Phase One Final Report | Detailed Chapter

Low-Carbon Electricity

VERSION 1.0

LOS ALAMOS NATIONAL LABORATORY

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About this report

The Intermountain West Energy Sustainability & Transitions (I-WEST) initiative is funded by the U.S. Department of Energy to develop a regional technology roadmap to transition six U.S. states to a carbon-neutral energy economy. I-WEST encompasses Arizona, Colorado, Montana, New Mexico, Utah, and Wyoming. 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, economics, and energy, environmental, and social justice. This chapter presents work led by an I-WEST partner on one or more of these focus areas. A summary of the entire I-WEST phase one effort is published online at www.iwest.org.

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Introduction

Low-carbon technologies for producing electric power are important for achieving carbon neutrality. This report provides an overview of several electricity production technology pathways available, and their respective challenges.

Overview of regional electricity capacity

Electricity production in the Intermountain West relies on many fuel sources, from CO_2-emitting fossil fuels to clean energy renewables. The region has abundant natural gas and coal resources, which are currently the primary sources for electricity production. The Intermountain West has an installed capacity of 90,568 megawatts (MW) of production—33,160 MW from natural gas and 24,008 MW from coal. Coal plants provide baseload for the system and natural gas plants provide a fast-ramping source of electricity critical for load balancing. Baseload generation is approximately 30% of total capacity. Figure 1 shows the locations of all electric power plants in the region.

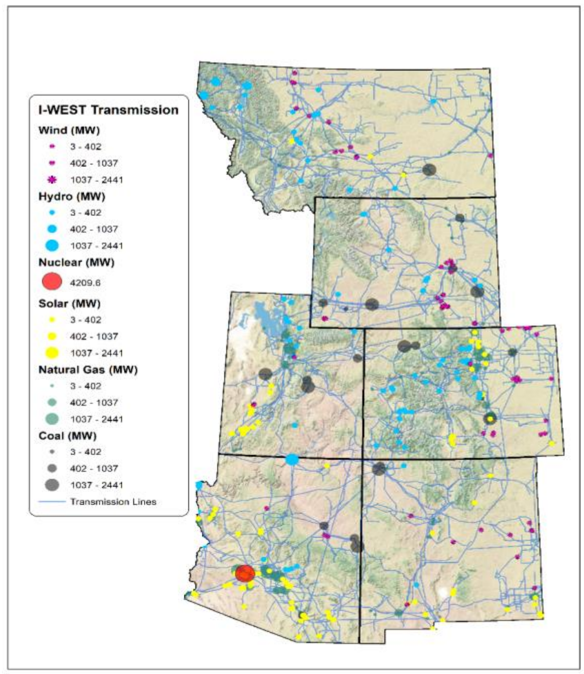

Figure 1. Electric power plants.

Hydroelectric plants have installed capacity of 7,400 MW, with Glenn Canyon Dam and Hoover Dam (AZ) having a combined capacity of ~2300 MW. Montana has the next largest installed capacity of hydroelectric power at 2,653 MW.

The greatest potential for wind production of electricity is east of the Rocky Mountain range. The states with the largest installed capacity of wind production are Colorado and New Mexico. The largest wind farm is in Rush Creek, Colorado with a capacity of ~600 MW. Total wind capacity in the region is 14,556 MW.

Arizona is home to the only nuclear plant in the region, Palo Verde, with an installed capacity of 4,209 MW.

Solar production in the region continues to grow with a current installed capacity of 6,178 MW. The four southern states of Arizona, New Mexico, Utah, and Colorado have the largest solar potential. Arizona has the largest installed capacity of solar power at 2,810 MW, followed by Utah with 1,457 MW.

The largest solar farm in the region, Agua Caliente Solar Project (AZ), has a capacity of 347 MW. Solar projects require a large amount of land—the Agua Caliente Solar Project takes up roughly 2,000 acres. When comparing individual power plants, it's important to note that the region's energy-dense fossil fuel plants have roughly five to eight times the installed capacity of the regional solar/wind plants and a much smaller land footprint. For example, the largest coal plant in the region is the Jim Bridger plant located in Wyoming with installed capacity of 2,441 MW, and the largest natural gas plant in the region is the Gila River Power Plant located in Arizona with installed capacity of 2,476 MW.

Regional CO_2 emissions

Using 2020 data from EPA emissions atlas and EPA eGrid, we mapped the 45Q[1] point source emitters and overlay the fossil fuel electric power plants. The electricity sector of the Intermountain West emits a total of 166 million tons of CO_2 per year—129 million tons from coal plants and 37 million tons from natural gas plants. Figure 2 shows the point source emissions from fossil fuel plants in the region, as well as other non-electricity sources.

Beyond the electricity sector, CO_2 emissions are also produced from natural gas processing plants, oil/gas extraction, oil refineries, mining operations (excluding oil/gas), and industry processes such as cement production. However, the electricity sector is the largest emitter of CO_2 in the region.

Colorado and Wyoming produce the most 45Q point source emissions at 58 million tons/yr and 56 million tons/yr respectively. The state that produces the least emissions is Montana at 13 million tons/yr.

