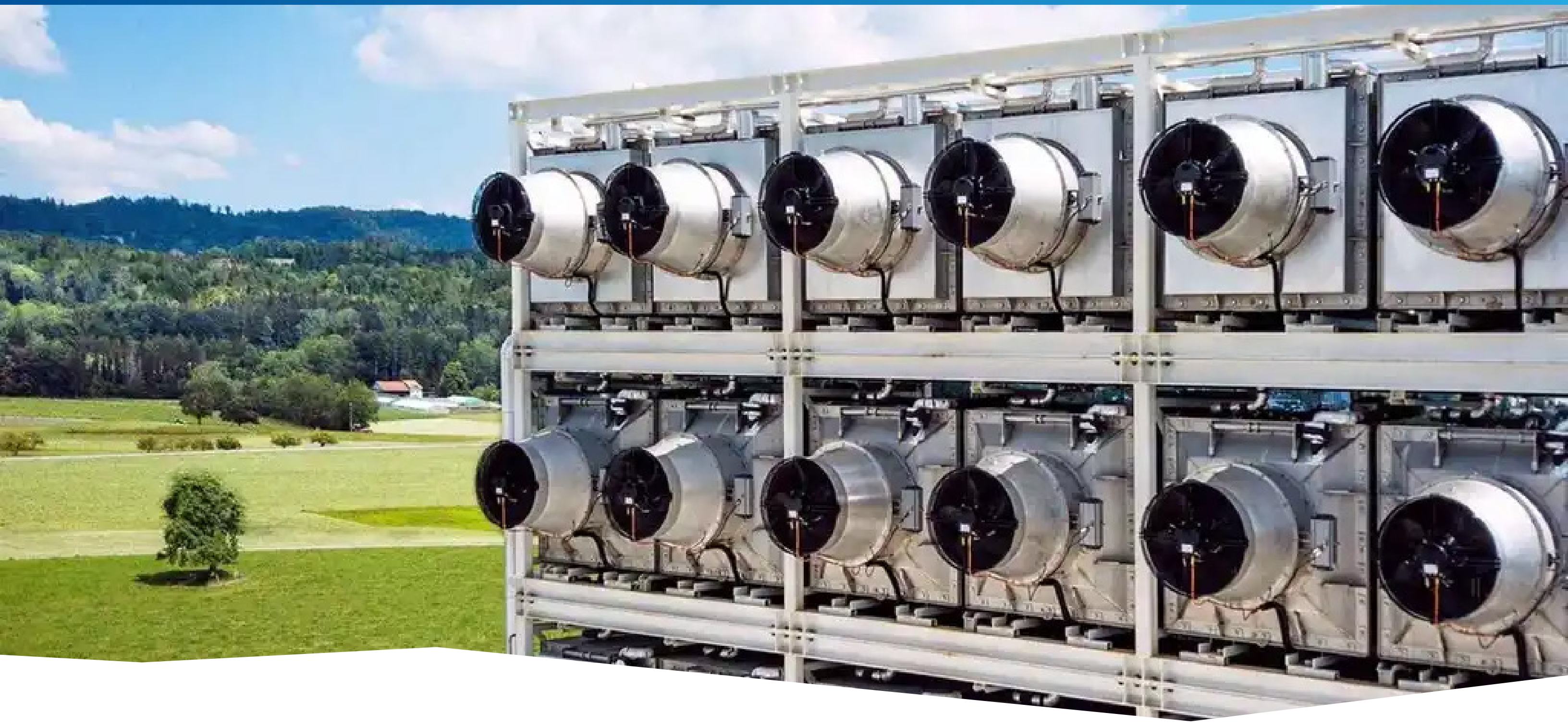


CHAPTER 3

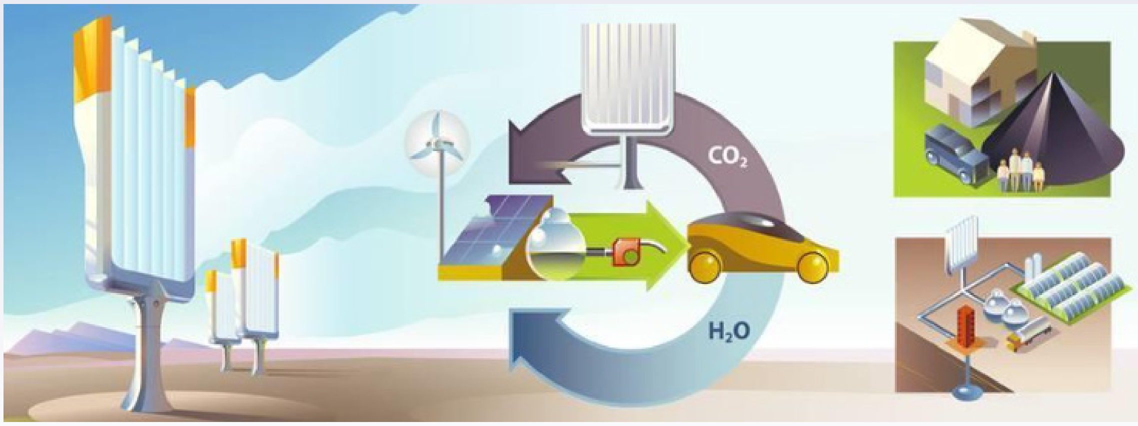
Direct Air Capture

To reach carbon neutrality, CO_2 emissions must either be eliminated entirely, or released into and removed from the atmosphere. Direct air capture (DAC) is a CO_2 removal technology that extracts and concentrates CO_2 from the atmosphere, enabling it to be permanently stored in geologic reservoirs or used for other applications. By removing CO_2 already emitted into the atmosphere, DAC could, in principle, be used to lower atmospheric CO_2 to a desired level. DAC is an emerging technology that will require large-scale demonstrations to refine the technology and reduce capture costs.

Several technical pathways are being explored for DAC, including sorbents, membranes, and other approaches that can separate CO_2 from other atmospheric gases, pulling the CO_2 directly out of the air like trees and plants do but without using photosynthesis. Because CO_2 is present in the atmosphere at low concentrations (approximately 0.04 percent), DAC requires large volumes of air to pass over the sorbent, which can be done actively (using fans to pass air over or through a sorbent) or

Highlights

- The Intermountain West's arid climate, abundant open space, access to renewable energy sources, existing energy infrastructure, and skilled workforce are ideal for DAC.
- Scale up and deployment of DAC technologies are in the early stages but progressing rapidly, with several regional initiatives well underway.
- In the long term, DAC will be central to developing a regional economy built on the supply and use of captured CO_2.



Captured CO_2 combined with renewable energy can be transformed into fuels and can be sequestered in various carbon reservoirs. Credit: Klaus Lackner

passively (relying on natural air movement). The latter case has the advantage of not requiring energy to move the air; one such system under development at Arizona State University is 1,000 times more effective than trees at removing CO_2 from air.

Sorbents are currently the most commonly explored approach. After the sorbent captures the CO_2, it is exposed to heat, moisture, and depressurization (or some combination of these) to "regenerate" the sorbent, releasing the CO_2 into an enclosed space and allowing the capture process to be repeated. For DAC to be effective and efficient, a carbon-neutral energy source must be used to power the regeneration process, as well as the fans in the case of active DAC.

At present, roughly two dozen DAC plants operate worldwide, capturing 0.01 million metric tons of CO_2 per year. For comparison, the United States currently emits billions of metric tons per year. Hence, deployment and scale up of DAC technology are still in the early stages. Nevertheless, DAC scale up is occurring; the latest DAC plant to come online, in September 2021, is in Iceland and captures 4,000 tons of CO_2 per year. Larger-scale projects are underway, including in Texas, where the 1PointFive enterprise is in the advanced stages of developing a facility to capture 1 million metric tons per year. The International Energy Agency's Net Zero Emissions by 2050 scenario, which is a roadmap to global energy-related carbon neutrality by 2050, assumes that DAC will have scaled up to approximately 85 million metric tons per year by 2030 and 980 million metric tons per year by 2050—requiring roughly 100 facilities comparable to the one being developed by 1PointFive. The recently announced Bison project in Wyoming is indicative of the scale of future DAC farms.

Regional relevance

A CO_2 removal strategy will be key to reaching carbon neutrality in the Intermountain West by 2050, whether it's DAC or another form of removal, such as bioenergy with carbon capture and storage, enhanced weathering, or reforestation. Currently, DAC has not been deployed in the Intermountain West, except for a prototype in Arizona. The region has many attributes favorable for DAC deployment, including existing infrastructure and workforce, open spaces, abundant renewable resources to drive the DAC process, and low humidity, which favors some DAC technologies. There are also several organizations in the region at the forefront of DAC research and development, including Arizona State University.

As the first region in the world to extract CO_2 from natural deposits and to transport it for use in enhanced oil recovery, the Intermountain West has decades of experience in handling CO_2. The Intermountain West has developed the workforce and infrastructure to support these activities, and the region's significant geologic storage resources—in the form of saline-bearing formations, depleted oil and gas reservoirs, depleted natural CO_2 reservoirs (like Colorado's McElmo Dome), and others—afford significant opportunities for storing CO_2 safely and permanently. Unlike point source capture technologies, which require the capture facility to be collocated with a CO_2 source, DAC facilities can be sited near sequestration sites, thereby reducing the need for new CO_2 pipeline infrastructure. Moreover, the Intermountain West's arid climate would favor the type of harvest that suits many of the known sorbent technologies. The region also benefits from access to wind, solar, and geothermal resources that could power DAC.

Finally, DAC could enable new economies tied to the production of green hydrogen in the Intermountain West states. The same regionally abundant renewable resources that could power DAC, including wind, solar, and geothermal, could also power the production of green hydrogen, which could then be blended with DAC-CO_2 to produce carbon-neutral synthetic fuels for use by the aviation industry—one of the largest global emitters of greenhouse gases.

Key findings

With its ample open space, renewable energy resources, skilled workforce, and well-developed CO_2 infrastructure, the Intermountain West is among the most promising regions in the nation for widespread DAC deployment. Today, DAC scale up and deployment are in the early stages but progressing rapidly. If realized on a significant scale, DAC could help the Intermountain West achieve carbon neutrality on an accelerated timeline, serving to eliminate emissions that could not be achieved by other strategies.

Additionally, DAC is central to developing a regional economy built around the supply and use of captured CO_2, which is critical to accelerating the path to carbon neutrality. In the near term, CO_2 capture at point sources can drive emissions down, provided there is robust and enduring demand for captured CO_2. However, the projected phase out of large point sources would limit a robust and enduring supply unless DAC is phased in. Moreover, DAC-CO_2 opens up new regional opportunities for producing sustainable substitutes for petroleum, such as carbon-neutral synthetic fuel. Indeed, DAC-CO_2 could drive new markets for sustainable CO_2 used in food, beverages, synthesis of chemicals and materials, agriculture, and other industries. The Intermountain West region has an opportunity to be an early mover in an economy that meets growing CO_2 supply with increased demand.

Next steps

A more detailed analysis of the technology needed for DAC deployment and performance in the Intermountain West will be necessary, with special attention given to research, development, and infrastructure needs. This includes infrastructure needs as related to geologic storage and synthetic fuel production.

Parameters will need to be defined that dictate what constitutes an acceptable DAC technology, including requirements for long-term storage and verification. Standards boards are commonplace in industrial applications, and a standards board that prescribes best practices for DAC technologies could help guide DAC development. Workforce development will also be important. While the Intermountain West benefits from a workforce that is well acquainted with carbon capture, utilization, and storage, training procedures for DAC must be written and operating practices must be developed. Further coordination between educational and research facilities studying carbon capture would promote the sharing and cross-fertilization of ideas. ◆

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CHAPTER 4

CO_2 Storage and Utilization

Technologies like point source capture (PSC) and direct air capture (DAC) create a supply of captured CO_2 that requires an equal demand to create a new carbon economy. Ideally, some of this demand will be for use as a feedstock or as part of a process to create high-value products. However, the anticipated volume of captured CO_2 from large-scale decarbonization efforts is expected to be considerable, and will require permanent and safe underground storage where extensive storage capacity exists. This "demand" can be driven by tax credits tied to 45Q, as well as growing interest in "green" commodities.

Captured CO_2 can be stored safely and permanently in subsurface geologic resources, including saline-bearing formations, depleted oil and gas reservoirs, coal seams, and potentially enhanced geothermal systems. Saline-bearing formations, which are filled with a high salinity water called brine, offer the greatest potential to store captured CO_2 due to their large pore volume, high storage capacity potential, and extensive spatial distribution.

Highlights

- Geologic formations in the Intermountain West have the capacity to store roughly 6,000 years' worth of current emissions.
- There is a high level of interest in carbon capture, utilization, and storage in the region, with more than 40 related projects currently underway.
- Tax credit incentives, such as 45Q, represent billions of dollars in savings for regional companies.
- Policies in the Intermountain West states are generally favorable to storage expansion.

Carbon storage is a safe, proven process that has been performed since 1972, when the initial enhanced oil recovery (EOR) project began operations. Today, it is incentivized by the 45Q tax credit, which has already spurred interest in CO_2 storage projects across the United States. The 45Q tax credit is likely to drive CO_2 storage projects in the short- to medium-term. While the costs associated with CO_2 storage are variable depending on both geography and geology, they are lower than those associated with CO_2 capture, which is the most expensive part of the carbon capture, utilization, and storage (CCUS) value chain. The high technology readiness level of many CO_2 storage technologies, coupled with the potential for large-scale CO_2 abatement, makes large-scale CO_2 storage viable in the short-term.

Regional relevance

The states that compose the Intermountain West region have an excellent combination of CO_2 sources, existing CO_2 pipeline infrastructure, and subsurface geologic resources for safe and permanent storage. It is estimated that geological resources in the region can potentially store between 0.35 and 3.4 billion metric tons of CO_2. Currently, the Intermountain West region emits roughly 385 million metric tons of CO_2 per year, of which approximately 250 million metric tons come from point sources. Although most of these storage estimates remain to be proven by site-specific evaluations, it is likely the region has sufficient storage capacity for supporting CO_2 storage demand for generations. This storage capacity, which is significantly greater than that of a region like Appalachia, will prove ample even if technologies like DAC and blue hydrogen production (which is emissions intensive) affect a net increase in the overall volume of regional captured CO_2 supply.

The Intermountain West is a major producer of natural gas, with many regional emissions arising from natural gas production. Such large-scale production presents a unique opportunity for the deployment of CCUS technologies, since capturing and storing CO_2 from natural gas processing would yield a significant reduction in regional emissions.

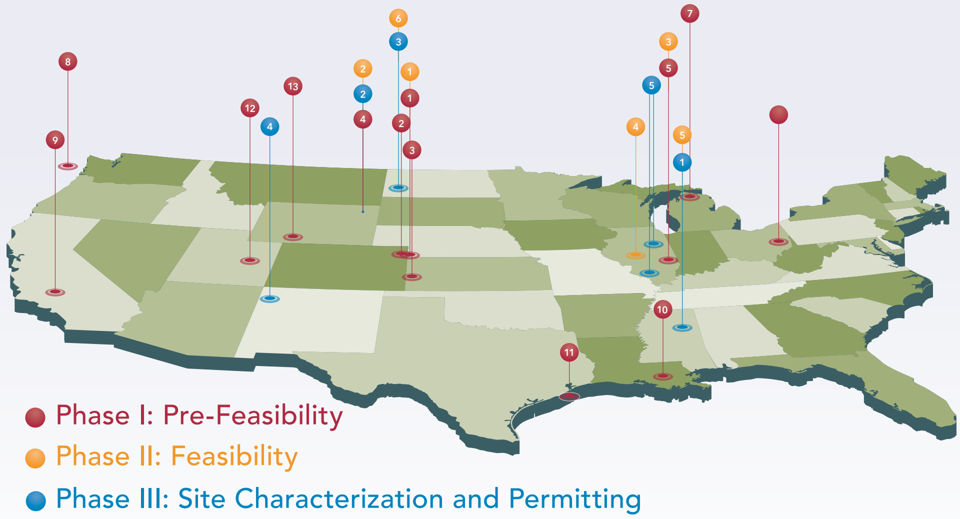
Overview of the 45Q Tax Credit

The 45Q tax credit (Section 45Q of the Internal Revenue Code) originated in 2008 through the Energy Improvement and Extension Act. Specifically, Section 45Q of the U.S. tax code provides a performance-based tax credit which can be claimed by a carbon capture project when the CO_2 is either securely stored in geologic formations, like oil and gas or saline reservoirs, or through beneficial use as a feedstock to produce products like chemicals, concrete, or fuels.

In 2018, U.S. Congress passed the Bipartisan Budget Act (BBA), which prompted a revision of the CCUS tax credit accessible under Section 45Q. Tax credits increased for CO_2 captured from new facilities, following a steady ramp up to \$35 per metric ton CO_2 in 2026 stored by EOR and up to \$50 per metric ton CO_2 in 2026 for storage in saline reservoirs.

The Inflation Reduction Act, signed into law in August 2022, further enhanced CCUS tax credits. Beginning in 2022, industrial captured CO_2 garners a flat \$85 per metric ton CO_2 for storage in saline reservoirs and \$60 for use or EOR; CO_2 captured via DAC sees further benefit at \$180 per metric ton CO_2 and \$130 per metric ton CO_2, respectively. Additional improvements include the option for direct pay–the ability to transfer credits to a third party, and substantially reduced capture volume thresholds for qualification.

Now, power plants must capture 18,750 metric tons per year and at least 75 percent of baseline emission. Whereas, DAC is now 1,000 metric tons per year and all other facilities must capture at least 12,500 metric tons per year. Currently, construction of a CCUS project's carbon capture equipment must begin before January 1, 2033. Needless to say, the passage of this bill could be monumental for spurring CCUS development.



