Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Deployment in Washington

Washington State Department of Commerce

Report submitted pursuant to Chapter 292, Laws of 2022

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Report to the Legislature

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Executive summary

Purpose and legislative requirements

Chapter 292, Laws of 2022 requires the Washington State Department of Commerce (Commerce) to develop a report and recommendations related to the role of green electrolytic hydrogen and renewable fuels in Washington.[1] This report aligns with the Washington 2021 State Energy Strategy, state greenhouse gas (GHG) reduction requirements, and economic and environmental justice responsibilities. Commerce must submit the report to the Legislature by December 1, 2023.

Overview

Hydrogen (H2) is a topic of great interest in Washington, thanks to its potential to help achieve decarbonization and clean energy targets. Hydrogen is the lightest and most abundant material in the universe, and it is an energy carrier. Pure hydrogen is not found in nature and must be produced (as a gas or supercooled liquid) from other materials, then transported, stored, and ultimately used through a fuel cell or in combustion turbines to generate energy. Used strategically, it can provide fuel pathways with no or low greenhouse gas (GHG) emissions, which is vital for the hard-to-decarbonize parts of our economy. It is considered a renewable fuel when produced with renewably-generated electricity.

The Washington State Legislature has passed several important laws and incentives for green electrolytic and renewable hydrogen deployment.[2] Additionally, the federal government is providing significant new funding opportunities for clean hydrogen including a new Production Tax Credit (PTC) and the Regional Clean Hydrogen Hubs (H2Hubs) grant program.[3] These programs are part of a broader federal Hydrogen Shot initiative that aims to reduce the cost of clean, low-carbon hydrogen within the next decade so that it is competitive with fossil-derived hydrogen and can help to decarbonize the US economy.[4]

This report also includes consideration of additional fuels derived from green electrolytic hydrogen, including liquid fuels produced through the Fischer-Tropsch process and ammonia produced through the Haber-Bosch process.[5] These fuels are renewable fuels when produced with renewable resources, and can be used to power specialized equipment or "dropped in" to existing uses as a one-to-one fossil fuel replacement.[6]

Producing green hydrogen and hydrogen-derived fuels is energy-intensive. On average, it takes about 50 kilowatt hours (kWh) of electricity and 14-20 liters of water to produce one kilogram of H2; one kilogram of hydrogen provides about 39 kWh of energy.[7] Despite this energy-intensive process, it is valuable to produce

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[1] Relevant elements of the legislation are codified in RCW 43.330.560, RCW 43.330.565, RCW 43.330.570, and RCW 43.330.575

[2] Green electrolytic hydrogen" is defined in RCW 54.04.190(6)(a), and "renewable hydrogen" in 54.04.190(6)(c). IIJA definition: 2kgCO2e per kgH2 at the point of production.

[3] US Department of Energy (DOE) defines "clean hydrogen" based on carbon intensity. DOE's fall 2022 draft Clean Hydrogen Production Standard proposes a full "well-to-gate" lifecycle carbon intensity for clean hydrogen as 4kgCO2e/kgH2.

[4] The Hydrogen Shot - part of DOE's Energy Earthshot project - was launched on June 7, 2021. It aims to reduce the cost of clean hydrogen to $1 per one kilogram within one decade, also known as "1-1-1." https://www.energy.gov/eere/fuelcells/hydrogen-shot Accessed 10/18/2023.

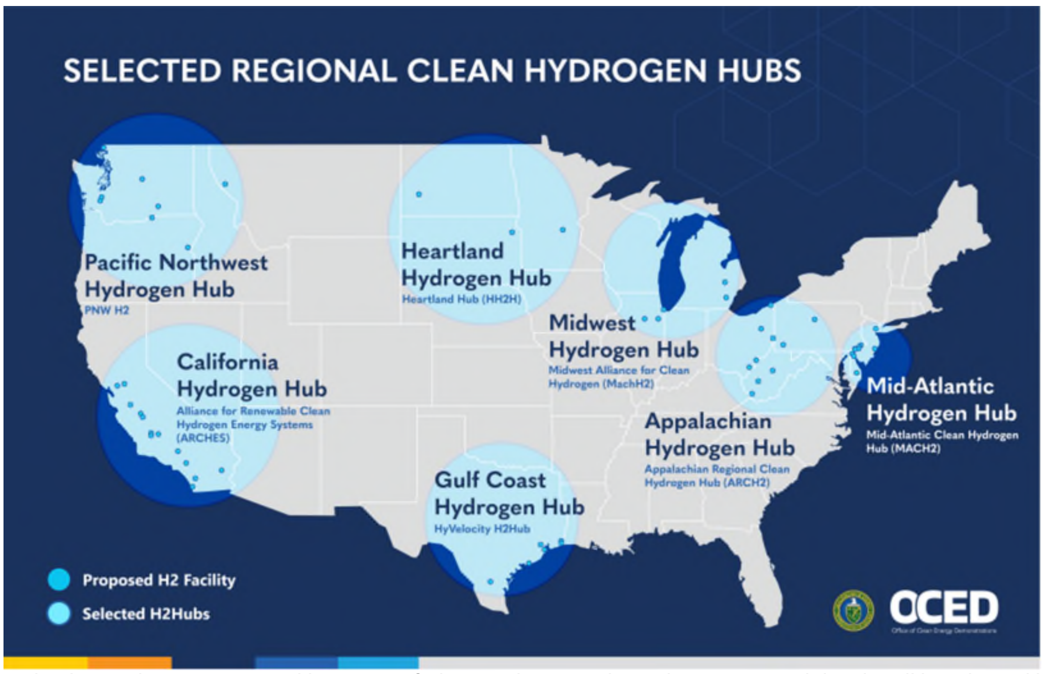
[5] These fuels are produced in a process known as Fischer-Tropsch, and this report refers to them as "Fischer-Tropsch liquid fuels" or "FT Liquids." The Fischer-Tropsch process converts synthetic gas (syngas, a mixture of hydrogen and carbon monoxide) to produce hydrocarbon fuels that can be used as drop-in clean fuels for petroleum product substitution. For more information see Table 1 Summary of Conversion Technologies. Ammonia is produced through a process known as Haber-Bosch, and involves producing ammonia using hydrogen and nitrogen.

[6] This includes those materials defined as a "green hydrogen carrier" in Chapter 185, Laws of 2002.

[7] The stoichiometric requirement to produce 1 kg of H2 is 9 liters of water. However, additional water is required for system cooling or other process needs. Total water demands may be 14-20 liters per 1kg H2, depending on electrolyzer characterizes and system design.

and use these fuels when they are deployed in activities or sectors that are not readily served directly with electricity, energy efficiency, or other decarbonization pathways. In these circumstances, deploying green electrolytic hydrogen and renewable fuels is an important decarbonization strategy and will assist Washington in reducing and eventually eliminating use of natural gas and other fossil fuels in buildings, transportation, and industry.

Importantly, in October 2023 the US Department of Energy (DOE) announced the beginning of negotiations to award up to $1 billion for a Pacific Northwest Hydrogen Hub, as part of the H2Hubs program.[8] This funding is expected to be combined with private and other funding to leverage more than $8 billion overall in public and private investments in green electrolytic hydrogen projects in Washington, Oregon, and Montana, accelerating deployment and driving down costs of low-carbon hydrogen in Washington and across the Pacific Northwest. While the scope of this report is to focus on modeling and policy recommendations to advance green hydrogen and renewable fuels in Washington, rather than modeling or assessing the Pacific Northwest Hydrogen Hub proposal, news of the anticipated new funding is significant and the H2Hub award will be referenced where relevant in this document as part of discussions about green hydrogen and renewable fuels advancement in the state.



Federal map showing proposed locations of Clean Hydrogen Hubs and projects. Final details will be released by DOE following a negotiation period.[9]

The opportunities to deploy green electrolytic hydrogen and renewable fuels are particularly significant in Washington. Washington's 2030 emissions target is a nation-leading model, requiring clean transportation fuels in addition to clean electricity and building and vehicle electrification. This provides a market opportunity for hydrogen and hydrogen-derived fuels, which we expect to be the earliest opportunity to advance this economy at scale in the US. While final details regarding federal funding opportunities including H2Hubs and the Production Tax Credit are under review at the time of publishing this report, it is likely that they will provide

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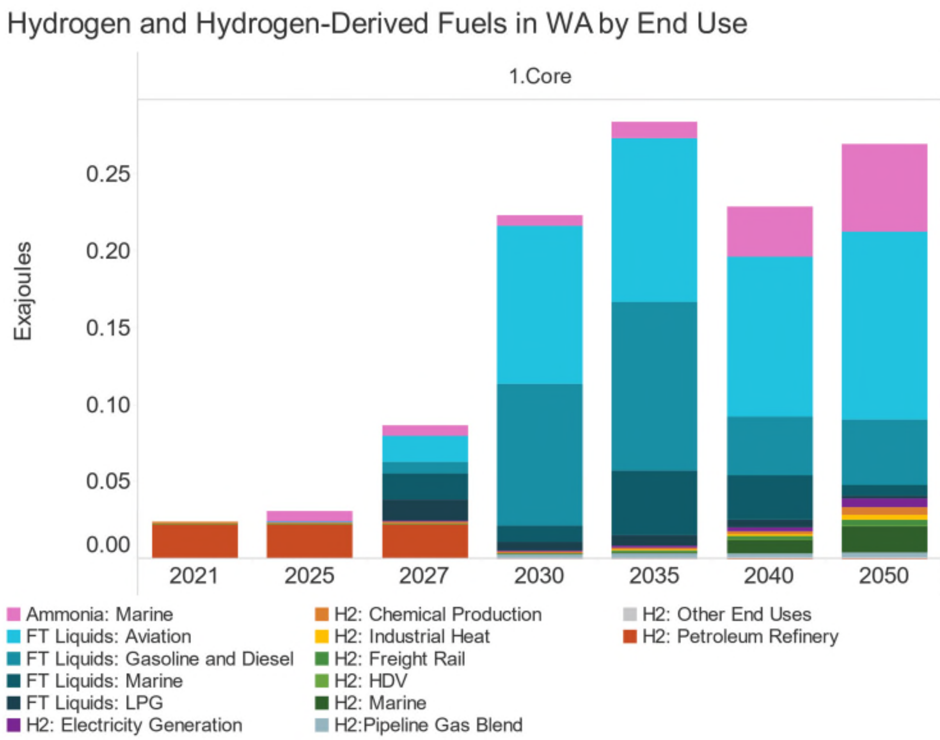
[8] "Biden-Harris Administration Announces $7 Billion For America's First Clean Hydrogen Hubs, Driving Clean Manufacturing and Delivering New Economic Opportunities Nationwide." October 13, 2023. https://www.energy.gov/articles/biden-harris-administration-announces-7-billion-americas-first-clean-hydrogen-hubs-driving. Accessed 10/16/2023.
[9] Regional Clean Hydrogen Hubs Selections for Award Negotiations | Department of Energy. Accessed 10/18/2023.

critical support for hydrogen deployment in Washington.[10] Federal funding opportunities, along with state incentives, policy, and partnerships provide an accelerated pathway for Washington to advance a green hydrogen economy.

Key findings

- **Washington will have strong demand for green electrolytic hydrogen and renewable fuels as part of a net zero economy.** This will include demand for hydrogen gas as well as renewable fuels that include green hydrogen as an input (including Fischer-Tropsch liquid fuels and ammonia).[11] State demand will reach 0.224 exajoules (EJ) of hydrogen and hydrogen-derived fuels by 2030, and 0.27 EJ by 2050.



Graph showing demand for green hydrogen and renewable fuels in Washington under the Core Case, the central scenario modeled in this report. Details of the Core Case and other scenarios are described in Chapter 1.

- **Washington will need to scale up production of green hydrogen through electrolysis rapidly.** The current baseline for in-state green electrolytic hydrogen production via electrolysis is near zero.[12] This report anticipates that Washington will install 0.8 gigawatts (GW) of electrolysis capacity and produce 200,000

[10] The US Treasury Department and Internal Revenue Service published proposed regulations regarding qualification for the § 45V Clean Hydrogen Production Tax Credit on December 22, 2023. At the time of writing, the US Treasury Department has opened a comment period on the proposed rules, with final regulations expected in early 2024. IRS, "Treasury, IRS issue guidance on the tax credit for the production of clean hydrogen." December 22, 2023. https://www.irs.gov/newsroom/treasury-irs-issue-guidance-on-the-tax-credit-for-the-production-of-clean-hydrogen

[11] These fuels are produced in a process known as Fischer-Tropsch, and this report refers to them as "Fischer-Tropsch liquid fuels" or "FT Liquids." The Fischer-Tropsch process converts synthetic gas (syngas, a mixture of hydrogen and carbon monoxide) to produce hydrocarbon fuels that can be used as drop-in clean fuels for petroleum product substitution. For more information see Table 1 Summary of Conversion Technologies. Ammonia is produced through a process known as Haber-Bosch, and involves producing ammonia using hydrogen and nitrogen.

[12] At the time of publication, one small electrolyzer owned by Air Liquide is operating in Kalama, Washington. Others are planned or announced across the state but not yet operational.

metric tons (MT) per year of hydrogen by 2030, and 4.5 GW of electrolysis and 700,000 MT per year of hydrogen by 2035.

- **Production of renewable Fischer-Tropsch liquid fuels will also require significant electricity capacity**: 0.5 GW by 2030 and 2.5 GW by 2035.[13]
- **Hydrogen and renewable fuels production must be developed in coordination with expanded renewable electricity capacity.** Based on the modeling in this report, we expect new in-state renewable electricity capacity to grow by 3.4 GW by 2030, and 36.8 GW by 2050 as part of overall expansion of renewable and non-emitting generation and transmission in the state.
- **Robust siting and permitting processes for green hydrogen are needed, and siting and permitting of new renewables to support a hydrogen economy and economy-wide decarbonization poses even greater challenges.** Where the 2021 State Energy Strategy envisioned using excess renewable generation to produce hydrogen, the level of hydrogen and renewable fuel production envisioned here cannot be met without new transmission and generation capacity. Supporting efforts to expedite and improve siting and permitting across the clean energy supply chain - in coordination with state entities, tribes, industry, communities and more - is critical.
- **Green hydrogen and renewable fuels should be used strategically for end uses where they are well-positioned to support efficient decarbonization.** Because it is energy-intensive to produce, transport and store hydrogen, it is important to use it where it is the most effective option and avoid applications where renewable or nuclear electricity, energy efficiency, or other clean fuels are more efficient and less costly. Markets for these strategic end uses of hydrogen should be developed in coordination with hydrogen production.
- **Importing hydrogen and renewable fuels from other states may develop as part of a cost-effective approach.** Washington may import approximately 70% of its total demand for green hydrogen and renewable fuels by 2050 under the Core Case. With H2Hub funding, our modeling suggests Washington may produce more of our hydrogen products in-state, although some imports from other states will remain likely in the longer-term. These outcomes are consistent with the regional partnership planned for the PNWH2 hub which includes Oregon and Montana.
- **Federal policy and funding decisions can significantly impact Washington's hydrogen economy.** The Inflation Reduction Act (IRA) and Infrastructure Investments and Jobs Act (IIJA) resources for hydrogen lead to modeling showing hydrogen and renewable fuels markets taking off approximately five years faster than modeled only a few years ago in the 2021 Washington State Energy Strategy.[14]
- **The recent DOE announcement that the Pacific Northwest Hydrogen Hub is expected to be funded through the H2Hubs program will support Washington's deployment of green hydrogen and renewable fuels.** If negotiations are successful and funding is delivered at anticipated levels, this grant is expected to support in-state hydrogen production for numerous valuable end uses including heavy-duty transportation and green fertilizer. Scenario Four, modeled in this report, projects the impacts of an H2Hub award in the region, and anticipates that an additional approximate 190,000 MT per year of green electrolytic hydrogen would be produced in Washington in 2040 above the Core Case levels.
- **Other federal policies and incentives - particularly the IRA Production Tax Credit (PTC) - are critical to support Washington's hydrogen and renewable fuels market.** Modeling demonstrates that access to this

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[13] The unit referenced here is GW to represent the energy required to produce the fuels, since they will not be measured in kilograms in the same way the green hydrogen is represented.

[14] The 2021 Washington State Energy Strategy (Electrification Scenario) identified many sectors of the economy showing demand for green hydrogen beginning in the 2035 to 2040 timeframe. This report finds numerous key demand sectors advancing by 2030. This likely is due to federal incentives through the IRA and IIJA, including the US Treasury Department's 45v Production Tax Credit (PTC), and state programs like Washington's Clean Fuel Standard (CFS) and Climate Commitment Act (CCA) cap and invest policy.

credit strongly supports green hydrogen deployment, and that early expiration of the tax credit would significantly reduce in-state supply of and demand for these fuels.

- **There are environmental justice concerns unique to hydrogen and renewable fuels across the supply chain, which are important for project developers, tribes, and stakeholders to understand and address.** The use of appropriate frameworks and best practices to partner with tribes and engage communities can help to identify shared priorities, reduce or remove disproportionate environmental health burdens, and equitably distribute project benefits. These practices can improve public support and deliver equitable outcomes from hydrogen and renewable fuel advancement in Washington, in alignment with key environmental justice responsibilities under the Healthy Environment for All (HEAL) Act and the federal Justice40 Initiative.

More information and context regarding these key findings are provided below.

Green hydrogen and renewable fuels demand and electricity requirements

This study relies on economy-wide modeling of Washington's energy demand and supply options to identify the cost-minimizing methods of satisfying those energy demands while complying with the state's emissions limits and clean electricity laws. Commerce used this modeling approach in the Washington 2021 State Energy Strategy (SES), where we first identified an important role for green hydrogen in the state's energy transformation.[15]

Key findings in the Core Case demonstrate that Washington will have strong demand for green electrolytic hydrogen and renewable fuels as part of a cost-effective pathway to economy-wide decarbonization. The production of these fuels will require a rapid scale up of electrolyzer capacity in the state. With only one small electrolyzer operating in Washington at present, the baseline of green hydrogen production in 2023 is virtually zero. The modeling in this report indicates that Washington should seek to produce 200,000 metric tons (MT) of green hydrogen per year by 2030, and 700,000 MT per year by 2035.

At the time of publication, the PNWH2 hub is negotiating with DOE and final details of any final award and production levels are still being determined. Based on what is currently known, we anticipate that the levels of green hydrogen produced in Washington through implementation of the H2Hub would align well with though not exceed the 2030 projected levels of in-state hydrogen production. Therefore, the investments supported by the PNWH2 hub will strongly support Washington's pathway to securing these fuels, though Washington can anticipate requiring further hydrogen and renewable fuel production or imports from other states in the region to satisfy predicted demands.

It is critical to emphasize that these levels of hydrogen and renewable fuels require a significant increase of new renewable electricity supply and transmission infrastructure. The 2021 SES discussed the use of excess renewable generation to produce hydrogen, which is likely to occur to some degree, including from non-firm hydroelectric capacity, meaning that hydroelectric generation above projected needs could be used by utilities to power electrolyzers to produce hydrogen.[16] However, in order to deliver the levels of green hydrogen and renewable fuels modeled in this report, we will need new renewables and transmission as part of economy-wide increased demand for renewable electricity capacity. We expect in-state electrolysis capacity will require renewable electricity levels of 0.8 GW by 2030 and 4.5 GW by 2035. The electric capacity to support renewable fuels production adds to those requirements. New renewable electricity capacity in Washington is projected to

[15] Washington 2021 State Energy Strategy. https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/
[16] Non-firm hydropower is the electricity generated in excess of firm power, where firm power is the amount of generation available during the lowest annual river flows on record. Non-firm power cannot be counted on for planning purposes and is often sold at a discounted price in the electric power markets.

grow by approximately 3.4 GW by 2030, and 36.8 GW by 2050, including to produce hydrogen and renewable fuels, as part of overall expansion of renewable generation and transmission in the state. This growth is critical to meet the state's overall decarbonization goals.

We cannot meet the levels of hydrogen and renewable fuel production envisioned in this report without new transmission and generation capacity.

The importance of new renewable electricity capacity is significant and is likely to develop differently depending on the final provisions in the federal 45V PTC.

The modeling conducted in this study assesses different decisions that the US Treasury could make in terms of final accounting rules that would provide access to the highest $3 per kilogram of hydrogen PTC level. The Core Case assesses stricter rules (which more closely resemble the draft rules released by Treasury), and additional scenarios investigate less stringent final rules.[17] The modeling in this report indicates that new renewables are critical for deployment of green hydrogen at scale, although the strictest application of accounting rules in the 45V PTC is not necessary in Washington in order to achieve the necessary scale of new renewables to support cost-effective green hydrogen deployment.[18] This report assesses economy-wide expectations; specific assessments of how the credit will impact individual proposed projects will also be important to understand impacts to specific production projects. We discuss this further in Chapter 1.

Strategic end uses of green hydrogen and renewable fuels

This report identifies numerous sectors where hydrogen and renewable fuels will be in demand in the coming decades. The nature of green hydrogen and renewable fuel supply chains, which are energy-intensive, emphasize the importance of focusing on the most strategic uses for these fuels.[19] Displacement of fossil-generated hydrogen in Washington's refineries will likely provide the first near-term demand for green electrolytic hydrogen, followed by significant opportunities to produce synthetic liquid "drop-in" fuels for use in the transportation sector by 2030.

The primary end uses for which we expect hydrogen to play a significant role in Washington include:

- **Replacing fossil-derived hydrogen in refining and other chemical production processes** (0.024 EJ by 2027, with use in petroleum refining tapering off in the 2030s);[20]

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[17] Proposed rules issued on December 22, 2023 indicate that access to the 45V PTC will require time matching, deliverability, and additional/incremental power generation in order to qualify for the highest levels of credit. Final rules will be released in 2024 following a comment period. The White House, "Treasury Sets Out Proposed Rules for Transformative Clean Hydrogen Incentives." December 22, 2023. https://www.whitehouse.gov/cleanenergy/clean-energy-updates/2023/12/22/treasury-sets-out-proposed-rules-for-transformative-clean-hydrogen-incentives/

[18] Commerce has submitted letters to the US Treasury Department on the topic of the 45V PTC, explaining that it may be appropriate for states with strong climate and clean energy laws to differentiated in the final rules with less strict requirements on questions such as additionality (also called incrementalism or new renewable capacity), because our state laws already protect against unintended increases in GHG emissions. These and other federal comment submission letters can be viewed on the Office of Renewable Fuels webpage: https://www.commerce.wa.gov/energy-blog/renewable-fuels/federal-comment-submissions/

[19] On average, it takes about 50 kWh of electricity and 14-20 liters of water to produce one kilogram of H2; one kilogram of H2 provides about 39 kWh of energy.

[20] These figures represented the amounts of energy used to produce the corresponding levels of H2 or derived fuels by 2050, using the findings in the Core Case. While use in refineries tapers off in the 2030s, use of hydrogen in chemical production including fertilizer production continues to grow through 2050.The modeled scenarios are explained in Chapter 2.

- **Production of renewable liquid fuels for use in on-road, maritime, and aviation transportation**[21] (0.211 EJ by 2030 and 0.174 EJ by 2050);
- **Production of ammonia**, predominantly for use as a maritime fuel (0.057 EJ by 2050);[22]
- **Direct use of hydrogen in fuel cell electric vehicles**, specifically **heavy-duty vehicles, freight rail, and marine fuel cells** (0.021 EJ by 2050);
- **Other direct uses of hydrogen gas in electricity production, industrial heat, and pipeline gas blends** (These uses combined reach 0.013 EJ by 2050).