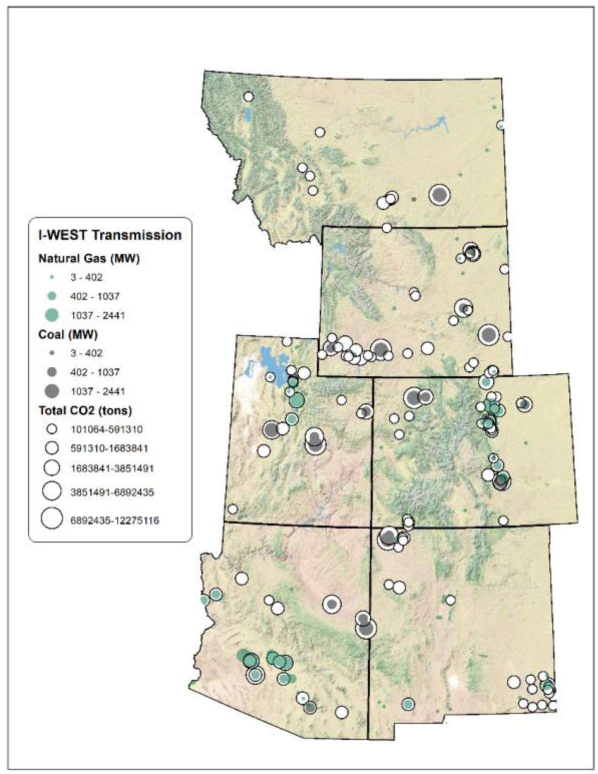

Figure 2. Point source emissions.

Regional transmission

During the I-WEST Electricity Workshop[2], regional stakeholders and industry leaders identified transmission as one of the major constraints for energy transition—adding new generation sources will

[1] Facilities that emit CO_2 can receive tax credits, referred to as "45Q,"by applying carbon capture technologies.

[2] I-WEST Electricity Workshop Summary: https://70n17f.p3cdn1.secureserver.net/wp-content/uploads/2022/07/I-WEST-Electricity-Workshop-Summary.pdf

require an increase in transmission capacity, storage, and reserves. The current trend of replacing fossil fuels with renewable resources has already created a backlog of interconnection requests to the transmission and distribution grids. Additionally, since the region exports electricity to the West Coast, there is a need to expand the transmission pathways to that region. Figure 3 shows the major transmission lines and associated voltages throughout the region. Also included in the figure are locations of coal and nuclear plants.

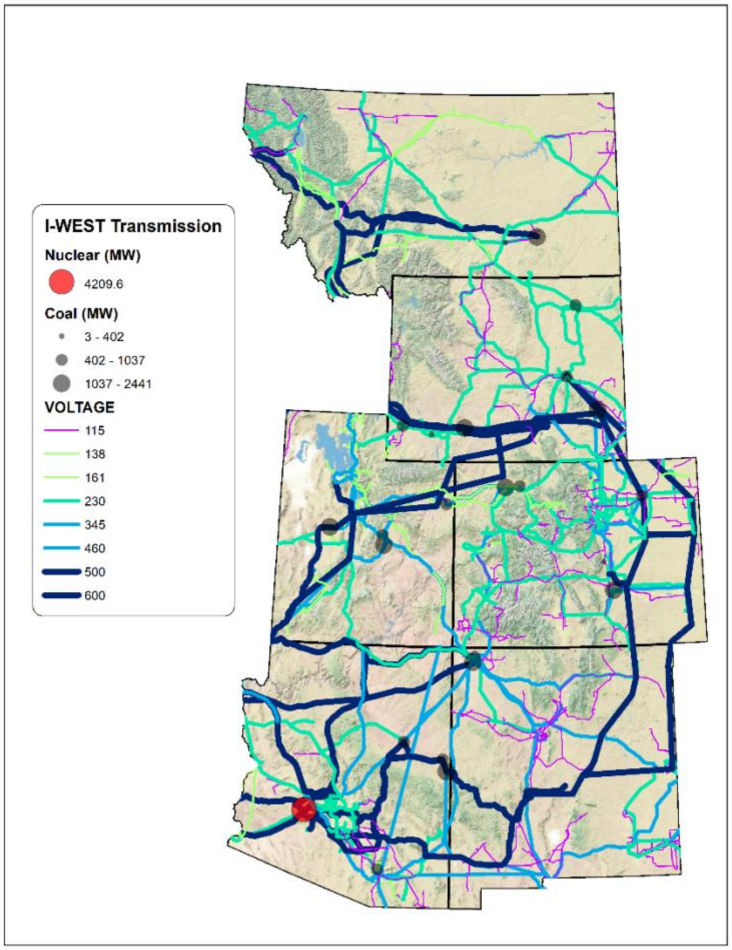

Figure 3. Transmission lines and associated voltages and locations of coal and nuclear power plants.

From the figure you can see that the high voltage lines (500-600 kV) are anchored by coal-fired power plants. The Palo Verde nuclear power plant also anchors several high voltage lines and exports electricity to the West Coast. These coal and nuclear plants provide the "baseload" for electricity transmission. Baseload capacity is the generation that can serve loads around the clock. As coal plants continue to be retired, the baseload they provide will need to be replaced. Carbon-neutral options for baseload include: nuclear, renewables with utility-scale batteries, natural gas with hydrogen blending, and coal with carbon capture technology. Each technology has efficiency challenges and varying load-balancing capabilities. These technologies are discussed later in this report.

Regional balancing authorities

The Intermountain West has several balancing authorities, as shown in Figure 4. Currently, each utility is responsible for balancing their electricity system.