Funded by the U.S. Department of Energy, the CarbonSAFE program develops projects focused on ensuring carbon storage complexes will be ready for integrated Carbon Capture, Utilization, and Storage (CCUS) system deployment in the 2025-2030 timeframe. Source: National Energy Technology Laboratory

The Intermountain West has benefitted from early investments in CO_2 infrastructure, much of which is related to CO_2-enhanced oil recovery (CO_2-EOR) expansion, largely in the Permian Basin of New Mexico and Texas but also for operations in Wyoming and Montana. For example, in late 2021, Denbury Resources completed the Cedar Creek Anticline CO_2 pipeline in southeastern Montana. This pipeline has a capacity of about 7 million metric tons of CO_2 per year and enables CO_2-EOR operations in oil fields within the Cedar Creek Anticline. Other CO_2 pipeline networks are also operational in the region.

Regional state policies are favorable to CCUS. Wyoming has been granted primacy by the U.S. Environmental Protection Agency for Underground Injection Control Class VI wells (those used for CO_2 storage); other entities in the region are also considering/pursuing primacy, which can speed the permitting process for new storage projects. States have also enacted policies related to CO_2 pipeline corridor mapping, pore space ownership, and long-term liability transfer.

Key findings

The Intermountain West likely has generations (or more) of capacity to store CO_2 permanently and safely in geologic reservoirs. These early capacity assessments provide confidence that CO_2 storage can account for much/all of the demand for CO_2 captured from existing point sources, as well as those anticipated with new regional sources due to blue hydrogen, direct-air capture, etc.

At present, over 40 projects involving CO_2 capture, utilization, and storage are underway or in the midst of project planning in the Intermountain West, among the most of any equivalently-sized region in the United States. Lucid Energy's (Targa Resources Corporation) Red Hills Gas Processing Plant in Lea County, New Mexico, captures and stores approximately 45 thousand metric tons of CO_2 per year. The plant has also received the EPA's approval to drill two wells that will be used for additional CO_2 storage, each of which will be able to store 330,000 metric tons of CO_2 per year. Other projects include the Department of Energy-funded Wyoming CarbonSAFE project, which has completed drilling of test wells that could lead to CO_2 injection. In New Mexico, Enchant Energy's San Juan Generating Station retrofit would capture 6 to 7 million metric tons of CO_2 per year for potential use in EOR with Class II injection wells or in saline storage with Class VI injection wells.

The deployment of CO_2 storage within the region would also produce and sustain jobs. It would allow for the continued short- or long-term operation of point sources such as power plants, many of which are also major local employers. CO_2 storage will require workers with a variety of skills to carry out site appraisal, development, and operation, plus a workforce to address permitting oversight and independent monitoring, etc.

Carbon storage must be considered as part of the infrastructure planning for the larger regional energy economy and other CCUS processes—it will provide most/all of the demand needed to account for the supply of captured CO_2. Although future point sources of CO_2 (e.g., blue hydrogen production or DAC) could in some cases be strategically located near storage locations, existing point sources will need to transport their captured CO_2 if no suitable storage reservoir happens to be co-located with the facility. Project planners will need to consider the unique CO_2 storage potential of different areas within the region. For example, Arizona exhibits markedly less potential for CO_2 storage than the other assessed states.

Next steps

A CCUS future for the Intermountain West is within reach if the region focuses on investing in and accelerating the development of technologies that complement its skills, experience, existing infrastructure, and natural resources. Historically, the high cost of carbon capture and lack of market "pull" (i.e., a demand for captured CO_2) has hindered the deployment of CCUS technology, resulting in a scarcity of viable business models for deployment at scale. However, regional attributes and the expanded 45Q tax credit are motivating development of early-mover projects, with examples including CO_2-EOR expansion in Wyoming and Montana, as well as expanded CO_2 separation and storage associated with oil and gas processing sources in New Mexico.

Opportunities exist to improve our knowledge of storage potential that co-exists with viable containment strata. This would help identify "shovel-ready sites," facilitating rapid project deployment. An atlas of Intermountain West geologic opportunities, like the Department of Energy's 2015 Carbon Storage Atlas, would help coordinate projects in the region.

State-level geologic assessments will also be necessary to complete economic models that allow for the evaluation and refinement of regional outlooks.

Engagement with industry and government stakeholders would further facilitate design of a roadmap for CCUS. Engagement with disadvantaged communities around issues like pipeline infrastructure would ensure that future projects in the region are conducted in accordance with the Department of Energy's Justice40 initiative. Outreach, including news releases and coordinated social media content related to successful CCUS projects or relevant policy developments, would help encourage the adoption of CCUS in the region.

An integrated macroeconomic assessment would integrate all components of a roadmap to carbon neutrality in the Intermountain West. This assessment would include the influence of national and international constraints on the implementation of different strategies for achieving carbon reductions, including inquiry into the extent to which research and development can reduce constraints and cost. Such an assessment would consider realistic and optimistic scenarios for implementing renewables, battery backup, hydrogen, carbon capture, and saline storage into the regional energy economy. ◆

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CHAPTER 5

Certification for Decarbonization Technologies

Certification can be the difference between failure and success. In the context of carbon sequestration and the disposal of carbon waste, failure can mean wasting money, harming communities, wrecking biodiversity, and failing to address the climate crisis. At the simplest level, certification is a demonstration to the public (and to buyers) that an activity or product is behaving as it is intended. It is a social bond based on trust. We trust our cars to not fall apart, our outlets to not electrocute us, our household waste to stay in the landfill. We're able to do this because we trust that the certification process caught mistakes and fraudulent behavior. The same applies to carbon sequestration. Certification is a means of requiring science-based measurement, verification, and reporting protocols that guarantee carbon has been disposed of safely and properly. We want to be assured that sequestered carbon will not be released and if it is, that it will be remediated by the responsible party.

Highlights

- A carbon sequestration certification verifies that the storage operator takes responsibility for the sequestered carbon.
- Certification also guarantees that any release of carbon will be remediated by re-sequestration.
- Currently, many certification schemes for carbon sequestration exist; going forward, an international certification accreditation system would be beneficial.

Regional relevance

An assessment of existing certification around the world found at least 20 organizations that develop standards and propose methodologies for various sequestration approaches across six different carbon reservoir types [1]. For the Intermountain West region specifically, the main potential carbon reservoirs are geological formations (e.g., depleted oil and gas wells and saline reservoirs), above and below ground biomass (e.g., reforestation and ecosystem restoration), soil carbon, and minerals (e.g., turning CO_2 into stone). Multiple standards exist for each, available in voluntary and compliance carbon markets.

With choice comes differences. For example, CarbonPlan, a non-profit that uses data to analyze climate solutions, reviewed 14 soil carbon certification protocols, finding wide variety in rigor and various other metrics [2]. Many different groups work to guide the public and buyers to make their own quality assessments but clearly, a single set of standards would be in everyone's best interests [3, 4].

Key findings

The world spent $1 billion in voluntary carbon credits [5] and $1 trillion in compliance carbon allowances [6] in 2021. This is set to increase. Almost 43 percent of 632 public companies reviewed across the world plan to use carbon credits to meet their net-zero pledges [7].

The Intergovernmental Panel on Climate Change estimates the need for carbon sequestration to be on the order of 100-1000 gigatons of CO_2 over this century to uphold climate goals established by the Paris Agreement [8]. For perspective, the global annual carbon sequestration in geologic reservoirs hit 36.6 million tons in 2021 [9]. The scale of carbon sequestration will be enormous, and the growth of the industry is well underway, but without independent oversight, there's great potential for fraud, error, and too much variability in standards.

Next steps

This large amount of sequestration will need to be certified, but the burden of quality assessment should not rest on the public nor on carbon buyers [10]. The certification industry must be held responsible for ensuring a certain level of quality that we expect from other industries. In addition to improving oversight, the industry must also develop guidelines for what constitutes robust certification of carbon sequestration. Committing to an international certification accreditation system would address the public interests of safety and performance while enabling faster standards development. ◆

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CHAPTER 6

Hydrogen Supply

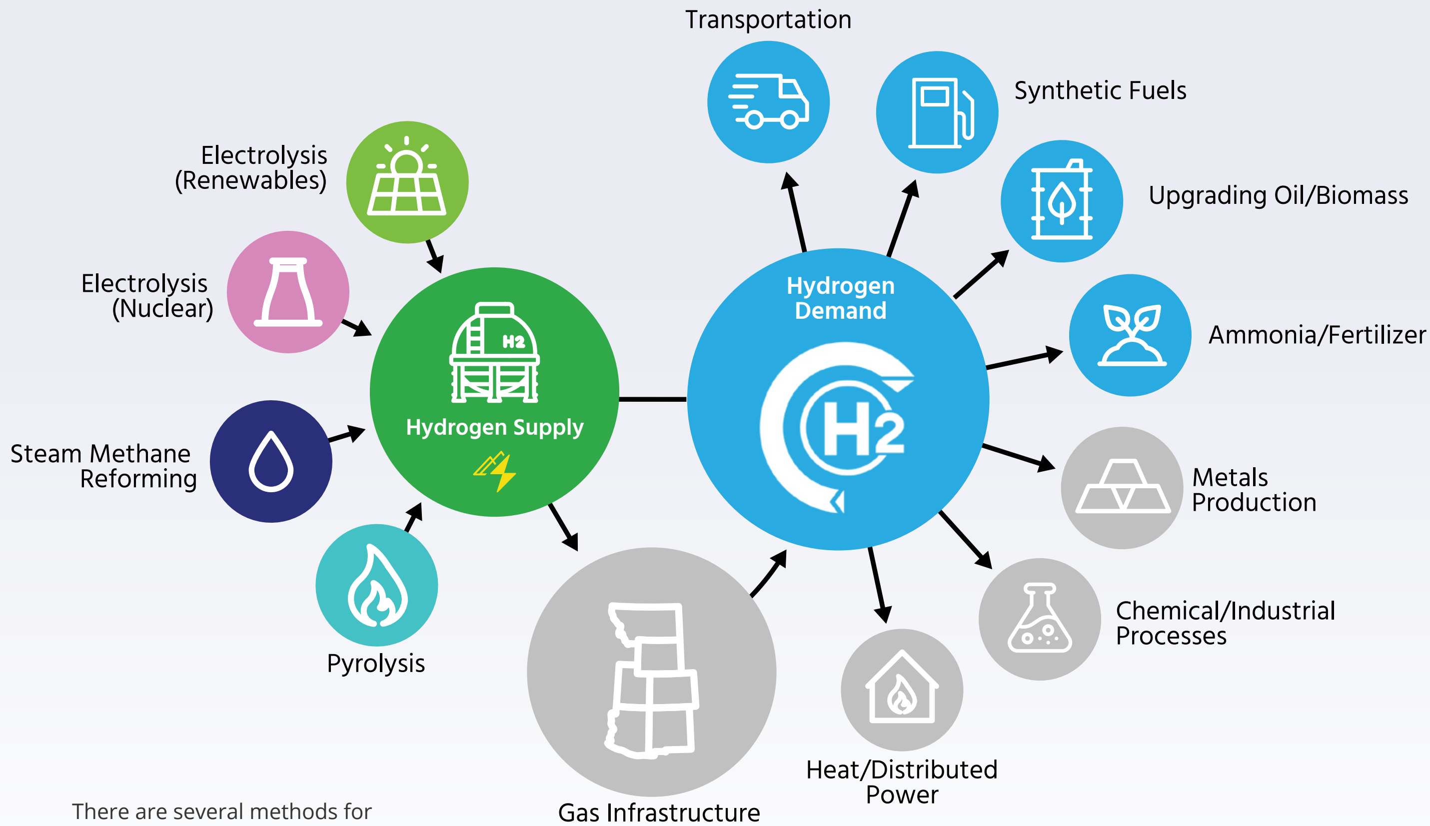
Hydrogen emits only water when burned or when used in a fuel cell, making it an attractive alternative fuel source to traditional petroleum-based products. While today's hydrogen is typically produced in a manner that yields greenhouse gas emissions, technologies have been developed that increasingly allow for low-emission hydrogen production.

Hydrogen can be produced by a variety of methods, including steam-methane reforming (SMR) and electrolysis. SMR involves producing hydrogen from natural gas (contributing over 70 percent of the total hydrogen production in the world), whereas electrolysis produces hydrogen from water.

In SMR, natural gas, which is mostly methane, is heated in the presence of steam to over 700 °C, and through a number of steps, ultimately produces CO_2 and hydrogen. This process yields substantial quantities of CO_2. In both cases, technologies are available to capture most of the CO_2, which can then be injected into saline formations deep underground

Highlights

- Abundant natural resources, including natural gas, wind, and solar, make the Intermountain West an ideal region for large-scale hydrogen production.
- Existing infrastructure and workforce could be utilized, which would reduce the time and cost often required to introduce a new energy source.
- Hydrogen production is a water-intensive process that can only be sustainable in the region with enabling technologies that allow for the use of non-potable water.
- Greenhouse gas emissions, particularly methane leakage, must be addressed with further research.



There are several methods for producing hydrogen—often identified by color. I-WEST is considering a spectrum of hydrogen production and use options as part of its regional energy transition roadmap.

for geologic storage. Hydrogen produced using SMR and CO_2 capture is often referred to as "blue hydrogen." Renewable energy can also be used as a heat source in the SMR process; hydrogen produced by SMR with renewable energy and CO_2 capture is often referred to as "turquoise hydrogen," and generates significantly lower heat source-related CO_2 emissions. SMR has an additional challenge in the context of greenhouse gas emissions; namely, methane production and transport can result in unwanted (fugitive) emissions of methane (a potent greenhouse gas). Ensuring methane leakage is low is central to producing low-carbon hydrogen from SMR.

Electrolysis involves using electricity to split water into hydrogen and oxygen. When renewable energy (or nuclear energy) is used to produce electricity, the electrolysis process produces very low net CO_2 emissions. Hydrogen produced with electrolysis and renewable energy, such as wind or solar, is often referred to as "green hydrogen."

Currently, SMR without carbon capture is the least expensive form of hydrogen production, costing approximately $1-2 per kilogram of hydrogen. Other forms of hydrogen production face greater economic barriers. Blue hydrogen costs approximately $1.5-3 per kilogram, while green hydrogen can cost $5-7 per kilogram, reflecting the energy-intensive nature of the current approach to electrolysis. The aim of the U.S. Department of Energy's Hydrogen Shot program is to reduce the cost of green hydrogen to $1 per kilogram within the decade.

In short, SMR has economic advantages but requires research and development to address several issues related to greenhouse gas emissions. Electrolysis is more expensive, but has the least greenhouse gas emissions. SMR can act as a bridge for transitioning toward green hydrogen.

Regional relevance

Hydrogen production in the Intermountain West represents an opportunity to utilize the region's natural gas resources to produce a low-carbon fuel for transportation. Though at present there is no commercial hydrogen production in the region, several projects are underway. Utah's Big Navajo Power, in a collaboration with Power Innovations, recently began a project to collect methane from petroleum drilling sites for conversion into hydrogen. The Intermountain Power Project in Utah also is developing hydrogen production and storage for use in power generation, beginning with blue hydrogen and transitioning to green hydrogen. In New Mexico, Escalante H2Power is converting a decommissioned coal-fired power plant into a first-of-its-kind facility that will allow for the production and use of blue hydrogen in electricity generation.

These projects demonstrate the region's readiness to deploy hydrogen as a part of its energy economy. In the case of blue hydrogen production, the region has abundant natural gas resources and infrastructure, along with ample capacity for storing the captured CO_2. In the case of green hydrogen production, significant wind and solar resources present a great opportunity for the region to eventually transition to green hydrogen as electrolysis technology advances and costs come down. Additionally, the region could become a major exporter of hydrogen, moving forward quickly with a multi-pronged strategy in which hydrogen production approaches evolve over time.

Water use poses one potential challenge to regional hydrogen production. Both SMR and electrolysis use water for cooling, and electrolysis uses water as a feedstock. The latter usage requires very clean water, while the former can in principle use a lower quality water resource. Hydrogen production at large scale and using conventional technology could introduce water needs at a level comparable to the current water use in the region for thermoelectric power (it should be noted that thermoelectric power accounts for roughly 1 percent of current water use in the region). There are several options for a regional solution that significantly lowers water needs in hydrogen production, including the use of air-cooled technologies or nontraditional water for cooling. Nontraditional water includes salty water that is brought to the surface of the earth during fossil fuel extraction (i.e. oil, gas, and coal). Such strategies could lower water needs for hydrogen production by as much as 90 percent.

Although the Intermountain West benefits from significant natural gas infrastructure, the region lacks infrastructure to transport and distribute the hydrogen from production to market. Research will be needed to explore the feasibility of converting natural gas pipelines into hydrogen pipelines. Workforce training will also be required to sustain new hydrogen production and transport projects.

Key findings

The Intermountain West region has a broad set of resources for building a hydrogen economy, including natural gas and renewable energy like solar and wind. Hydrogen produced using methane as a feedstock offers a regional pathway for starting a hydrogen economy early, with plans to transition to renewable-based electrolysis as technology evolves and costs decrease.

An I-WEST life-cycle assessment of hydrogen production via SMR or electrolysis shows that both routes offer reductions in greenhouse gas emissions when the hydrogen is used in a fuel cell to replace the use of petroleum-based fuels like diesel, provided methane leakage is low.

Co-location of SMR facilities for blue hydrogen production with facilities for natural gas extraction could be a regional strategy to reduce the need for additional pipeline infrastructure for the methane feedstock. Many of these locations may also be suitable for CO_2 storage, similarly minimizing infrastructure needs. Finally, co-location of SMR facilities at or near natural gas production sites could minimize the potential for methane leakage. Hydrogen production offers an opportunity for sovereign nations and rural communities currently dependent on fossil economies to become hydrogen exporters. With sufficient workforce development, facilities for hydrogen production have the potential to become large employers. Escalante H2Power's blue hydrogen project, for example, will create approximately 200 jobs. Blue hydrogen production would have the added benefit of utilizing the current workforce trained and experienced in methane production, as well as creating new jobs to produce and transport hydrogen.