The data used in this study draws from and aligns with the modeling data used in Commerce's Transportation Electrification Strategy (TES), which finds low anticipated light and medium-duty vehicle sales, and higher levels of heavy-duty and transit bus needs being served by hydrogen fuel cell vehicles through 2035.[23]

Opportunities and challenges for importing green hydrogen from other states

The modeling in this report indicates that Washington may import significant levels of green hydrogen and renewable fuels produced using abundant renewable resources in neighboring states, as part of a least-cost approach to meeting Washington's demand for these fuels. While Washington should seek to expand production of green electrolytic hydrogen and renewable fuels in state rapidly, this report indicates that the state may supplement in-state production with hydrogen imported from other states. In fact, as part of a least-cost pathway, Washington could import approximately 70% of its hydrogen in 2050.

This approach takes advantage of the greater abundance and productivity of renewable resources, such as wind in the Rocky Mountains, and it reduces demands on scarce electric power transmission capacity. There are also risks associated with this approach, in that it relies heavily on imported fuel, similar to the risks that Washington consumers and businesses face today when relying on imported fossil fuels. Washington is not able to control how other states approach hydrogen production, including the siting and permitting processes that might help such projects advance at scale. Washington also must ensure that any hydrogen imported from other states aligns with state climate laws including the Climate Commitment Act. While market incentives through DOE's Clean Hydrogen Production Standard and connected PTC are likely to promote low-carbon hydrogen production in all states through strong cost incentives based on lifecycle carbon intensity, Washington should remain vigilant to ensure we can track and account for any associated emissions from imported hydrogen. Washington also has a better ability to address and seek to promote additional benefits of hydrogen production such as labor standards for hydrogen workers when we produce these fuels in state.

Additionally, transportation by pipeline is often the most cost-effective manner of transporting hydrogen over longer distances, but transporting pure hydrogen typically cannot be achieved in existing natural gas pipelines, so new pipelines or significant retrofits would likely be needed. Given concerns about siting of fossil fuel

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[21] Sustainable aviation fuels (SAF), also known as "alternative jet fuels" can be produced through various production pathways. This report focuses on production through "power to liquid fuels" pathway. Due to its focus on hydrogen, this report focuses on fuel production via this pathway only and does not model other or project total SAF production levels via additional pathways. For more information see WSU ASCENT: https://ascent.aero/participant/washington-state-university/

[22] On-site ammonia production for fertilizer is included in the modeled category for chemicals production. The modeling program used also has an explicit pathway for ammonia production for maritime shipping.

[23] The modeling in this report aligns with the Strong Electrification Scenario in the TES. The TES modeling identified 10.2% of transit buses, 0.3% of heavy-duty trucks, and a negligible amount of light-duty passenger vehicle sales being served by hydrogen fuel cell vehicles by 2035. The findings in the TES are based on modeling total vehicle cost of ownership for consumers, although it does not model consumer habit or preferences, or specific geographic or transportation needs that might impact choice of zero-emission vehicles. The TES modeling runs through 2035, whereas the modeling in this report extends to 2050 and predicts additional growth in heavy-duty vehicle sectors post-2035.

pipelines in this region, the state and relevant stakeholders would need to proceed with caution and incorporate significant tribal and community engagement when considering any new hydrogen pipelines or major retrofits.

Opportunities for hydrogen production in Washington

The various risks associated with relying on out of state production and imports suggest Washington should seek to encourage in-state hydrogen production as long as that production is supplied with new clean energy generation and transmission capacity, and in alignment with developing demand markets in hard to decarbonize sectors. An emphasis on supporting the deployment of green hydrogen and renewable fuels at scale in Washington will improve our state's ability to meet our 2030 emissions targets.

The deployment of hydrogen and renewable fuels at scale will require significant public and private investments. While calculation of specific projections for such investments in Washington is beyond the scope of this study, the scale of state and federal investments thus far is a testament to the recognition that the required resources will be substantial. Private sector investments will likely be the principal source of investment, supported by federal, state and other grants and incentives, such as the 45V PTC, where needed to help drive strategic deployment. Research by US DOE demonstrates that different end users of green hydrogen have varying willingness-to-pay levels depending on the sector.[24] Washington should consider ways to support and incentivize especially those sectors that may require lower price levels for green electrolytic hydrogen or renewable fuels. New federal demand-side supports announced by DOE to complement H2Hub funding will also play a valuable role in comprehensive, economy-wide deployment.[25]

Additionally there are important non-economic measures the state can use to expedite development of these industries. These include creating tools and providing technical assistance to project proponents to help navigate the upcoming Treasury rules for receiving the 45V PTC, as well as supporting effective implementation of recent siting and permitting improvements in state law and continued reforms where needed.

Siting and permitting

Supporting an improved siting and permitting process for green electrolytic hydrogen that enables projects to move forward expeditiously while not sacrificing environmental or community considerations is a key way the state can help deploy hydrogen and renewable fuels in Washington. One primary opportunity will be through the process established in Chapter 230, Laws of 2023 to expedite siting and permitting processes for clean energy projects including green electrolytic hydrogen, and the development of a Programmatic Environmental Impact Statement (PEIS) for green electrolytic hydrogen.

Efforts to make siting and permitting of green hydrogen projects more efficient and effective should focus initially on sectors most likely to advance in the near term and where environmental and community considerations are critical, such as production systems and pipeline transportation. Additionally, Washington should take further steps to facilitate green hydrogen siting and permitting through advance planning efforts. This could include: defining designated geographic areas in Washington that are preferred sites and corridors

[24] U.S. DOE "Pathways to Commercial Liftoff Clean Hydrogen" (2023). https://liftoff.energy.gov/wp-content/uploads/2023/05/20230523-Pathways-to-Commercial-Liftoff-Clean-Hydrogen.pdf Accessed 9/30/2023.
[25] U.S. DOE "U.S. Department of Energy Seeks Independent Entity for New Demand-Side Initiative to Accelerate Clean Hydrogen Economy." September 14, 2023. https://www.energy.gov/oced/articles/us-department-energy-seeks-independent-entity-new-demand-side-initiative-accelerate.

and focusing expedited processes in these regions; prioritizing hydrogen production projects with long-term input supply contracts for renewable electricity generation and water rights; and streamlining the process for existing users of hydrogen produced through steam methane reforming (SMR) to convert to use of green or renewable hydrogen. The state should also ensure robust tribal consultation and community engagement process to address environmental justice considerations generally and especially that those unique to hydrogen projects are included as part of siting and permitting considerations.

Environmental justice considerations

Deploying green hydrogen and renewable fuels at scale to support decarbonization is an extremely important opportunity to improve Washington's ability to reach net-zero targets, and using hydrogen and hydrogen-derived fuels where direct electrification or other decarbonization strategies are not feasible will help our state make critical reductions in all sectors. If done well, it presents opportunities to create equitable benefits for overburdened communities, in alignment with Washington's Healthy Environmental for All (HEAL) Act, and the federal Justice40 Initiative. However, the legacy of energy projects that have created disproportionate burdens in the past and unique concerns related to aspects of a hydrogen supply chain pose challenges for advancing green hydrogen in the state.

With intention and effort, it is possible to address such concerns and to support deployment of green electrolytic hydrogen and renewable fuels in ways that advance environmental justice, though these outcomes should not be assumed or taken for granted. In order to meaningfully address environmental justice concerns and considerations, it will be important for all stakeholders — from project developers to state leaders advancing hydrogen incentives — to have a clear understanding of the concerns and risks often voiced, and strategies that can impact the ability of community input to be meaningfully heard and addressed.

> Advancing a green hydrogen economy provides a critical opportunity to create more equitable outcomes than in fossil fuel energy deployment, if we focus on inclusive practices and equitable distribution of benefits.

This report seeks to give voice to some of the concerns that have been articulated publicly and in conversation with tribes and stakeholders, to aid in this learning process.

Recommendations in this report include finding ways to address the most significant considerations about hydrogen throughout the supply chain, including:

- Safety standards in hydrogen projects;
- Air quality and human health risks related to nitrogen oxides (NOx) emissions resulting from combustion of hydrogen;
- Disadvantages of hydrogen solutions when other options are available that are lower cost, more energy efficient, and/or require less water;
- Avoiding outcomes wherein incorporation of hydrogen contributes to extending the life of fossil fuel energy systems.

Using environmental and energy justice frameworks such as the Social Life Cycle Assessment, the Social Framework for Projects, the Three Tenets of Energy Justice, or the MED Framework, will help decision-makers determine considerations, priorities, and plans for ensuring equitable development.

All hydrogen projects should focus on the distribution of benefits in hydrogen projects as well. US DOE has identified Justice40 policy priorities for energy projects.[26] Green hydrogen projects have the potential to contribute to numerous of these priorities to benefit overburdened communities, including:

- Decreasing environmental exposure and burdens
- Increasing clean energy jobs and workforce pipelines, and
- Increasing energy resiliency.

Tribal engagement

Tribal nations are critical partners in work that contributes to the state's clean energy and climate action. While perspectives and participation vary, tribal leaders and members have expressed interest and participated in key areas of hydrogen-related work, including:

- Taking leadership roles in regional hydrogen project planning, including several tribes with representation on the board and advisory committees of Pacific Northwest Hydrogen Association (PNWH2), which developed the regional H2Hubs proposal;[27]
- Partnering in the development or review of hydrogen projects where they align with renewable energy efforts, energy storage and energy sovereignty needs, as well as economic development opportunities for tribes and tribal citizens;
- Providing input on how we should strategically incorporate hydrogen into Washington's energy landscape. We must develop hydrogen's role in balance with interrelated issues regarding hydropower, cultural and natural resources, fish and wildlife impacts and other considerations.

Commerce is committed to supporting multiple pathways for tribal engagement on hydrogen and the many issues on which we work with tribal leaders.

Recommendations

In order to advance green hydrogen and renewable fuels deployment in ways that help Washington efficiently and equitably decarbonize our economy, there are a number of key recommended actions that should be considered. We provide additional details in the Recommendations chapter of this report.

1. Support and seek to accelerate in-state green electrolytic hydrogen production

- **1.1 Set a state target for in-state green electrolytic hydrogen production of 4.5 GW by 2035 with a stretch goal of 4.5 GW by 2030.**
- **1.2 Help green hydrogen producers access the 45V Production Tax Credit.**
- **1.3 Use existing and consider new incentives to support electrolyzer production and use in Washington.**
- **1.4 Evaluate and promote safe and efficient hydrogen storage, including evaluating underground storage opportunities.**

Context: Accelerating deployment to 2030 would be an aggressive policy and could be difficult to achieve, but it would take advantage of the IRA incentives that are available now and anticipated H2Hub funding. Building electrolyzers earlier could help prevent against the policy risk that the incentives are rolled off early (this would occur if a future federal decision were made to end these incentives earlier than is currently planned) or that hydrogen and renewable fuels cannot be imported from other states on the timeline or at the scale that

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[26] U.S. DOE "DOE Justice40 Initiative and Policy Priorities." https://www.energy.gov/diversity/justice40-initiative. Accessed 9/30/2023.
[27] Pacific Northwest Hydrogen Association, "Our Board." https://pnwh2.com/our-board. Accessed 10/4/2023.

Washington's demand will require. The state should seek balance in advancing the most cost-effective pathways to access green hydrogen and renewable fuels and the speed at which Washington can develop a competitive hydrogen economy.

2. Provide targeted state support for green hydrogen in strategic end uses

- **2.1 Clearly identify and direct state and federal investments and incentives to strategic end use sectors.**
- **2.2 Fund pilot and demonstration projects.**
- **2.3 Provide technical assistance to support market development in strategic sectors.**
- **2.4 Support access to DOE H2Hubs Demand-side Initiative as part of H2Hubs implementation.**
- **2.5 Work with refineries to replace in-state fossil-derived hydrogen with green electrolytic hydrogen.**
- **2.6 Evaluate policy options that will accelerate production and use of renewable Fischer-Tropsch liquid fuels and reduce statewide transportation emissions.**
- **2.7 Direct hydrogen initiatives and investments for on-road hydrogen use to the most strategic vehicle types and corridors.**
- **2.8 Support efforts to deploy hydrogen, ammonia, and other renewable fuels as part of decarbonizing maritime fuels and operations.**

Context: State resources should be targeted to helping advance hydrogen use in strategic sectors of the economy that will provide opportunities for the highest and best use of hydrogen and the renewable resources used to produce it. The state should seek to find ways to complement final plans for a PNWH2 award and the end uses that can be served. It is also important to provide additional analysis and technical support to support green hydrogen and renewable fuels market development in strategic sectors.

3. Ensure that Washington's green hydrogen economy is consistent with GHG reduction requirements and a net-zero economy

- **3.1 Support increased renewable electricity capacity and transmission infrastructure to supply hydrogen and economy-wide loads.**
- **3.2 Address and control GHGs from imported hydrogen in the context of state carbon cap.**
- **3.3 Monitor and reduce leakage of hydrogen to minimize indirect greenhouse gas impacts.**

Context: State and local policies already provide strong incentives driving hydrogen and renewable fuels production toward the lowest possible lifecycle carbon intensity. However, additional actions and policy changes may be needed to ensure that sufficient renewable power is available to support a production of low- or zero-carbon hydrogen, and to ensure the carbon footprint of hydrogen across the full lifecycle is known and accounted for.

4. Promote expedited and equitable siting and permitting practices for hydrogen and renewable electricity systems

- **4.1 Work with the Washington State Department of Ecology to develop an effective and equitable PEIS for green hydrogen.**
- **4.2 Develop a process to evaluate preferred geographic locations for hydrogen infrastructure.**
- **4.3 Promote local or on-site hydrogen and renewable fuel production where appropriate.**
- **4.4 Conduct additional activities that support efficient and effective siting and permitting for green hydrogen production and use.**
- **4.5 Support efforts to site and permit renewable electricity and transmission infrastructure.**

- **4.6 Ensure robust tribal input and community engagement informs state and regional approach to hydrogen and ammonia pipelines.**

Context: The need for hydrogen-derived fuels in 2030 to meet Washington's emissions target places an imperative on the pace of development of the hydrogen industry. Ensuring permitting processes can keep pace with expansion of the industry is one way to increase the opportunity for Washington to meet the 2030 targets.

5. Promote equity and environmental justice in all green hydrogen projects and activities

- **5.1 Develop environmental justice tool for hydrogen projects.**
- **5.2 Support implementation and oversight of PNWH2 Community Benefits Plan.**
- **5.3 Support analysis and recommendations regarding hydrogen combustion and NOx generation, to avoid air quality and health burdens.**

Context: It is essential that environmental justice and equitable distribution of benefits be a central focus of deploying green hydrogen and renewable fuels in Washington. Washington is already committed to environmental justice in significant agency actions under the HEAL Act, and at the federal level the Justice40 Initiative directs benefits of certain environmental programs to overburdened or disadvantaged communities; the H2Hubs program is included in the Justice40 Initiative. However there are additional actions the state should consider to increase the likelihood that environmental justice is advanced through all hydrogen projects implemented in or impacting Washington, whether part of our outside the PNWH2 projects.

6. Support positive and equitable economic impacts from a green hydrogen economy

- **6.1 Evaluate workforce impacts and opportunities related to hydrogen and renewable fuels.**
- **6.2 Increase resources for workforce development opportunities with equitable benefits.**
- **6.3 Evaluate tax and fiscal impacts of hydrogen deployment.**

Context: The workforce development opportunities and considerations are significant, as hydrogen and renewable fuels production, transportation, storage and use all provide opportunities to create and support good jobs in a clean energy economy. We can make efforts to model and invest in these career pathways and direct benefits equitably across our communities, and can support development of new hydrogen credentials to support workforce development. Overall economic and tax considerations should also be reviewed and advanced.

Additional details about each of these recommendations is offered in Chapter 5.

This report represents the agency's best analysis available based on what is known at the time of publication. However, key variables are unknown at the time of release, including results of DOE negotiations around a PNWH2 award that will impact size and scope of this H2Hub, and final rules related to accessing the IRS production tax credit. Our modeling shows that these and other key variables can impact the trajectory and funding needs for the hydrogen economy. It may be advisable for the state to conduct an update to this modeling and analysis in the coming years so that adjustments to approach and state efforts can be made if needed.

Introduction

Background

In 2022, Washington passed legislation designed to accelerate the generation and use of green electrolytic hydrogen, Chapter 292, Laws of 2022[28], which required the Washington State Department of Commerce (Commerce) to:

> "By December 1, 2023, develop a plan and recommendations for consideration by the legislature and governor on renewable fuels and green electrolytic hydrogen policy and public funding including, but not limited to, project permitting, state procurement, and pilot projects."[29]

This report and recommendations are meant to help state decision makers understand the primary opportunities and challenges related to deploying hydrogen and renewable fuels in implementing the recommendations of the 2021 State Energy Strategy[30] and achieving Washington's greenhouse gas emission reduction limits.

SB 5910 established an Office of Renewable Fuels at Commerce and directed Commerce to work with tribes and stakeholders and advise on funding and projects related to renewable fuels and green electrolytic hydrogen. Additionally, Chapter 183, Laws of 2022[31] addressed siting of hydrogen production projects and Chapter 185, Laws of 2022[32] provided incentives for green electrolytic hydrogen manufacturing and storage projects.

Concurrently, the federal government announced numerous new initiatives and draft guidance in 2022 aimed at advancing the deployment of clean hydrogen nationally. The US Department of Energy (DOE) produced a draft National Hydrogen Strategy and Roadmap,[33] including recommendations about the most strategic end uses for hydrogen, methods to reduce the cost of clean hydrogen (the "Hydrogen Shot"),[34] as well as recommending regional approaches to aligning production and use (the Regional Clean Hydrogen Hubs, or H2Hubs, program).

Furthermore, DOE has proposed a draft Clean Hydrogen Production Standard[35] that defines the lifecycle carbon intensity for clean (low-GHG emitting) hydrogen and connects to a proposed new hydrogen production tax credit included in the Inflation Reduction Act.[36] These federal standards and incentives had public comment periods in late 2022, and final provisions are expected in 2023.

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28 Relevant elements of the legislation are codified in RCW 43.330.560, RCW 43.330.565, RCW 43.330.570, and RCW 43.330.575
29 RCW 43.330.570(1)(f)
30 Washington State Department of Commerce, "Washington 2021 State Energy Strategy," (2020), https://www.commerce.wa.gov/wp-content/uploads/2020/12/Washington-2021-State-Energy-Strategy-December-2020.pdf; Clean Energy Transition Institute, "Net-Zero Northwest: Technical and Economic Pathways to 2050," (2023), https://www.nznw.org/
31 Washington State Legislature, "Chapter 183. Laws of 2022"
32 Washington State Legislature, "Chapter 185, Laws of 2022"
33 U.S. Department of Energy, "U.S. National Clean Hydrogen Strategy and Roadmap," (2023), https://www.hydrogen.energy.gov/pdfs/clean-hydrogen-strategy-roadmap.pdf
34 U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, "Hydrogen Shot," (accessed 8/12/2023), https://www.energy.gov/eere/fuelcells/hydrogen-shot
35 U.S. Department of Energy, "Clean Hydrogen Production Standard Guidance," (accessed 8/12/2023), https://www.hydrogen.energy.gov/clean-hydrogen-production-standard.html
36 U.S. Department of Energy, "Financial Incentives for Hydrogen and Fuel Cell Projects," (accessed 8/12/2023), https://www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects

Washington Governor Jay Inslee directed Commerce to coordinate the formation of an entity to respond to the DOE H2Hub funding opportunity. In March 2022, Commerce established the Pacific Northwest Hydrogen Association (PNWH2),[37] which brought together public and private sector partners to develop a compelling, results-oriented Pacific Northwest H2Hub proposal. The PNWH2 is chaired by Commerce's Assistant Director Chris Green and co-chaired by Director Janine Benner of Oregon's Department of Energy. Numerous tribes, private companies, utilities, labor unions, and environmental groups sit on the board and advisory committees. The PNWH2 submitted a full proposal for the H2Hubs program in April 2023. At the time of writing, DOE has announced that it has selected the PNWH2 as one of seven H2Hubs with which it is negotiating awards. While final award decisions are not known, this is a positive indication that the PNWH2 will likely receive significant funding to implement an H2Hub in the Pacific Northwest.

With multiple developments surrounding green electrolytic hydrogen at the state, regional, and federal levels, it is critical that state lawmakers receive current analysis about approaches to producing, transporting, storing, and using hydrogen in Washington. Commerce contracted with the Clean Energy Transition Institute (CETI) and Evolved Energy Research (Evolved) to provide technical consulting to answer the following key questions:

- What levels of green electrolytic hydrogen does Washington need to most efficiently decarbonize?
- How much electricity and water are needed to deliver these levels of hydrogen?
- What are the best sources of new renewables that the state will need to produce the recommended levels of hydrogen?
- How should the state approach siting and permitting?
- What are the best approaches to addressing environmental justice considerations?
- How should hydrogen development be phased?

Project description

This report examines the questions above with the following chapters:

Chapter 1. Green electrolytic hydrogen requirement

Chapter 1 explains results from the technical modeling that underpins this report and examines levels of green electrolytic hydrogen deployment and consumption that could contribute to an efficient economy-wide decarbonization strategy for the state of Washington. This chapter also discusses modeling results on the amount of electricity and water needed to deliver the levels of hydrogen, as well as the best sources of new renewables to produce the recommended levels of hydrogen.

Chapter 2. Phases for advancing hydrogen

Following the modeling results discussed in the previous chapter, Chapter 2 lays out three phases of investments and actions, along with their associated risks, to establish a hydrogen economy in Washington. These include one near-term phase (between now and 2030); a medium-term phase (2030 to 2040), during which Washington's stringent emissions policy drives early demand for clean fuels; and a long-term phase (2040 to 2050), when achieving a net-zero economy and decarbonizing the remaining fuel use are the primary drivers of hydrogen consumption.

[37] Pacific Northwest Hydrogen Association (accessed August 12, 2023), https://pnwh2.com/

Chapter 3. Siting and permitting

Chapter 3 reviews key modeling results to inform hydrogen permitting and siting processes in Washington. It also provides detail on the types of hydrogen infrastructure projects that are likely to be developed in Washington. It reviews existing Washington permitting processes — as well as proposed and implemented permitting reforms — relevant to hydrogen projects and concludes with recommendations for Washington's permitting processes and broader energy policies that can support increased production of and access to green electrolytic hydrogen in the state.

Chapter 4. Addressing environmental and energy justice considerations

Chapter 4 provides a literature review of best practices for incorporating equity and environmental/energy justice into energy development projects; it discusses environmental and energy justice concerns specific to green electrolytic hydrogen production, distribution and storage, and end uses; and it provides recommendations on applying environmental and energy justice frameworks to development and use of green electrolytic hydrogen.

Chapter 5. Recommendations

Chapter 5 brings together the full range of policy and funding recommendations that the work of this report identifies as priorities for Washington. The chapter describes key recommendations and related sub-recommendations that will help the state support a strategic and equitable deployment of green hydrogen in Washington. This chapter reviews specific items proposed for inclusion in a 2024 Commerce Decision Package. The recommendations in this report will be discussed and refined through tribal, stakeholder and community engagement, including conducting Environmental Justice Assessments where needed where recommendations lead to development of Significant Agency Actions related to green hydrogen and renewable fuels.

Chapter 1. Green electrolytic hydrogen requirement

Introduction

Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Development in Washington examines the levels of green electrolytic hydrogen deployment and consumption that could contribute to an efficient economy-wide decarbonization strategy for Washington. Decarbonization studies conducted to date for the Northwest region and specifically for Washington have shown that green electrolytic hydrogen is a key component of reaching net-zero goals in Washington.[38]

The decarbonization pathways modeling developed for this project was designed to explore the state's opportunity to develop green electrolytic hydrogen at a much more detailed level than in prior studies. The questions that the modeling aimed to answer include:

- How much hydrogen and hydrogen-derived products are consumed in Washington?
- What are the most economic end uses for hydrogen-derived products?
- How much hydrogen could be produced in Washington versus in other regions?
- What levels of green electrolytic hydrogen are needed to decarbonize Washington most efficiently?
- How much electricity and water would be needed to deliver the potential levels of hydrogen?
- What are the best sources of new renewables that will be needed to produce the potential levels of hydrogen?