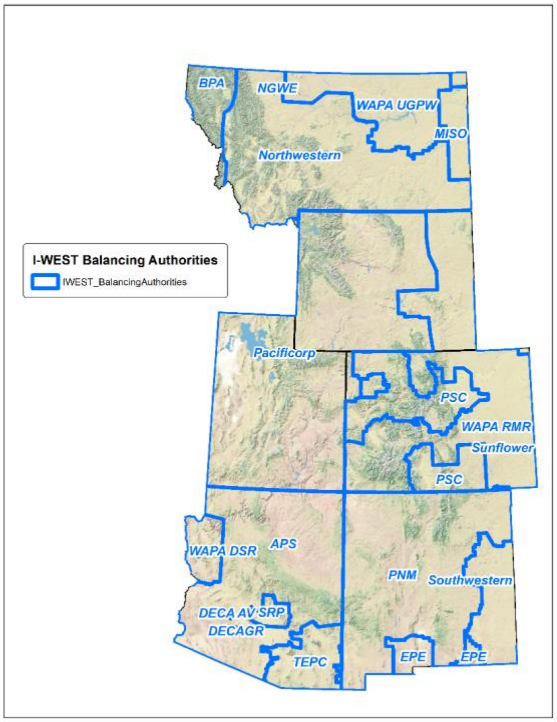

Figure 4. Balancing authorities.

Another key takeaway from the I-WEST Electricity Workshop was that the Intermountain West states could benefit from the development of a single regional transmission organization (RTO). RTOs, such as CAISO in California or ERCOT in Texas, include generators, transmission companies, utilities, and power marketers. They use complex optimization software to dispatch power based on day-ahead and real-time bids from generators and utilities.[3] RTOs also provide better price transparency and result in more efficient grid dispatch services. Creating an RTO that spans the entire region would require the approval of the Federal Energy Regulatory Commission (FERC) as well as coordination at the utility and state levels.

State-by-state assessment

Montana

Montana has an abundance of water resources including the Yellowstone and Missouri rivers and is one of the top hydroelectric producing states in the Intermountain West. Coal plants in Montana were built to complement the hydroelectric dams on the Missouri River when water levels run low, and were largely situated next to lignite mines. Coal production at the mines is ending, with the mines going through a multi-year reclamation process. As coal plants are retired, they are being replaced with natural gas facilities to maintain electricity supply to the grid. This conversion is largely driven by the low cost of natural gas. Looking ahead to adopting cleaner sources of energy, Montana's large amount of private land makes siting issues for new technologies achievable.

[3] Eia.gov

Table 1. MONTANA			
Technology	**MW**		**Water Source**
Coal	1814		
Largest Coal Plants	*Colstrip*	*1693 MW*	*Yellowstone River + Wells*
	Hardin	*115 MW*	*Bighorn River*
Natural Gas	492		*Muni, Yellowstone River*
Hydro	2653		*Missouri River and others*
Solar	17		-
Wind	1121		-

Wyoming

Wyoming also has an abundance of surface water resources that are used for cooling coal-fired plants. The state's natural gas plants are cooled with groundwater wells and municipal water resources. Wyoming has the smallest population of the six Intermountain West states and therefore consumes less electricity than it produces. The excess electricity is sold to the West Coast. Coal production in Wyoming peaked in 2008 and has been declining ever since. However, Wyoming still exports Powder River Basin coal to Texas, and profits from this account for a large portion of the state's revenue. Additionally, Wyoming's Black Thunder coal mine is the second largest producing coal mine in the country. Despite the potential for clean energy production in the state, Wyoming is currently dependent on its coal customers (TX) and electric power customers (CA). In terms of fossil alternatives, Wyoming has a proposed nuclear power project in development (Terra Power), and has the highest wind potential of all six states in the region with a large capacity of wind installations east of the Rocky Mountains. Wyoming has a good amount of private land east of the Rocky Mountains making siting issues for new technologies achievable.

Table 2. WYOMING			
Technology	**MW**		**Water Source**
Coal	7023		
Largest Coal Plants	*Dave Johnston*	*922 MW*	*North Platte River*
	Dry Fork	*483 MW*	*Wells*
	Jim Bridger	*2441 MW*	*Green River*
	Laramie Riv	*1863 MW*	*Laramie River*
	Naughton	*448 MW*	*Hams Fork River*
	Wygen	*301 MW*	*Wells*
	Wyodak	*402 MW*	*Muni*
Natural Gas	824		*Wells, Muni*
Hydro	301		*N.Platte, Shoshone & others*
Solar	92		-
Wind	**3130**		**-**

Utah

Utah has several water resources including the Green River, and several creeks and reservoirs, that are used for cooling coal-fired plants. Natural gas plants are cooled with groundwater wells and municipal water sources. Utah Associated Municipal Power Systems is building a small modular reactor (SMR) plant at the Idaho National Laboratory and will benefit from the electricity produced there. The reactor will be a six-module, 462 MW SMR and will cost an estimated 5.1 billion[4] to build. Utah is actively increasing solar capacity and is converting coal plants to natural gas facilities. Federal lands make up 60% of the state, which could pose siting issues for new power technologies.