Hydrogen production will interface with other regional energy economies. Hydrogen may be used in the production of synthetic fuels or to power direct air capture technologies. Demand will evolve over time as hydrogen fuel cells are deployed in automobiles and for other uses. Blending hydrogen with natural gas, as the Intermountain Power Project plans to do, can reduce emissions from natural gas-fired power plants and stoke hydrogen demand. In the long term, hydrogen may become a replacement for petroleum-based fuels.

Next steps

Innovation, infrastructure investments, and social acceptance are needed to make hydrogen an economically viable carbon reduction pathway for the Intermountain West. In the case of SMR, further research is needed to assess the potential use of nontraditional water in large-scale hydrogen production. Additionally, improved understanding of the volume of emissions produced by SMR, and the extent to which these emissions can be mitigated by carbon capture and storage is needed. For example, direct data on methane leakage during the production and distribution of natural gas in the region would improve life-cycle assessments on SMR-generated greenhouse gas emissions. Such efforts are already underway; Escalante H2Power is examining ways to increase the efficiency of SMR and electrolysis, a critical step in reaching economic feasibility.

There are other hydrogen production technologies that could be well suited to the region but require additional assessment, including auto-thermal reforming, biomass reforming, and pyrolysis. For example, green oxy-combustion might also be explored. In this process, a fuel such as methane mixed with hydrogen is combusted in pure oxygen rather than air to aid CO_2 capture.

Hydrogen can be stored and deployed to help meet regional energy needs in combination with other low-carbon approaches, such as when wind and solar resources do not produce sufficient energy. Storing excess hydrogen that results from daily and seasonal mismatches in production and utilization, which also sometimes occurs with natural gas, is being considered. All of these options depend on hydrogen storage technologies that still need further research and development.

Finally, hydrogen production and storage technology must be developed in collaboration with communities where the technologies will be deployed. This involves expanded outreach to regional energy stakeholders to better understand how hydrogen will impact local jobs, natural resources, and environments, and to have a sustained dialogue with the public about potential risks and benefits. ◆

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CHAPTER 7

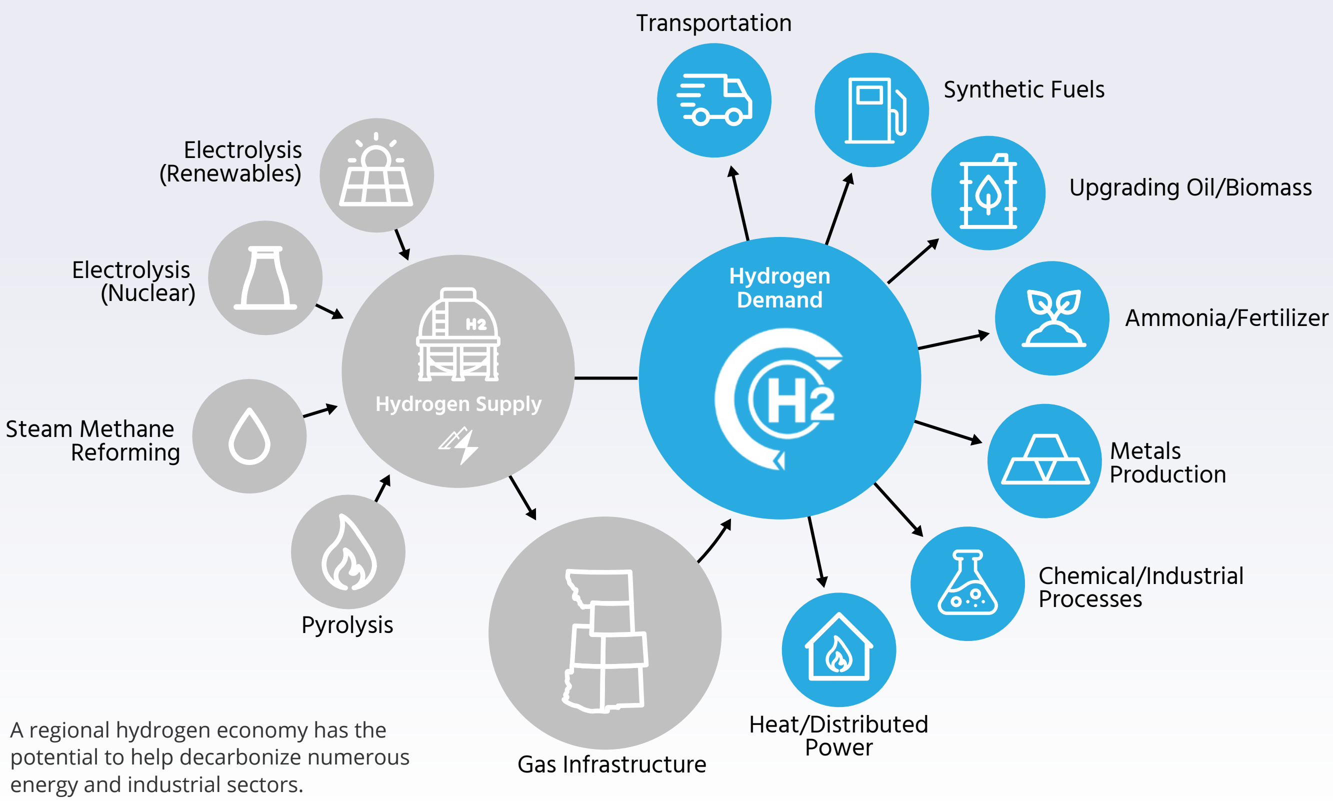
Hydrogen Demand

Hydrogen can be used in many applications. Today, its largest uses are to produce ammonia for fertilizer, and to "upgrade" some types of fossil fuels. In an evolving energy economy, hydrogen also has great potential as a carbon-neutral fuel, particularly for transportation but also for heat and electricity in industrial operations and power production. Hydrogen is an attractive fuel source because it produces zero carbon emissions when combusted (as in a turbine) or used in a fuel cell to make electricity. Hydrogen fuel can be used directly, or it can be blended and transported with natural gas to partially decarbonize natural gas consumption.

Fuel cell electric vehicles (FCEVs) operate by converting hydrogen and oxygen (from air) into electricity to power an electric motor. Emitting only water vapor and warm air, FCEVs are often more efficient than traditional internal combustion engine vehicles (ICEVs). Hydrogen fuel cell technology has existed for decades, and while a growing number of FCEVs are available commercially today, the expense of FCEVs and a lack of hydrogen infrastructure remain

Highlights

- Hydrogen is a promising pathway for reducing regional CO_2 emissions in several key areas of energy consumption, including transportation and electricity.
- As hydrogen production projects ramp up across the Intermountain West, technologies and infrastructure to enable widespread utilization will also be needed.
- Widespread adoption of FCEV in the region will likely be slow, but in the short term, replacing medium-heavy trucks would be the most cost-effective route to reducing highway vehicle CO_2 emissions.



A regional hydrogen economy has the potential to help decarbonize numerous energy and industrial sectors.

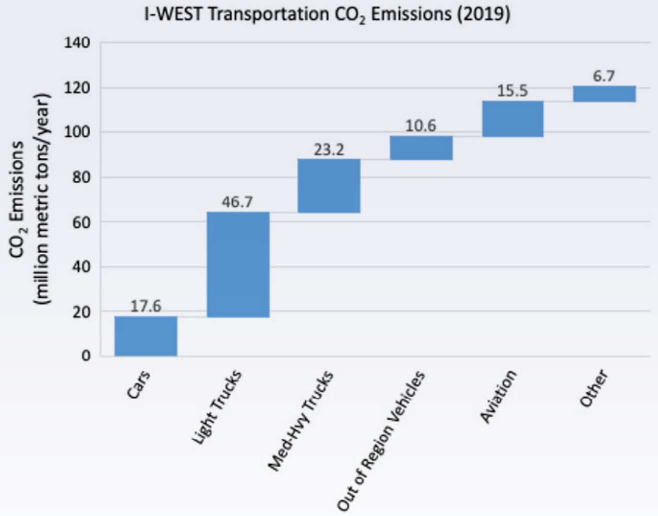
barriers to widespread adoption. In California, which leads the nation in FCEV adoption, state and private funding have made possible the construction of some 50 hydrogen fueling stations, with more expected to come online soon. FCEVs sold in California come with fuel vouchers and rebates from the California Clean Vehicle Rebate Project, although these measures have yet to encourage adoption at a level comparable to that of battery electric vehicles.

Hydrogen can be blended with natural gas to reduce emissions from natural gas-fired power plants. Additionally, blended natural gas can reduce emissions when used in consumer appliances like furnaces, heaters, and stoves. Research suggests that consumer appliances can combust fuel that is up to 20 percent hydrogen. At present, fuel blending has achieved little commercial adoption, although projects in the United States—including by SoCalGas, which in its testing facility has blended and used up to 20 percent hydrogen in household appliances—have demonstrated hydrogen blending's feasibility. In 2021, German energy provider Avacon began to distribute natural gas blended with 10 percent hydrogen to consumers. The company plans to blend up to 20 percent hydrogen into its natural gas by 2023.

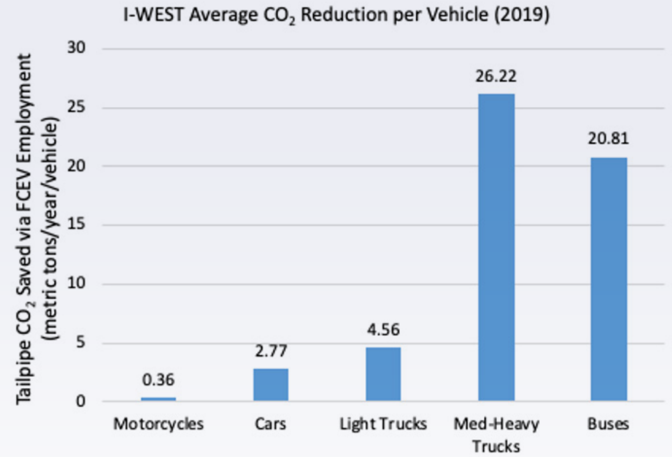
Regional relevance

Hydrogen is a transition technology that has the potential to supplement the Intermountain West's current fossil-energy production portfolio while also taking advantage of the region's significant solar, wind, and geothermal resources. At present, there is no hydrogen production in the Intermountain West states, but several production facilities are being developed. As production increases and new technologies are developed, hydrogen has the potential to become an affordable regional energy source.

Currently, there is no deployment of FCEVs or fuel blending in the Intermountain West, but FCEVs may be well suited to the geographically diffuse region due to their greater range relative to battery electric vehicles. Like gas- or diesel-powered vehicles, FCEVs can be fueled in minutes and have a driving range of over 300 miles. To spur FCEV adoption, hydrogen fueling stations will need to be constructed in the region in time



In 2019, emissions from the transportation sector in the assessed states totaled 120.3 million metric tons. Light trucks include all trucks under 10,000 pounds, as well as minivans and SUVs. “Other” includes CO_2 emissions from motorcycles, buses, RVs, rail, and marine sources.



Average annual CO_2 reduction that could be achieved by replacing an internal combustion engine vehicle (ICEV) with a fuel cell electric vehicle (FCEV). Based on 2019 data.

to meet FCEVs consumer needs. A lack of FCEV manufacturers relative to the number of battery electric vehicle manufacturers poses a barrier to adoption.

Hydrogen blending can be accomplished without significant alteration to the region’s natural gas infrastructure. However, because hydrogen has the lowest energy density by volume of any fuel, natural gas mixed with hydrogen is less efficient, which leads to increased overall fuel consumption by consumers. Although net emissions from blended fuel will still be lower than emissions from unblended natural gas—natural gas blended with 20 percent hydrogen should yield a 6-7 percent reduction in CO_2 emissions—greater consumption of fuel by volume entails a higher cost to consumers, which may lead to consumer pushback.

Key findings

While FCEV adoption in the Intermountain West is likely to be slow, the potential impacts of replacing all internal combustion engine vehicles (ICEV) in the region with FCEVs are significant. At full deployment, FCEVs would eliminate approximately 88.9 million metric tons of tailpipe CO_2 emissions, or roughly one-quarter of annual regional CO_2 emissions. This would require hydrogen production on the order of 1.6-4.7 million metric tons annually. While wholesale adoption of FECVs is not feasible in the near term, benefits of partial adoption can still be significant.

One such scenario would be to replace all medium-heavy (class 3-8) vehicles, including work trucks and freight trucks, with FCEVs. As a group, these vehicles emit 23.3 million metric tons of CO_2 per year. If replaced with FCEVs, this would yield an average savings of 26.2 metric tons of CO_2 per vehicle annually. Even though medium-heavy vehicles only represent 5 percent of vehicles in the region, collectively they would represent a 26 percent reduction in tailpipe CO_2 if replaced with FCEVs. This is due to (1) the high number of miles that these work trucks, as well as long- and regional haulers, drive each year compared to other highway vehicles, and (2) the significantly larger amounts of diesel fuel that the medium-heavy truck group consumes compared to other highway vehicle classes.

A scenario in which trucks weighing 10,000 pounds or less (including SUVs and minivans) are replaced with FCEVs would require more widespread adoption of the technology. These “light trucks” represent 55 percent of vehicles in the region, and contribute the most CO_2 emissions as a group—approximately 46.8 million metric tons of CO_2 per year. If replaced with FCEVs, this would yield an average savings of 4.6

metric tons of CO_2 per vehicle annually. Collectively, this would represent a 53 percent reduction in tailpipe CO_2.

These preliminary studies suggest that replacing medium-heavy diesel trucks with FCEV is the highway transportation pathway most likely to provide the best decarbonization efficiency in the short term—meaning the largest CO_2 reduction for the lowest cost or effort. Additionally, this could be accomplished with only 25-35 percent of the hydrogen that would be necessary to replace all vehicles in the region.

Another scenario I-WEST considered is replacing buses with FCEVs, which would yield an average savings of 20.8 metric tons of CO_2 per vehicle annually. While buses only represent about 1 percent of the region's highway tailpipe CO_2 emissions—approximately 0.9 million metric tons of CO_2 per year—there could be ancillary benefits to making the switch. Because buses are usually fleet vehicles owned or leased by a business, government agency, or other large organization, there is likely more federal and state funding available to help establish the necessary infrastructure to support a hydrogen-based transportation sector. Having more hydrogen transportation and filling stations around the region will help increase access to fuel for non-fleet vehicles as well.

Regional CO_2 emissions can also be reduced if natural gas suppliers employ hydrogen-natural gas blending. To result in a meaningful emissions reduction, the hydrogen used in fuel blending would need to be green hydrogen—that is, hydrogen produced with electrolysis powered by renewable energy. Green hydrogen production, which is not commercially scalable at present, would make use of the region's ample wind and solar resources. Green hydrogen might also have applications in petroleum refining, and it can be further processed into ammonia to bolster fertilizer production. Blue hydrogen, which is produced by reforming natural gas and using carbon capture and storage, and which at present yields some CO_2 and methane emissions, may be better suited for FCEVs than for natural gas blending.

Hydrogen blending will require cooperation between producers and consumers. Because hydrogen is a lighter gas, it is more prone than natural gas to leakage in transportation and storage, posing an economic risk for producers.

Next steps

Additional research is needed to better understand the potential benefits and risks related to hydrogen utilization across regional transportation and power sectors, including impacts on the economy and environment. Focusing on the transportation sector, future work regarding FCEVs in the Intermountain West will require a granular look at vehicle data to more clearly identify CO_2 emissions coming from various transportation sources. Risks associated with FCEV pollutants, including various gasses and particulates, also need further evaluation. Finally, an in-depth evaluation of the economic and policy conditions necessary to begin and accelerate adoption of FCEVs within the region is needed in order to develop a reasonable strategy and timeline for the technology to have a measurable climate impact.

Focusing on the power sector, more detailed analyses on natural gas blending and broader power applications are needed to determine where, and under what conditions, hydrogen can play a role in a regional energy roadmap.

Future work to create a regional demand for hydrogen must be done in coordination with experts working on strategies to scale up production. This requires that all sides carefully consider the technological, economic, and environmental factors that are unique to the Intermountain West region, including how hydrogen production can be scaled up to support demand while minimizing impacts on local water resources and maximizing opportunities for the regional workforce. ◆

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CHAPTER 8

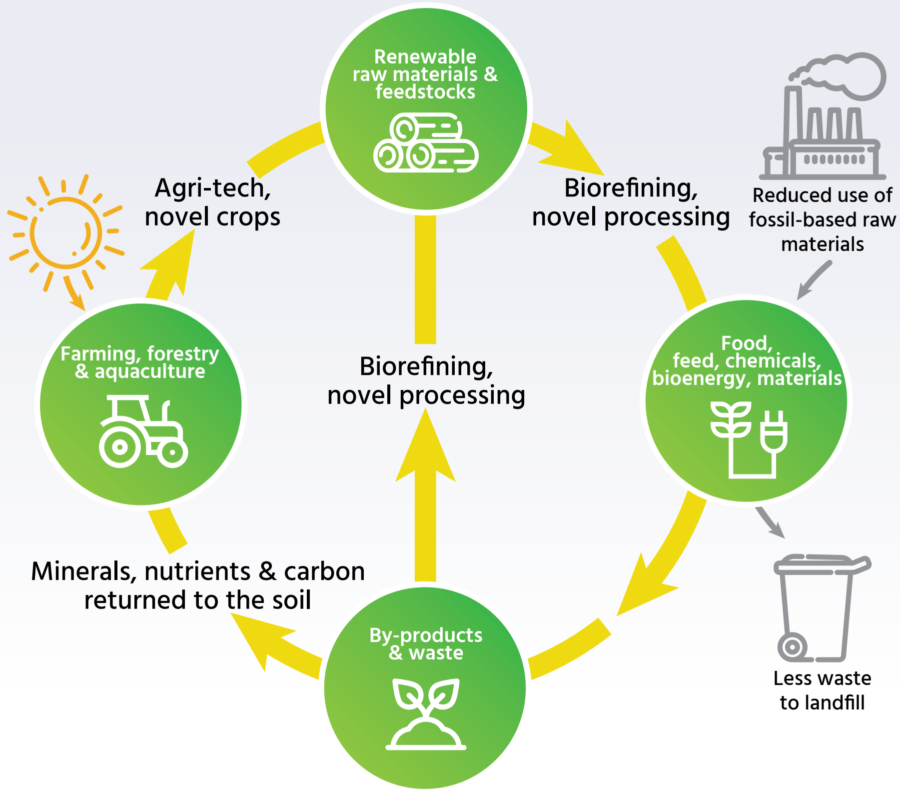
Bioenergy

The term “bioenergy” refers to a diverse set of technologies that convert organic materials into renewable energy for heat, electricity, or liquid fuel for transportation. These organic materials also have a complex tie to hydrogen: they can be converted to a more usable fuel with the addition of hydrogen, or they can be used as a feedstock to produce hydrogen, thereby creating a hydrogen supply and demand.