Many factors will impact hydrogen infrastructure development in Washington, some of which state leaders will be able to control, others of which national or global trends will dictate. This analysis explores several different futures for hydrogen deployment to assess the factors that may have the greatest impact. The analysis also supports recommendations for how Washington might prioritize policy to encourage green electrolytic hydrogen deployment.

Three broad categories drive green electrolytic hydrogen production and consumption in Washington and the surrounding Northwest region: feasibility, economics, and policy, each of which will impact the overall extent and timing of hydrogen production, location, and consumption.

Feasibility

The two key feasibility constraints on hydrogen market growth are: (1) barriers to technology development, an example of which is supply chain constraints that affect the pace at which electrolyzers can be built, or renewable energy resources can be developed, and (2) siting and permitting constraints that will affect where, when, and at what quantity new renewables, transmission lines, and pipelines will be constructed.

Economics

Hydrogen production, conversion, and consumption offers a set of pathways to decarbonizing different sectors of the economy. These can include displacing natural gas in end uses such as boilers to provide

[38] Washington State Department of Commerce, "Washington 2021 State Energy Strategy," (2020), https://www.commerce.wa.gov/wp-content/uploads/2020/12/Washington-2021-State-Energy-Strategy-December-2020.pdf; Clean Energy Transition Institute, "Net-Zero Northwest: Technical and Economic Pathways to 2050," (2023), https://www.nznw.org/

industrial process heat, direct use in transportation to power vehicles, or conversion to drop-in hydrocarbon fuels to decarbonize vehicles, aircraft, and shipping.

The relative economics of different decarbonization pathways will determine when, where, and how much hydrogen deployment is part of an efficient decarbonization strategy. The generous Inflation Reduction Act (IRA) incentives[39] for clean hydrogen production make hydrogen and derived fuels competitive based on economics alone, regardless of emissions policy.[40]

However, the price of electrolyzers and availability of incentives are uncertain and could impact hydrogen deployment across the United States. The economics of other parts of the economy also impact hydrogen deployment indirectly, including the cost and availability of renewables (electricity is the largest cost component of electrolytic hydrogen production), the cost and availability of hydrogen conversion technologies and transportation networks, and the cost of other modes of reducing emissions.

Policy

Policy could exert some control over the feasibility and economics of hydrogen development by removing barriers to development or providing additional incentives. A prime example of this influence is the Pacific Northwest Regional Hydrogen Hub (PNWH2 Hub)[41] which the U.S. Department of Energy announced as one of the H2Hubs selected for award negotiations on October 13, 2023. Final details that would impact projections in this report will only be known after negotiations conclude, likely in early 2024, though the selection and resources accompanying an H2Hub designation are likely to have a significant impact on the deployment of green hydrogen in the region. Other policies that will impact the feasibility and economics of hydrogen development include siting and permitting process reform, prioritizing support for energy resource deployment, and integrating decarbonization planning across sectors of the economy, among other policy mechanisms.

Neither feasibility nor economics are fully controllable. National and global forces will constrain the supply chain, and renewable resource quality and transportation costs will impact the economics of where hydrogen in produced in the United States. Washington can direct policies to address these constraints and favor hydrogen deployment in the state as part of an efficient decarbonization strategy.

Modeling methodology

The model represents the whole energy economy — where energy is consumed, in what form, and how that energy is produced — and optimizes how to meet energy and emissions goals most efficiently by determining the infrastructure to invest in the energy system and how is operated, while satisfying reliability requirements. The outcomes are therefore in the context of economy-wide emissions reductions and prioritize the most impactful and cost-effective energy system portfolio of investments. This ensures that we capture the full value of each investment in integrated operations with other parts of the energy economy.

The technical analysis deploys two models in tandem to calculate the energy needed to power the Northwest economy and the least-cost way to provide that energy under clean electricity and emissions goals. EnergyPATHWAYS (EP) is a scenario analysis tool used to develop demand for fuels (electricity, pipeline gas, diesel fuel, etc.) over time. EP is a bottom-up energy model that characterizes stock (replacement of

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[39] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, "Financial Incentives for Hydrogen and Fuel Cell Projects," (accessed September 9, 2023), https://www.energy.gov/eere/fuelcells/financial-incentives-hydrogen-and-fuel-cell-projects

[40] Evolved Energy Research, "45V Hydrogen Production Tax Credits: Three-Pillars Accounting Impact Analysis," (2023), https://www.evolved.energy/post/45v-three-pillars-impact-analysis

[41] Pacific Northwest Regional Hydrogen Association, https://pnwh2.com/

appliances, vehicles, buildings, and other infrastructure) across time and simulates the change in total energy demand and load shape (change in electricity use over time) for every end use within 70 demand sub-sectors (e.g., air-conditioning, lighting, refrigeration, industrial boilers, light-, medium-, and heavy-duty vehicles, marine vessels, etc.). The Regional Investment and Operations (RIO) model is an optimization tool that identifies the cost-optimal energy supply required to meet energy demand. RIO develops portfolios of low-carbon technology for electricity generation and balancing, various fuels production, and direct air capture. RIO also identifies least-cost clean fuels to achieve emissions targets.

For details on how EP and RIO work separately and together; a list of the key energy-consuming subsectors; an explanation for how the models approach reliability and integrate electricity and liquid and gaseous fuels; and the methodology modeling overview, see the accompanying Methodology section of the Technical Report (Appendix A). The modeling methodology and data development underpinning the analysis is based on the Evolved Energy Research Annual Technology Baseline 2022.[42] The Technical Report notes where this has been adapted for the Northwest.

Hydrogen and clean fuel potential end uses and modes of supply

This section summarizes where hydrogen deployment and clean fuels could potentially be of use, how they are represented in the model, and the modes of use and delivery. The model optimizes production and delivery of clean fuels, including hydrogen, ammonia, and clean drop-in fuels derived from hydrogen, to serve the energy needs of the economy and hard-to-decarbonize sectors.

Hydrogen production

Energy supply chains involve taking primary energy in the form of fossil hydrocarbons, wind, solar radiation, biomass etc., through a series of conversion, storage, and transportation stages to delivery in the form of energy services, such as heat, light, and propulsion. In a decarbonizing economy, hydrogen becomes increasingly valuable as a means of carrying energy, either directly to consumers to convert to energy services, such as in fuel cells in transport or combustion to produce industrial heat, or for conversion to other energy carriers, such as drop-in hydrocarbon transportation fuels.

This section describes the different processes for producing hydrogen and converting hydrogen to other types of fuel. Figure 1 shows the hydrogen and clean fuels conversion pathways in the RIO model. RIO optimally builds infrastructure to capture, convert, store, and transport energy along each of the pathways in the figure. In addition to hydrogen production, the flowchart shows the sources of carbon dioxide and production of other forms of low-carbon fuel to illustrate complementary or competitive supply chains to hydrogen. Which pathway is favored depends on their relative economics, availability, and how they are impacted by policy.

[42] Evolved Energy Research, "Annual Decarbonization Perspective 2022," (2022), https://www.evolved.energy/post/adp2022

Figure 1. Low-carbon fuel production pathways[43]

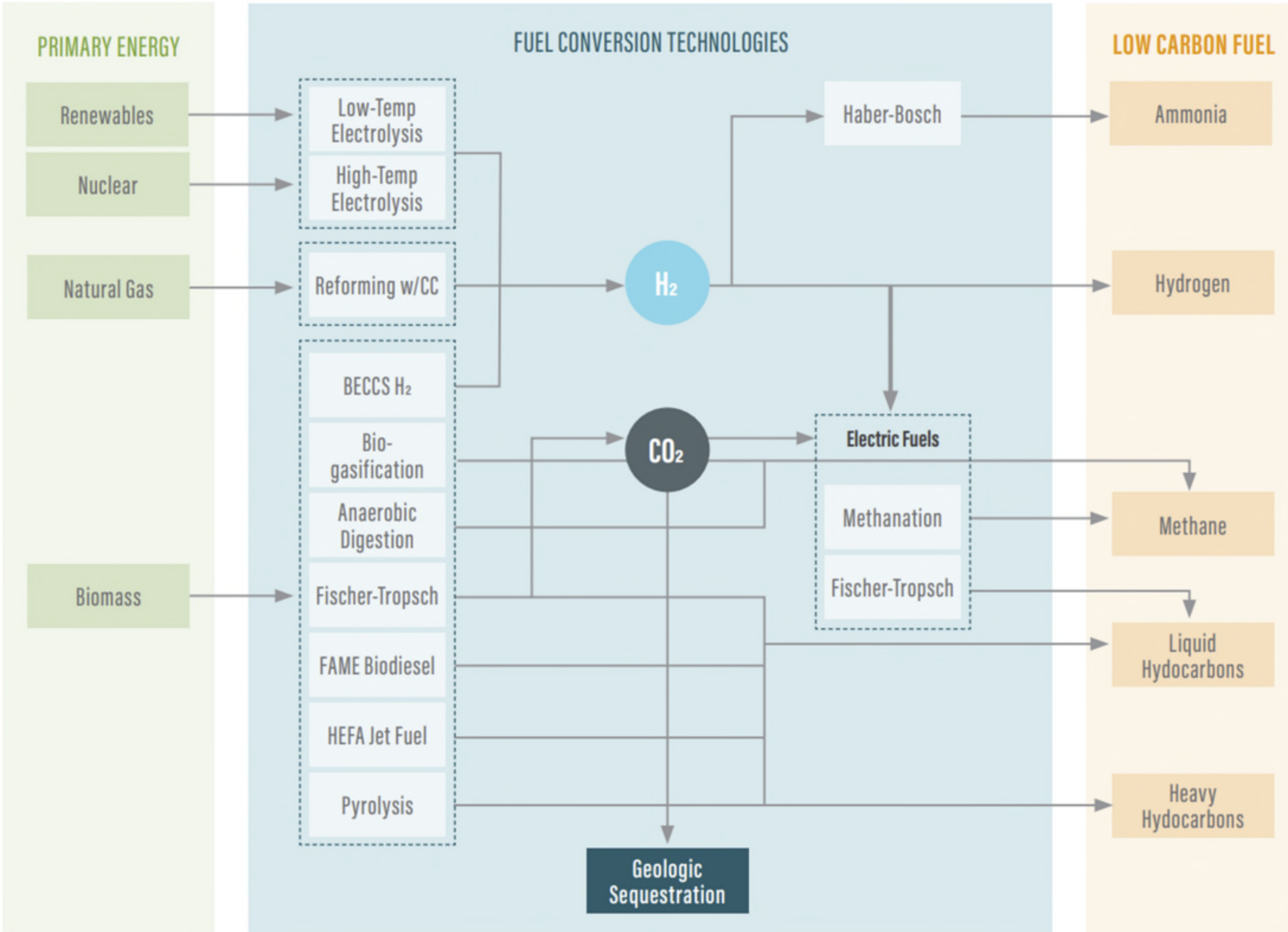


Table 1. Summary of conversion technologies

Conversion technology	Description
Low-Temperature Electrolysis	Low-temperature electrolysis conversion involves electrocatalytic reduction in alkaline or polymer electrolyte reactors.
High-Temperature Electrolysis	High-temperature electrolysis (also HTE or steam electrolysis or HTSE) is a technology for producing hydrogen from water at high temperatures, typically 750-950 degrees C to produce steam.
Methanation	Methanation is the conversion of carbon monoxide and/or carbon dioxide to methane (CH4) through hydrogenation.

43 Ibid.

Conversion technology	Description
Steam Methane Reforming (SMR) with or without Carbon Capture	Steam methane reforming (SMR) is a process in which methane from natural gas is heated, with steam, usually with a catalyst, to produce a mixture of carbon monoxide and hydrogen used in organic synthesis and as a fuel.
Bio-Gasification H2 with or without carbon capture	Biomass gasification is a mature controlled process involving heat, steam, and oxygen to convert biomass to hydrogen and other products, without combustion. The process produces hydrogen gas, carbon monoxide, carbon dioxide, and methane in varying quantities depending on the type of biomass. Hydrogen can be separated, the carbon monoxide converted to carbon dioxide, and the carbon dioxide sequestered or utilized in other processes.
Bio-Gasification CH4 with or without carbon capture	Biomass gasification CH4 is the same process as Bio-Gasification H_2 with a second step at higher pressure to favor methane production. This is the combination of bio-gasification H2 with methanation.
Anaerobic Digestion	A process through which bacteria break down organic matter — such as animal manure, wastewater biosolids, and food wastes — in the absence of oxygen. Anaerobic digestion generates biogas, which is mostly methane (CH4) and carbon dioxide (CO2), with very small amounts of water vapor and other gases. The carbon dioxide and other gases can be removed, leaving only the methane.
Fischer-Tropsch	This process converts synthetic gas (syngas, a mixture of hydrogen and carbon monoxide) to produce hydrocarbon fuels that can be used as drop-in clean fuels for petroleum product substitution.
Bio-Gasification Fischer-Tropsch with or without carbon capture	This process combines bio-gasification, described above, and Fischer-Tropsch, converting the synthesis gas from bio-gasification (CO + H2) into longer chain, branched hydrocarbons that can be used as drop-in fuels in gasoline, diesel, and aviation fuel blends.
FAME Biodiesel	Fatty acid methyl ester (FAME) biodiesel: A renewable alternative fuel produced from esters of fatty acids with physical characteristics similar to those of fossil diesel fuels.
HEFA Jet Fuel	HEFA (Hydroprocessed Esters and Fatty Acids), also called HVO (Hydrotreated Vegetable Oil), is a renewable diesel fuel that can be produced from a wide array of vegetable oils and fats and used in this case for aviation.
Pyrolysis	Pyrolysis is the heating of an organic material, such as biomass, in the absence of oxygen. The reaction is similar to bio-gasification but with steam only and no oxygen.
Haber-Bosch	The primary method of producing ammonia from nitrogen and hydrogen.

Hydrogen storage and transportation

Primary energy, conversion processes, and end users are the destinations in the supply chain, but between those are storage and transportation resources to move hydrogen to where it is needed. The RIO model includes the cost of hydrogen storage at production facilities; the costs to move hydrogen via long-distance pipelines and the opportunity to optimally build those pipelines; the cost of hydrogen distribution to end uses either via pipeline or truck and storage at distribution facilities; and the costs to move and distribute hydrogen derived products, including via optimized expansion of ammonia pipelines. The sources for these costs are described in the Evolved Energy Research Annual Decarbonization Perspective 2022.[44]

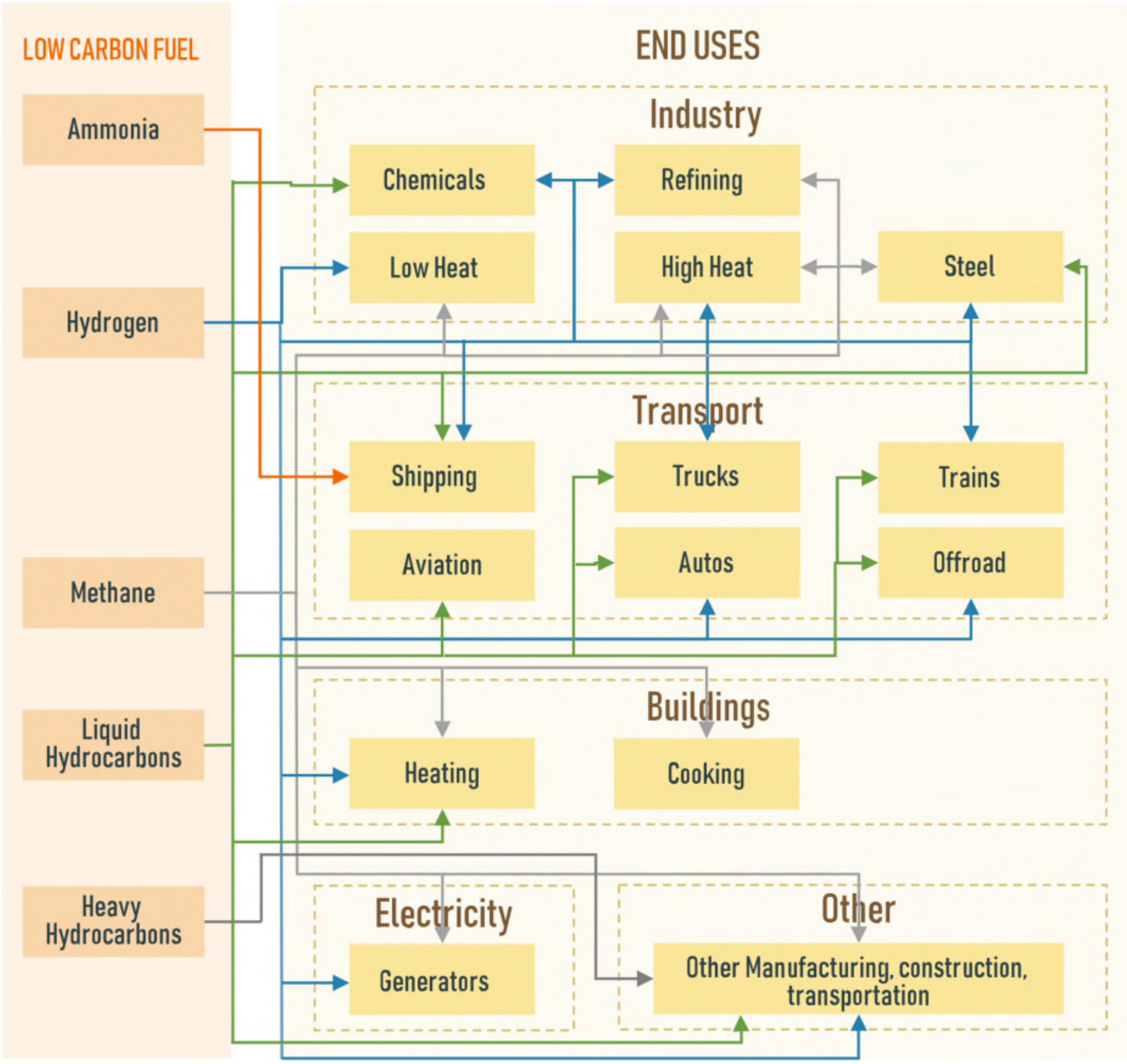
The model assumes that drop-in fuels that substitute for existing conventional fuels such as gasoline, diesel, and aviation fuel, can be transported in existing infrastructure used for fossil fuels. Hence, the model does not build separate transportation networks for these fuels. The analysis also assumes that blending of chemically dissimilar fuels is possible up to a defined percentage. In the natural gas network, the model allows blending of up to 20% by volume of hydrogen gas. In fuel oil, the model allows up to a 12.5% blending of ammonia by 2030 and up to 50% blending by 2050.

Hydrogen end uses

Hydrogen can be used directly in some end uses or in the form of hydrogen-derived fuels in others. Across these two categories of consumption, hydrogen can be integrated either as an energy carrier or as a feedstock for production of non-fuel chemicals into most subsectors of the economy. We show the various end uses for hydrogen and hydrogen-derived fuels in Figure 2, as well as the different linkages between low-carbon fuels (produced via the pathways in Figure 1) and different end uses for those fuels in the economy, split into industry, transport, buildings, electricity, and other.

[44] Ibid.

Figure 2. End uses for hydrogen and hydrogen-derived fuels



Refining is currently the dominant industry use of hydrogen in Washington. Hydrogen can also be used in high- and low-temperature heat applications and in iron and steel production. Additionally, hydrogen can be used as a feedstock for chemicals production, such as ammonia for fertilizer (on-site ammonia production for fertilizer is included in chemicals production, but the modeling also has an explicit pathway for ammonia production for maritime shipping). Existing fuels used in industry can be decarbonized with drop-in hydrogen-derived fuels, utilizing existing equipment.

The same is true in transportation, where clean liquid hydrocarbons can displace fossil fuel use in existing internal combustion engines. The model assumes ammonia, either blended with, or in place of, heavy fuel oil can be used in shipping. Blending of ammonia into fuel oil for marine applications up to a maximum of 12.5% by 2030 and 50% by 2050 is allowed. Marine engines burning 100% ammonia are assumed to rapidly displace fuel oil in shipping in the 2040s.

In addition, a fraction of domestic shipping is assumed to be converted to fuel cell direct usage of hydrogen gas. In aviation, the model conservatively assumes that jet fuel will remain through 2050 as the only source of energy. Therefore, decarbonization of aviation happens through decarbonizing the fuel supply.

For on-road transportation, the analysis uses the Washington Department of Commerce's Transportation Electrification Strategy[45] Strong Electrification Policy scenario, developed by Rocky Mountain Institute, for sales shares of zero-emission vehicles. This forecast has very little hydrogen fuel cell adoption, so the modeling for this study also looked at a scenario that transitions long-haul trucking sales to fuel cells starting in 2035. Remaining internal combustion engine vehicles use a fuel blend that becomes increasingly decarbonized with hydrogen-derived liquid hydrocarbons.

The buildings sector includes aggressive electrification assumptions in the model. The remaining methane gas usage in buildings can employ methane derived from hydrogen and up to a 20% by volume blend of hydrogen gas. The same is true in electricity generation, where gas generators can receive a blend of fossil and decarbonized methane with up to a 20% by volume fraction of hydrogen gas.

Other manufacturing, construction, and transportation include miscellaneous uses of hydrogen and hydrogen-derived fuels in the economy. One of the larger uses of hydrogen in this group is electricity use in construction, where fuel cells can be used in place of on-site generators, improving air quality and reducing CO2 emissions.

Modeling methodology: Optimization versus forecasting

The previous two sections describe low-carbon fuel production pathways and hydrogen end uses. It is important to understand which of these are optimized and which are input assumptions when interpreting the modeling results that underpin Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Development in Washington.

In general, the difference is whether hydrogen can be used in end use demands without changes to the technology consuming it, or whether new technologies are needed on the demand side. The model optimizes all pathways to producing hydrogen products that drop into existing fuel blends and can be consumed with existing technologies.

An example of this would be if the gasoline fuel blend is 100% fossil fuel or some blend of fossil fuel, hydrogen-derived products, and biofuel. On the other hand, where a technology change is needed to consume a product, e.g., in the case of fuel cell vehicles to consume hydrogen gas directly in transportation, the model uses an input assumption to represent that opportunity.

Table 2 describes different hydrogen demands and whether they are optimized or forecast in the model.

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[45] Washington State Department of Commerce, "Transportation Electrification Strategy (TES)", (accessed September 16, 2023), https://www.commerce.wa.gov/growing-the-economy/energy/clean-transportation/ev-coordinating-council/transportation-electrification-strategy/

Table 2. Forecasted versus optimized hydrogen demands

Hydrogen Demand	Description	Optimized or Forecast
Chemicals production	Annual Energy Outlook (AEO) 2022 Forecast[46] for bulk chemicals production (including fertilizer) used as a forecast for hydrogen demand in chemicals production.	Forecast
Transport	Based on modeled adoption of hydrogen fuel-cell vehicle (HFCV) across all on-road transportation. Forecast of transition in maritime propulsion to burning 100% ammonia rather than a fuel oil blend.	Forecast
Petroleum refining	Refinery hydrogen demand represented explicitly within RIO. Declines with reduced demand for refined fossil products.	Optimized
Synthetic Fuels – Fischer-Tropsch/methanation	Model can construct and operate Fischer-Tropsch and methanation facilities to produce synthetic hydrocarbon fuels with hydrogen as a feedstock. Also requires captured carbon feedstocks that can be sourced with IRA-incented carbon capture on cement, biofuels, and direct air capture.	Optimized
Synthetic Fuels – Ammonia as shipping fuel	Model can construct and operate new Haber-Bosch facilities using hydrogen as a feedstock. Ammonia can displace a share of residual fuel oil associated with shipping.	Optimized
Power	Model can blend hydrogen in new and existing gas plants up to 7% by energy. This applies to pipeline gas to buildings as well. Model can build new hydrogen combustion turbines that burn 100% hydrogen gas.	Optimized
Industrial steam	Model can construct and build hydrogen boilers (in competition with new and existing fuel boilers, combined heat and power (CHP), heat pumps, thermal storage, etc.) to produce steam for industry.	Optimized

Scenarios

To assess the impact of different feasibility, economic, and policy factors, the analysis that underpins Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Deployment in Washington ran a series of scenarios that constrained what the model could invest in or how the energy system could be operated. The model determines the level of green electrolytic hydrogen production and the supporting infrastructure investment in the state under the different conditions represented in each scenario, providing valuable economic counterpoints for decision-makers to assess policies and risk.