[4] https://gazette.com/premium/colorado-remains-uninterested-as-others-turn-to-nuclear-power/article_e7491614-c596-11ec-86d3-638636c39afd.html

Table 3. UTAH			
Technology	***MW***		***Water Source***
Coal	4812		
Largest Coal Plants	*Bonanza*	*499 MW*	*Green River*
	Hunter	*1577 MW*	*Cottonwood Creek*
	Huntington	*1037 MW*	*Huntington Creek*
	Intermountain	*1640 MW*	*DMAD Reservoir*
Natural Gas	3242		*Wells, Muni*
Hydro	265		*Rivers, Reservoirs, Creeks*
Solar	1457		-
Wind	389		-

Colorado

Colorado has numerous water resources for cooling coal-fired plants including the Arkansas River and the Yampa River. The state also uses groundwater wells and municipal water for cooling both coal-fired and natural gas-fired plants. Roughly 50% of Colorado's land is under private ownership, most of which is east of the Rocky Mountains, allowing for beneficial siting.

Table 4. COLORADO			
Technology	***MW***		***Water Source***
Coal	4581		
Largest Coal Plants	*Comanche*	*1635 MW*	*Arkansas River*
	Craig	*1427 MW*	*Yampa River*
	Hayden	*465 MW*	*Yampa River*
	Pawnee	*552 MW*	*Wells*

	Rawhide	*293 MW*	*Municipality*
	Ray D Nixon	*207 MW*	*Wells*
Natural Gas	8006		*Rivers, Wells, Muni*
Hydro	1184		*Rivers, Lakes, Reservoirs*
Solar	1060		-
Wind	5032		-

Arizona

Arizona uses groundwater wells for cooling coal-fired plants and natural gas plants. Arizona also has access to Central Arizona Project (CAP) water for the cooling of some natural gas plants. Arizona has the highest hydroelectric capacity of the six states due to the Glenn Canyon and Hoover Dams. However, the current megadrought caused water levels in Lake Powell to drop significantly in 2022, which threatens hydroelectric production at Glenn Canyon Dam. Arizona, with its high solar potential, has the largest amount of installed solar capacity in the region. This is due in part to the state's systems that encourage solar adoption. For example, Arizona uses an online permitting platform, SolarAPP+, for automated permitting approvals of rooftop solar installations. The Salt River Project launched a study on converting its Coronado coal-fired power plant to a green energy plant. Options include bioenergy, hydrogen, or nuclear— or turning the site into a battery storage plant for solar and wind energy.[5] A large swath of Arizona consists of tribal and federal lands, making siting for new technologies difficult.

Table 5. ARIZONA			
Technology	***MW***		***Water Source***
Coal	3217		
Largest Coal Plants	*Apache*	*204 MW*	*Wells*
	Cholla	*425 MW*	*Lake Wells*
	Coronado	*821 MW*	*Wells*

[5] https://www.wmicentral.com/business/srp-launches-study-on-converting-coal-fired-plant-to-clean-green-energy/article_d48b52c1-ea2c-5cb6-8cd1-898afa8a7f17.html

	Springerville	*1765 MW*	*Wells*
Natural Gas	16981		*Wells, CAP, Muni*
Hydro	2912		*Colorado River and others*
Solar	2810		-
Wind	617		-

New Mexico

New Mexico uses water from the San Juan River and Morgan Lake for cooling at the Four Corners and San Juan coal plants. Groundwater wells are used for cooling at natural gas-fired plants. New Mexico has a good amount of private land east of the Rocky Mountains, making siting issues for new technologies achievable.

Table 6. NEW MEXICO

Technology	***MW***		***Water Source***
Coal	2560		
Largest Coal Plants	*Four Corners*	*1636 MW*	*San Juan River/ Morgan Lake*
	San Juan	*924 MW*	*San Juan River*
Natural Gas	3613		*Wells*
Hydro	81		*Rio Grande, San Juan*
Solar	740		-
Wind	4265		-

Technology pathways for electricity production

Renewables with utility-scale batteries installed close to load

Energy storage in the form of utility-scale batteries allows the power grid to function with more up-to-date manufacturing/sales, flexibility, and resilience. The cost of installing bulk electric storage systems has declined in recent years—the average battery energy storage capital cost in 2019 was $589 per kilowatt hour (kWh)[6]. Co-locating battery systems with renewable power plants, such as solar and wind, allows the batteries to be charged during times of overgeneration. During peak solar hours, curtailed wind energy can be used to charge the battery systems, maximizing the use of clean energy sources. The batteries can then discharge during low solar hours. For example, Figure 5 shows the CAISO supply trend profile. CAISO has ~1600MW of battery systems that charge during peak renewable hours and discharge as renewable production declines.