The organic materials used in these processes, known as feedstocks, can be food or crop wastes, forest residues, microalgae, or other substances. Bioenergy technologies use various conversion processes such as combustion or bacterial decay to repurpose the carbon inherent in these resources, or gasification and liquefaction to convert resources into gas or liquid fuels like ethanol or biodiesel. In short, bioenergy technologies can produce alternatives to fossil fuels and can replace fossil energy feedstocks, yielding lower CO_2 emissions in both production and use.

Highlights

- Abundant sunshine, wind, and solar potential in the Intermountain West present opportunities for building a regional bioeconomy, but challenges such as water scarcity must be considered.
- Although bioenergy is currently a small industry in the region, numerous projects are emerging to deploy technologies that could help grow a more robust bioeconomy.
- A distributed model of small-scale technologies that engages local communities may also help accelerate bioenergy industry growth in the region.
- Synergies with bioenergy, agriculture, and forestry industries are opportunities to grow regional bioenergy technologies, but competition for natural resources must be minimized.



The bioeconomy represents the infrastructure, technologies, and processes needed to produce energy and products from organic materials. It is a circular carbon economy, which is more sustainable than the linear carbon economy mainly in use today. I-WEST is exploring how a regional bioeconomy can help reduce dependence on fossil fuels, reduce carbon emissions, and generate less waste, while driving new economic growth.

Bioenergy technologies are in various stages of readiness, ranging from research and development to commercial deployment. First-generation biofuels, for example, are well established. These fuels are made from food crops such as corn, sunflower oil, and sugarcane, which can be processed into fuels like ethanol and biodiesel. Second-generation biofuels, which are made from wood, organic waste, food waste, and crops grown specifically for bioenergy, are in various phases of development. Third-generation biofuels are made from lipids produced by algae and used as liquid fuel for transportation (e.g., biodiesel). While this is still an emerging field, it holds great potential—algae is energy-dense and can grow in areas unsuitable for first- or second-generation biofuel crops, and with reduced requirements for water and fertile land.

Regional relevance

At present, bioenergy is a small industry in the Intermountain West, due in part to the region's relatively small agricultural economy. Still, there are a number of active and emerging projects to deploy modular, portable, and standalone technologies as well as integrated circular systems.

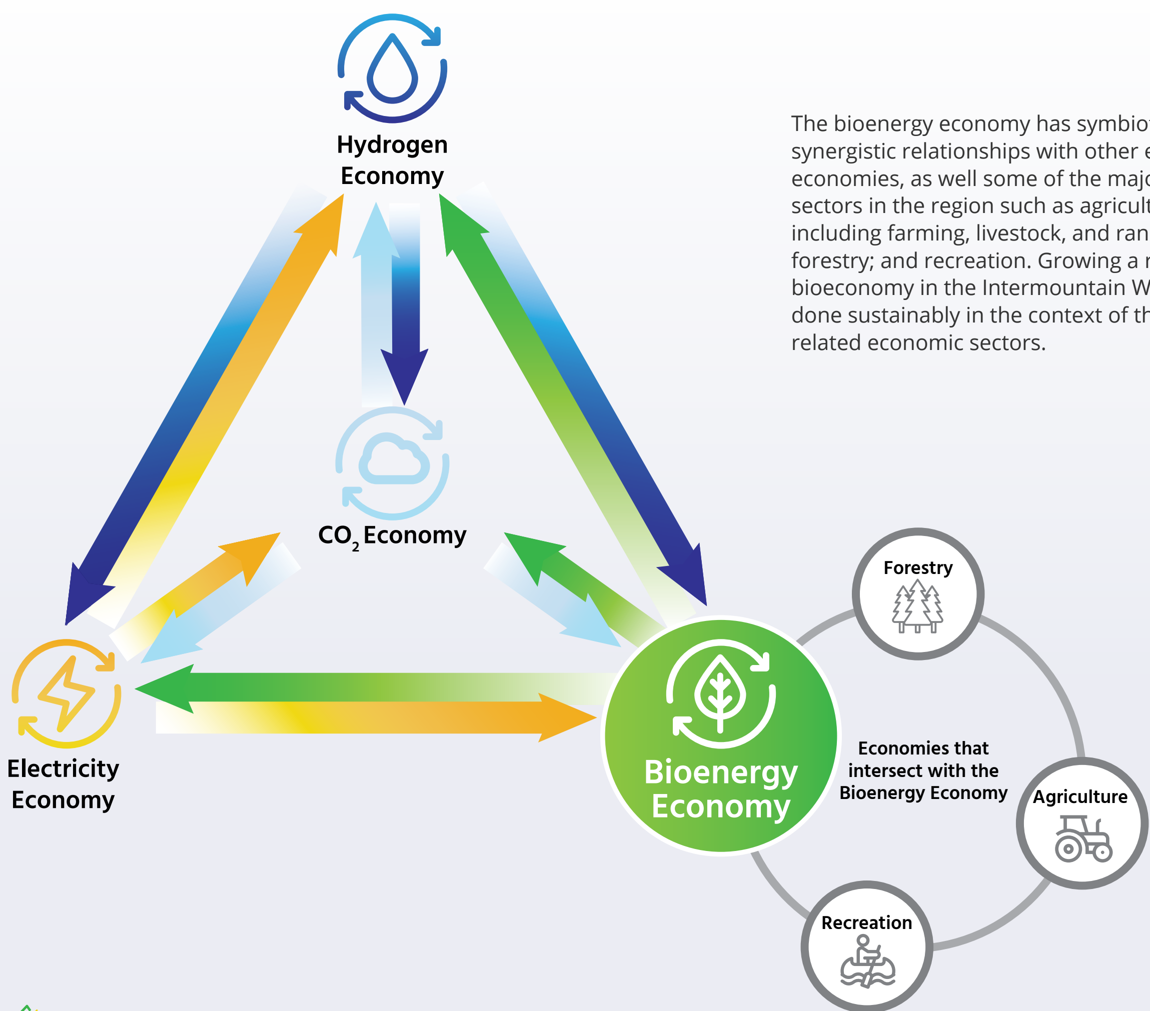
These technologies convert a variety of biomass feedstocks and organic wastes into biogas or other bioenergy products. For example, Novo BioPower in Arizona, which has been operational since 2008, collects broken branches, wood chips, and undergrowth vegetation from the nearby northern White Mountains region and turns it into electricity. In the fall of 2022, Montana Renewables will begin processing up to 15,000 barrels per day of renewable feedstocks, (i.e., seed oils, used cooking oils, and tallow) into low-emission alternatives to fossil fuel.

Algae production could be ideally suited to the Intermountain West, taking advantage of the region's abundant sunshine to promote algae growth and renewable energy (particularly solar and wind) to power the processes that convert algal lipids to usable fuel. Furthermore, an algae-to-fuels economy could leverage the existing regional infrastructure currently being used for processing and distributing fossil fuels. Although algae production requires the use of water (a limited resource), there are opportunities to utilize low-grade (i.e., salty), nontraditional waters present in the region, which algae can tolerate. Specifically, water as a byproduct of oil and gas production, or water co-extracted with fossil feedstocks, could be used by algae in third-generation biofuel production. Microalgae can be grown in indoor systems, in greenhouses, or in specialized photobioreactors that can be temperature and light controlled, much like industrial fermentation systems. The southernmost parts of Arizona and New Mexico are especially well suited for open pond algae cultivation since the growing season would be longer there. In Montana, CLEARAS is using microalgae grown in photobioreactors to clean up wastewater, and then harvest the microalgae biomass for use in a range of products, from fuels and plastics to fertilizers, inks, and textiles.

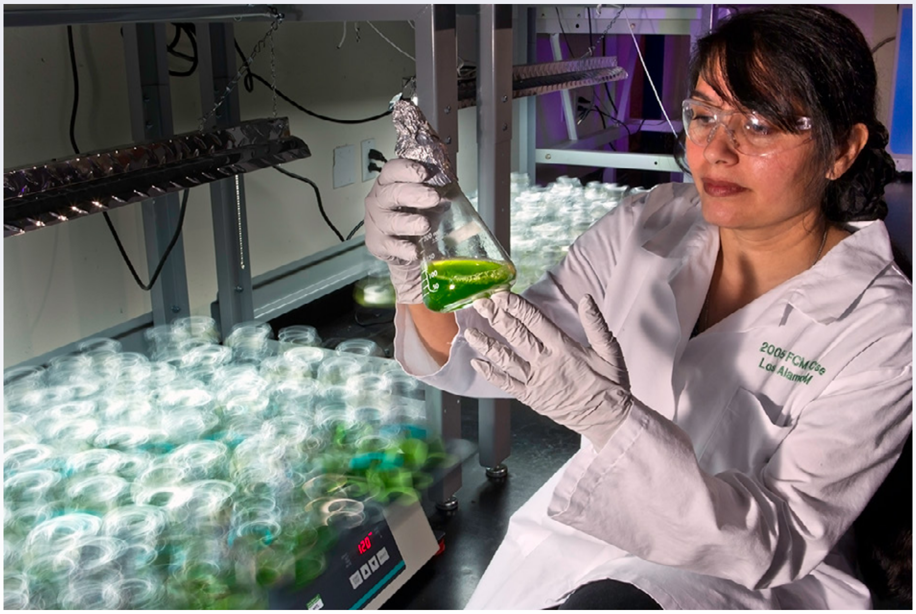
At present, growth of a bioenergy economy in the Intermountain West is stymied in part by a lack of demand for bioenergy products. Regional demand for biofuels might increase if a low-carbon fuel standard were implemented on a state-by-state basis. Other challenges to bioenergy production include the region's size, which precludes centralized biorefinery concepts of the kind that have been implemented elsewhere, and the broad array of feedstocks needed for a variety of technologies. One way to address this obstacle would be to focus on localized feedstock processing, which would reduce the need to transport the biomass from one location to another. For example, Trio Renewable Gas has designed trailer units that allow for mobile feedstock pyrolysis.

Key findings

The Intermountain West has many attributes that could give it an advantage in biofuels, including high solar incidence to produce biomass, as well as solar and wind resources that could be harnessed to process biomass feedstocks into biofuels. One potential limitation is water needed for biomass production; this limitation could be minimized by utilizing nontraditional waters or biowastes for some feedstocks. The Intermountain West has ample unused land that could be used for bioenergy crop



The bioenergy economy has symbiotic and synergistic relationships with other energy economies, as well some of the major economic sectors in the region such as agriculture, including farming, livestock, and ranching; forestry; and recreation. Growing a robust bioeconomy in the Intermountain West must be done sustainably in the context of these other related economic sectors.



Scientists are investigating how to use captured industrial waste gases to fuel advanced algal systems. Various strains of algae are able to absorb large amounts of inorganic carbon, such as CO_2, and convert it to biomass using the energy from the sun. This algal biomass can produce 3-10 times the yield of traditional crops per area unit It is also rich in lipids and carbohydrates, and is suitable for conversion to high-performance fuels and products. Continued advancement of algal system technologies will increase demand for captured carbon and other greenhouse gases used to "feed" algae, contributing to the new, integrated bio- and carbon economies.

production, or restored using biochar for agricultural processes that support bioenergy production. Regional waste resources, including forests that have been affected by wildfire, drought, or pests, might be harvested for bioenergy or bioproducts production.

A regional bioenergy economy would intersect with other economic sectors. Crops for bioenergy might be grown on unusable land, and wastewater from coal and gas production could be used in bioenergy production. Given the close ties between bioenergy and bioeconomy-related technologies with other sectors, it is important to ensure that there is minimal competition for resources such as fresh water and land use. Because algae consume CO_2, algae production may be a way to repurpose CO_2 captured from industrial sources, such as coal- and natural gas-fired power plants or blue hydrogen production. Biomethane production from anaerobic digestion is a promising source of renewable natural gas to replace conventional natural gas. There are hundreds of biogas facilities in the U.S. associated with hog and dairy farms including in the Intermountain West; for example, the Smithfield Foods and Dominion Energy project in Utah.

Workforce training will be necessary to support a bioenergy economy in the region. Collaborations with local academic institutions can increase regional readiness for adoption of these technologies, including through vocational programs and by incorporating bioenergy curricula into existing academic programs. Collaborations between bioenergy project developers and local communities will help ensure workforce readiness.

Next steps

Increased development of bioenergy technologies with relationships to other established economic sectors could help provide a stable foundation for growth of the bioenergy economy in the Intermountain West. For example, agrivoltaics—the practice of using farmland simultaneously for solar energy and agricultural production—can reduce CO_2 emissions from agricultural sources. There are current efforts to integrate agrivoltaics into bioenergy production in the Intermountain West, including at Tucumcari Bioenergy and Trollworks in New Mexico. The ability to grow algae in greenhouses on the same land as solar electricity generation would extend the growing season of outdoor algae cultivation operations, while achieving low-carbon algae cultivation for biofuels, bioenergy, or bioproducts.

Additionally, since all terrestrial plants, as well as aquatic photosynthetic bacteria and algae, need CO_2 to make biomass, co-locating greenhouses and/or algae cultivation ponds or photobioreactors with CO_2 emitting industries (i.e., power plants, biorefineries, etc.) would allow captured waste CO_2 to be used to enhance biomass growth and yield, without the expense of transporting the CO_2. An additional benefit may be the use of "free" low-quality heat from power plants that may be used to heat cultivation environments.

Finally, biohydrogen is hydrogen produced biologically from microorganisms: algae or bacteria. Microalgae are capable of producing high levels of carbohydrates such as starch or cellulose, which are ideal substrates for hydrogen production. Sustainable processes could be developed where the production of biohydrogen from microalgae is integrated with industrial CO_2 utilization, or cultivation in municipal wastewater or produced water.

In terms of feedstocks, the water-stressed Intermountain West is in a good position to lead the way in using non-traditional water sources to develop a bioeconomy based on second- and third-generation biofeedstocks, CO_2, municipal solid waste, forest and crop residues, and microalgae.

Advancing the development of small, modular, process-intensification technologies would make bioenergy and bioproduct production accessible to rural as well as urban communities for more modest investments than construction of large-scale, central biorefineries. The ability to bring a small portable pyrolysis unit to the site of harvesting to process biomass would be a gamechanger for converting alternative biomass feedstocks, such as forest residues into syngas. Likewise, hydrothermal liquefaction systems and anaerobic digesters are smaller in scale and can be used on location to process biomass or waste carbon feedstocks into fuel or energy intermediate products.

Further research could elucidate how best to optimize regional bioenergy production, taking into account all of the potential feedstocks (biomass and alternative waste carbon feedstocks) and available resources (water, land, existing infrastructure, etc.). Deployment of pilot or demonstration projects in communities across the Intermountain West, in conjunction with bioenergy industry partners, would help advance technologies and increase community engagement. Resultantly, bioenergy technologies would become more widespread in the region.

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CHAPTER 9

Low-carbon Electricity

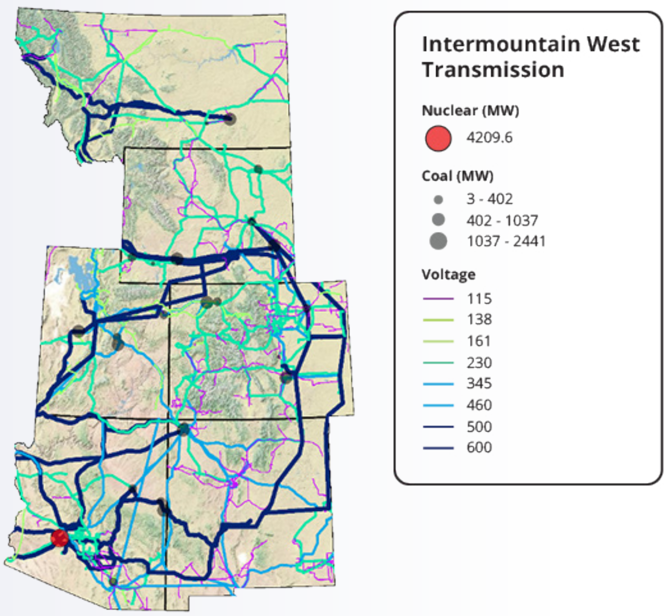
Most of the electricity produced in the United States today is generated from natural gas, coal, and nuclear energy. One-third of all domestic energy-related CO_2 emissions are from the electric power sector. Demand for electricity is only expected to grow, so further developing low-carbon technologies for this sector is a key component to achieving carbon neutrality.

Fossil-based electricity facilities can significantly lower emissions via multiple technologies. The primary technology for retrofitting existing fossil-based facilities involves capturing CO_2 and storing it permanently and safely underground; this technology is commercially available and can reduce facility emissions by over 90 percent. Some natural-gas power plants are experimenting with blending natural gas with hydrogen for energy production as a transition pathway that can significantly lower CO_2 emissions, provided the hydrogen is produced via a low-carbon route.