The analysis commenced by developing a Core Case with a common set of assumptions about Washington and the rest of the U.S. In addition to the Core Case, a series of “what if” questions were developed in consultation with the Commerce team and an Advisory Committee (see the list of Advisory Committee

[46] U.S. Energy Information Administration, “Annual Energy Outlook 2022,” (2022), https://www.eia.gov/outlooks/aeo/pdf/AEO2022_Narrative.pdf

members selected to advise this project), as well as through iterative learning from different model runs that revealed the factors most important to investigate.

Scenario design

The starting principle for scenario design is that if green electrolytic hydrogen developers can receive the full IRA production tax credit (PTC) of $3/kg, the economic barrier to hydrogen production will be lifted in many parts of the country. Later, this report discusses the implementation and accounting question of whether hydrogen production can receive the full $3/kg. The modeling assumes that green electrolytic hydrogen can receive the full $3/kg incentive under different modeled qualifying criteria, representing the tax guidance not yet finalized by the United States Department of the Treasury (Treasury) at the time of writing.[47]

A recent national study indicates that the $3/kg production tax credit drives hydrogen production and makes new modes of hydrogen consumption economic.[48] This study also finds that the $3/kg production tax credit drives significant hydrogen production across the country by 2030 and facilitates new uses for hydrogen in the economy.

The scenario design principles therefore focus on other non-economic barriers to developing green electrolytic hydrogen, including the feasibility challenges of scaling up infrastructure investments and factors that influence the relative economics of producing hydrogen in Washington versus other parts of the country.

Barriers to developing green electrolytic hydrogen include:

- **Scaling electrolyzer and renewable energy resource supply chains.** If the rate of producing new electrolyzers, wind turbines, or solar panels is constrained nationally or globally relative to demand, Washington will compete with other regions to deploy these scarce resources.
- **Access to resources both temporally and geographically.** How fast can new renewable resources, transmission lines, and pipelines be sited, permitted, constructed, and interconnected? Electrolytic hydrogen production requires significant amounts of renewable energy, adding to already unprecedented growth forecasts for renewable resource additions. Can the processes to develop those renewables support the rate needed? What are the options for access to hydrogen markets outside of Washington?
- **Expansion of new markets for hydrogen**. Growth of electrolytic hydrogen partially depends on growth of new markets for that hydrogen, such as clean drop-in fuels, industrial heat in industry, or ammonia production. How fast can new markets scale up?

Washington competes with other regions for producing hydrogen. Therefore, these barriers to development influence whether hydrogen production happens in Washington or whether it happens elsewhere. The question is how much hydrogen is beneficial for the state to produce versus import from elsewhere, and what factors change this equation for both the supply and demand for hydrogen? The scenarios provide additional information regarding where hydrogen is likely to be produced; with the H2Hub announcement, it is appropriate

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[47] The US Treasury Department and Internal Revenue Service published proposed regulations regarding qualification for the § 45V Clean Hydrogen Production Tax Credit on December 22, 2023. At the time of writing, the US Treasury Department has opened a comment period on the proposed rules, with final regulations expected in early 2024. IRS, "Treasury, IRS issue guidance on the tax credit for the production of clean hydrogen." December 22, 2023. https://www.irs.gov/newsroom/treasury-irs-issue-guidance-on-the-tax-credit-for-the-production-of-clean-hydrogen

[48] Wilson Ricks and Jesse Jenkins, Princeton Zero Lab, “The Cost of Clean Hydrogen with Robust Emissions Standards: A Comparison Across Studies,” (2023), https://zenodo.org/record/7948769

to assume that cost reductions and increased production will occur in the Pacific Northwest, although full details of the scope and cost implications may require additional modeling once finalized.

Expanding new hydrogen markets depends on the relative economics of hydrogen usage versus other alternative forms of energy; the relative economics of one use of hydrogen versus another (where is hydrogen, limited by supply constraints, most beneficially used in the economy?); and policy drivers such as Washington's emissions targets.

Three pillars accounting

Treasury has not released final tax code guidance to qualify the IRA hydrogen production tax credit at the time of this report's model development and writing, although proposed regulations were published in December 2023.[49] Based on the draft regulations, Treasury is proposing to include requirements aligned with the so-called "Three Pillars" accounting[50] that would require hydrogen producers to demonstrate that the renewable energy resources that they build to support hydrogen development have three characteristics to receive the generous IRA incentive:

1) **Additionality:** Hydrogen producers would ensure that new, low-carbon electricity generation meets the demand to produce hydrogen. This provision would keep electrolyzers from consuming clean power that would otherwise be used to decarbonize other sectors, such as transportation or buildings.[51]
2) **Hourly Matching:** Hourly matching of electricity resources to demand, instead of weekly, monthly, annually (or some other timeframe) matching. This provision would ensure that demand from electrolyzers would be closely matched with clean generation supply to minimize reliance on carbon-intensive resources.
3) **Deliverability/Regionality:** Hydrogen developers would be required to prove that additional, hourly matched clean electricity can be delivered to the hydrogen project in a congestion-free manner, connecting clean electrons to the electrolyzers used to produce the hydrogen.

The draft PTC rules, while proposing a stricter approach, are still considering whether alternative, less strict requirements may be appropriate in circumstances where there is limited risk of significant induced grid

[49] The US Treasury Department and Internal Revenue Service published proposed regulations regarding qualification for the § 45V Clean Hydrogen Production Tax Credit on December 22, 2023. At the time of publishing this report, the US Treasury Department is taking comments on the proposed rules, with final rules expected in early 2024. "Treasury, IRS issue guidance on the tax credit for the production of clean hydrogen." December 22, 2023. https://www.irs.gov/newsroom/treasury-irs-issue-guidance-on-the-tax-credit-for-the-production-of-clean-hydrogen

[50] Alex Piper et al., Rocky Mountain Institute, "The Hydrogen Credit Catalyst," (2023), https://rmi.org/hydrogen-credit-catalyst/; American Clean Power, "3 Pillars for Building a Green Hydrogen Industry for Decarbonization," (2023), https://cleanpower.org/wp-content/uploads/2023/06/ACP_GreenHydrogenFramework_OnePager.pdf; Rachel Fakhry, Natural Resources Defense Council, "New Analysis: The 3 Pillars Will Support Large Hydrogen Deployment," (2023), https://www.nrdc.org/bio/rachel-fakhry/new-analysis-3-pillars-will-support-large-hydrogen-deployment; Ben Haley and Jeremy Hargreaves, Evolved Energy Research, "45V Hydrogen Production Tax Credits: Three-Pillars Accounting Impact Analysis," (2023), https://www.evolved.energy/post/45v-three-pillars-impact-analysis

[51] The word "additionality" has typically been used to describe the need for new renewable or clean electricity. The draft Treasury regulations use the term "incrementalism" instead. This report continues to use the term "additionality" to describe this concept in order to align with terminology that is more familiar to most readers.

emissions. This could include production in states with 100% clean grid electricity or with a statutory cap on statewide GHG emissions, such as Washington.[52]

It is important to note that a robust national discussion has occurred regarding these provisions, with some analysts predicting that the Three Pillars inclusion is important to avoid unintended emissions increases, and others who assert that the less strict accounting provisions are necessary to enable a clean hydrogen economy to develop efficiently in the near term and provide these low- or zero-carbon fuels at a competitive costs to end users.[53]

This report provides an economy-wide assessment of the impacts of the final rules on Washington's supply and demand of green electrolytic hydrogen. Economic analysis of the impacts of final PTC rules on individual proposed hydrogen production projects is outside the scope of this report.

Scenario 1: Core Case

The Core Case is the baseline scenario to which we compare the other scenarios. The Core Case includes assumptions about resource availability and policy that are representative of a "most likely," "most desired" or more conservative outcome. Core Case assumptions include the following principles, which are maintained across all scenarios, unless an assumption is the subject of investigation in a "what if" scenario:

- **Aggressive on efficiency and electrification.** This assumption is in line with past regional studies, including the Washington 2021 State Energy Strategy,[54] that show electrification lowers decarbonization costs.
- **Regional clean energy policy.** Emissions targets include net-zero emissions by 2050 in all U.S. states and state-specific targets through 2030. This means that if a state like Montana or Wyoming does not have a 2030 emission reduction target policy, none is imposed. State-by-state targets for clean electricity policy where they exist are also assumed.
- **States can utilize out-of-state resources to count toward clean energy requirements in state.** This assumes a future with access to the most valuable resources, constrained only by the potential to build transmission to access them.
- **Service demands remain business as usual through 2050.** The assumption that energy services are used in the same way as today is conservative, but it is a useful upper bound on energy service consumption to show what investments in energy infrastructure are needed without reducing energy demand.
- **All resource options are permitted for electricity and fuels production.** The best investments to meet future energy needs are made regardless of the technology.

[52] The draft rules specifically seek feedback on alternative approaches to avoiding GHG emissions. For example, the proposed language states: " The DOE has advised that there are circumstances during which diversion of existing minimal (that is, zero or near-zero) emissions power generation to hydrogen production is unlikely to result in significant induced GHG emissions.[13] Such circumstances may include generation from minimal-emitting power plants (i) that would retire absent the ability to sell electricity for qualified clean hydrogen production, (ii) during periods in which minimal-emitting generation would have otherwise been curtailed, if marginal emissions rates are minimal, or (iii) in locations where grid-electricity is 100 percent generated by minimal-emitting generators or where increases in load do not increase grid emissions, for example, due to State policy capping total GHG emissions such that new load must be met with minimal-emitting generators." Federal Register :: Section 45V Credit for Production of Clean Hydrogen; Section 48(a)(15) Election To Treat Clean Hydrogen Production Facilities as Energy Property

[53] American Council on Renewable Energy (ACORE) and E3. "Analysis of Hourly and Annual GHG Emissions: Accounting for Hydrogen Production" (2023). https://acore.org/analysis-of-hourly-annual-ghg-emissions-accounting-for-hydrogen-production/ Accessed 11/8/2023.

[54] Washington State Department of Commerce, "Washington 2021 State Energy Strategy," (December 2020).

- **Biomass potential for fuels production** nationwide comes from the U.S. Department of Energy Billion Ton Study Update for all states outside of the Northwest,[55] and Northwest biomass potentials developed by University of Washington with the Land Use and Resource Allocation (LURA) model for the Washington 2021 State Energy Strategy.[56]
- **Fuel potentials from waste gases** and renewable fuels from waste oils are represented in the model.
- **Transmission and pipeline expansion between states is permitted** allowing electricity and fuels trading when economic. Transmission expansion is limited by reconductoring and greenfield corridor opportunities identified by The Nature Conservancy Power of Place – West study.[57]
- **Load management** is permitted through dispatch of new flexible load technologies.
- **Three Pillars** accounting is included. While Treasury's decision on whether to include these provisions is pending at the time of writing, the Core Case includes them in order to provide a more conservative analysis.

We summarize the Core Case assumptions in Table 3.

Table 3. Core Case assumptions

Assumption type	Core Case assumptions: Policy and supply side
Clean Electricity Policy	State-by-state clean electricity policy. Oregon: 100% clean electricity by 2040; Washington: Clean Energy Transformation Act (CETA), 100% clean by 2045, coal retirements by 2025
Economy-Wide GHG Policy	State targets by 2030; net-zero by 2050
Clean Resource Qualification	Renewables and 100% clean fuels, nuclear, fossil gas with carbon capture
Inflation Reduction Act Incentives	Supply-side incentives included for hydrogen production, renewable electricity generation, battery storage, carbon sequestration, clean fuels, and nuclear
Resource Availability	Transmission supply curves and resource potential developed for TNC Power of Place-West;[58] 4th generation and SMR nuclear not permitted in Oregon or California. New gas build not permitted in Oregon
Fuels	EIA AEO 2022 Reference fuel prices;[59] sequestration potential across the West where geologic formations exist; clean fuels have zero emissions associated with them, so sequestration credit is left in state of origin. Oregon and Washington clean fuel standards incorporated

55 U.S. Department of Energy, "2016 Billion-Ton Report," (2016), https://www.energy.gov/eere/bioenergy/2016-billion-ton-report
56 Latta, G., Baker, J., Ohrel, S., "A Land Use and Resource Allocation (LURA) modeling system for projecting localized forest CO2 effects of alternative macroeconomic futures", Forest Policy and Economics, Volume 87, 2018, Pages 35-48, https://doi.org/10.1016/j.forpol.2017.10.003
57 The Nature Conservancy, "Power of Place-West: High Electrification the Best Path for Meeting Climate and Land Conservation Goals," (2022), https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/
58 The Nature Conservancy, "Power of Place," (2023), https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/
59 Energy Information Agency, "Annual Energy Outlook 2022", (2022), https://www.eia.gov/outlooks/aeo/IIF_carbonfee/

Assumption type	Core Case assumptions: Policy and supply side
Land sink	Supply curve of land sink measures
Non-energy emissions	Non-energy emissions abatement curve

Assumption Type	Core Case assumptions: Demand side
Energy Service Demand	EIA AEO 2022
Buildings: Electrification	Fully electrified appliance sales by 2035
Buildings: Tech Energy Efficiency	Sales of high-efficiency technology: 100% in 2035 High-efficiency building shell sales: 100% by 2035
Transportation: Light-Duty Vehicles	WA Commerce forecast of vehicle sales shares (100% sales of EV/PHEV LDVs by 2030, 100% sales of EV/PHEV LDTs by 2035)
Transportation: Medium and Heavy-Duty Vehicles (MDV and HDV)	WA Commerce forecast of vehicle sales shares through 2035 (HDVs: EV sales 65% by 2030 and 2035, FCEV sales 0.3% by 2035; MDVs: EV sales 57% by 2030, 82% by 2035). Assumed HDV and MDV sales reach 100% ZEV by 2045 (HDV: 99.7% EV, 0.3% FCEV; MDV: 100% EV).
Industry	Generic efficiency improvements over AEO of 1% a year; fuel-switching measures; 1.5% a year efficiency improvement in aviation. Process heat storage opportunities
DER Schedule	State-by-state rooftop solar schedule, 75% of light duty vehicle load and 10% of heating and cooling load is flexible by 2050

"What If" scenarios

Determining the most efficient investments in hydrogen and the supporting infrastructure in each scenario builds an interconnected picture for decision-makers to understand cause and effect across energy types, geographies, and sectors of the economy.

The results of the Core Case in this analysis, as well as past national analyses of hydrogen economics of the IRA tax credits, show that production of green electrolytic hydrogen is cost-effective if producers receive the full $3/kg hydrogen incentive. Initial challenges to realizing the full tax credit may slow deployment of hydrogen, which is discussed later in the report. However, assuming green electrolytic hydrogen receives the full credit, hydrogen production will be cost-effective and deployed at scale across the United States.[60]

While hydrogen development is significant in all scenarios given the generous IRA tax credit, what is assumed about state, regional, and national policy and supply chain limits alters the competitive landscape for hydrogen

[60] Evolved Energy Research, "45V Hydrogen Production Tax Credits: Three-Pillars Accounting Impact Analysis," (2023), https://www.evolved.energy/post/45v-three-pillars-impact-analysis

production in Washington versus elsewhere. To investigate the factors that are most influential in determining the scale and nature of Washington's green electrolytic hydrogen opportunity, the model ran a series of scenarios varying assumptions in the Core Case.

We made incremental changes to the Core Case to investigate nine "what if" questions, described in Table 4.

Table 4. Green electrolytic hydrogen and renewable fuels modeling scenarios

#	Scenario	"What if" question	Model implementation
1	Core Case	The Core Case sets the baseline set of assumptions for comparison to the other scenarios to investigate each "what if" question. The principles for design of the Core Case are described in the previous section.	No national constraint on electrolyzers; includes Three Pillars accounting; pipelines are available from 2035 onward; no emissions constraints in 2030 for states without targets; WA Commerce vehicle adoption forecast.
2	Less Strict H2 Accounting	What if accounting for clean energy in hydrogen production is less strict than the Three Pillars requirement in the Core Case?	Relaxed accounting to annual matching only. No additionality, deliverability, or hourly matching.
3	Early Roll Off of IRA Credits	What if IRA credits end early?	IRA credits for all technologies end in 2026.
4	H2 Cost Reduction	What if hydrogen production and conversion costs less in the Northwest?	20% reduction in electrolyzer, hydrogen transport, Fischer-Tropsch, and Haber-Bosch costs within Washington, Oregon, Montana to reflect potential hydrogen hub funding (at time of modeling and publication, final award size and scope remains unknown).
5	H2 in long-haul, heavy-duty trucking (HDV High H2)	What if hydrogen becomes competitive as a fuel in long-haul heavy-duty trucking?	Sales shares of long-haul trucking are consistent with the WA Commerce forecast through 2035 then sales of fuel cell vehicles grow to 50% by 2045.
6	Accelerated Pipelines	What if pipeline builds are accelerated?	The year that pipelines would be available shifts from 2035 to 2030.
7	No Pipelines	What if no new pipelines can be constructed?	Hydrogen and ammonia pipeline builds will not be permitted.
8	Limited WA Renewables	What if the rate of renewable resource expansion is limited in Washington?	No renewable growth permitted in Washington
9	Restrict Renewable Rate of Supply (Restrict RE SC)	What if expansion of renewable energy supply chains were limited?	Restricts national rate of renewable build to simulate supply chain limitations

#	Scenario	"What if" question	Model implementation
10	Restrict Electrolyzer Rate of Supply (Restrict Electrolyzer SC)	What if electrolyzer supply chains were limited?	Restricts the rate of electrolyzer build to simulate supply chain limitations

By making changes to individual assumptions that represent barriers to deployment, policy action, or other realized uncertainties that impact hydrogen development, the model can assess the sensitivity of hydrogen development to that policy or uncertainty.

Scenario 2: What if accounting for clean energy in hydrogen production is less strict than the Three Pillars requirement in the Core Case?

The Core Case includes the Three Pillars accounting for deliverability, additionality, and hourly matching because this is the more conservative approach. While proposed regulations include stricter rules, Treasury may choose a less stringent accounting mechanism following review of comments on the draft rules, so this scenario investigates the impact of less strict accounting on deployment of hydrogen production in Washington. Table 5 describes the Three Pillars accounting currently under debate, and the relaxed requirements tested in this scenario.

Table 5. Three pillars accounting versus limited requirements

Pillar	Three pillars	Limited requirement
Additionality	Incremental electrolyzer loads must be met with an equivalent amount of incremental annual renewable energy.	Any clean energy qualifies, including existing nuclear and renewables.
Hourly Matching	Resources must be supplied with a resource portfolio of wind/solar/batteries time-matched to electrolyzer production. Electrolyzers are allowed to sell excess energy from the dedicated resource portfolio back to the grid.	No requirement.
Deliverability	Renewables must be deliverable within the zone the electrolyzer is located in.	No requirement.

Scenario 3: What if IRA credits roll off early?

The Core Case allows projects constructed through 2032 to receive the IRA tax credit. This scenario investigates the impact of the IRA tax credit expiring earlier: in 2026. Advanced warning of early expiry is given in this scenario, allowing adjustments to investment strategy prior to 2026.

Scenario 4: What if hydrogen production and conversion costs less in the Northwest?

At the time of writing, selection of the PNWH2 Hub for DOE negotiations had been announced though final projects and award levels were still pending. If a final award is made to the PNWH2, the H2Hub funding would lower costs for hydrogen projects in the region. This scenario was developed prior to award negotiation announcements. The case investigates how lowering hydrogen costs in the region versus other places impacts competition for hydrogen and hydrogen-derived products. While the actual reduction in costs due to hub funding is unknown, the model demonstrates the impact of a generic 20% cost reduction in electrolyzer and clean fuels production technologies through 2032. This case illustrates the sensitivity of economic competition between hydrogen produced in the Northwest and outside the region.

Scenario 5: What if hydrogen becomes competitive as a fuel in long-haul heavy-duty trucking?

The forecast of vehicle sales in the Washington Commerce Strong Electrification Policy scenario used in the Core Case includes aggressive electrification of vehicles in the light-, medium-, and heavy-duty sectors. It assumes that electric vehicles will outcompete fuel cell vehicles, so the Core Case has very little hydrogen use in vehicles. This scenario investigates the impact on hydrogen deployment if fuel cell technology were to become competitive in long-haul trucking.

Scenario 6: What if pipeline builds are accelerated?

Pipelines for carrying hydrogen or ammonia over long distances will face similar challenges to transmission. They cross multiple jurisdictions and may face siting and permitting challenges. In the Core Case, new pipelines can be built starting in 2035 and beyond to reflect the likelihood of obstacles to pipeline development, an assumption that limits hydrogen production to local electrolyzers. Scenario 6 investigates a quicker development phase, allowing new pipelines to be built from 2030 onwards.

Scenario 7: What if no new pipelines can be constructed?

New pipeline development may face greater obstacles than those that the Core Case assumes. This scenario represents a more pessimistic bookend by not permitting new pipeline development at any time. In this scenario, states must produce all hydrogen for direct in-state consumption.

Scenario 8: What if the rate of renewable resource expansion is limited in Washington?

Regardless of the accounting mechanism used to attribute electricity carbon content to qualify for the IRA production tax credit, Washington must meet its own aggressive emissions targets, reducing economy-wide emissions by 45% over 1990 levels by 2030, as well as a clean electricity target of 100% clean electricity with up to 20% coming from alternative compliance by 2030. Hydrogen production increases electric loads and therefore increases the demand for renewable electricity by 2030. Here, the analysis investigates the impacts of limiting deployment of renewable energy in Washington. This scenario illustrates the link between local hydrogen production and increased local electric loads. If resources are scarce, where is electricity sourced and what is the impact on hydrogen production?

Scenario 9: What if expansion of renewable energy supply chains is limited?

As technology costs drop and the IRA extends investment and production tax credits, wind and solar are the lowest cost options for energy in many regions of the United States, which should drive economic investments regardless of state energy or emissions policy.

At the same time, many states have aggressive clean electricity and emissions reduction policies, and more are adopting similar measures. Further renewable growth will result from policy-driven decarbonization of electricity. Green electrolytic hydrogen requires large quantities of clean electricity that will lead to further renewable energy growth.

If renewable supply chains cannot keep pace with accelerating demand, loads will compete for the available renewables. This competition would happen both across geographies, and between load types. This scenario examines the consequences of supply chain constraints on renewable energy growth.

Scenario 10: What if expansion of electrolyzer supply chains is limited?

Electrolytic hydrogen production is still a budding industry. Production of electrolyzers and associated plant infrastructure must scale rapidly to reach large-scale deployment by 2030. If demand for electrolyzers is higher than the rate at which electrolyzers can be manufactured, the supply chain will limit hydrogen supply, and regions across the US will compete for available capacity.