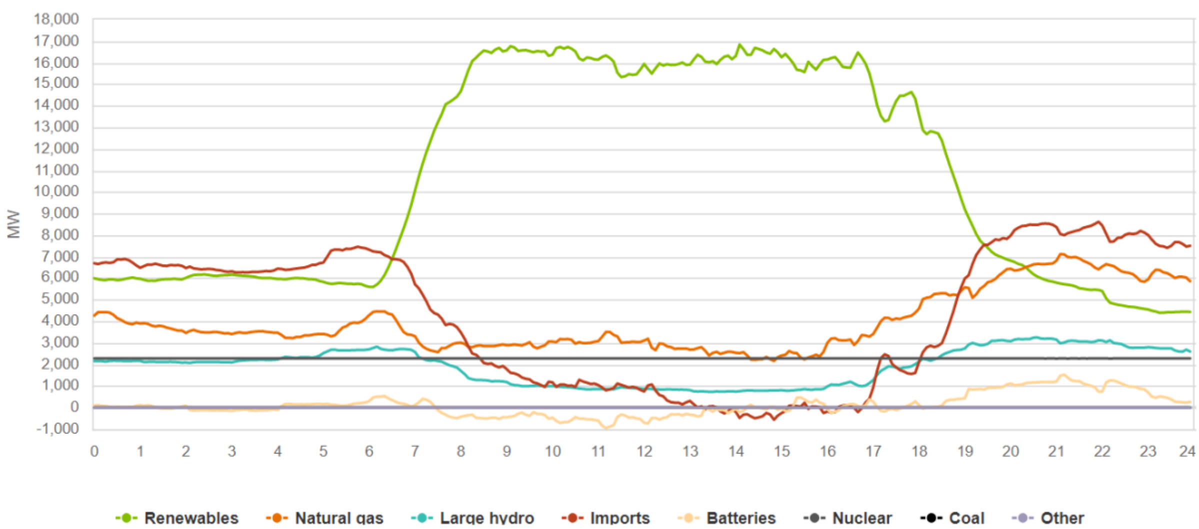

Figure 5. CAISO supply trend profile.

As of 2020, New Mexico has 1.8 MW, Colorado has 10 MW, and Arizona has 97 MW of battery storage installed. Renewables are actively increasing the variability of the system. The challenges for this technology pathway are to identify the best strategies for load balancing and planning for reserve margins, while also developing safer battery systems with more efficient fire suppression. An additional challenge is securing the vast amount of land needed for solar and wind projects, and the significant amount of lithium required to run utility-scale battery systems.

[6] https://eia.gov/analysis/studies/electricity/batterystorage

Retrofit natural gas plants with blended hydrogen/natural gas for co-fire

Interest in using hydrogen as a power plant fuel is growing in the United States. Several power plants are experimenting with blending natural gas with hydrogen for power production. One example is the Intermountain Power Agency conversion of an existing coal plant in Utah to a natural gas plant that will use a blend of 30% green hydrogen with 70% natural gas for co-firing. SoCalGas is pursuing a project to generate hydrogen, then blend hydrogen into natural gas to generate electricity for the California Institute of Technology in Pasadena. Natural Gas is an important fuel source for load balancing the grid and will likely continue to be a component of our electricity production profile. Natural gas is also needed to produce "blue" hydrogen, which is hydrogen created through reforming of natural gas. Hydrogen substitution for natural gas frees up the natural gas for competing uses such as home heating and industrial processes. Use of hydrogen in electricity production will also be key as regional clean hydrogen hubs are established through the Bipartisan Infrastructure Law—creating both demand and supply of hydrogen is key to a sustainable new hydrogen economy. The challenge for the Intermountain West will be finding sufficient water to produce "green" hydrogen, which is produced by water electrolysis powered by renewable electricity.

Repurpose coal plants with small modular reactors

A small modular reactor (SMR) is a new generating technology using advanced nuclear reactors with power capacity of up to 300 MW per module. The modules can be assembled in a factory and transported to a specific location, making them more affordable than building a traditional nuclear power plant. SMR designs are generally simpler and safer, relying on passive systems to remotely shut down. They require less frequent refueling (every 3-7 years) and some are designed to operate for 30 years without refueling.[7] SMR modules can be installed at retired coal plants where transmission and water supplies are already present. Utah Associated Municipal Power Systems is pursuing an SMR project that will use six small reactor modules. The challenge for this technology pathway will be political and community acceptance of nuclear energy, as well as the cost. SMR technology will need to clearly demonstrate the safety improvements over traditional nuclear designs, and define spent fuel management strategies that are credible.

[7] https://iaea.org

Carbon capture and storage

The region has several coal power plants where carbon capture methods could be used based on their existing process and current infrastructure. In New Mexico, Enchant Energy is planning a post-combustion retrofit of the San Juan Generating Station in San Juan County, New Mexico that will capture 6 to 7 million metric tons per year of CO_2 for local storage within the San Juan Basin. Traditional methods of carbon capture, utilization and storage (CCUS) require large amounts of water. The challenge for this technology is finding enough water resources required for the various methods.

Energy transition scenarios for electricity production

A key focus of I-WEST is to assess the existing energy landscape and offer up potential scenarios for how the Intermountain West could transition to net zero carbon as quickly and sustainably as possible. Following is a series of possible strategies considered.

Scenario #1: Aggressive renewables, fuel blending, and CCUS for remaining coal plants

This scenario requires:

- Aggressively deploying renewables co-located with utility-scale batteries to replace **some** coal-fired plants
- Adding small modular reactors to replace **some** coal-fired plants
- Retro fitting natural gas plants with a blended fuel source of 70% natural gas and 30% hydrogen
- Installing carbon capture technologies at remaining coal-fired plants

Figure 6 shows the locations, fuel types, and sizes of power plants proposed for scenario #1.