Nuclear power can provide "baseload" or energy generation that can meet power demands 24 hours a day. Small modular reactors (SMRs) are advanced nuclear reactors that have a much smaller generating capacity than traditional reactors (producing up to 300 megawatts, or one-third the power of many traditional reactors). Still, SMR modules can be assembled in a factory and transported to a specific location, making

Highlights

- Fossil-based power plants are the largest sources of electricity in the Intermountain West, making the electricity sector a critical component in a regional decarbonization strategy.
- Transitioning to low-carbon pathways for electricity generation could reduce regional emissions by roughly 80 percent.
- As an energy exporter to other western states like California, the Intermountain West is being challenged with rising demands for low-carbon electricity.
- While there is high potential for more renewable energy in the region, additional research is needed to address challenges related to energy storage.



High-voltage lines (500-600 kV) around the Intermountain West are currently anchored by coal- fired power plants. The Palo Verde nuclear power plant in Arizona also anchors several high-voltage lines, and exports electricity to the West Coast. As coal-based power plants are phased out in the energy transition, the “baseload” they provide will need to be replaced. Baseload power refers to the minimum amount of electric power needed to be supplied to the electrical grid at any given time.

them more affordable to construct than traditional nuclear power plants. SMRs are generally designed to be simpler and safer than traditional reactors and require less frequent refueling. It’s important to note that, while SMRs do not emit CO_2, they do produce radioactive waste.

Wind and solar power produce no emissions but lack the ability to provide baseload. Co-locating battery systems with renewable power plants allows the batteries to be charged during times of overgeneration. The California Independent System Operator (CAISO), for example, has installed battery systems with a storage capacity of approximately 600 megawatts that charge during peak daylight hours and discharge as renewable energy production declines in the evenings. Other technologies, such as pumped hydropower—which uses wind or solar energy to lift water to a higher elevation where it can be released to generate electricity with a hydropower generator—can help store electricity in areas with adequate water resources.

Regional relevance

Electricity generation is an important component of the Intermountain West economy. According to the U.S. Energy Information Administration EIA-860 final data for the year 2021, the region generated about 90 gigawatts of installed nameplate capacity—two thirds of which was fossil-based—and about $22 billion in annual revenues from electricity sales. The electricity sector is also the largest emitter of CO_2 in the region. Hence, while transitioning electricity generation to carbon neutrality is imperative, it will have a significant impact on the region’s economy. It will also involve deploying a breadth of technologies in a variety of possible configurations, including capturing emissions at fossil-based facilities or switching those facilities to a carbon-neutral electricity generation technology. In the latter case, some technologies can provide baseload capacity (in other words, they can operate continuously), whereas others produce electricity at different rates throughout the day/year and require the ability to store excess electricity until it is needed.

Coal- and natural gas-fired power plants are by far the largest regional sources of electricity in the Intermountain West. At present, the region has a total installed capacity of 90,568 megawatts per year of energy production, of which 33,160 megawatts are derived from natural gas and 24,008 megawatts from coal. The region’s reliance on natural gas, and its abundant natural gas resources, mean that natural gas/hydrogen fuel blending projects will be especially beneficial in reducing regional emissions. For example Utah’s Intermountain Power Agency is converting a coal-fired power plant to a natural gas plant that, beginning in 2025, will employ a blend of 30 percent green hydrogen and 70 percent natural gas for co-firing. The plant is expected to transition to 100 percent green hydrogen—that is, hydrogen produced from the electrolysis of water using renewable energy—by 2045 as technology improves.

Hydroelectric plants in the region account for the next highest generation capacity for electricity, with an installed capacity of 7,400 megawatts, much of which is in Arizona. Persistent drought conditions in the region threaten hydroelectric production in the future.

Arizona is also home to Palo Verde (currently the only nuclear power plant in the Intermountain West), which has an installed capacity of 4,209 megawatts. SMR projects are underway in the region, including one by TerraPower in Wyoming, and one by Utah Associated Municipal Power Systems, which plans to buy six small reactor units at Idaho National Laboratory.

Wind farms have a current capacity of 14,556 megawatts, and there is great potential for further wind installations east of the Rocky Mountains. Solar production is growing in the region—with a current installed capacity of 6,178 megawatts, the four southern states of Arizona, New Mexico, Utah, and Colorado have the largest solar potential. Despite the Intermountain West's strong potential for further expanding renewables, grid-scale energy storage such as the type employed by the California Independent System Operator (CAISO) will be necessary if the region is to take full advantage of its solar and wind energy resources.

The region also has abundant potential for geothermal energy, but currently only 109 megawatts installed capacity is available across Utah and New Mexico. Further research will be needed to make this technology viable.

Key findings

Modeling suggests that the Intermountain West can pursue a variety of pathways to carbon neutrality. By deploying carbon capture, utilization, and storage (CCUS) technology and SMRs; retrofitting natural gas-fired power plants with technologies to burn blended fuel; and increasing storage capacity for renewable energy, the region may be able to reduce emissions from 166 million tons of CO_2 per year to 26 million tons per year.

Adding new energy generation in the Intermountain West will necessitate increased transmission capacity, storage, and reserves. The replacement of fossil fuel energy resources with renewables has created a backlog of requests for interconnection with regional transmission and distribution grids. Expanded transmission pathways to the West Coast, where the Intermountain West exports energy, are needed. In the future, a workforce that understands both energy production and inter-state energy transmission will be critical.

The Intermountain West's existing energy infrastructure can be an advantage to some project leaders planning new energy projects. For example, blue hydrogen production technologies might be installed at retired coal plants where transmission and water supplies are already present, reducing the need for new infrastructure and utilizing natural gas resources. The Escalante H2Power project in New Mexico is upcycling obsolete coal-fired power plants into zero-emission hydrogen-fired power generation plants.

Next steps

Further research is needed to help address challenges facing states that envision greater use of renewable energy. This includes New Mexico, Arizona, Utah, and Colorado, which among assessed states have the most solar potential, and Wyoming and Colorado, which have the most wind potential. Energy transition models that incorporate more renewables into regional energy systems assume the addition of battery systems that increase capacity for electricity storage from approximately 109 megawatts to more than 5900 megawatts. In-depth analysis is needed to better understand the supply chain challenges related to battery acquisition, as well as the costs associated with the implementation of these new energy technologies.

The western part of the U.S. is home to more than a dozen regional transmission organizations (RTOs). These organizations, like CAISO in California and the Electric Reliability Council of Texas (ERCOT), include power generators, transmission companies, utilities, and power marketers, and use complex optimization software to dispatch power based on day-ahead and real-time bids from generators and utilities. Research is needed to investigate the potential benefits and risks of developing a single RTO for the Intermountain West region. ◆

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CHAPTER 10

Environmental, Energy, and Social Justice

Communities will undergo numerous intersecting transitions as they move toward carbon-neutral energy production and consumption. For example, transitioning to renewable energy like wind and solar will require modifications to the electrical grid, which could change local infrastructure. In regions with deep roots in energy industries, these transitions will have widespread impacts, and each community and state will experience unique changes. Furthermore, each energy project will have social and environmental impacts, and the transition may influence access to and the cost of electricity.

Collectively, energy transitions create an opportunity to advance environmental, energy, and social justice. These principles have been integrated into a federal initiative called Justice40, which requires federal agencies to ensure that 40 percent of the benefits from federal climate and clean energy investments benefit communities facing structural disadvantage and disproportionate environmental burdens. The Justice40 initiative is the latest step in the federal government's commitment to environmental justice. The first environmental justice directive was introduced in 1994 as Presidential Executive Order

Highlights

- While energy production has afforded the region with economic benefits, there have also been health and environmental costs; going forward, communities want to be involved in processes to evaluate the benefits and risks of new energy technologies.
- A place-based approach is needed to understand the unique social, economic, and environmental aspects of the region and its stakeholders, including its 63 sovereign nations.
- Federal initiatives, such as Justice40, demonstrate a renewed commitment to ensure climate and energy investments benefit disadvantaged communities.

12898, which recognized that communities of color, indigenous peoples, and low-income communities faced disproportionate and unjust exposure to environmental harms.

Governmental and non-governmental parties alike have identified three different components necessary to advancing environmental justice in future projects: distributive, procedural, and restorative justice. Initial efforts primarily focused on distributive justice or how harms and benefits from different industries, manufacturing, or production sites are distributed among different social groups and places. More recently, demand for a more holistic approach has led to the inclusion of procedural and restorative justice. The former includes processes to develop collaborative efforts where affected communities have meaningful involvement in decision-making processes. Restorative justice recognizes that past public action has produced inequality and ongoing harm, and points to the need for new actions to address structural disadvantages such as increasing available opportunities to disadvantaged communities or remediating environmental burdens they face.

Regional relevance

The Intermountain West has a long history of fossil-based energy production, resulting in strong socio-cultural ties to energy industries. Much of the region's infrastructure, workforce, and economy is built around oil and gas industries. At the same time, some communities were not informed and/or did not fully realize the potential adverse impacts of energy production. The region developed abundant energy that came with local environmental costs, and yet, not all communities or households benefited from access to electricity or energy industry jobs.

I-WEST takes a broad approach to advancing justice, considering how energy transition will impact (1) access to and the cost of energy, (2) local land use and environmental change, including water, soil, and cultural landscapes, and (3) social change, importantly jobs and tax revenues, as well as transportation, housing, and cultural change. This approach recognizes the inevitable tradeoffs that come with each energy project or technology pathway. As communities explore opportunities for new energy economies, they will also have to evaluate environmental and social challenges that could arise throughout the supply chain, from energy extraction to waste disposal. As an example, mining in the Intermountain West has resulted in a disproportionately high rate of lung disease, particularly in tribal communities. Jobs created by low-carbon energy sectors will likely have few of these types of health risks, but the tradeoff may be that those jobs benefit different communities, leaving coal mining communities behind economically.

The pace of the transition will also present challenging tradeoffs. Rapid change could leave some energy communities behind if there is no time or opportunity for local stakeholders to be a part of the decision-making process. This is a major concern for the 63 sovereign nations in the Intermountain West region, especially those that are key actors in historical and emerging energy economies. Each has its own

In June 2022, the Arizona Corporation Commission organized public meetings in the towns of Shiprock and Farmington, NM, to gather input from local stakeholders about the impacts of power plant closures in the region. A diversity of perspectives were presented, including sentiments of worry about job losses and economic impacts to the surrounding communities, as well as urgent calls for energy transition and economic diversification to include renewable energy.

priorities and visions for the future energy landscape, and unique histories with energy production and access. Tribal sovereignty and territorial boundaries must be respected, and project developers must develop independent relationships with any nation that will be affected by a project. Any decisions that might affect their land or peoples must be made collaboratively. On the other hand, slower transitions might mean a perpetuation of inequalities from older industries, including harmful impacts of climate evolution, such as drought and water shortages.

As a resource-rich region, the Intermountain West is home to many energy communities, each of which has a store of knowledge on both the positive and negative effects of the industry. This bank of information gives the region great potential for innovation in governance to benefit communities and rectify past harms through energy transition. Initiatives like I-WEST will have a crucial role in this, as they not only focus on technology development and deployment, but also bring regional perspectives to the top of the priority list to ensure the transition is just and equitable.

Key findings

Land-based industries are integral to the identity of the Intermountain West, and communities have a deep connection to land-based resources. Farming and ranching has occurred alongside coal and uranium mining, as well as oil and natural gas extraction. New energy technologies will also have impacts on natural resources, with the potential for both benefits and harms. The key challenge will be to maximize the benefits, while ensuring that historically disadvantaged communities have an active role in evaluating the benefits and risks, and that they have a voice in the decision-making process.

The Navajo Generating Station encapsulates the complexity of energy production in the region. It was the largest coal plant in the region before its closure in 2019. The wages at the station were above average and the plant employed over 800 indigenous workers. At the Kayenta mine that fed the station, the average salary was $117,000. Together these two facilities created an economic backbone to support the surrounding areas. Despite the extensive energy production at the site, some nearby communities lacked electricity. The plant also tainted soil used by Navajo ranchers, emitted large amounts of greenhouse gasses, and polluted nearby water sources. This led to local organizations advocating to shut down the mine and the generating station while also advocating for good jobs and future economic opportunities. Environmental justice must account for who a project benefits and how, while simultaneously addressing local harms and who will experience them.

Energy transitions will require widespread collaboration amongst different levels of government, organizations, and community members. These collaborations involve more than one or two

THE WHITE HOUSE
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Justice40 Policy Priorities for Disadvantaged Communities

- **Decrease energy burden**
- **Decrease environmental exposure and burdens**
- **Increase parity in clean energy technology access and adoption**
- **Increase access to low-cost capital for current and new initiatives**
- **Increase clean energy enterprise**
- **Increase clean energy jobs, job pipeline, and job training for workers**
- **Increase resiliency in energy systems and infrastructure**
- **Increase energy democracy**

meetings—community members involved in I-WEST workshops stated a need for more engaged partnerships that develop shared goals and pathways. Using tools like liaisons and advisory committees can facilitate collaboration on individual projects and allow for involvement through all phases of a project. Intensive engagement and partnership-building takes time, and putting inclusivity and environmental justice at the forefront of an operation could help streamline technology deployment and implementation by addressing community concerns early in the process. It is important to note that fear of opposition should not preclude stakeholder involvement.

Next steps

Future deliberations on the role of energy, environmental, and social justice (EESJ) in energy transition should begin with two steps focused on relationship building. One involves developing a network of governmental and nongovernmental actors who are working on the transition and can serve as resources. The other equally important step is to collaborate on guidelines for project leaders to initiate conversations with sovereign nations around individual projects and locational decisions. The guidelines would codify the expectations for partnership building and help elevate the energy transition priorities of each tribal nation.

Many federal agencies are beginning to incorporate requirements for diversity, equity, and inclusion (DEI) into their funding opportunity announcements. For example, the DOE energy programs now require a DEI plan as part of every proposal package, weighting it between 5-10 percent in the total evaluation criteria. Funded projects are also required to report progress on their DEI goals and objectives, including metrics to measure the success of the proposed actions. While some aspects of EESJ are addressed through the DEI plans, more explicit plans for how a project will work to advance justice are needed. For example, some federal sponsors require a preliminary Environmental Justice Questionnaire, as well as preliminary Economic Revitalization and Job Creation questionnaires, as part of a proposal package. Future assessments of energy and environmental justice in the Intermountain West could be conducted to gather input from regional stakeholders on the effectiveness of these measures. Feedback gathered could help federal agencies refine and improve the EESJ requirements and evaluation criteria of future funding opportunities.

Finally, the Intermountain West can serve as an excellent testbed for innovative practices that advance EESJ. For example, exploring how federal agencies can partner with energy communities to offer regionally focused prizes or challenges for projects that build energy, environmental, and social justice innovation into demonstration projects. This would incentivize project leaders to integrate regional perspectives with technology development and deployment, creating more of an opportunity for end-users and those impacted by technology lifecycles to have active roles in projects. Successes and challenges from such initiatives could be shared through various channels, and serve as a model for other regions. ◆

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CHAPTER 11

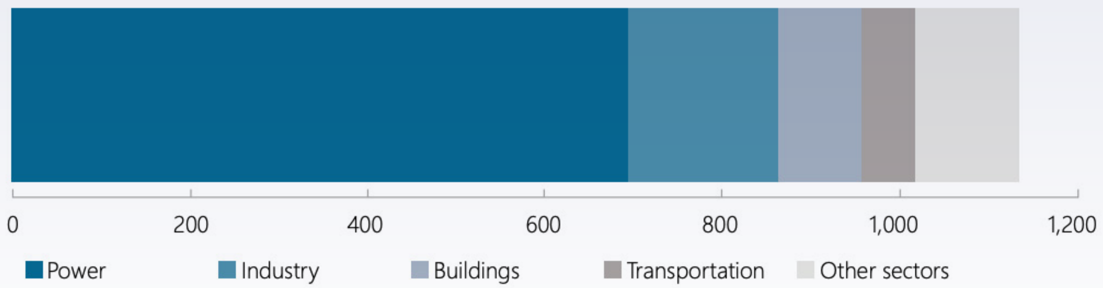
Policy

At any level of government, policies are important vehicles for driving the entrepreneurial and technological innovations that will help move us toward carbon neutrality. Policies are key to bridging the cost gap between today's energy systems and future clean energy pathways.

Federal policy can be impactful because of the amount of funding often involved and how that funding is directed, such as initiatives for innovative technology and tax incentive programs. At a regional level, federal policy can also help solve coordination issues across multiple states by providing a common regulatory context or goal, as well as the means to achieve those goals. However, due to its broad scope, federal policy can also struggle to harmonize with local nuances and needs. Furthermore, due to the challenges of national politics, federal policy has not been able to adequately address the decarbonization needs posed by climate change.

Highlights

- Aggressive decarbonization policies in nearby states have created an opportunity for the Intermountain West to access those markets by becoming a supplier of low-carbon energy.
- Federal funding for programs to support energy transition is at an all-time high, and regional-level coordination to increase access is an area of opportunity for the Intermountain West states.
- While several state-specific energy plans or pieces of legislation exist, an integrated framework would give the region a competitive advantage.



Estimated greenhouse gas emissions reductions (million metric tons) in 2030 from the Inflation Reduction Act and Bipartisan Infrastructure Law. Source: US Department of Energy

Congress recently passed two huge pieces of energy-related legislation (the Bipartisan Infrastructure Law and the Inflation Reduction Act) that present state and local governments, companies, and others with many well-funded programs to speed the deployment of low-carbon energy technologies. At the same time, the political dynamics in Congress have stalled regulatory policies, such as a carbon tax or performance standards, which complement deployment policies and can more efficiently drive economies toward both near-term CO_2 reductions and long-term innovation-driven reductions. This situation creates a huge opportunity for non-federal actors to take an active role in creating regulatory programs, as well as targeting additional innovation funding and addressing inter-state coordination and other challenges.