This scenario investigates the impact of a limited supply chain, which would divert electrolyzer deployment away from less competitive regions and into those with either better renewable resources or emissions policy that drives greater willingness to pay for hydrogen and hydrogen-derived products.

Key findings

Supply chain limitations

Opportunities for electrolyzer deployment exist in Washington and across the United States and internationally. In the coming years, production of hydrogen and hydrogen-derived fuels will become economic even in markets without emissions reduction policies. It will be competitive, on price with conventional fuels, if receiving the full IRA production tax credit. Electrolyzer production will need to scale up rapidly to meet this new market demand. At the same time, the added electricity demand of those electrolyzers must be met with new renewable energy investments. Growth in renewables is already straining the ability to site and permit new resources, and added demand for renewables could cause supply chain bottlenecks.

Modeling potential supply chain limitations, the analysis finds that if electrolyzer or renewable supplies are scarce, development is directed toward the highest value locations across the country, of which Washington is one.

Renewable energy

Restricting renewable energy supply chains drops the consumption of hydrogen-derived products in Washington significantly. With the supply of renewable generation limited, the cost-minimizing use of those resources to achieve emissions reductions is for end uses that directly displace fossil fuels. Compliance with renewable energy policy in many parts of the country also drives this use.

However, in parts of the country that have no emissions reduction or clean electricity requirement, the restricted availability of renewable generation could take renewables that would otherwise have been used economically to serve electric loads and use them for hydrogen production. Fossil fuels would then replace those renewables in serving electric loads. The consequence of this would be increased emissions by moving renewable use from where they can achieve the highest emissions reductions – displacement of fossil fuels serving electric loads – to a less efficient emissions reduction path – conversion to hydrogen and derived fuels.

Electrolyzers

A restriction on electrolyzer supply chains has a similar impact on the consumption of hydrogen-derived products in Washington. However, in this case, if renewable supply chains are not limited, renewables can serve both electric loads and electrolyzer loads where economic to do so, mitigating the emissions impact of expanding the hydrogen industry.

Supply chain limitations restrict the total size of the market in Washington for in-state hydrogen and hydrogen-derived products, causing Washington to import out-of-state clean fuels. Washington achieves the shortfall in emissions reductions that would have come from clean-fuels use in the economy through other means, such as increased electrification of boiler loads, increased biofuel use, and land sink and non-CO2 emissions reduction measures.

There are multiple factors beyond the economics of renewables and transport networks that could make Washington more favorable for hydrogen development than other regions. These may include support in accessing the IRA tax credit; options to site and permit new electrolyzers, conversion plants and renewable energy; proximity to markets for hydrogen and derived products; and other incentives the state might offer.

Accounting mechanism

The nature of the accounting mechanism that Treasury sets in the tax code for receiving the full $3/kg hydrogen PTC could impact deployment of hydrogen from two perspectives: economic and implementation.

Economic

By requiring strict accounting, such as the Three Pillars proposal, hydrogen producers are required to meet additionality, deliverability, and hourly matching requirements. Meeting these requirements demands both more investment in renewable energy and electrolyzer operations restricted to times when renewable energy is available, which therefore increases the cost of hydrogen production.

A national study by Evolved Energy Research shows that Three Pillars accounting reduces investment in electrolyzers in the very near term but the strong IRA PTC incentive drives large-scale adoption of electrolyzers even under the Three Pillars requirements.[61] That study used a strict version of Three Pillars where electrolyzers could contract with a portfolio of newly built renewable resources within the same transmission zone, but any energy not used in the electrolyzer had to be curtailed.

This study used a more permissive version of Three Pillars where excess renewable energy from a portfolio of resources could be sold back to the grid. It found little difference in deployment of electrolyzers or hydrogen conversion infrastructure in Washington between Three Pillars accounting and less strict accounting that allowed existing renewables and nuclear to provide energy to electrolyzers.

There is a slight increase in electrolyzer deployment in Washington under Three Pillars. Three Pillars accounting will disproportionately disadvantage the economics of hydrogen deployment in states without emissions policy. Loose emissions accounting may permit increases in emissions in states without emissions policy and lower development costs for hydrogen.

Strict emissions accounting drives up the cost of hydrogen production in states without emissions policy. Washington must reach emissions reduction targets anyway, driving a 100% clean electricity grid by 2030 in concert with clean electricity policy – in effect, enforcing additionality, so in Washington, strict accounting has less impact on hydrogen costs in 2030 and into the future.

Implementation

Implementing Three Pillars accounting will be more difficult than less strict requirements. , While proposed regulations have been announced, uncertainty remains about what the final rules will be and how hydrogen producers can comply with them. New mechanisms for tracking renewable and hydrogen production could have a dampening effect on hydrogen deployment as they go into effect.

In the version tested in this analysis, Three Pillars accounting has little impact on overall hydrogen deployment, but allowing sales of the renewable portfolio contracted by the electrolyzer back to the grid diminishes the benefits of Three Pillars accounting, unless other restrictions are placed on the size of the portfolio an electrolyzer can contract with. At the time of writing, it is hard to assess the impact on Washington hydrogen deployment of the tax code for the IRA hydrogen incentive without knowing the form it will take.

Stronger versions might be harder to comply with and could increase costs for hydrogen production. However, Washington requires clean fuels to meet its 2030 emissions target. Demand for hydrogen and derived

[61] Ben Haley and Jeremy Hargreaves, Evolved Energy Research, "45V Hydrogen Production Tax Credits: Three-Pillars Accounting Impact Analysis," (2023).

products will therefore remain in Washington. However, the state may need to provide greater support, particularly in implementation, if stricter accounting rules are included in the final regulations.

Term of the IRA Production Tax Credit (PTC)

How long developers have access to the IRA PTC will shape the way the market develops and how hydrogen is used in the future. At present, the PTC for hydrogen is set to expire in 2032. The model investigated the impact of early expiry in 2026 to see how hydrogen deployment is impacted.

The IRA tax credit drives adoption of electrolysis and clean fuels production that would otherwise not be economic. Expiring the IRA tax credit in 2026 first frontloads adoption of electrolyzers to take advantage of the credit. However, by 2035, hydrogen production falls dramatically compared with the Core Case.

While the IRA drives early hydrogen development through 2032, hydrogen is a critical net-zero solution and these markets are expected to be strong by 2050 even when the tax credits are no longer available.

Hydrogen and ammonia pipeline development

Access to hydrogen produced elsewhere via pipelines determines the size of Washington's hydrogen industry. Early pipeline development by 2030 decreases Washington electrolyzer deployment and increases imports, though not significantly. Regardless of the timing of pipeline development, most hydrogen is delivered to Washington in the form of clean fuels and comes from out of state in 2030.

Not permitting pipeline development in 2035 and after is much more impactful. Lack of hydrogen or ammonia pipeline availability increases electrolyzer deployment in Washington from 4 GW to 10 GW and requires development of an in-state Haber-Bosch plant to meet ammonia demands in shipping. This drives significantly more demand for electricity and water in the state.

Model results: Core Case

This section describes the impact of different assumptions on Washington's modeled economic deployment of hydrogen infrastructure and how Washington meets its economy-wide energy needs through 2050 with model time steps of 2021, 2025, 2027, 2030, 2035, 2040, and 2050. Recommendations focus on the near-term results for 2023 through 2030.

What does Washington use hydrogen for?

Hydrogen can be delivered to end uses in the economy and converted to other forms of energy carrier, as described in the Hydrogen production section earlier in this chapter.

Figure 3. Core Case hydrogen and hydrogen-derived fuels consumption in Washington

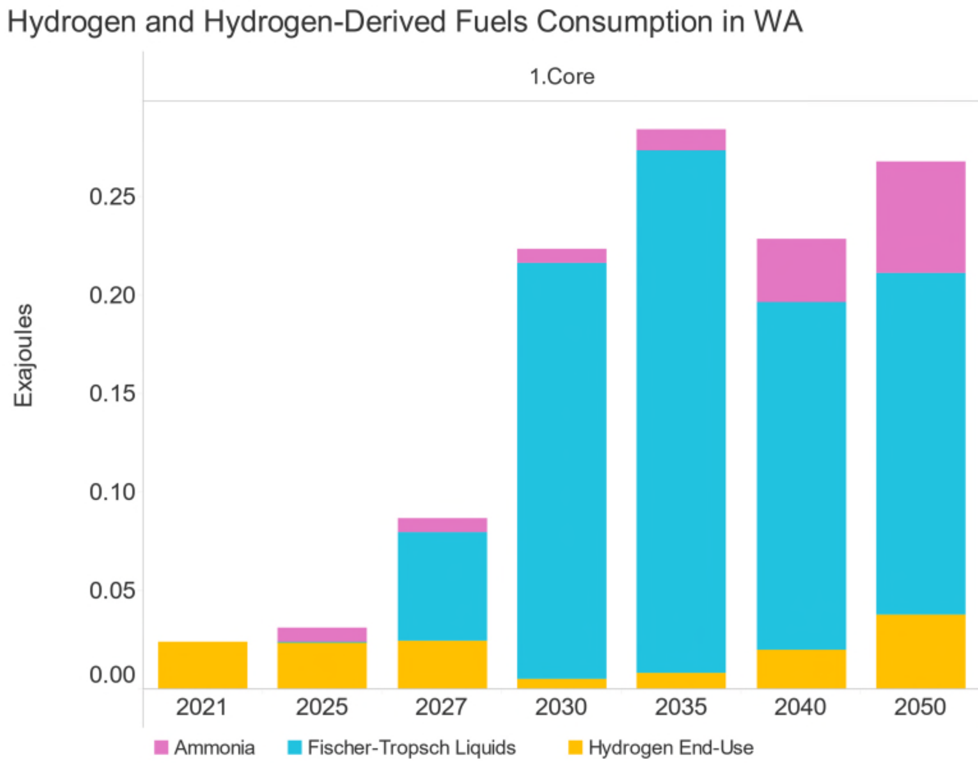


Figure 3 shows the form in which hydrogen is consumed in Washington over time in the Core Case, shown in exajoules (EJ).

Initially, hydrogen is used directly in petroleum refining and bulk chemical production in the state.

Over time, most of the hydrogen consumption shifts to hydrogen-derived fuels to use in engines and turbines that currently run on diesel, gasoline, fuel oil, and jet fuel – so called "drop-in" fuels.

Figure 4. Core Case hydrogen and hydrogen-derived fuels use in Washington

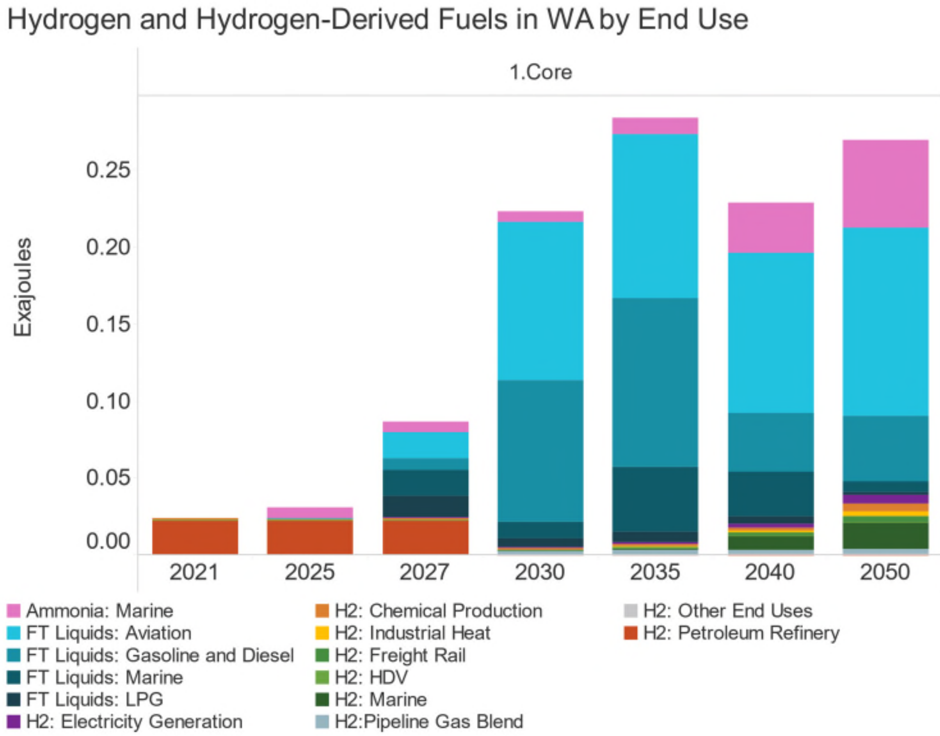
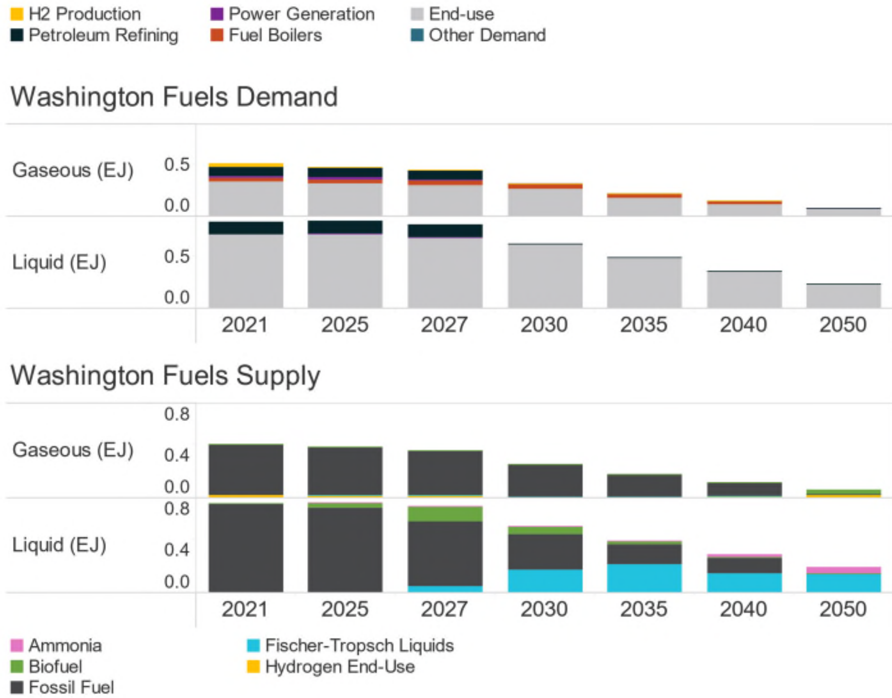


Figure 4 shows where in the economy hydrogen and hydrogen-derived fuels are used. Petroleum Refining decreases in 2030 as electrifying transportation lowers fuel demands and greater amounts of clean fuels are consumed in the state. The remaining refined fossil products in the economy have tapered significantly, and the model chooses to consolidate refining activity outside of Washington. However, refining activity may taper more slowly than this, in which case hydrogen electrolysis in the state would increase to meet additional refining demand for hydrogen.

The transition from hydrogen in refining to hydrogen and hydrogen-derived fuels begins in the late 2020s. The dominant new use of hydrogen in the state is for clean drop-in fuels. Ammonia displaces fuel oil in domestic and international shipping. Fuels produced with Fischer-Tropsch (FT Liquids) displace gasoline and diesel in on-road transportation and the marine sector, jet fuel in aviation, and liquefied petroleum gas (LPG) in heating and industry.

At the same time, direct consumption of hydrogen outside of refining increases, including for industrial process heat to produce iron and steel, as well as for marine applications, rail, and small quantities of electricity generation in 2040 and 2050. Hydrogen blending in pipeline gas also increases to the maximum 20% by volume permitted in the model by 2050, both to electricity generators, and to buildings and industry.

Figure 5. Core Case Washington fuels demand and supply



Replacing liquid fuels in the economy is both necessary to reach emissions targets in the state, as demonstrated in the Washington 2021 State Energy Strategy,[62] and is one of the highest value uses of clean hydrogen. Figure 5 shows the demand for gaseous and liquid fuels in Washington, and how that demand is met with fossil, biofuel, hydrogen, and hydrogen-derived products.

Economy-wide liquid fuels usage drops over time as vehicles are electrified. The remaining demand is increasingly met with hydrogen and hydrogen-derived fuels, as seen in Figure 5 above. The largest volumes of clean liquid fuels, largely derived from hydrogen, are needed in 2030 and 2035 to meet emissions targets. Even though the fraction of clean fuels in the economy increases over time – by 2050, fuels come from 100% clean sources – the overall volume of clean fuels demand decreases as electrification increases.

Whether hydrogen is used as an energy carrier in a particular supply chain depends on the economics of hydrogen versus other alternatives. The economics differ between regions with emissions policy versus those without. In places with emissions policy, like Washington, emissions reductions must be achieved, driving the need for measures that attain those reductions.

It is unlikely Washington can electrify vehicle fleets fast enough to meet its 2030 emissions target if fossil fuels alone continue to be used in transportation. Vehicles have a useful lifetime (15 years or more) that restricts how fast the stock of the vehicle fleet can transition to electric, so emissions must be reduced in additional ways.

Emissions could be offset with carbon capture, but this is expensive and there are feasibility questions about how much carbon can be captured on the timeline that Washington requires to meet its emission reduction targets. They could also be offset by increasing the land sink, but the extent to which the land sink can be

[62] Washington State Department of Commerce, "Washington 2021 State Energy Strategy," (December 2020), Chapter 2.3.2.

increased is highly uncertain. Neither of these options is compliant at the scale required to reach Washington's 95% gross emissions reduction target by 2050. Alternatively, some of the fossil fuel used in vehicles and other forms of transportation in 2030 can be displaced by clean drop-in fuels.

There are both hydrogen and biomass pathways to produce drop-in fuels. These are reviewed in the Hydrogen production section of this chapter (see Figure 1). Which pathway is more favorable depends on costs and feasibility. In analyses prior to the IRA, biomass and biofuels were often more cost-effective than hydrogen-derived fuels. However, this analysis found that the generous IRA incentives have made fuels derived from hydrogen cheaper than biofuels in most cases.

This analysis finds both Fischer-Tropsch liquids and biofuels competitive for decarbonizing liquids in 2027, but hydrogen-derived fuels outcompete biofuels by 2030. The biofuels in 2027 come from existing U.S. corn ethanol, fatty acid methyl ester (FAME) biodiesel supplies, renewable diesel (hydroprocessed esters and fatty acids — HEFA fuels) and a small amount of corn ethanol with carbon capture.

However, it may not be possible to divert existing supplies of biofuels to Washington away from current consumption. The analysis modeled emissions targets in 2027 in Washington to avoid investments in new infrastructure all happening in 2030, but current policy does not require emissions reductions until 2030. By 2030, electrolyzer prices have dropped sufficiently so that biofuels are no longer competitive with hydrogen-derived liquid fuels.

How much hydrogen and hydrogen-derived fuel is produced in state versus out of state?

In addition to Washington consuming hydrogen and hydrogen-derived fuels in state as described in the previous section, Washington also has the option to produce hydrogen and derived fuels locally or import them from other states.

Figure 6. Origin of hydrogen and derived fuels in the Core Case

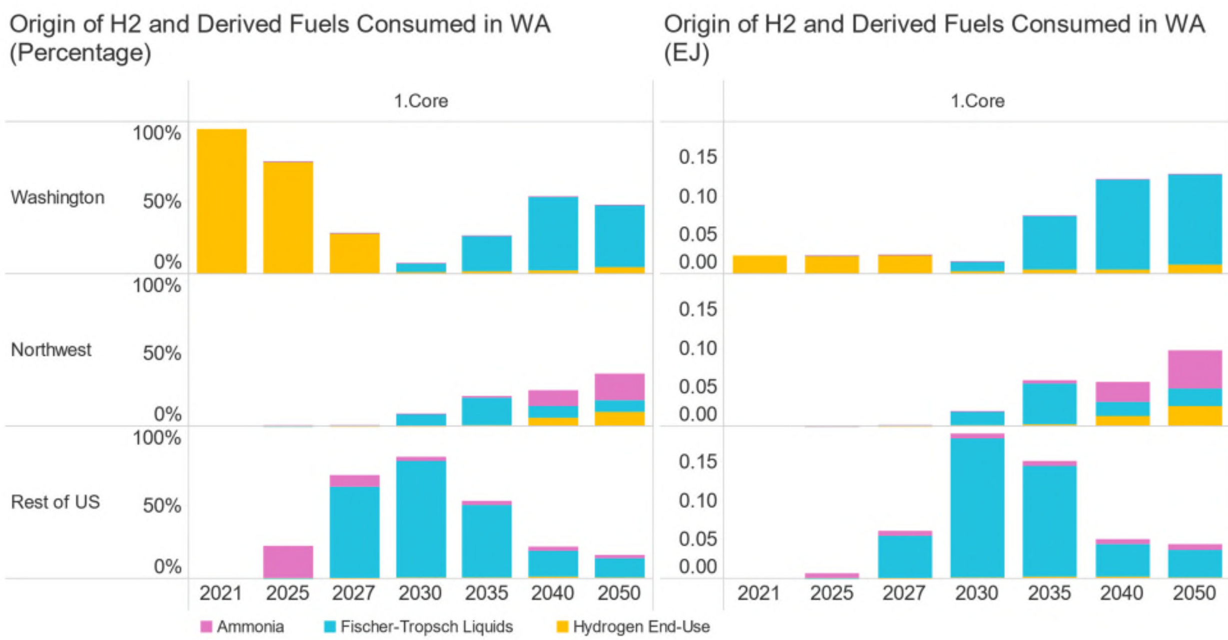
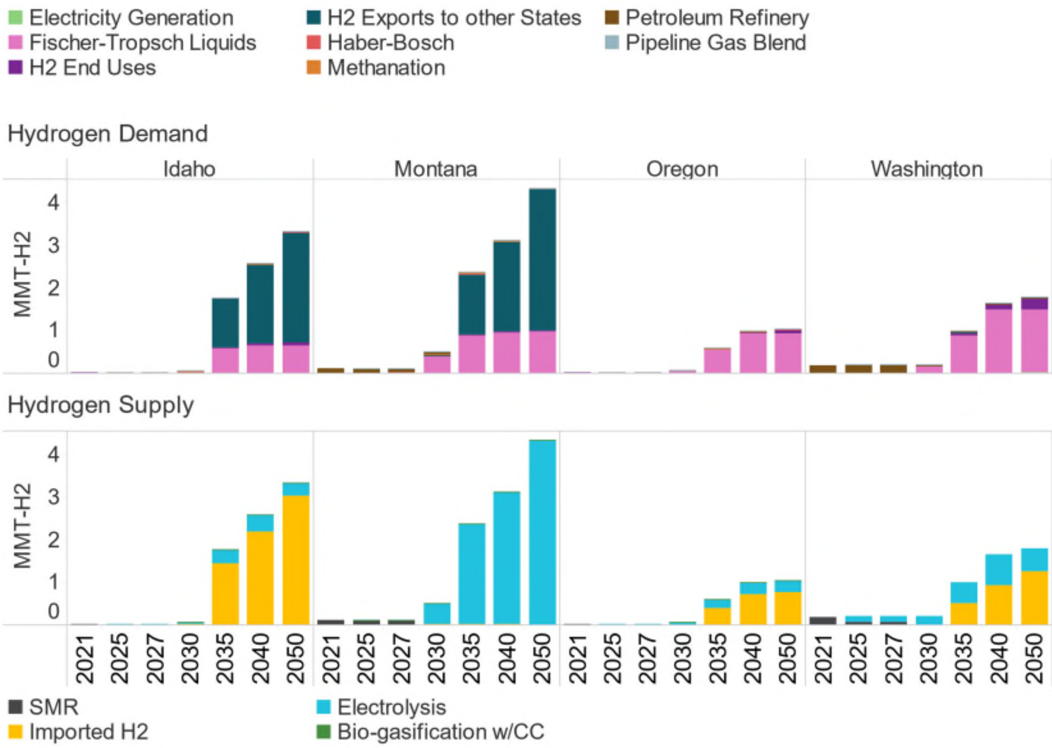


Figure 6 shows the origin of hydrogen for end use consumption, ammonia, and Fischer-Tropsch liquid fuels, including those produced in Washington, those produced in the Northwest, and those coming from outside of the Northwest.