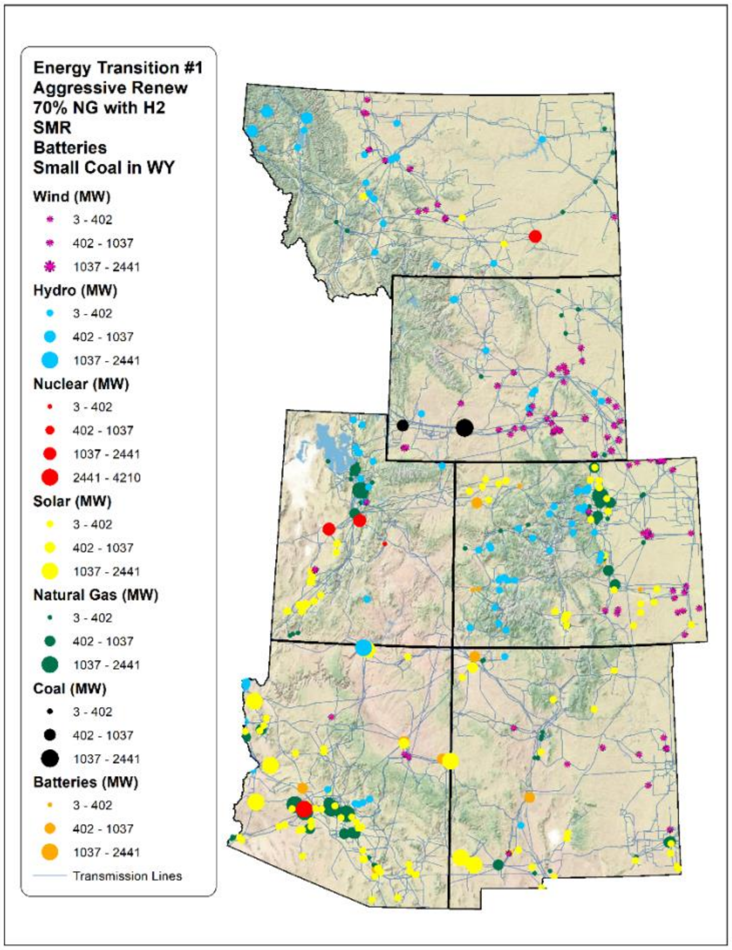

Figure 6. Locations, fuel types, and sizes of power plants proposed for scenario #1.

Coal-fired capacity is reduced from 24,008 MW to 3,273 MW and the remaining coal-fired plants are located in Wyoming with CCUS technologies installed.

Wind capacity is increased from 14,556 MW to 18,450 MW and is mostly located in the highest wind potential areas in Wyoming and Colorado.

Solar capacity increases from 6,178 MW to 15,805 MW and the additions are located in the highest solar potential areas in Arizona, New Mexico, Utah and Colorado.

Utility-scale battery systems are added near renewable sites in Arizona, New Mexico, and Colorado, increasing total capacity in the region by 5900 MW.

Nuclear capacity increases from 4209 MW to 10541 MW with the addition of SMR technologies in Utah and Montana.

The number of plants and capacities of natural gas-fired plants do not change, but we assume that each natural gas plant is retrofitted with blended fuel of 70% natural gas and 30% hydrogen. The natural gas capacity remains the same at 33160 MW for the region.

Hydroelectric capacity remains unchanged at 7400 MW.

Load balancing is accomplished by using a broad spectrum of energy sources: nuclear, natural gas, and coal (from remaining plants, and utility-scale battery systems.

Under this scenario, CO_2 emissions are reduced from 166 million tons/year to 40 million tons/year in the electricity sector. The remaining emissions result from the natural gas-fired plants and the coal-fired plants with CCUS installed, which reduces 85% of emissions from coal plants. Further research is needed to determine infrastructure investments required and to calculate a detailed cost analysis for this scenario.

Scenario #2: Replace coal with small modular reactors, plus fuel blending

This scenario requires:

- Replacing all coal-fired plants with SMRs
- Retrofitting all natural gas plants to operate with blended fuel of 70% natural gas and 30% hydrogen
- No change to renewable energy capacity

Figure 7 shows the locations, fuel types, and sizes of power plants proposed for scenario #2.

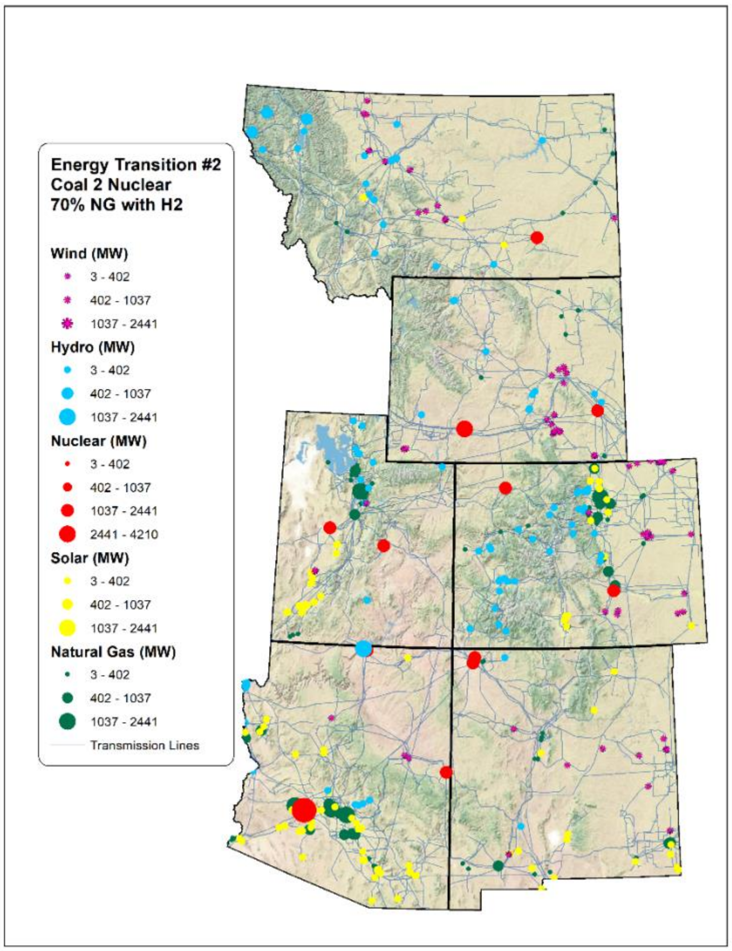

Figure 7. Locations, fuel types, and sizes of power plants proposed for scenario #2.