Integrating environmental, energy, and social justice (EESJ) considerations into policies is a critical dimension. EESJ adds complexity to the policy development process, as it necessitates additional time for innovation and collaboration between policy makers, communities, and technology developers and deployers. There may also be costs associated with certain laws and regulations that ensure a just energy transition, but federal policies are already taking that into account and specific funds have been earmarked for EESJ-focused projects (e.g., the Justice40 Initiative). Certainly, the states could do more to support these initiatives. A further complication is that EESJ groups have a wide range of opinions on how to reduce our carbon footprint and how quickly that should occur. Thus, there may well be tradeoffs between addressing EESJ needs that satisfy all stakeholders and reaching decarbonization goals in an economically feasible way. The states are probably in the best position to strike the right balance. Regardless of whether or not all stakeholders are satisfied with the final policy decisions, states can seek to ensure that all interested parties have a voice in the decision-making process.

Regional relevance

Within the Intermountain West region, the degree to which fossil fuels dominate the energy sector poses a real challenge. Many communities, and in some cases entire states, have become heavily reliant on these industries; thus, any sort of transition would ideally include policies to help those communities manage the transition. The region also faces serious coordination challenges. Integration across the energy grid among the states is lacking, leading to a disjointed infrastructure framework that must be remedied for decarbonization efforts to succeed. Addressing this will be a significant challenge, as the states are at different stages in terms of developing and enacting their own energy policies. Permitting reform and inter-state coordination to help build infrastructure is another similar opportunity.

Even with the numerous challenges the region faces, there are plenty of opportunities that can be leveraged. The presence of ambitious decarbonization policies in nearby states like Washington, Oregon, and California creates an opportunity for Intermountain West states to access those markets by becoming low-carbon energy suppliers. This could incentivize the construction of low-carbon energy production plants (such as renewable electricity generation, hydrogen production, and biofuels production) and infrastructure to connect to those states, hastening the transition while bringing additional jobs into the region.

There is also an immense amount of federal financial assistance available for some technologies and mitigation efforts. For instance, one tax incentive known as 45Q offers up to $85 per metric ton of CO_2 that is stored, with the incentive value varying depending on certain storage and use factors. Other policies like the renewable electricity production tax credit and energy investment tax credits (including the new 45V hydrogen tax credit) can significantly reduce the tax liability for companies, increasing production and usage of these technologies and fuels. Accessing that funding, removing roadblocks, and adding state and local incentives on top of what is available at the federal level could serve as a strong motivating factor for the development of cleaner energy production and use facilities, helping to kickstart a broader shift across the region.

As with other areas of the energy transition, sovereign nations located within the Intermountain West region have a distinct set of opportunities and challenges. With the passage of the Inflation Reduction Act of 2022, tribes will for the first time be able to fully access federal tax credits for clean energy development, which will encourage new development on tribal lands. Still, some sovereign nations, including the Navajo, Southern Ute, and Jicarilla Apache, will face disruptions due to their dependence on fossil fuel production as a major driver of economic activity and government revenue. Looking forward, the federal government and Intermountain West states can work closely with sovereign nations to develop policy solutions that enhance their sovereignty and ensure that tribes benefit from the energy transition.

Key findings

Given the premium on regional coordination, it is noticeable that regional (as opposed to state) roadmaps and related planning frameworks don't exist in all key energy sectors, largely because states are working toward different goals or visions for a carbon-neutral economy. The Intermountain West region would benefit from an integrated energy transition roadmap focused on both independent, state-, and tribe-specific concerns, as well as regional cooperation. A cohesive plan that acknowledges the interdependencies across state lines would give the states in the region a competitive advantage for federal funding—the plan could serve as the foundation for joint proposals that benefit from their comparative advantages rather than applying for funding separately.

While there is some cooperation within the region, much more work is needed to increase efficiencies and leverage partnerships across and between states, tribes, and localities. As a region in the country with a fragmented electric grid and market (not under the umbrella of an independent system operator), the Intermountain West faces a significant challenge. As solar- and wind-generated electricity becomes more economically viable and widely used, utilities must account for the fact that its production is intermittent and reliant on environmental factors. With an integrated grid for the region, management and storage of electricity generated by renewables would arguably be simpler and more efficient, with the operator able to lead region-wide planning initiatives. More uniform policy would also prevent companies from moving from one state to another based on who has the more beneficial set of incentives or to evade stringent state-specific regulations.

Implementing green procurement policies at the state level could further help with decarbonization efforts in the industrial sector. These policies could require the production of carbon-intensive construction materials to meet certain standards in line with decarbonization goals. By increasing demand for such resources, production costs could be brought down through economies of scale. There are new federal initiatives that could set green procurement requirements for projects to receive federal funding, which could encourage states to adopt similar standards. California is a leader in this area.

Although an obvious objective for energy transition is to reduce the use of fossil fuels, many states in the Intermountain West generate a significant amount of revenue from taxes, royalties, and other proceeds from fossil fuels. Furthermore, those revenues often find their way to other localities that also benefit from the jobs and economic vitality associated with fossil fuel extraction activities. This emphasizes the need to plan for energy transition at both the local and regional levels.

Finally, the federal government is not well equipped to interact with local stakeholders on a consistent basis, which makes avenues of communication through regional and state channels critical. Any ensuing dialogue must be capable of flowing in either direction such that local communities can provide input on state and federal policy. This observation also applies to how federal and state entities interact with sovereign nations on issues related to the energy transition.

Next steps

Moving forward, the primary policy focus should be creating regional roadmaps for the reasons mentioned above and then acting on them. Developing short- and long-term goals will allow for more desirable proposals for federal support, further inter-state policy initiatives, and a framework for gauging the success of the region's progress.

In terms of future research, a key avenue is an analysis to determine which level of government should handle which policy initiatives, and how to best harmonize federal and state efforts. Furthermore, additional research on regional policies in the areas of water, agricultural, and land-use is needed to help inform a regional transition plan. ◆

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CHAPTER 12

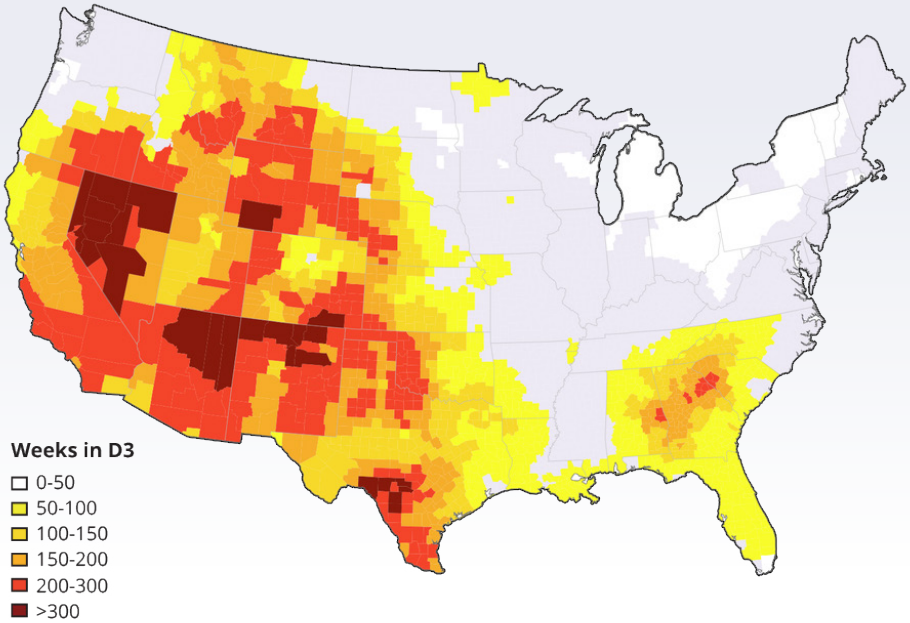
Economic Impacts

On a broad scale, climate change and environmental impacts are the main drivers for energy transition projects, but at the local level, economic impacts related to factors such as jobs and tax revenue are of primary concern. As global and national energy markets start to shift, economic development and revitalization plans must be developed to help energy communities navigate the impacts of energy transition.

The extensive dissimilarity from one region to the next complicates the issue. For areas that are already involved in energy production, a plan must be developed to phase out or modify fossil-based resources, and also introduce new industries. In regions where energy production is limited or nonexistent, different types of plans are needed, often more heavily focused on developing entirely new infrastructure and workforce capabilities. In both cases, these plans must be developed within the specific spatial and resource restrictions of a region.

Highlights

- Across the Intermountain West states, economics is a common motivator for energy transition—ensuring that energy communities are not left behind is a central concern for stakeholders at all levels.
- States that depend on extractive industries are economically more vulnerable to energy transition.
- Technology acceptance is tied to an individual's understanding of how the technology works and how it will impact jobs.
- A systems dynamics model is needed to allow for a more holistic evaluation of energy transition factors from one county to the next.



This map shows the number of weeks each county in the U.S. was in D3 (extreme) drought between 2000 and 2019. In addition to the typical factors of importance for regional economies—including job retention and creation, tax revenues, and environmental impacts—the availability of natural resources is also of paramount importance. As much of the Intermountain West faces unprecedented drought, competing demands for water may become a larger factor in local economic development plans.

Map by Becky Bolinger, data from U.S. Drought Monitor, 2000-2019

At a macro level, energy transition will have important environmental effects, but, if done correctly at the micro level, the aggregate benefits of job growth, new industry, and innovation will be just as important.

Regional relevance

The economics of energy transition is no less complicated for the Intermountain West states than for the nation as a whole. While they share many similarities as energy-producing states, their energy economies vary significantly, both at state and county levels.

Between 2015 and 2020, the economies of Arizona, Colorado, and Utah each grew faster than the national economy. The economies of Montana and New Mexico grew slightly faster than that of the U.S., while Wyoming—for reasons mainly attributable to the COVID pandemic—saw a net contraction of its economy. These rates belie strong inter-county differences within states, however. For example, New Mexico saw most of its counties' economies contract between 2015 and 2020 but still experienced growth overall. By contrast, all counties in Arizona saw economic growth in that same time period.

The rural and urban divide in the Intermountain West accounts for some of the stark differences across different localities. The USDA Economic Research Service identified 170 of the 220 counties in the region as non-metropolitan, and a study by the Bureau of Labor Services in 2013 revealed that rural households are likely to have higher energy expenditures despite earning significantly less than urban households. This indicates there is a higher likelihood that rural communities will feel the negative financial effects of energy transition more acutely than urban communities. Rural communities are also faced with higher fixed costs, like transportation, associated with energy production and consumption that are difficult to eliminate.

Variations in the type of energy used in each county also account for some of the differences in economic productivity. Overall, the Intermountain West states have seen a growing demand for utilities, including electricity, in recent years. At the same time, the number of counties whose economies have an extractive sector—meaning a sector reliant upon oil, gas, and quarrying—has declined in the past decade. In 2011, 104 of the 220 counties in the region produced oil, while 113 produced natural gas; in 2022, 90 counties produced oil, while 103 produced natural gas. The Intermountain West states with the highest dependence on the extractive sector, namely Wyoming and New Mexico, saw the worst economic outcomes between 2015 and 2020, while Arizona, the state with the least dependence on the extractive sector, saw the strongest growth. The variation in economic growth rates among Intermountain West states, and the differences between those states' counties, adds complexity to the project of introducing transition technologies at the county level, since no two economies are the same.

In considering the large-scale implementation of transitional technologies in the region, it is also important to consider unemployment and workforce availability. Overall, in 2021 the region's unemployment rate of 4.8 percent was lower than the U.S. average of 5.4 percent. In total, 84 of the 220 counties in the region had an employment rate above the regional average. Of these above-average counties, all were coal-, natural gas-, or oil-producing, while 65 percent of the counties were non-metropolitan. Moreover, workforce availability varies significantly across counties and states, with the size of the workforce in Arizona and Colorado dwarfing that of all other Intermountain West states.

Drought and land ownership are additional factors that must be considered in the implementation of transitional technologies. Of the assessed states, only Montana and Colorado have counties that experienced less than 50 weeks of drought between 2000 and 2019. Arizona, New Mexico, and Wyoming all have counties that experienced more than 300 weeks of drought between 2000 and 2019. Land ownership across the region is also complicated, with private, state, federal, and tribal lands intermixed across each state.

San Juan County, New Mexico, and Lincoln County, Wyoming, are two counties that have initiated or are considering transitional energy projects. Both have faced boom-and-bust cycles due to their economies' long-time reliance on fossil fuel production, which is often heavily tied to the cyclical nature of the national economy. Moving toward newer energy technologies may provide a wider economic base to guard against these cycles and stabilize local economies.

In San Juan County, reduced demand for coal, a push toward carbon neutrality, and the San Juan Generating Station closure have led city and county officials to consider introducing both solar and carbon capture technology projects into the region. Both types of projects would bring jobs and additional tax revenue to San Juan County. Lincoln County is home to several innovative energy projects, including the Shute Creek Processing Facility, which is the third largest carbon capture, utilization, and storage facility in the world. Lincoln County also plans on initiating solar and nuclear power technology projects. The county's unemployment rates are among the lowest in Wyoming.

Key findings

While there are hurdles facing a transition to new energy technologies, the Intermountain West is poised for such a change. Many of the states in the region have a history of energy production, which comes with a wealth of knowledge and resources that could be utilized in future projects.

At the county level, those currently producing energy could serve as a foundation for additive energy technologies to be implemented. Those not involved in energy production could serve as the locations for introducing alternate projects, depending on what is available in the county. Ultimately, no two counties face the same set of circumstances, and careful consideration must be made for each county individually. Many factors contribute to a county's readiness to adopt a given transitional energy technology. The economic software IMPLAN can be used to forecast the effects of different hypothetical projects across the Intermountain West, considering substantial variation between counties; however, such forecasts also suggest the importance of inter-county collaboration across the region.

Studies show that collective attitudes toward climate change and the goal of achieving carbon neutrality vary by county across the region. For example, within each state, counties expressed different degrees of anxiety about climate change. In Colorado's Denver

County, for example, 76 percent of respondents to a 2022 Yale University survey said that they were worried about climate change. In Kiowa County, Colorado, only 50 percent of respondents said that they were worried about climate change.

A 2022 study in New Mexico found that 20 percent of survey respondents would not support the pursuit of carbon neutrality, regardless of cost, while 50 percent of respondents would support carbon neutrality regardless of cost. By contrast, a 2021 survey of residents in 12 Wyoming counties found that 43 percent of respondents felt it was important for the state to transition to carbon-neutral energy.

In both studies, greater support for certain carbon neutral technologies was tied to an individual's understanding of the technology. For instance, carbon capture and hydrogen technologies tended to be less understood and, in turn, had lower levels of support. Respondents in the studies also placed an emphasis on the individual impacts of implementation, with jobs serving as a primary motivating factor when considering carbon neutral options. Results also showed that communities were more trusting if they sensed a company would try to establish an enduring presence in the region, which would support the local economy in the long run.

Next steps

Overall, the states and counties within the Intermountain West region exhibit diverse economic conditions, including with respect to land ownership, drought, population density, and reliance on energy. These disparities make assessing the impact of projects and comparing projects across counties difficult. A successful roadmap for energy transition will need to consider county-level factors, while taking into consideration that various technologies and projects may have impacts beyond the area in which they are deployed. A system dynamics model would allow for a more holistic evaluation by focusing on the interactions among the different factors. This, in turn, would enable proper evaluation of the economic impacts and tradeoffs that a project may have specific to the surrounding area.

Considerations must also be made for how to address the potential gap between the phasing out of older energy technologies and the implementation of new technologies. Fossil fuel production plants across the region are facing closure dates while there is no parallel timeline for deploying new technologies. Because newer technologies are reliant on three drivers—technology, policy, and regulation—deployment may be a lengthy process. This could leave the region vulnerable to lower levels of energy production as fossil-based energy continues to be phased out.

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CHAPTER 13

Workforce Impacts

One of the most human aspects of energy transition is how it will impact the workforce. The ability to replace well-paying jobs provided by the fossil-fuel industry with new ones that offer similar levels of pay, security, and benefits will be vital to securing the public support needed to implement and sustain new energy economies. Managing shifts in the workforce will require the retraining or upskilling of workers to prepare them for the shifting needs of the industry. This reeducation will naturally take time, and there will likely be a transitional period in which states will be forced to adapt quickly and predict what the future job market will look like.

There are also two labor trends that may obscure localized effects as the industry shifts. First, while most estimates predict new energy industries will create at least as many, if not more, jobs as there are in the current energy sector, local impacts may differ. National, regional, and even state data might reflect a leveling off or growth in employment, but local numbers could fluctuate wildly because energy extraction, production, and transportation facilities won't necessarily remain in the same location. So, while a state or region as a whole may benefit from

Highlights

- Roughly 500,000 Intermountain West residents are directly employed in the energy sector, primarily in the coal, oil, and natural gas industries.
- Workers throughout the region understand the energy sector and are well positioned to transition their skills to new energy technologies and economies.
- Energy workers are often reluctant or unable to relocate for new jobs; this means new opportunities are needed locally to bring down the risk of economic instability.
- Regional colleges and universities are key to retraining the current workforce, and developing programs to prepare next-generation workers for jobs in new energy industries.

energy transition, smaller communities may be left behind. A related trend is that energy workers in smaller communities often lack the resources needed to relocate and as a result aren't as apt to seek alternatives as is often assumed. Because of this, as fossil energy jobs are lost, communities will be faced with limited options: bring in a new replacement industry or brace for economic downturn. In many cases, these trends are playing out in primarily rural areas where, even if workers wanted to relocate, the remoteness of their communities makes any such action difficult.