Hydrogen and derived fuel use in Washington is initially 100% locally produced when conventional refining and bulk chemicals comprise all demand. As demand for clean fuels grows, the percentage of hydrogen and derived fuels produced in Washington shrinks to only 7% of the total in 2030. Fuels from Fischer-Tropsch liquids are produced more cheaply elsewhere and imported into the state. Pipeline construction is not permitted until 2035, so Washington does not have the option of producing clean liquid fuels using imported hydrogen prior to then.

In 2035 and beyond, clean liquid fuels production increases in state. Hydrogen imported via pipeline is available and imported from other states. This improves the economics of in-state production, allowing Fischer-Tropsch and Haber-Bosch plants to take advantage of local hydrogen production and hydrogen produced in Montana and other states. By 2050, Washington produces 47% of the hydrogen and derived products consumed in the state.

Figure 7. Core Case hydrogen gas demand and supply in the Northwest



Hydrogen and derived fuels produced in Washington use a mixture of hydrogen gas produced in state and imported from out of state. Figure 7 shows hydrogen gas demand and supply across the Northwest in the Core Case. Growth in Fischer-Tropsch liquids production is largely met by expanding imports of hydrogen into Washington between 2035 and 2050.

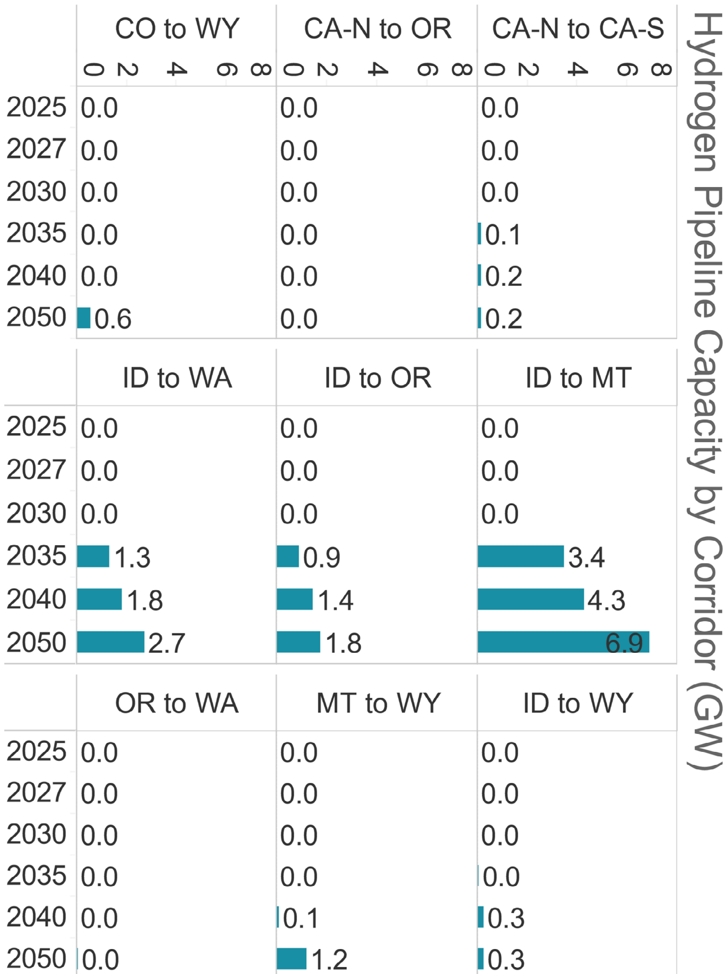
While demand for hydrogen does not grow until 2030, supply for existing hydrogen consumption is partially decarbonized, displacing steam methane reforming (SMR) with electrolysis starting in 2025. Existing SMR continues to produce hydrogen in 2025 and 2027 at lower quantities than in 2021 before being fully displaced by electrolysis in 2030.

Displacing SMR with electrolysis is a cost-effective means of reducing emissions if electrolyzers receive the $3/kg IRA incentive. As described above, clean fuels are required in Washington to meet the emissions target in 2030. There is, therefore, both economic value in displacing hydrogen production from SMR due to the IRA incentives, and policy pressure to reduce emissions from SMR.

Hydrogen imports from other states enter Washington via pipelines constructed in 2035 and after. Pipeline construction across the U.S. facilitates the economic movement of hydrogen for end uses and production of derived fuels. Within the Northwest, Montana is the largest producer of hydrogen, taking advantage of high-quality wind resources. Some of that hydrogen is converted to liquid fuels; however, most of it is exported via pipeline to other states in 2035 and after. The other states in the Northwest are net hydrogen importers. Hydrogen pipeline builds between states in the Northwest and connections that might impact Northwest hydrogen supply are shown in Figure 8.

While this modeling was conducted prior to H2Hub award decisions, the announced award negotiations for the PNWH2 for hydrogen production in Washington, Oregon, and Montana align well with the overall expectation supported by this modeling that coordination and transport of renewable resources, green hydrogen and other renewable fuels in the Pacific Northwest is appropriate as part of a cost-effective pathway to a net-zero economy in our region. A final hub award is expected to support similar coordination and may lead to increased production of green hydrogen in Washington (per Scenario 4), while driving down costs for hydrogen across the region.

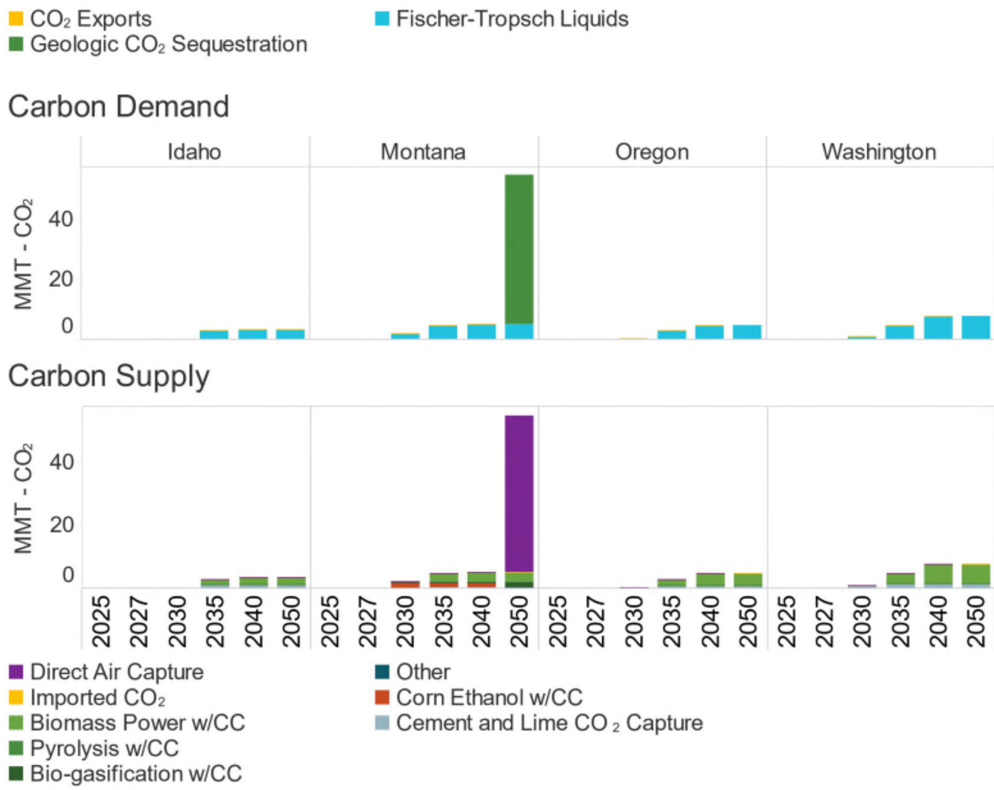
Figure 8. Core Case Northwest hydrogen pipeline capacity



The model assumes that transporting clean drop-in fuels is relatively cheap and that they can be injected into existing transportation networks for diesel, gasoline, jet fuel etc. Either the physical flows of these products can be tracked, or credit for the injection may be conferred to the fuel producer. Fuels produced out of state but under contract to Washington suppliers could then receive clean fuels credit that counts toward Washington emissions targets. This analysis did not determine the mechanism for delivery or emissions accounting but assumes that transporting liquid fuels to Washington will be lower cost than building new hydrogen pipelines.

The economics of clean liquid fuels therefore opens up market opportunities outside of Washington more than for hydrogen gas. Clean liquid fuels may be economically produced elsewhere in the country and imported into Washington from these other states, whereas doing so with hydrogen gas would require long pipeline development. Areas with low-cost liquid fuels are those with high-quality renewable portfolios, which lower the cost of hydrogen production relative to other regions. This tends to concentrate hydrogen production and clean fuels production in regions where these favorable conditions exist, subject to: constraints on developing high-quality renewables, access to markets for hydrogen and hydrogen-derived products, and, in the case of drop-in fuels, access to captured carbon dioxide.

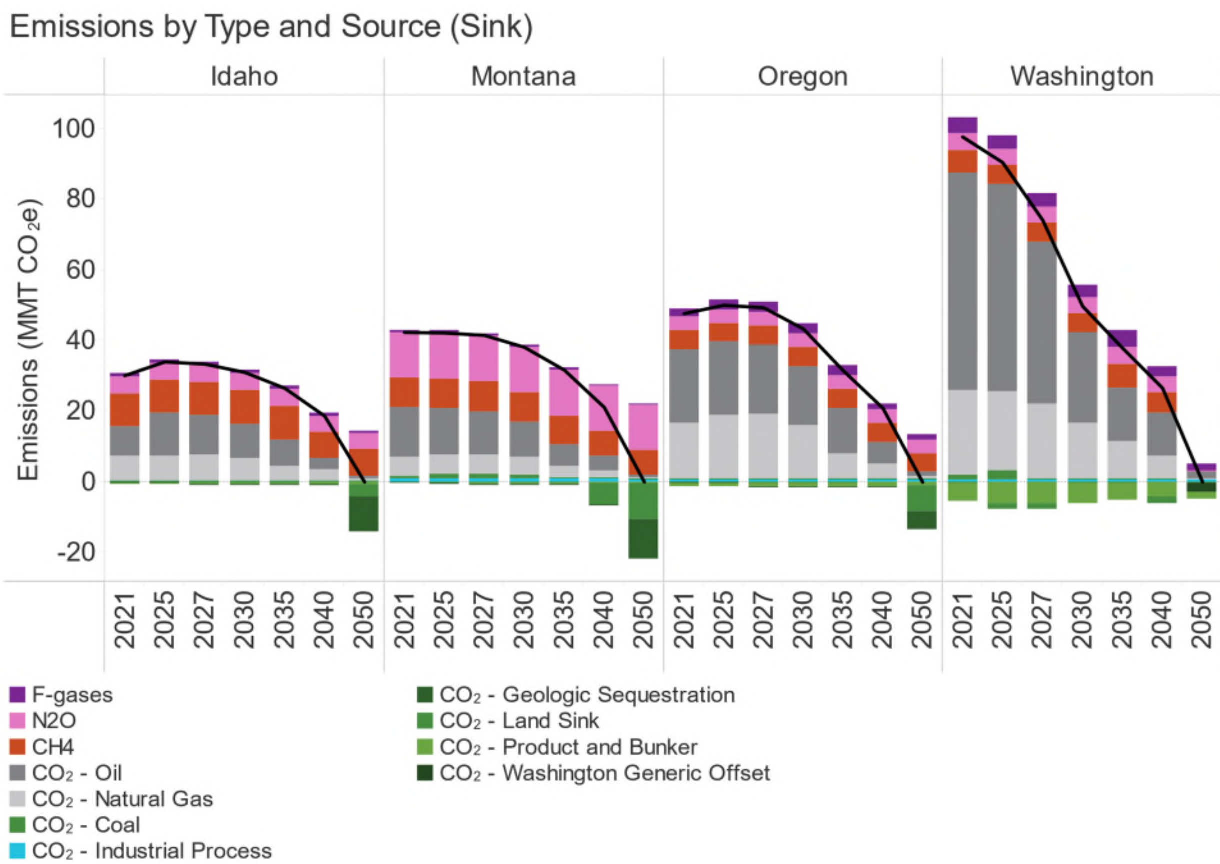
Figure 9. Core Case carbon demand and supply by state in the Northwest



Options for access to carbon dioxide include local capture of carbon from industry, carbon dioxide from biomass such as through bioenergy with carbon capture technologies, direct air capture, or imported carbon dioxide from another region. Figure 9 shows the carbon demand and supply by state in the Northwest for the Core Case.

The carbon for Fischer-Tropsch liquids production is largely provided by biomass power with carbon capture across all states, supplemented with cement and lime CO2 capture, corn ethanol in Montana, and other types of biomass carbon capture. Large-scale sequestration of emissions happens by 2050 in Montana and is met with direct air capture of carbon dioxide.

Figure 10. Emissions by state in the Northwest in the Core Case



To reach net-zero in 2050 requires negative emissions technologies including carbon capture and sequestration. These offset the remaining emissions in the economy, most of which are from non- CO2 sources like agricultural methane and nitrous oxide, for which we currently have no plans that support significant reductions. Figure 10 shows these remaining emissions and the offsets to get to net-zero.

The analysis allows states to bear the cost of carbon capture and sequestration in another state and count the resulting emissions offsets on their own emissions accounting ledger. No physical sequestration occurs in Washington, Oregon, and Idaho – it all happens in Montana and other states with potential for carbon sequestration – but these states count offsets and bear the cost for sequestration happening elsewhere.

As the charts above show, Washington's emissions are higher than those in neighboring states. Economic factors, notably Washington's significant industrial operations — including refining and aerospace — are the primary reason for these differences.

Electricity requirements

Core Case electricity requirements grow significantly from the present through 2050.

Figure 11. Core Case electricity generation and consumption

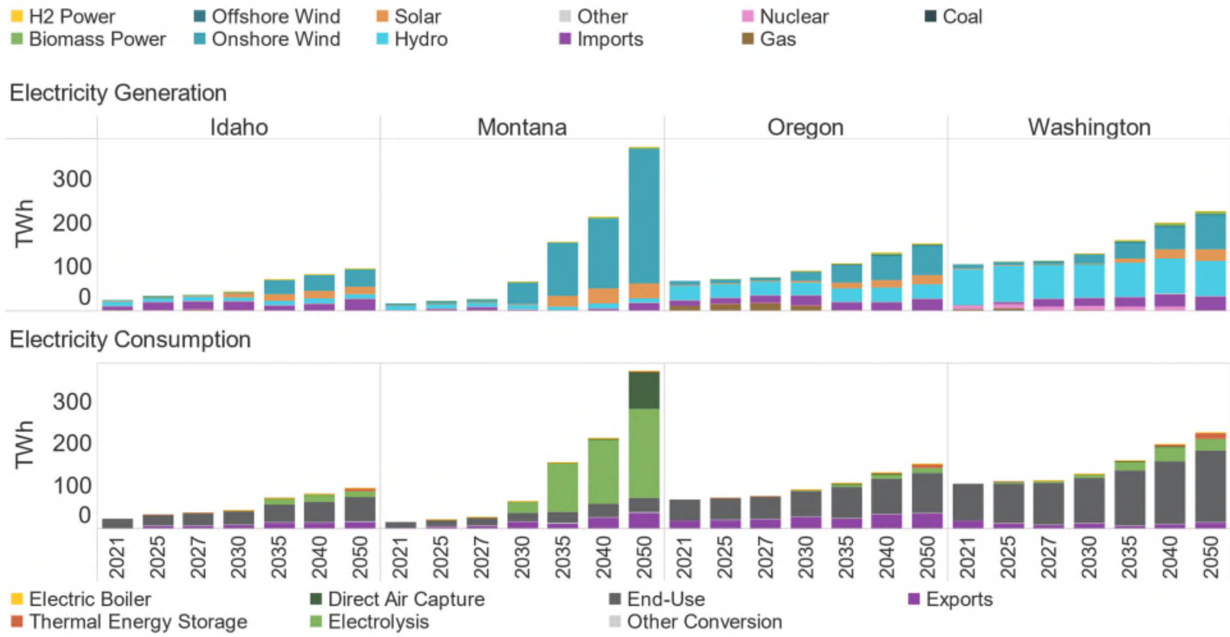
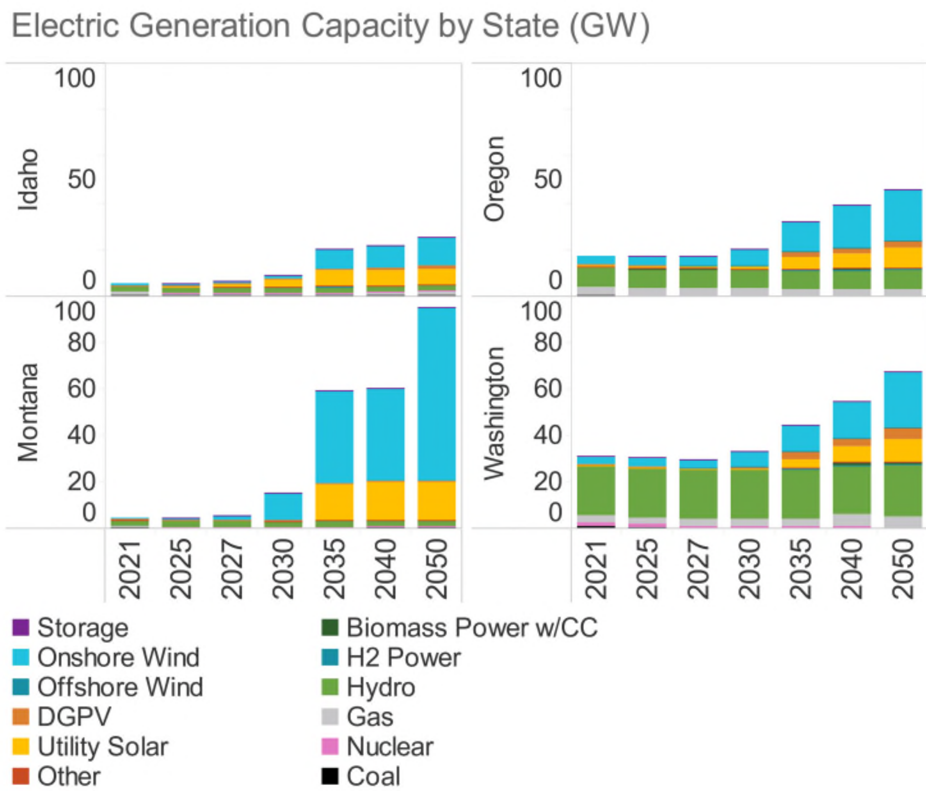


Figure 11 shows electricity generation and consumption for each of the states in the Northwest. By 2030, all loads including electrolysis grow by 29%. By 2050, all loads grow by 142%, reflecting aggressive electrification of vehicle transportation, buildings, and industry, and growth in electrolysis and thermal energy storage loads.

The pattern of load growth in Idaho and Oregon is like Washington, although electrolyzer investments begin in 2035 rather than 2025. Montana, on the other hand, becomes a major producer of hydrogen, with electrolysis loads dwarfing end use loads in the state and electrolyzer growth beginning in 2030. This is an economic solution restricted only by technical potentials on renewable investment in Montana. Whether Montana can transform into a major exporter of hydrogen and derived products will depend on whether other barriers prevent this level of development.

Figure 12. Electricity capacity by state



Electricity capacity follows a similar trend, with growth in solar and wind in Washington, Idaho, and Oregon driven largely by in-state energy demand growth, whereas Montana invests in a large onshore wind sector far exceeding in-state loads to export energy to the rest of the West (Figure 12).

Figure 13. Hydrogen conversion capacity by state

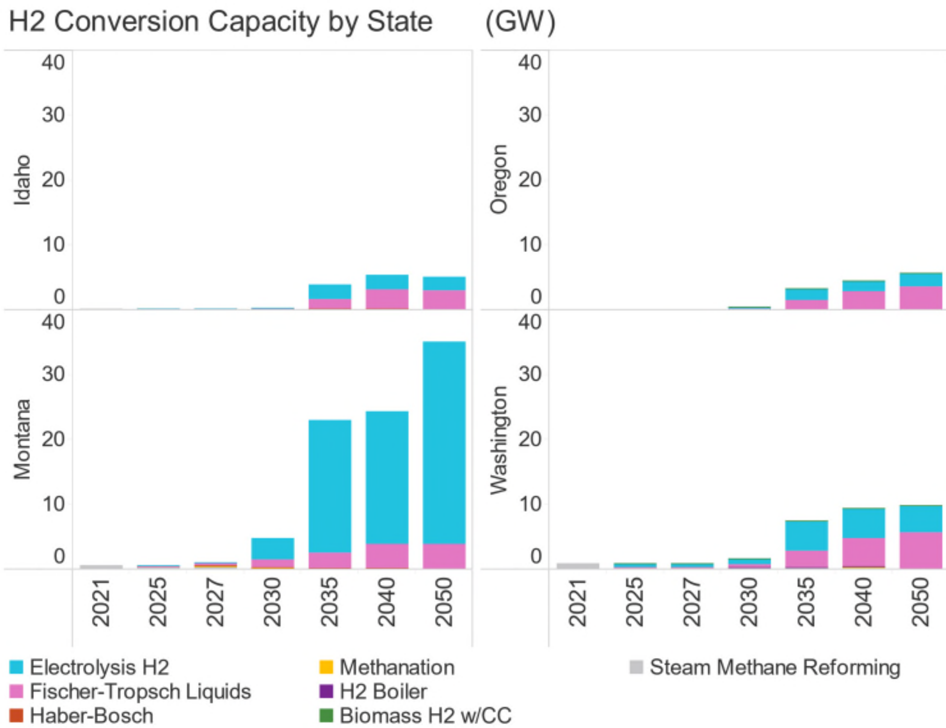
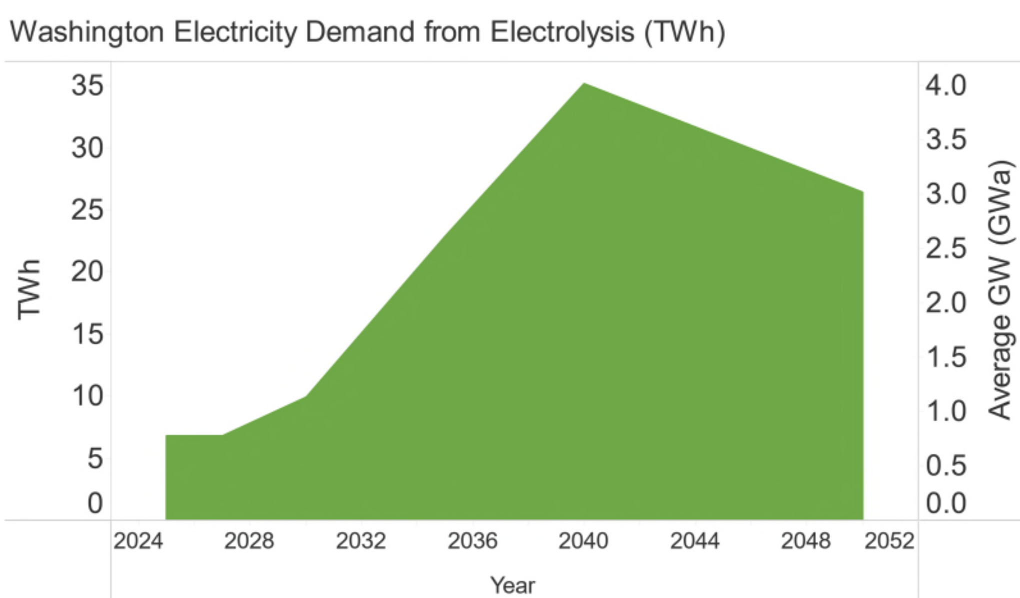


Figure 13 shows the hydrogen conversion capacity build by state. Washington has 0.6 GW of electrolyzer capacity by 2025; 0.8 GW by 2030; 4.6 GW by 2035; and 4.2 GW by 2050.