SMRs are installed at locations of coal-fired plants where transmission and water resources are already established, providing easy connections to the grid and on-site cooling. SMRs replace the coal capacity MW with nuclear MW— nuclear capacity increases from 4209 MW to 33069 MW.

All natural gas plants are assumed to operate with blended fuel of 70% natural gas and 30% hydrogen. There is no change to the overall capacity of natural gas.

No changes are made to solar, wind, or hydroelectric capacities.

Utility-scale battery systems are not needed/installed due to nuclear and natural gas serving as the baseload.

Load balancing is accomplished by using a broad spectrum of energy sources: nuclear plants, natural gas plants, and SMR plants.

Under this scenario, CO_2 emissions are reduced from 166 million tons/year to 26 million tons/year in the electricity sector. The remaining emissions result from the natural gas-fired plants. Further research is needed to determine the infrastructure investments required and to calculate a detailed cost analysis for this scenario.

Scenario #3: Replace coal with renewables, aggressive batteries, and fuel blending

This scenario requires:

- Replacing all coal-fired capacity with renewable energy plants (solar and wind)
- Retrofitting all natural gas plants to operate with blended fuel of 70% natural gas and 30% hydrogen
- Adding utility-scale battery systems installed close to renewable energy plants

Figure 8 shows the locations, fuel types, and sizes of power plants proposed for scenario #3.

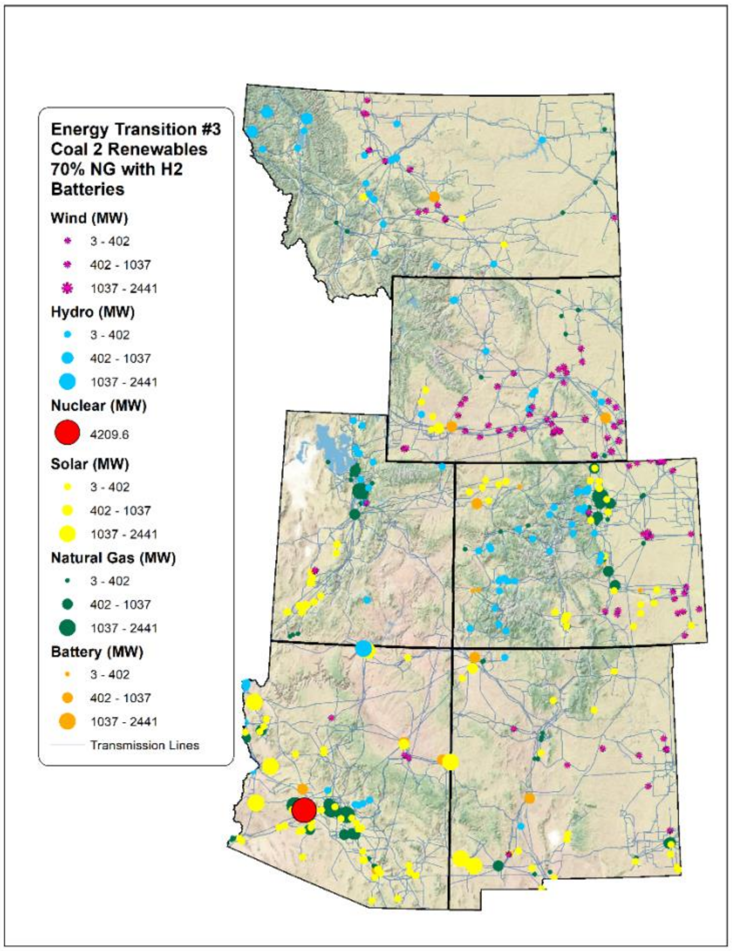

Figure 8. Locations, fuel types, and sizes of power plants proposed for scenario #3.

Solar capacity increases from 6,178 MW to 17,409 MW with additions in high solar potential areas of all states. Where feasible, solar plants are located close to former coal plant sites.

Wind capacity increases from 14,556 MW to 18,450 MW with most of the increases located in the high wind-potential states of Wyoming and Colorado. Where feasible, wind plants are located close to former coal plant sites.

Utility-scale battery systems are added near renewables sites in Arizona, New Mexico, Colorado, Wyoming, and Montana, increasing total battery system capacity in the region to 7,500 MW.

All natural gas plants are assumed to operate with blended fuel of 70% natural gas and 30% hydrogen. There is no change to the overall capacity of natural gas.

No changes are made to hydroelectric or nuclear capacities.

Load balancing is accomplished by using a broad spectrum of energy sources: nuclear plants, natural gas plants, and utility-scale battery systems.

Under this scenario, CO_2 emissions are reduced from 166 million tons/year to 26 million tons/year in the electricity sector. The remaining emissions result from the natural gas fired plants. Further research is needed to determine the infrastructure investments required and to calculate a detailed cost analysis for this scenario.

Scenario Comparison

Table 7 compares the installed capacity for the three scenarios.