Even in the face of these challenges, there are some clear opportunities present that could be exploited to help ease the transition for the workforce. There are enough similarities between some older and newer energy industries that skills can transfer relatively well. This not only allows workers to take on similar jobs without much need for retraining, it also allows for individual companies to remain rooted in their current communities, as long as new technologies can be applied to enable low-carbon operations.

Regional relevance

Shifting focus to the Intermountain West, the labor force involved in the energy industry has always been an integral part of the region's identity. Currently, over 500,000 people are believed to be directly employed in the energy sector, and indirect employment is even higher. The majority of these jobs are tied to historically prominent industries in the region like coal, oil, and natural gas, and it is these workers that are most at risk. Further exacerbating the issue is the large number of Native American tribes in the region—a historically disadvantaged population that relies heavily on the energy sector for employment.

Across the board, many of these workers are from relatively isolated rural areas without access to alternative industries or employment options to mitigate the consequences of job losses. Furthermore, power plant and mine closures have significant domino effects, as a large number of indirect jobs in the region are also structured around current energy sectors. Consequently, without adequate planning for such a transition, energy communities are at risk of being destabilized, with potential impacts reaching far beyond the workers and localities that will obviously be affected.

An assessment of the regional workforce revealed that many workers in the more rural parts of the Intermountain West are reluctant to relocate, and some communities are actively working to keep workers from doing so. There are personal, cultural, and practical reasons for this reluctance; for example, in tribal communities, workers often have to contend with the fact that young or elderly dependents rely on their presence in the community.

While large economic structures built around fossil-based energy technologies definitely have challenges up ahead, the Intermountain West has a leg up on other regions. Leaders and workers alike from Sovereign Nations, states, cities, counties, and small communities alike are familiar with how energy economies are established and operated, and while the technologies might change, the business aspects and nuances of the industry remain the same. The region has also navigated through significant changes before—not long ago, it transitioned from being solely an energy-producing region to becoming an exporter as well, which demonstrates there is flexibility to the infrastructure and workforce underpinning the industry.

The physical capital available to the Intermountain West also presents opportunities. There are numerous facilities in the region that could be retrofitted or leveraged to support new energy sectors. Manufacturing is a potential area of growth; although the region does not have a great deal of experience in this sector, some states have made inroads in recent years standing up electric vehicle manufacturing plants, including a battery plant in Arizona. These initiatives will be key to a successful energy transition, as they provide stable, stationary jobs while also ramping up the commercial

After more than 40 years of operation, the Navajo Generating Station in Page, Arizona, officially shut down in November 2019. The station provided hundreds of jobs with salaries much higher than average for the area. Together, the Navajo Generating Station and the Kayenta Mine mine that fed the plant employed about 800 people, with about 90 percent of employees from the Navajo Nation. Closures such as these have tremendous impacts on the local workforce and create an urgent need for job replacement.

production necessary to implement newer technologies. Bidding for more of these projects could give the region a foothold in emerging markets, and put the Intermountain West on the radar as an up and coming leader in new sectors.

Key findings

Education may be the most critical factor in transitioning the workforce to new employment opportunities. Some of the Intermountain West states have a strong or acceptable educational base. In others, such as Arizona and New Mexico, the secondary education landscape is more concerning. Following a good foundational education, post-secondary education programs at regional colleges and universities can build the specific education/training curriculums necessary to educate the future workforce. While several degrees and certifications related to climate and environment are currently offered, virtually no programs exist to prepare students for careers in low-carbon energy sectors. For example, courses in carbon management—a critical component of emerging industries in the Intermountain West—are not widely offered. Entirely new fields of study and research will likely need to be developed, not just to train future workers, but also educators and faculty. Additionally, institutions of higher education will need to acknowledge the role of professional workers as educators, as well as the importance of technical training for craft workers and facility operators. These types of innovative approaches in education and training may blur the traditional lines of universities and community colleges.

There are a few decarbonization pathways that would create good transitional workforce opportunities for the Intermountain West region. Carbon management, including CO_2 point source capture and CO_2 storage, would allow fossil-based energy industries to operate for the short-term, thus bridging the gap for workers before they must make the full leap to fossil-free energy sectors. This, of course, would depend entirely on the public's appetite for the continued use of fossil fuels, even if CO_2 emissions are largely reduced. The tradeoff would be that current facilities would remain open and workers could continue to use their existing skills and earn a living as they are retrained.

Analysis of the workforce potential of various other technologies revealed several suitable options for the unique attributes of the Intermountain West. Solar jobs on average pay 12.4 percent above the national average, and tariffs on foreign solar components were recently imposed, indicating a likely expansion of the manufacturing industry domestically. Also, the region's topography and climate are compatible with solar, making it a possible hub for future solar fields. An integrated regional effort to get supportive policies in place for siting solar farms would help proliferate the technology throughout the region. In terms of workforce effects, solar farms tend to have fewer on-site operators than fossil fuel plants, but numerous ancillary support jobs would be added, and overall compensation would be competitive. Direct air capture (DAC) could also emerge as a large growth sector—it could serve as a workforce multiplier by creating a sustained supply of CO_2 that could be utilized by off-shoot industries that specialize in CO_2 storage or utilization. This supply and demand could have a significant impact on employment in the region, with high potential for jobs in a whole spectrum of energy-related industries, from hydrogen production to bioenergy to low-carbon electricity. Essentially, a whole new supply chain would be created and need to be staffed.

Other new and largely unfamiliar markets to the Intermountain West, such as nuclear power and battery storage manufacturing, could also become significant job creators, but further study is needed to determine how feasible these technologies would be in the region.

Next steps

Having identified where structural improvements can be made to ease the transition for workers, actions must be taken to keep up with the rapid pace of innovation in this sector. A comprehensive assessment of regional educational institutions from primary to graduate level is needed to help inform the development of new fields of study, educator training programs, and infrastructure (e.g., labs and testbeds for hands-on experience). Additionally, emerging energy industries need to be assessed in detail to better understand the number of jobs they will create, as well as the types of skills that will be required. This would enable the region to determine how the current workforce can be transitioned with skills and expertise they already possess, and also which industries will require retraining programs. Finally, tools are needed to evaluate not only the quantity of jobs created at a local level, but also the quality of these jobs. Creating indicators for things like compensation, security, and skill level would help energy transition planners analyze new energy projects on an individual level, and weigh them against the merits of long-standing fossil-based opportunities.

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Roadmapping

A Regional Roadmap to Carbon Neutrality

One of the main objectives for I-WEST is to build a roadmap to guide the Intermountain West to carbon neutrality on an accelerated timeline. The initiative is targeting two primary outcomes: the region will reduce its net CO_2 emissions to zero by 2050, and it will build new, sustainable energy-related economies.

1

THE FIRST OUTCOME recognizes the need to reduce emissions of greenhouse gasses that remain in the atmosphere for long periods of time—namely CO_2 and methane, which persist in the atmosphere for on the order of centuries and a decade, respectively. To start, the I-WEST roadmap focuses primarily on CO_2, but also considers fugitive methane associated energy production.

2

THE SECOND OUTCOME recognizes a regional need to build new energy-related economies that are consistent with achieving carbon neutrality. The Intermountain West has a rich history in fossil-based energy and to this day produces more than it uses. These existing energy economies are the source of well-paying jobs and revenue streams that support communities, states, and tribal entities. Currently, these economies fall into three categories: electricity production, fossil fuel production and processing (coal, oil, and natural gas), and CO_2 production for enhanced oil recovery. Each is being impacted by shifts in national and global markets in response to customer demands for cleaner energy options, and the latter two economies are further impacted by the boom-and bust-cycles associated with petroleum. At the same time, these economies are supported by highly trained workforces and infrastructure that will give the region a jump start on new energy economies that are responsive to market shifts. These considerations are integrated into the various assessments I-WEST is conducting to inform its regional roadmap.

Pathways to carbon neutrality

The I-WEST roadmap conceptualizes pathways to carbon neutrality with an approach that parallels a “wedge” concept used by the Intergovernmental Panel on Climate Change (IPCC) in its 2018 Special Report (SR15). The IPCC approach considers pathways that are compatible both with limiting a global temperature rise to 1.5 °C and with sustainable development. The I-WEST roadmap requires a reduction in CO_2 emissions by approximately 385 million metric tons per year. This is illustrated schematically in Figure 1 with a solid green line that reaches net zero by 2050. Although the transition will certainly not be linear, this simplification enables an easier description of multiple pathways to carbon neutrality, which emphasizes the essence of the I-WEST roadmap.

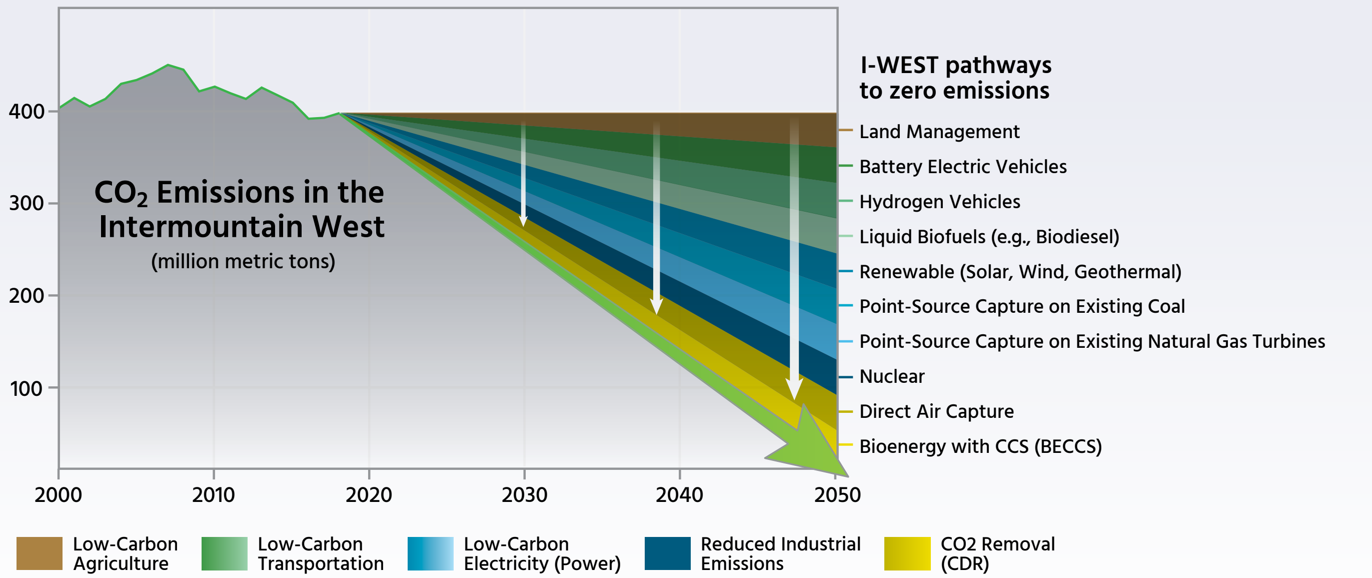

Figure 1. This graph shows the annual CO_2 emissions in the Intermountain West region. The solid green arrow shows a linear path from current emissions to net zero emissions by 2050. Also shown are several regionally relevant mitigation pathways that can be used to achieve this goal. Each pathway is shown schematically as an equal wedge, and I-WEST is assessing how big each one might get over time based on regional potential and how communities are currently planning for energy transition.

The IPCC recognizes that achieving carbon neutrality globally will require multiple mitigation pathways—this will certainly be true regionally as well. Figure 1 shows an initial assessment of potential regionally relevant mitigation pathways, many of which tie to energy production and use. These pathways are shown schematically as equal wedges that begin at current emissions—starting in 2019, which is based on the latest emissions data available on EIA.GOV at the time of this writing—and that grow linearly to 2050. The I-WEST roadmap is considering each of the wedges in terms of the likely timing and size of growth based on regional potential, emerging efforts, community-based energy goals, and the goals of various energy-related projects either currently or soon-to-be operating in the region.

The wedges are roughly categorized by color, following a scheme used in the IPCC's 2018 Special Report. Land management (brown wedge) is not directly related to energy but involves changes in the management and use of land to increase the uptake of carbon (often referred to as terrestrial carbon sequestration), which can improve water retention and land productivity.

Transportation represents a significant source of regional emissions and includes vehicles (e.g., cars, trucks, buses, and motorcycles), aviation, rail, and others. Potential mitigation pathways for vehicles are shown as green wedges, and represent a shift from petroleum-based fuel to battery electric vehicles, fuel-cell vehicles, and biofuels, each of which would need to be based on low-carbon production for electricity, hydrogen, biodiesel, etc. Other regionally relevant pathways for transportation could also be considered in the future, such as natural-gas powered vehicles.

Pathways to reduce emissions tied to fossil-fuel based electricity production is shown by a series of blue wedges. One set of mitigation pathways involves a replacement of fossil-based facilities with facilities that produce no CO_2. This includes renewable energy—relevant to the Intermountain West due to its abundant solar, wind, and geothermal resources—as well as some potential for additional hydroelectric power. The first two of these are periodic in nature, varying daily and annually; hence, these mitigation pathways also require the additional consideration of balancing the energy load through energy storage (e.g., batteries) or through the use of a compensating power source that can be ramped (e.g., natural gas turbines). Another no-carbon option is nuclear energy; currently, there is at least one community in the Intermountain West region planning to replace a coal-based facility with nuclear power. In addition to total replacement strategies, retrofitting fossil-based facilities with carbon capture technologies is also an option. For example, point source capture at large, industrial CO_2-emitting facilities (e.g., coal-fired power plants, cement plants, refineries, etc.), could be an effective short-term mitigation strategy for the region.

Finally, Figure 1 shows an additional set of mitigation pathways in yellow that are associated with CO_2 removal (CDR). Direct air capture (DAC) involves an engineered capture of CO_2 from the atmosphere, whereas bioenergy with carbon capture and storage (BECCS) involves the use of biomass (which extracts CO_2 from the atmosphere) to produce feedstocks for energy production via processes that are equipped with technology to capture CO_2 before it can be released into the atmosphere.

Evaluating maximum potential

As a first step toward developing a regional roadmap, I-WEST focused on evaluating the maximum potential for mitigation pathways tied to transportation and point source capture. The intent of focusing on maximum potential is not meant to imply that these wedges will indeed grow to the maximum size; rather, it provides boundaries for scenarios that can be explored in the context of reduction potential and implications for natural resources, workforce, policy, and economics.

Transportation

Results of an I-WEST assessment on the maximum potential for emissions reduction in the transportation sector are presented in Figure 2. Based in part on a complementary analysis of registered vehicles in the region, which is summarized in Table 1, these results illustrate the scale of the alternative fuels needed to support a low-carbon transportation sector in the region. Furthermore, they provide an essential set of parameters that can inform plans for the scale of technologies that will be required to decarbonize the various transportation wedges. Current modeling, as detailed in Figure 2 and Table 1, does not account for factors like general life-cycle analysis.

Each wedge is based on an assessment of emissions tied to registered vehicles in the region. Aviation is based on the amount of aviation fuel consumed by each state, as listed by the U.S. Energy Information Administration (EIA) State Energy Data System, in conjunction with EIA's fuel-CO_2 conversions. "Other" is what remains after

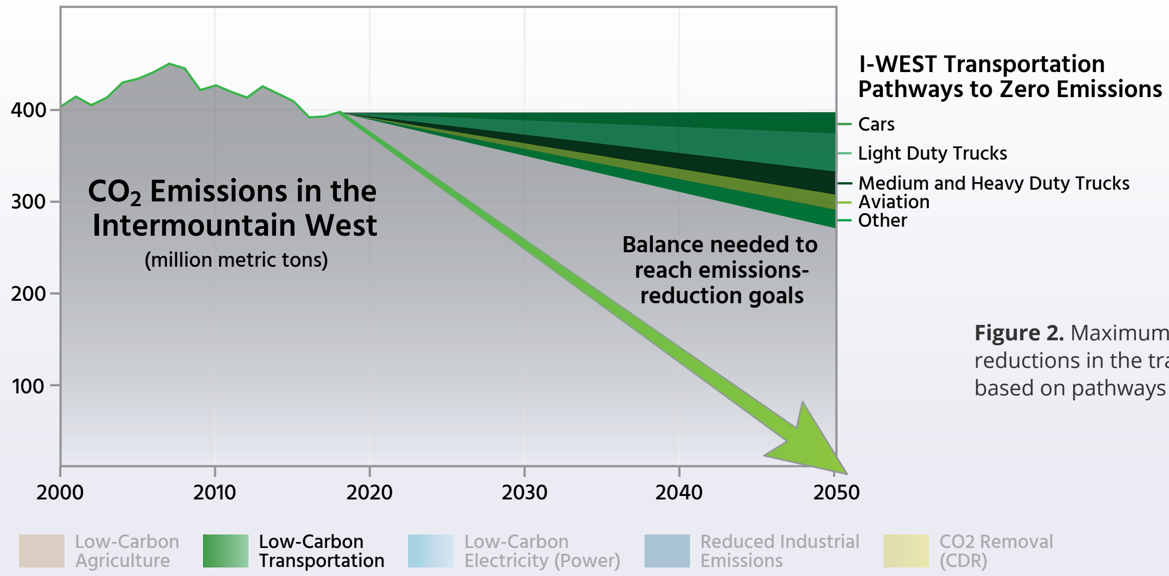

Figure 2. Maximum potential for CO_2 reductions in the transportation sector based on pathways to zero emissions.