Figure 14. Core Case electrolyzer electricity demand in Washington

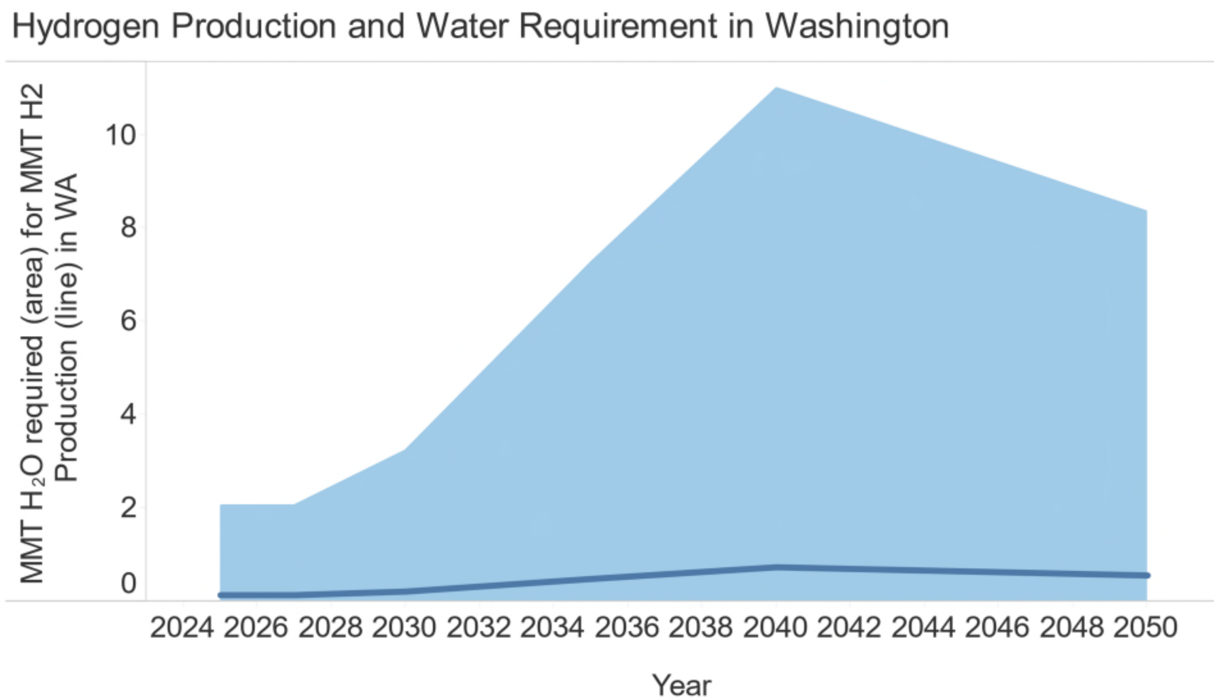


The corresponding electricity demand from these electrolyzers is shown in Figure 14. Electrolyzer load is equal to 1.1 GWa in 2030; 4 GWa in 2040; and 3 GWa in 2050.

Water requirements

To calculate water requirements, the model uses the ratio of 15 kg of water per 1 kg of hydrogen produced.[63]

Figure 15. Hydrogen production and water requirement in Washington



At peak hydrogen production in 2040 (0.73 million metric tons), water consumption would reach 11 million metric tons per year (Figure 15). In comparison, estimated water usage for coal and gas generation in Washington in 2021 was 393 million metric tons.[64]

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[63] Philip Woods et al., Energy Nexus, Volume 7, 100123, "The hydrogen economy – Where is the water?", (2022), https://doi.org/10.1016/j.nexus.2022.100123

[64] Water usage per MWh of generation from EIA (accessed 9/14/2023), https://www.eia.gov/todayinenergy/detail.php?id=56820#:~:text=In%202021%2C%20natural%20gas%20combined,very%20low%20water%2Dwithdrawal%20intensity; Washington historical coal and gas electricity generation from EIA, (accessed 9/14/2023) https://www.eia.gov/electricity/annual/.

Model results: Scenarios

The “what if” questions explored in this analysis were divided into those that examine policy outcomes, for example “what if IRA credits roll off early?” and those that examine availability of resources, for example “what if no new pipelines can be constructed?” In some cases, these are not mutually exclusive (not permitting pipeline construction could be a policy decision).

Figures 16-21 present side-by-side comparisons across all scenarios for reference, while the discussion below focuses only on the differences between the scenarios and the Core Case.

The reference charts include electricity capacity (Figure 16) and electricity generation and consumption (Figure 17) in Washington; conversion capacity in Washington (Figure 18), including electrolyzers, Fischer-Tropsch plants, and Haber-Bosch plants; consumption of hydrogen and derived fuels in Washington (Figure 19); hydrogen gas demand and supply in Washington (Figure 20); and Washington fuels supply (Figure 21).

These reference charts are presented in this report because they provide key data about critical drivers of hydrogen and renewable fuels economics and market development. Their inclusion allows readers to compare across scenarios that have the greatest potential to impact market liftoff in Washington. Additional charts and data can be viewed in Appendix A Technical Report and Appendix B Data Accompanying Report.

Unit of measure	Abbreviation
Average gigawatts	GWa
Exajoule	EJ
Gigawatt	GW
Million metric tons of hydrogen	MMT-H2
Terawatt hour	TWh

Figure 16. Electricity generation capacity in Washington

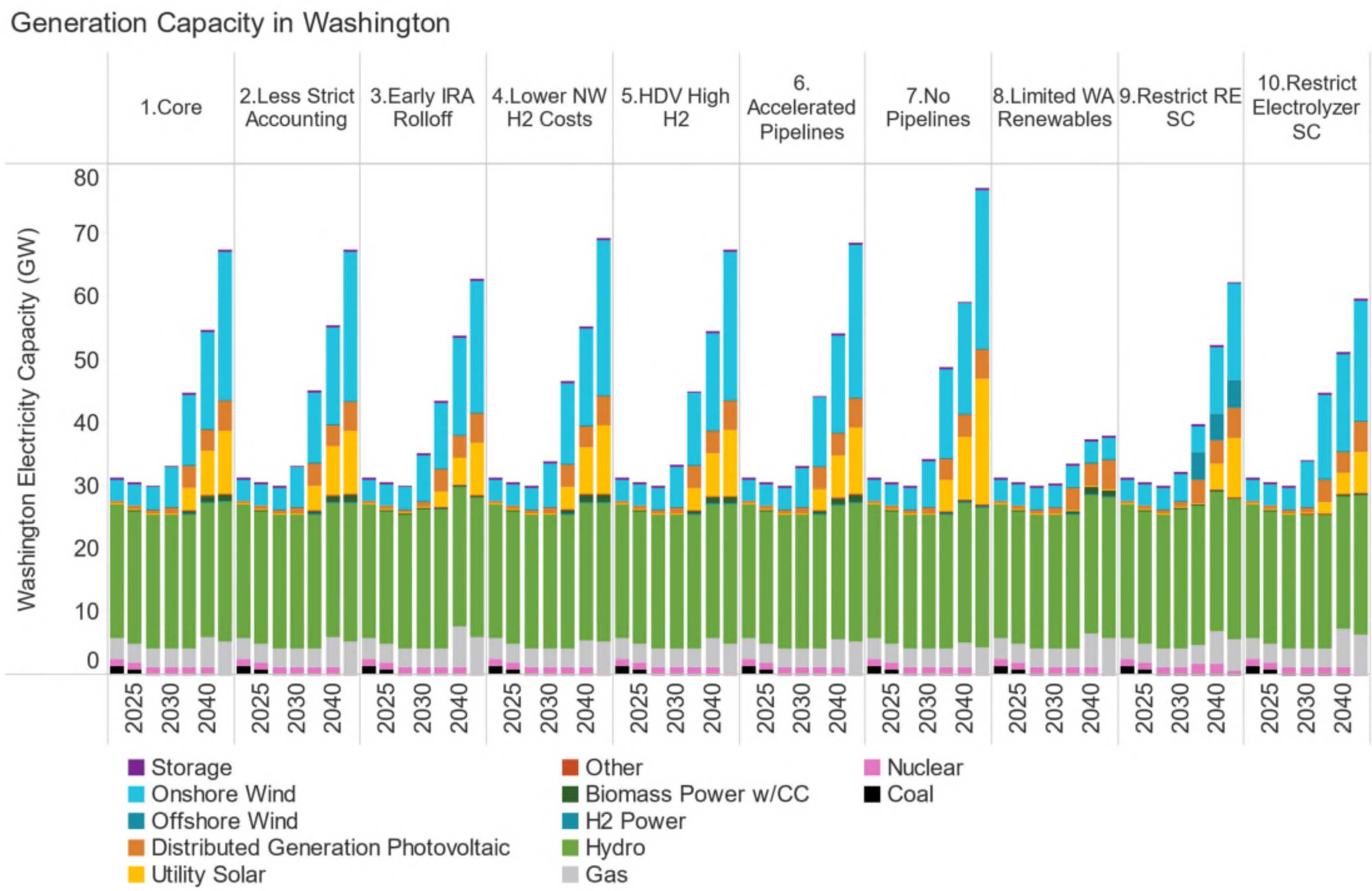


Figure 17. Electricity generation and consumption in Washington

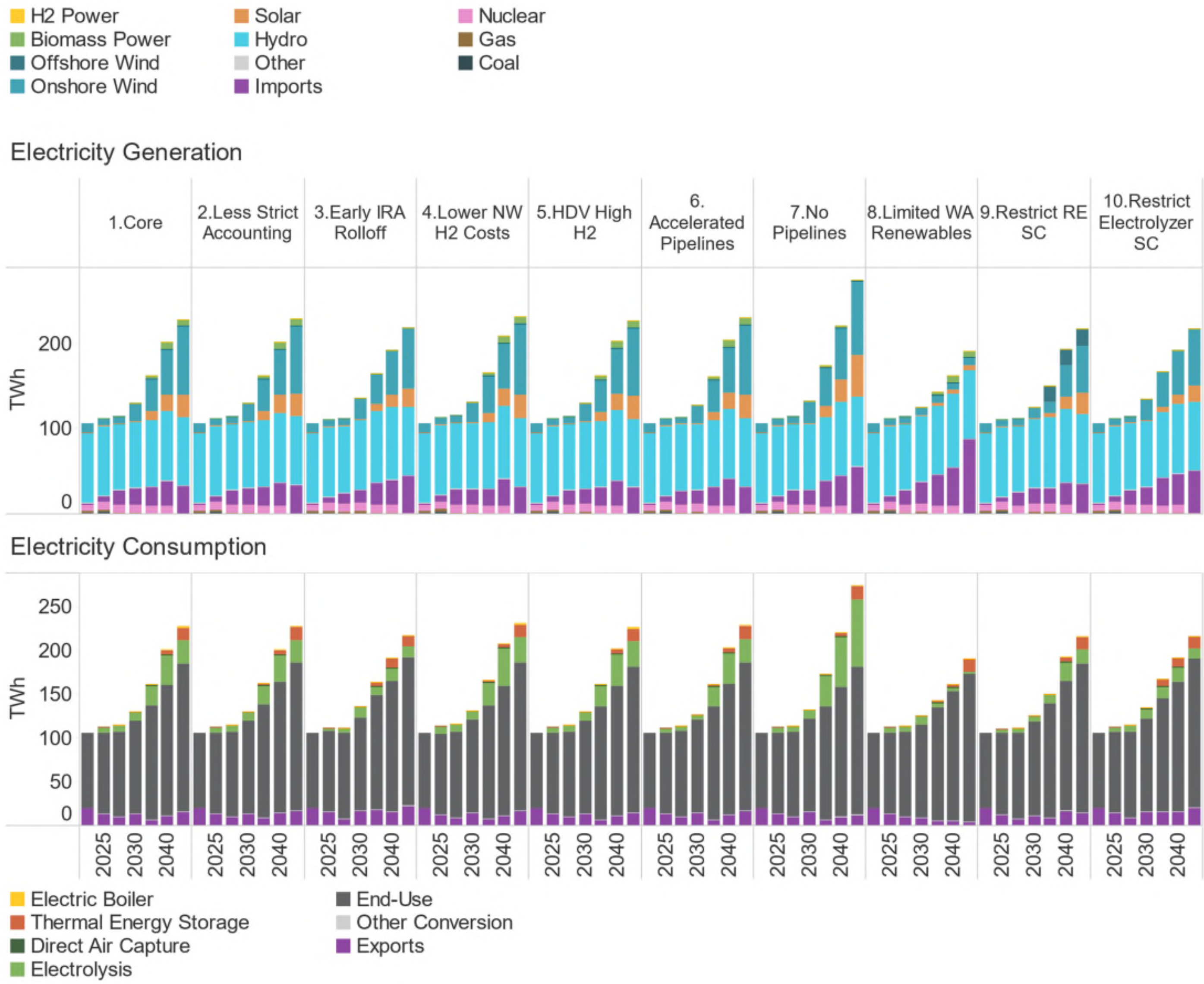


Figure 18. Conversion capacity in Washington

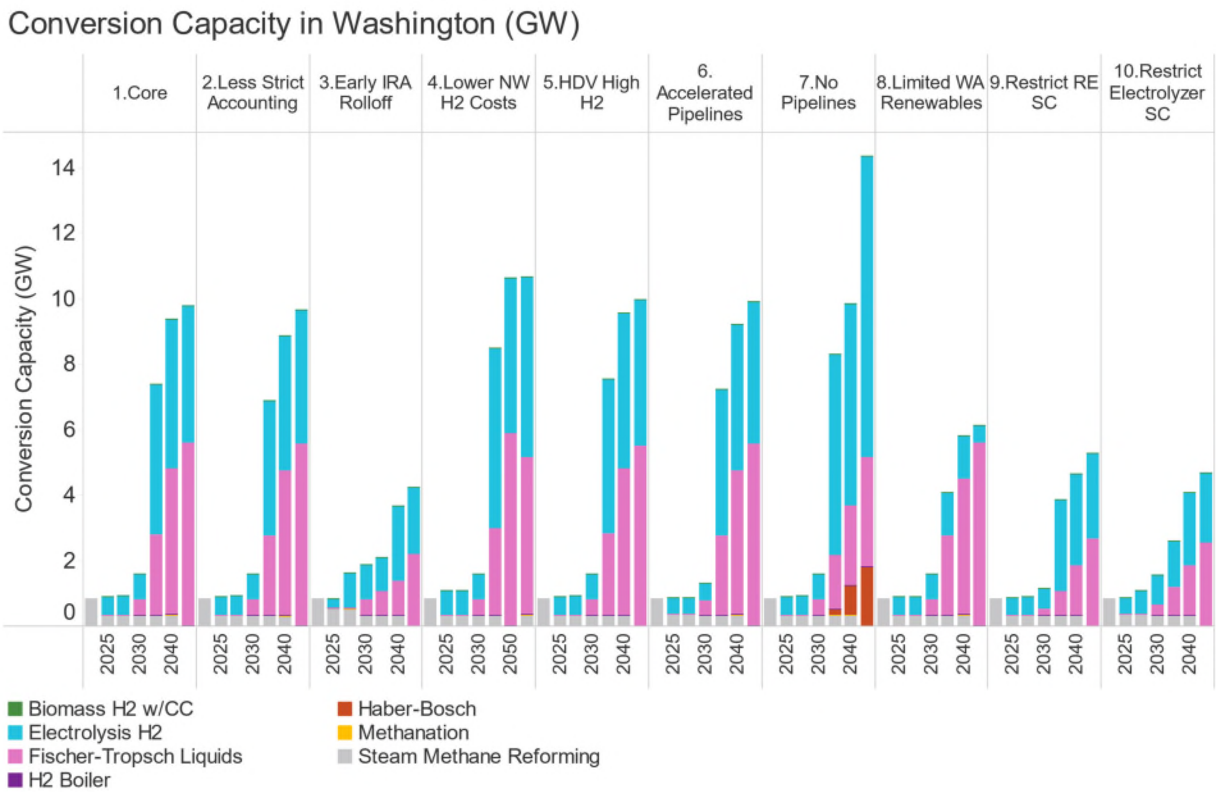


Figure 19. Hydrogen and hydrogen-derived fuels in Washington by end use

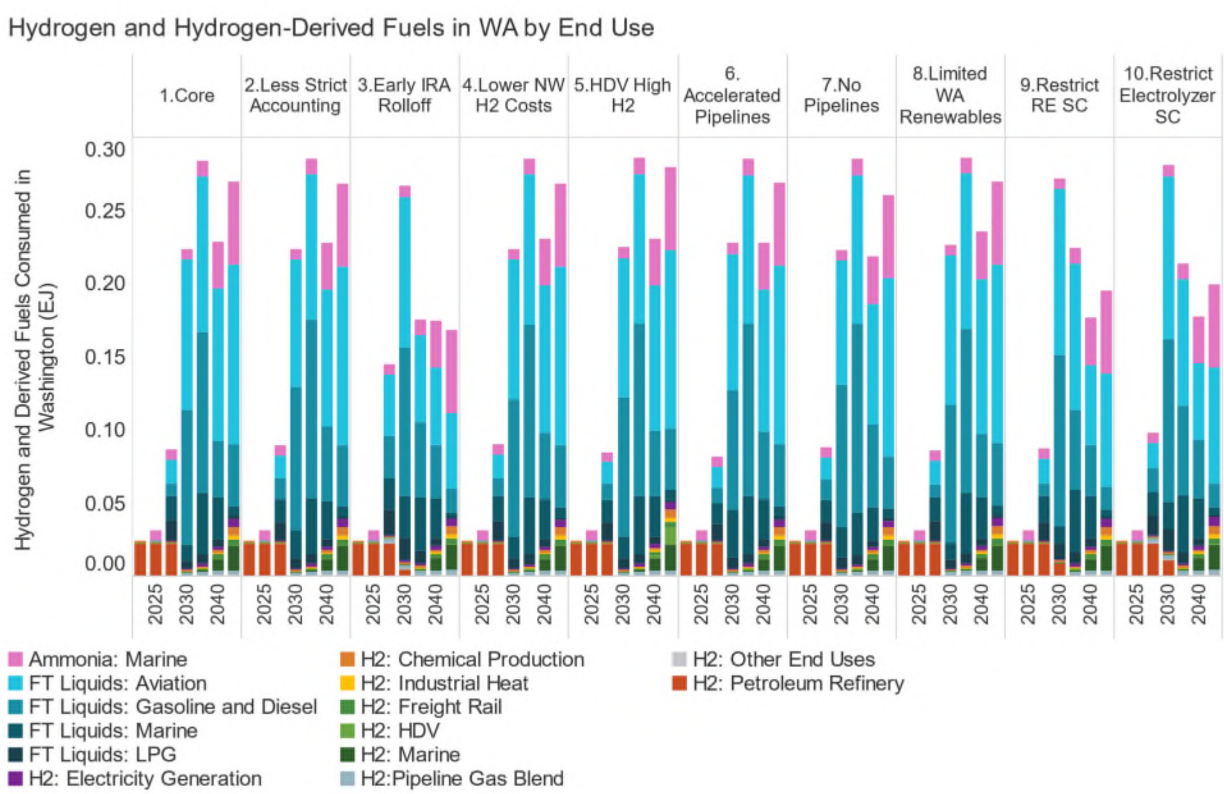


Figure 20. Hydrogen gas demand and supply in Washington

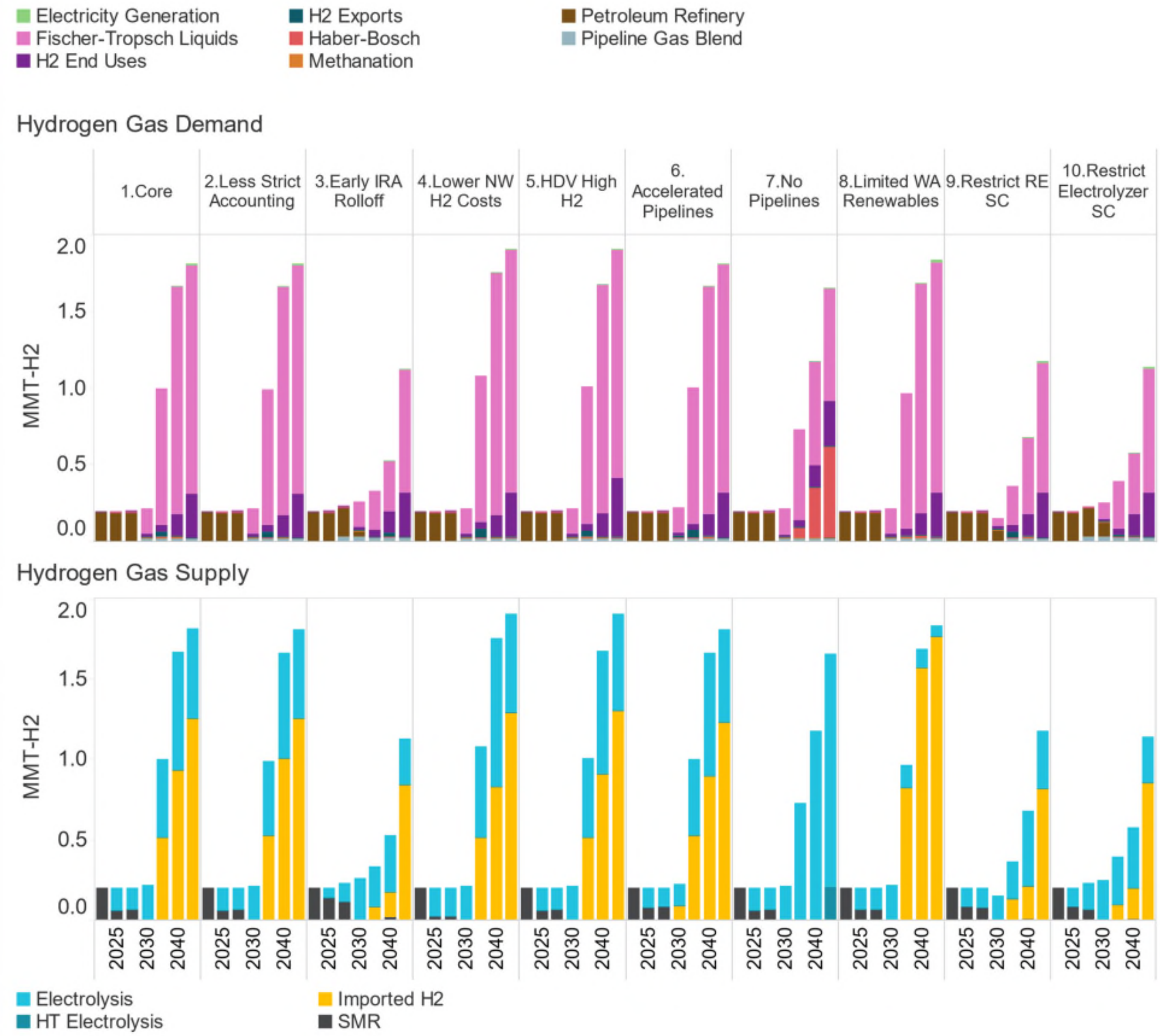
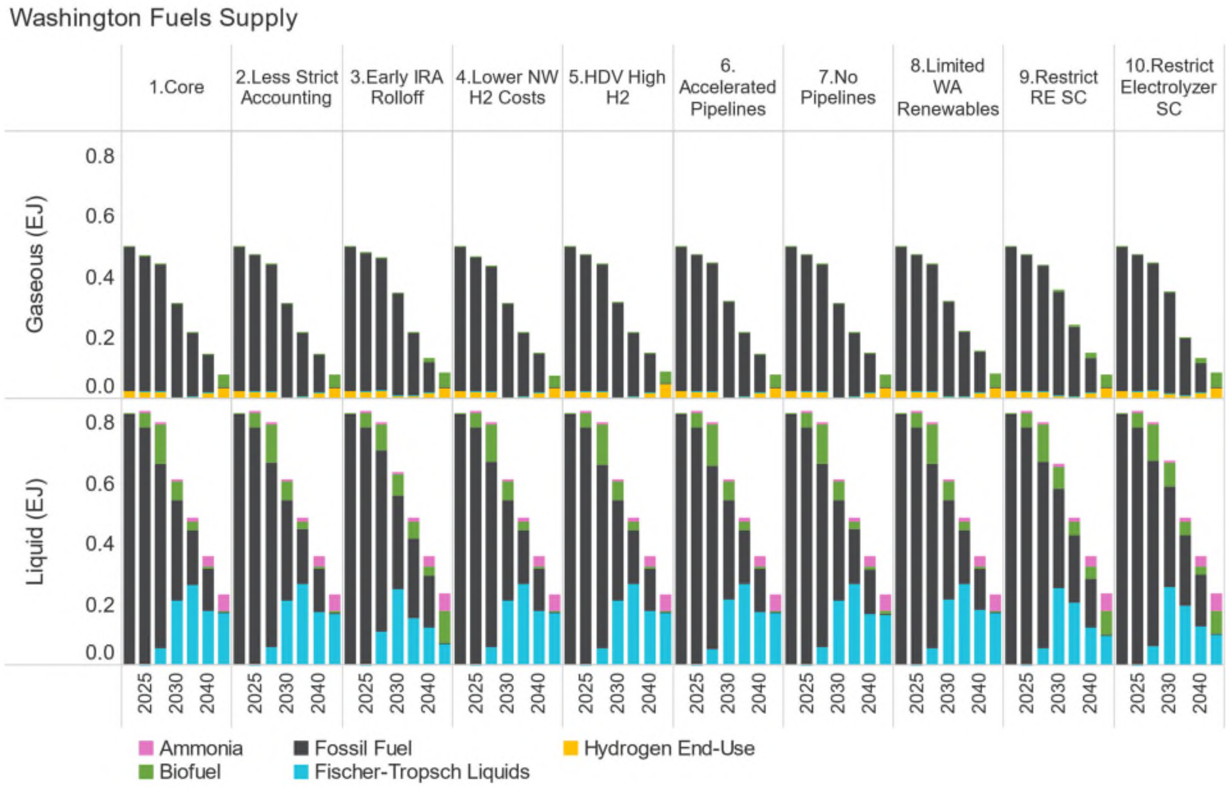