Table 7. Installed Capacity for Scenarios

	Current	Scenario #1 Renewables, SMR, fuel blending, coal CCUS, batteries	Scenario #2 Coal to SMR, fuel blending	Scenario #3 Coal to renewables, fuel blending, batteries
Coal	24,008	3273	0	0
Natural Gas	33,160	33160	33160	33160
Hydroelectric	7,400	7400	7400	7400
Solar	6,178	15805	6178	17409
Wind	14,556	18450	14556	19950
Nuclear	4,209	10541	28189	4209
Battery	108	5900	0	7500
Total Capacity	***89,619***	***94,529***	***89,483***	***89,628***
Total CO_2	***166 mil. tons/yr.***	***40 mil. tons/yr.***	***26 mil. tons/yr.***	***26 mil. tons/yr.***

R&D needs assessment

Over the course of several stakeholder engagement workshops on energy transition in the Intermountain West, it became increasingly clear that there are several pressing challenges to achieving carbon neutrality. The region, as with many others, is fragmented when it comes to electricity generation planning. The states have different priorities and within each state, local communities and industries have their own set of needs and challenges. Further, the grid industry and utilities themselves have competing objectives. This presents challenges to centralized planning for regional goals such as getting to carbon neutral, as many planning decisions are made locally. Yet, such decisions must adhere to regional requirements and standards that are maintained through regional transmission organizations (RTO), independent system operators (ISO), and, ultimately, the Western Electricity Coordination Council (WECC). Given the structure of the electricity economy in the Intermountain West, research and development (R&D) efforts must bear these constraints in mind. While a centralized planning model is needed to inform, for example, funding decisions that impact the entire region, localized considerations must be integrated into that model in order to accurately identify emerging trends, opportunities, and possibilities.

Future infrastructure investments

Core R&D for the regional electricity economy must be focused on how to support future infrastructure investments in the Intermountain West. R&D requirements of I-WEST from an electricity perspective include:

Decision support planning tools (DSPT): These tools are needed to evaluate technology pathways and their synergistic effects to identify cost effective investments that will yield desired decarbonization outcomes. Such tools should leverage existing capabilities, repurpose existing tools, and develop new features that are required for specific regional goals and aims. Features of these planning tools should include at a minimum:

> *No-regrets planning:* Since many investment decisions are made locally, DSPTs should help identify investments that account for uncertainty in how investments will be made across the region and which are most likely to yield benefits for a wide range of external investment scenarios.
>
> *Economic analysis:* DSTPs need to model investment economics and help identify incentives to encourage adoption of technologies that will yield the desired decarbonization outcomes. Many technologies will have adoption challenges unless they are economically viable.
>
> *Social analysis:* DSTPs need to model the social implications of infrastructure investments and the potential for stranded assets, which may unequally impact and benefit different areas of the region.
>
> *Variability:* DSTPs need to model uncertain electricity generation capacity (wind, solar, etc.) and ensure sufficient reserve capacity is available to balance out such uncertainty with high probability.

Capacity expansion planning: DSTPs need to be able to explore the decision space of possible investments—new transmission lines, both AC and DC, storage, green generation, etc., to make recommendations on capital investments. These recommendations need to account for the features noted above.

Analysis studies: The Intermountain West could benefit from several analytical products to develop higher understandings of the needs and requirements of the region, including, but not limited to:

Transmission expansion: Grid oversubscription is becoming a problem in high-density population areas. Further studies are needed to examine line upgrades, pathway expansions, and detailed cost analysis for both. Ongoing efforts, such as those outlined in the DOE National Transmission Planning Study, should be leveraged and augmented to address the specificity of the Intermountain West.

Distribution upgrades: Rooftop solar and residential EV chargers are oversubscribing distribution feeders. Further studies are needed for considering distribution upgrades, their impact on the bulk transmission system, and detailed cost analysis.

Detailed cost analysis of each technology pathway: Economics will drive adoption of technology pathways as industry looks for the least expensive options. A detailed cost analysis will also provide governments with options for subsidies on preferred technologies.

Equipment lifetime analysis: A lifetime analysis of each technology pathway should be included in the detailed cost analysis to determine the total cost over the life of the equipment. An expensive technology that lasts 40 years may be preferred over a cheap technology that lasts only 10 years.

Deployment timelines: Carbon neutral by 2050 requires adoption of technologies with the shortest deployment timelines, so studies are needed to identify technologies that are available now or are likely to be available in the near future.

Private/industry/academic/government/tribal collaborations: Efforts and engagement are needed to include all stakeholders in technology pathway decisions.

Operational tools: Complimentary to DSPTs, are tools and capabilities to help support operations of the Intermountain West's future electricity system. Such tools should leverage existing capabilities, repurpose existing tools, and develop new features that are required for the specifics of the region's goals and aims. Such features include:

Control under uncertainty: Operational tools need techniques to handle uncertainty and variability in renewable energy production that goes beyond fast-ramping generation sources, such as those provided by natural gas units.

Definitions: As variability increases in the Intermountain West, new definitions of reliability and resilience need to be developed and deployed that go beyond today's definitions that guide operational decisions.

Demand response: Technologies in demand response need to continue to be developed, in particular to leverage and account for the expected coming wave in electrified transportation deployment.

Materials: One of the barriers to decarbonization is the cost of technologies that support green energy systems relative to conventional alternatives. Examples include:

Utility-scale storage: New materials and manufacturing are needed to bring the cost of utility-scale storage down to the point where it is cost effective option for electricity utilities.

Solar: While the cost of solar panels continues to drop, such efforts should continue in order to encourage further deployment of solar.