	Cars	Light Duty Trucks	Medium/Heavy Duty Trucks
Number of registered vehicles	6,345,959	10,259,920	885,938
Emissions based on ICE	17.6 Mtonne CO_2 yr^{-1}	46.8 Mtonne CO_2 yr^{-1}	23.2 Mtonne CO_2 yr^{-1}
Fuel needed for ICE	**Gas:** 2.2 billion gal yr^{-1} / 274,480 TJ yr^{-1} **Diesel**: 8.1 million gal / 132 TJ **Total:** 274,612 TJ	**Gas:** 5.5 billion gal yr^{-1} / 703,128 TJ yr^{-1} **Diesel:** 191.5 million gal / 3113.4 TJ **Total:** 706,242 TJ	**Gas:** 553.4 million gal yr^{-1} / 70,235 TJ yr^{-1} **Diesel:** 1.8 billion gal / 29,901 TJ **Total:** 100,136 TJ
Hydrogen needed to replace fuel	Min: 426468 tonne H_2 Max: 1217924 tonne H_2	Min: 1101089 tonne H_2 Max: 3132852 tonne H_2	Min: 201849 tonne H_2 Max: 450733 tonne H_2
Electricity needed to replace fuel	Min, Total: 139.8 TW hr Max, Total: 419.5 TW hr	Min, Total: 359.7 TW hr Max, Total: 1079.0 TW hr	Min, Total: 51.0 TW hr Max, Total: 153.0 TW hr
Biodiesel needed to replace diesel-based vehicles	8.1 million gal	191.5 million gal	1.8 billion gal

Table 1. This table summarizes an analysis of registered vehicles in the Intermountain West region, current emissions and fuel needs based on an internal combustion engine (ICE), and estimated alternative fuel needs. Note that "light duty trucks" are trucks below class 3 and weigh less than 10,000 pounds, including minivans and SUVs, and "medium/heavy duty trucks" are all trucks class 3 and above.

taking the difference between the region's transportation CO_2 emissions as provided by EIA and the sum of the other categories listed; it includes CO_2 emissions from motorcycles, buses, RVs, rail, marine sources, and out-of-region vehicles.

Even at maximum potential, transitioning the transportation sector to zero-carbon emissions would not be enough to achieve carbon neutrality—additional pathways would be needed to fill the gap.

Point source management

Results of an I-WEST assessment on the maximum potential for emissions reduction tied to point source management are presented in Figure 3. Using the U.S. Energy Information Administration's 2022 energy mix projects as a starting point, adding aggressive adoption of carbon capture, use, and sequestration technologies to decarbonize fossil-based electricity generation would have a dramatic impact on total emissions. The gap to zero emissions emphasizes that additional transition pathways, such as DAC, will still be needed.

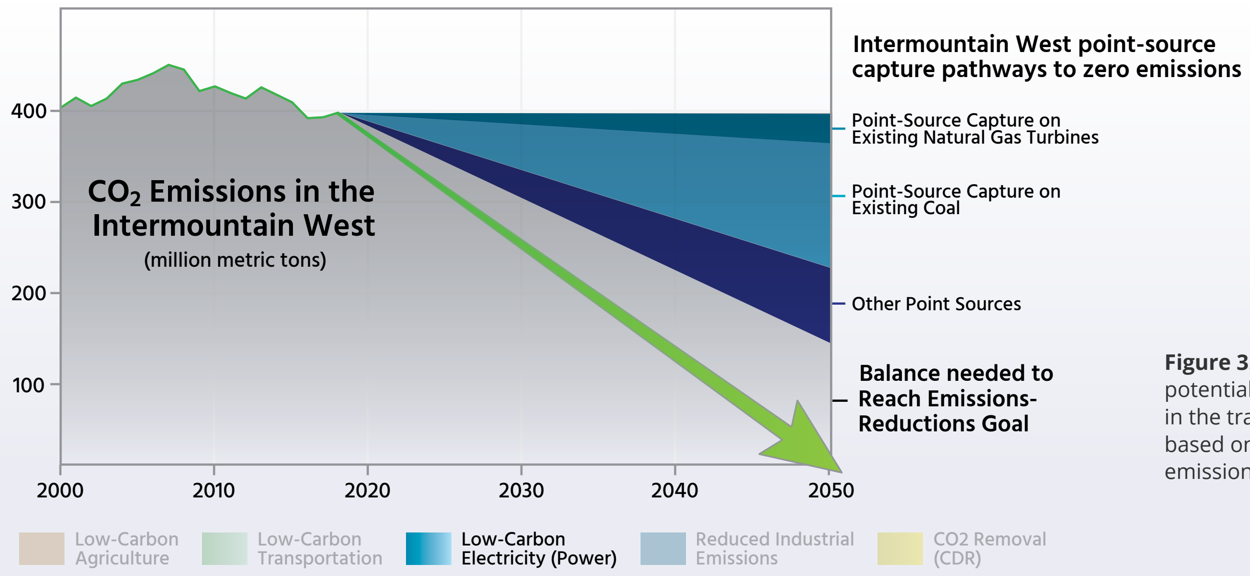

Figure 3. Maximum potential for CO_2 reductions in the transportation sector based on pathways to zero emissions.

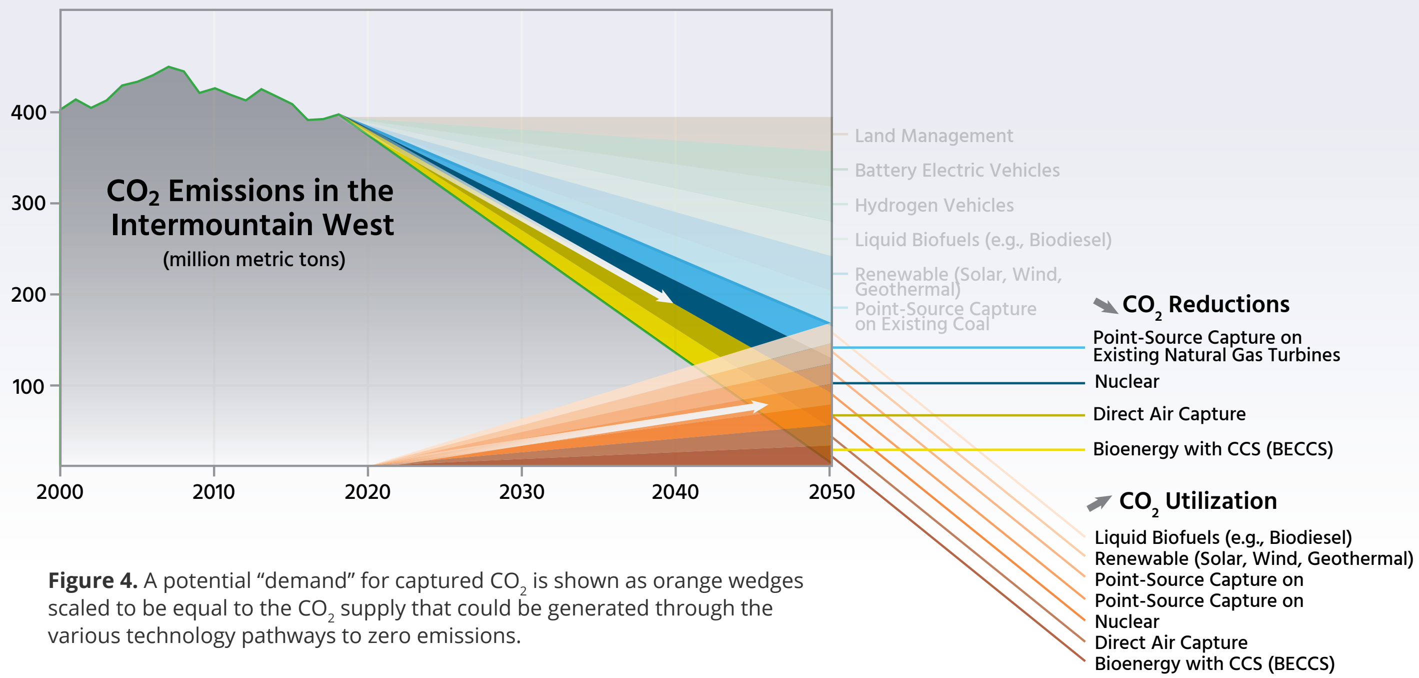

Figure 4. A potential "demand" for captured CO_2 is shown as orange wedges scaled to be equal to the CO_2 supply that could be generated through the various technology pathways to zero emissions.

New energy economies

The I-WEST roadmap is structured around four "new" economies that could be built around a supply of 1) captured CO_2, 2) low-carbon hydrogen, 3) low-carbon electricity, and 4) low-carbon bioenergy—each with a matching industry or demand that would make the economy sustainable. These economies were selected based on their relevance to the Intermountain West, meaning they can be developed by leveraging regional assets such as workforce, infrastructure, and natural resources.

This emphasis on supply and demand is central to the I-WEST approach to developing an energy transition roadmap. A robust energy economy essentially translates to a diverse portfolio of industries that can be sustained over time. This is an important lesson learned from previous attempts at technology deployment, including in the energy sector. As a recent example, the Petra Nova project successfully demonstrated CO_2 capture technology, but its single option for CO_2 demand (a CO_2-enhanced oil recovery project) was impacted by the shifting economics of petroleum so the project could not be sustained. Similar situations can be avoided in the Intermountain West with thoughtful planning for multiple options for demand, which could evolve over time.

Figure 4 illustrates the potential for "demand" of captured CO_2 as orange wedges that are scaled to be equal to the CO_2 supply wedges from Figure 1. (The wedges that do not produce a supply of CO_2 are grayed out.) Screening-level assessment efforts of the subsurface storage options in the region point to an abundance of geologic resources that offer ample CO_2 storage potential. For instance, it is estimated that geological resources in the region can potentially store between 0.35 and 3.4 billion metric tons of CO_2. Storage volumes at this magnitude could sufficiently store 100 percent of the CO_2 emissions from all the existing point sources for over 6,000 years. As a result, the outlook is promising for balancing a CO_2 supply—captured from point sources and DAC—with demands via intra-region storage resources.

As illustrated in Figure 5, the four economies under assessment by I-WEST are symbiotic, meaning they are distinctly different but depend on one another. For example, a hydrogen economy depends on a CO_2 economy: carbon capture and storage are critical in blue hydrogen production, and CO_2 captured from the atmosphere can be used with green hydrogen to produce sustainable, carbon-neutral chemicals and fuels as replacements for petroleum-based products. Many similar dependencies exist amongst the four economies.

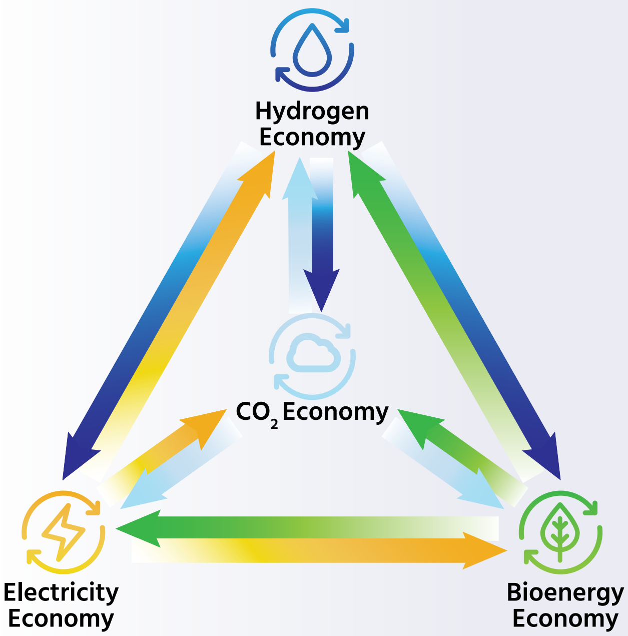

Figure 5. I-WEST is exploring how the development of four symbiotic economies can support a sustainable transition to carbon neutrality in the Intermountain West.

The symbiotic nature of these economies has many implications—the development of each requires co-development of all the others. This must be factored into any energy transition plan, especially since co-development could create competition for infrastructure, natural resources, and workforce, which could slow down progress. On the other hand, symbiosis can accelerate growth and deployment, as demonstrated in other economies throughout history. The rapid co-development of coal, steel, and rail is an example of how the "supply" for one economy might be driven by the "demand" from another. Furthermore, this could spur growth in other adjacent economies that will likely need to be developed to support new energy ecosystems; in the Intermountain West, this could be in the areas of land and water management, agriculture, and forestry.

Additionally, I-WEST anticipates that emerging technologies developed to support carbon neutrality within the four economies will inevitably create additional, synergistic economies. One example might be solar-powered agriculture, where waste materials are converted locally into power, hydrogen, or useful chemicals. Across the board, when new economies are developed, it most often translates into new jobs and revenue streams for communities.

Energy and water

Most Intermountain West states are experiencing prolonged and severe droughts, and yet, water is used in all phases of energy production: in electricity generation, water keeps power plants cool enough to function safely and efficiently; and in oil and gas production, water is used for hydraulic fracturing and enhanced oil recovery. Water is also essential for most renewable energy, including hydropower, concentrated solar power, geothermal energy, and bioenergy production. Many of the technology options to decarbonize these energy sectors also require water.

Given the interdependencies between water and energy systems, I-WEST has integrated water management into its roadmap as a cross-cutting factor across all energy economies. Additionally, I-WEST is assessing how water treatment technologies can be deployed to either use existing wastewater streams, or recycle water produced in decarbonization processes. These considerations for how water resources will be impacted by energy transition directly address concerns expressed by regional stakeholders about how emerging technologies will impact future water usage. Going forward, an additional area of need is to better understand the role of climate on surface water availability.

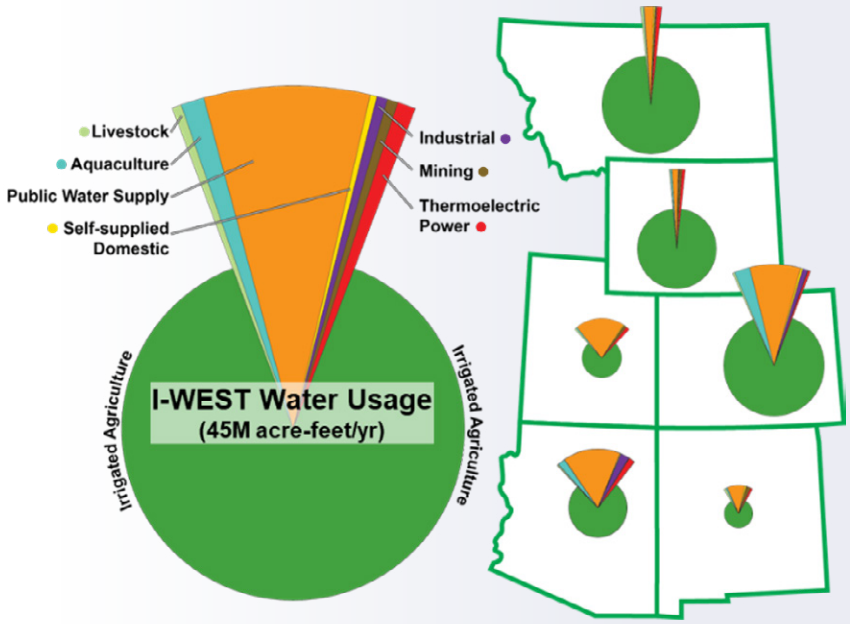

Figure 6. Water usage in the Intermountain West. The sizes of pie charts are scaled to the volume of water used. The slices for usages other than irrigated agriculture have been expanded by a factor of two to facilitate viewing.

Figure 6 details current water use in the Intermountain West region, with largest sectors being:

- agriculture, at 40M acre-feet/year with 85 percent in the form of surface water;
- public water supply, at 3.6M acre-feet/year with 57 percent in the form of surface water; and
- thermoelectric power, at 0.4M acre-feet/year with 72 percent in the form of surface water.

In a preliminary assessment of water needs for the new energy economies, I-WEST has started to place future water needs in some degree of context for pathways related to zero-carbon transportation, as well as carbon management. Early results can be summarized as follows:

Water for zero-carbon transportation

Based on 2019 data on registered vehicles in the region, if all cars, pickups, and trucks were converted to hydrogen:

- approximately 98k – 231k acre-ft water/yr would be required to produce enough hydrogen via steam-methane reforming (this is about 121-285 Mtonne water/yr and corresponds to 2.6-6.1 Mtonne hydrogen/yr); and
- approximately 27k – 63k acre-ft water/yr would be required to produce enough hydrogen via electrolysis (this is 32.8-77.2 Mtonne water/yr and corresponds to the same range as above).

Corresponding water requirements for gas and diesel production are:

- gasoline: 199.1k acre-ft water/yr in 2019 (245.6 Mtonne water/yr), and
- diesel: 67.8k acre-ft water/yr (83.6 Mtonne water/yr).

This analysis is based on assumptions about internal combustion engines (ICEs) and fuel cell electric vehicles (FECVs). As we look forward to replacing ICEVs with FCEVs, these preliminary results suggest that the region would consume less gasoline/diesel and, in turn, consume less water during fossil fuel production. It is important to note that the water necessary to produce hydrogen is not in addition to the water necessary for fossil fuel production; in fact, the analysis suggests that switching from ICEVs to FCEVs will likely save the region some water.

Water for carbon management

A preliminary analysis of water required to capture all CO_2 emissions from point sources for electricity generation in the region shows that approximately 200k acre-feet/yr would be needed—this is almost double what is currently used. However, this could be reduced by about 90 percent or more with the use of air cooling technologies and/or the use of nontraditional water resources. Additionally, if all point-source captured CO_2 (about 200 million metric tons/year) is stored in regional reservoirs, co-producing brine while injecting the CO_2 (to manage pressure) would produce about 200k acre-feet/yr of nontraditional water that could be reused in some energy production technologies.

Next steps

Further research and analysis are needed to better understand the complexities of the symbiotic economies outlined in this report. More detailed and precise forecasts for the Intermountain West require a holistic look at the energy-water-climate nexus, an in-depth assessment of the deployment and demonstration feasibility of existing and emergent technologies, an inventory of regional infrastructure, and integrated social, economic, and environmental justice assessments. The technological advances required to bring more fidelity to our models, as well as the compilation of more detailed socio/economic drivers for the region, will frame the next steps of the I-WEST initiative.

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