Figure 21. Washington fuel supply



Policy and economics

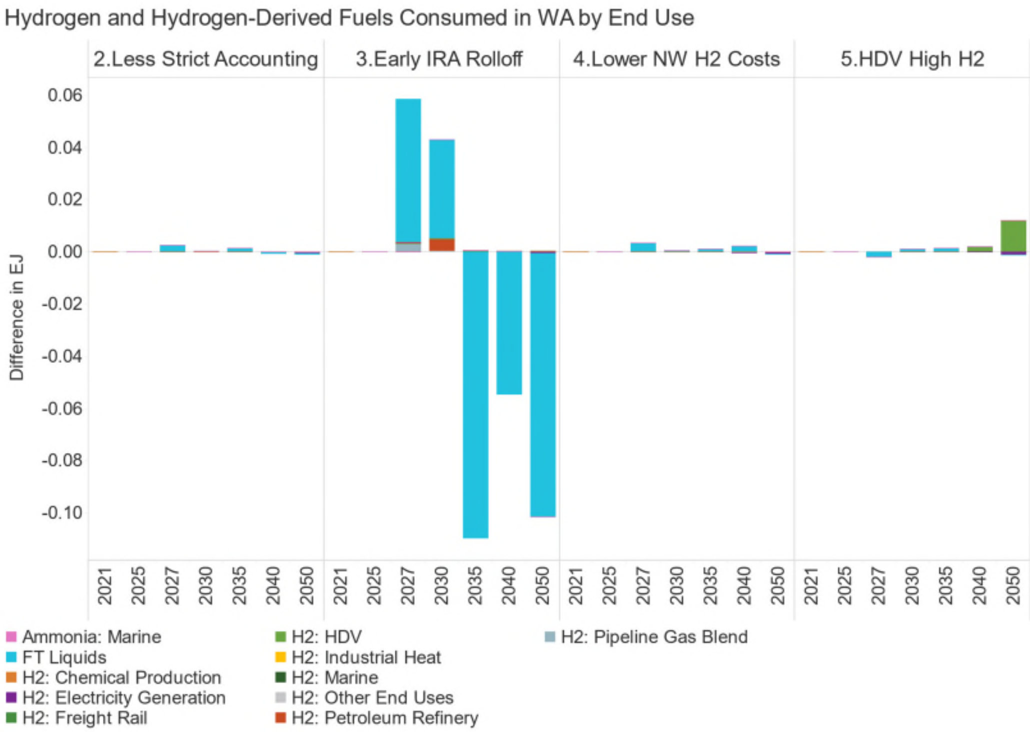
How does state or national policy impact hydrogen deployment in Washington? These results answer the following "what if" questions:

- **Scenario 2. Less Strict Accounting:** What if accounting for clean energy in hydrogen production is less strict than the Three Pillars requirement in the Core Case?
- **Scenario 3. Early IRA Rolloff:** What if the IRA credits expire early?
- **Scenario 4. Lower NW H2 Costs**: What if hydrogen production and conversion costs less in the Northwest?
- **Scenario 5. HDV High H2:** What if hydrogen becomes competitive as a fuel in long-haul, heavy-duty trucking?

Finding: Ending IRA credits early would significantly impact Washington's green hydrogen economy in the near- and medium-terms

If IRA credits were available only through 2026, consumption of hydrogen-derived products in Washington would initially increase in 2027 and 2030, then decline steeply in 2035. Figure 22 shows Fisher-Tropsch liquids (FT Liquids) consumption increasing early in **3. Early IRA Rolloff** versus the Core Case.

Figure 22. Difference to the Core Case of hydrogen and hydrogen-derived product consumption in Washington by end use



Electrolyzer investment increases in Washington, the Northwest, and across the country prior to the IRA tax credits expiring in 2026 so that projects can claim the production tax credit.

Figure 18 above shows this increase in 2027 versus the other scenarios. The analysis assumes that investors receive advance warning that the tax credit will expire early in this scenario. Increased early capacity drives additional clean fuels consumption in Washington through 2030.

In 2035, consumption declines significantly. Instead of continued growth of hydrogen and derived fuels production, the lack of tax credit for new projects makes additional investments not cost-effective in 2035. Even without the IRA tax credit, hydrogen is a valuable resource as Washington approaches net-zero emissions, and hydrogen-derived liquid fuels are the largest share of the clean liquid fuels used to decarbonize the economy.

Figure 22, Washington's liquid and gaseous fuels composition, shows the uptick in hydrogen-derived drop-in fuels in 2027 and 2030, followed by the decline in 2035. Emissions reductions are more economically met by other means without the IRA credit, including earlier adoption of non- CO_2 emissions reduction measures, an increase in land sink, greater electrification of boilers, and in 2040, partial decarbonization of natural gas with biogas. By 2050, the model finds biofuels in liquids taking a larger role in this scenario.

Finding: Higher heavy-duty trucking demand would drive up long term demand

In contrast to **3. Early IRA Rolloff**, the other scenarios have little impact on hydrogen and derived fuels consumption. The exception is Heavy-Duty Vehicles High Hydrogen (**5. HDV High H2**), where sales of hydrogen fuel cells in long-haul trucking between 2035 and 2050 have impacted stocks, driving greater hydrogen demand by 2050.

Figure 23. Difference to the Core Case of hydrogen gas supply and demand in Washington

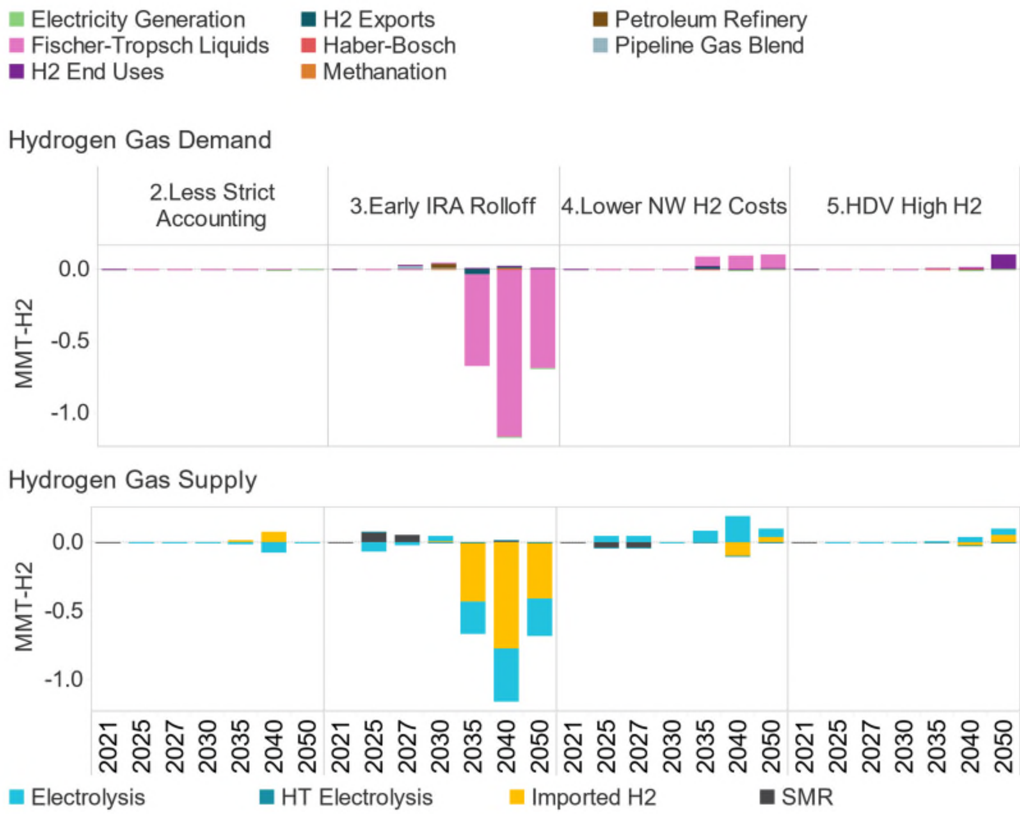


Figure 23 shows the impact on hydrogen gas supply in Washington — how much electrolysis takes place in Washington and how much hydrogen is imported — and hydrogen gas demand — what hydrogen gas is used for in Washington. Hydrogen production and imports in **3. Early IRA Rolloff** drops off in 2035 and is matched by a decrease in the production of Fischer-Tropsch liquid fuels.

Finding: Less strict IRA accounting does not impact demand, though leads to some shifts in electrolyzer locations

In contrast to the impact that an early IRA tax credit expiry would have on hydrogen and derived fuels consumption, less strict accounting for the hydrogen tax credit (**2. Less Strict Accounting**) has little impact. The representation in the model allows electrolyzers to hourly match with a contracted portfolio of resources within the same state as the electrolyzer. Any renewable energy not used in an hour by the electrolyzer can be sold back to the grid. This is a permissive version of the Three Pillars that allows larger portfolios of resources than hydrogen demand to be contracted with the excess sold back to the grid. There is little difference between the Core Case with this permissive version of the Three Pillars and the Less Strict Accounting findings on hydrogen production and consumption in Washington.

A stricter interpretation of Three Pillars in the Core Case would contrast more strongly with the **2. Less Strict Accounting** scenario. H2 producers are companies. They use electrolyzers to produce H2 and the electrolyzers need electricity to work. When contracted renewable produce more energy than electrolyzers can use, the H2 producers can sell electricity back to the grid thereby getting value for that renewable energy.

The consequence of this would be to lower electrolyzer capacity factors and/or increase curtailment of renewables contracted by the electrolyzer, increasing hydrogen costs.

A stricter interpretation may drive more hydrogen development in Washington and less in states without emissions policy compared to the Core Case. Loose accounting of carbon content in the energy going to electrolyzers may permit increased emissions in states without emissions policy.[65] Stricter accounting drives up the cost of hydrogen production in those states, but because Washington must reach emissions targets anyway, it will have less impact on hydrogen consumption and the cost of hydrogen production in state. In effect, the emissions policy enforces additionality of renewables.

Scenario **2. Less Strict Accounting** compared to the version of Three Pillars in the Core Case has little impact on electrolyzer deployment in Washington from an economic perspective. Stricter versions of Three Pillars could foreseeably increase the economic opportunity for hydrogen production in Washington over other regions and states, but that would also make hydrogen imports more expensive. However, in the very near term, Three Pillars or other forms of strict accounting could reduce hydrogen deployment as stakeholders navigate the requirements to receive the full $3/kg tax credit and develop mechanisms for compliance.

Finding: Winning a H2Hub leads to more green hydrogen and renewable fuel production, requiring additional renewable electricity and water use in Washington

Lower costs for hydrogen infrastructure in the state (**4. Lower NW H2 Costs**) increases Fischer-Tropsch liquids production in state, and brings more electrolysis in state, reducing imports in 2040 and 2050. Increased hydrogen demand in trucking in **5. HDV High H2** is met with a combination of increased electrolysis in state and increased imported hydrogen.

Lower Northwest hydrogen infrastructure costs (**4. Lower NW H2 Costs**) would drive more consumption of hydrogen-derived fuels and bring more hydrogen production into Washington. Demand for hydrogen from potential growth in fuel cell adoption in long-haul trucking would be met by a mix of additional in-state electrolysis and imports from out of state.

[65] Ben Haley and Jeremy Hargreaves, Evolved Energy Research, "45V Hydrogen Production Tax Credits: Three-Pillars Accounting Impact Analysis," (2023).

Figure 24. Difference to the Core Case of Washington electricity demand from electrolysis (TWh/GWa)

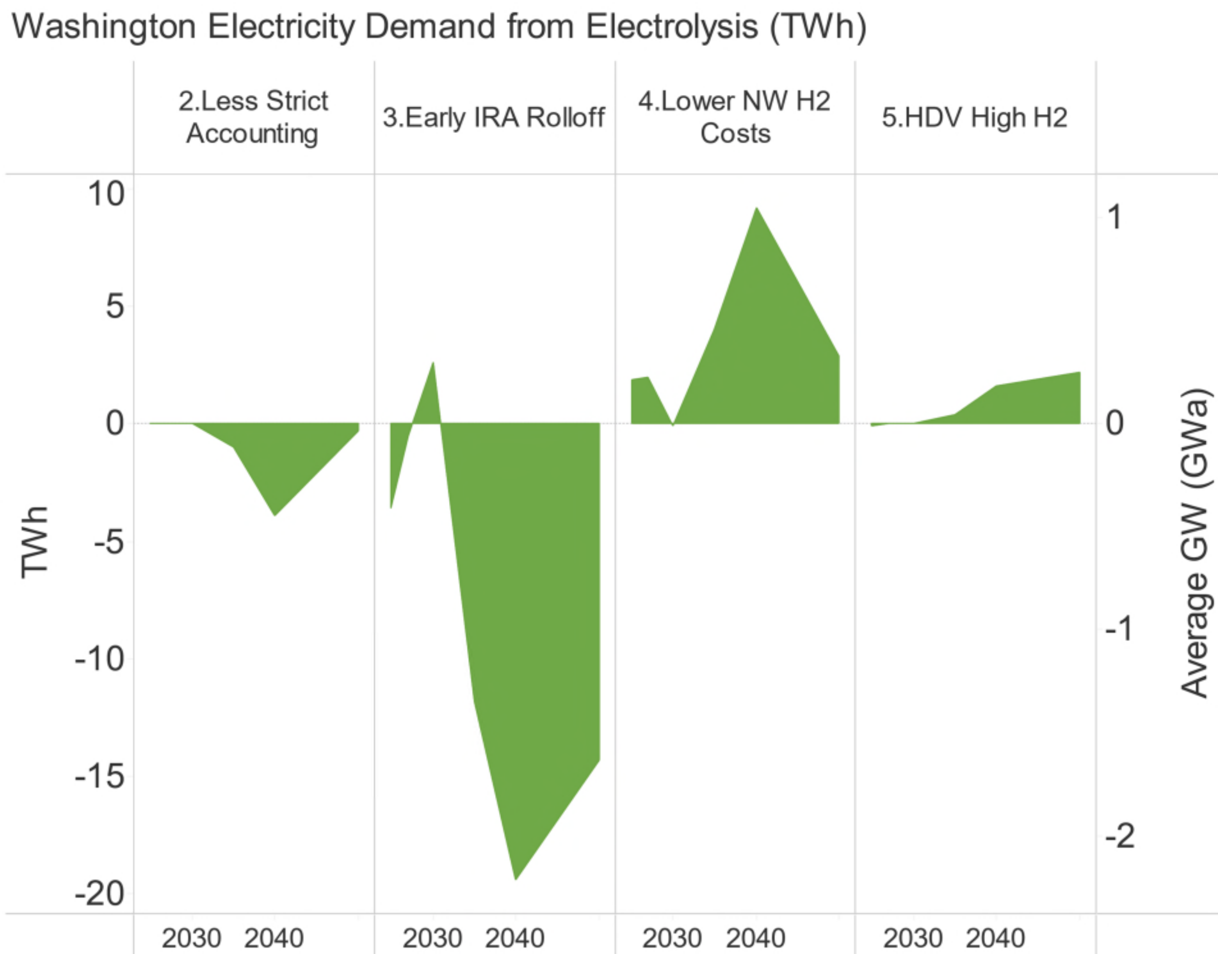
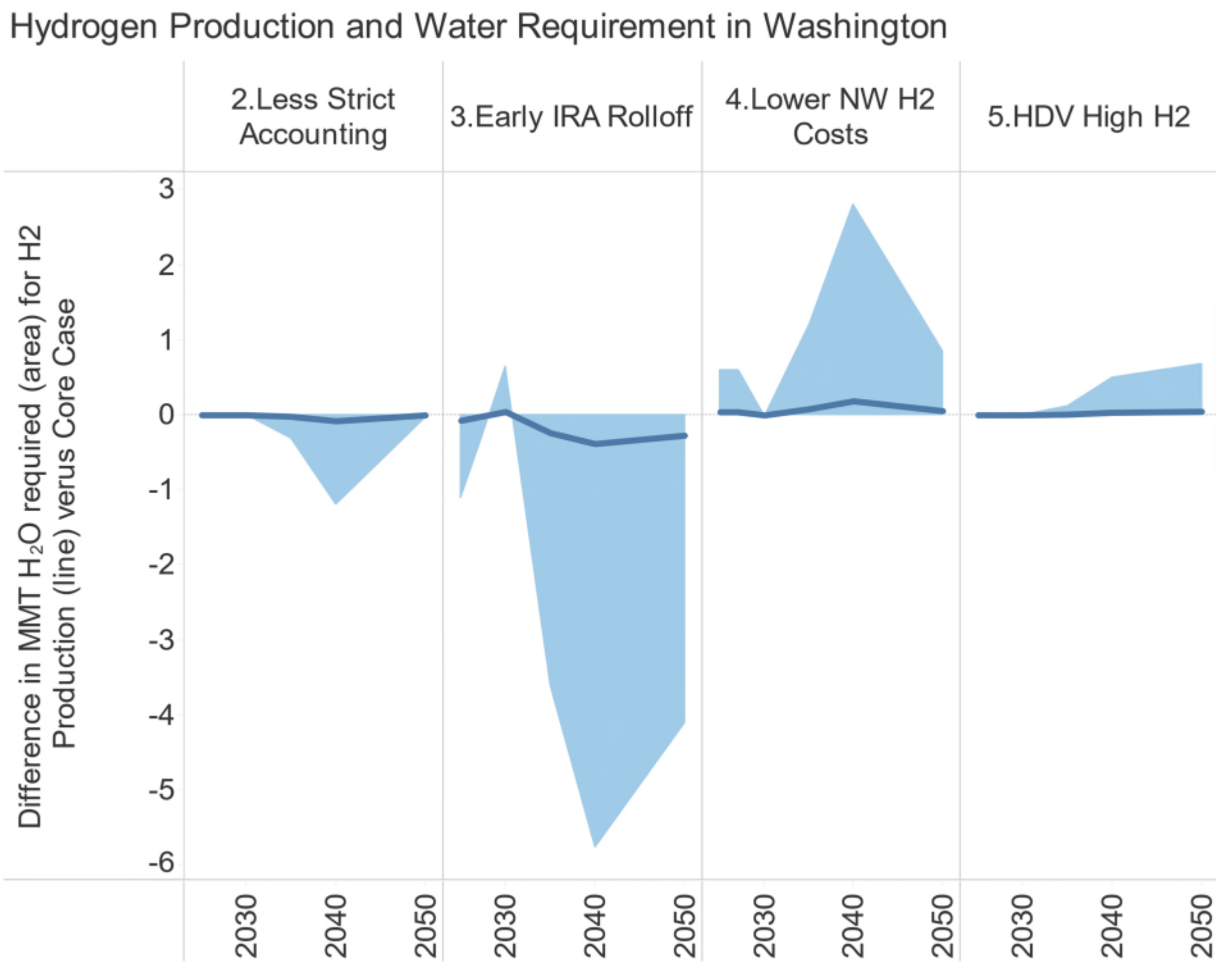


Figure 25. Difference to the Core Case of Washington hydrogen production and water demand



The impacts of these Policy and Economics scenarios on electricity and water demand are shown in Figure 24 and Figure 25:

- **2. Less Strict Accounting** has the impact described above, making other states more competitive with Washington and dropping hydrogen production in the state, but it is only a minor impact.
- **3. Early IRA Rolloff** sees the peak of 4 average gigawatts of electricity for electrolysis declines by more than 2 average gigawatts.
- **4. Lower NW H2 Costs** drives a peak increase of in-state electrolysis demand of 1 average gigawatt.
- **5. HDV High H2** drives increased hydrogen supply with growth of vehicle fuel cell demands.

The largest impact on peak water usage of 11 million metric tons in the Core Case is in **3. Early IRA Rolloff** where water usage declines by 6 million metric tons.

As noted in the Core Case water results, this water demand is minor compared to today's thermal electricity demand in the state, estimated at 393 million metric tons of water.

If the IRA were to expire early, it is economic to support investment in electrolyzers to take advantage of the credit while available. The trajectory toward emissions reduction goals in Washington and much of the West ensures that markets for hydrogen will exist in the future. Washington can only reach emissions goals with clean fuel use in 2030 and beyond, given the lack of emissions reduction opportunities in electricity.[66]

Therefore, early investment in electrolyzers prior to expiry of the IRA (2026 in this scenario) would be cost-effective even at the higher capital cost of early electrolyzer technology. If the IRA is present through 2032 as expected, less investment early and more investment later takes advantage of expected price declines in electrolyzers and aligns completion of large scale electrolyzer capacity with the need for clean fuels in 2030 and beyond.

Northwest resource availability

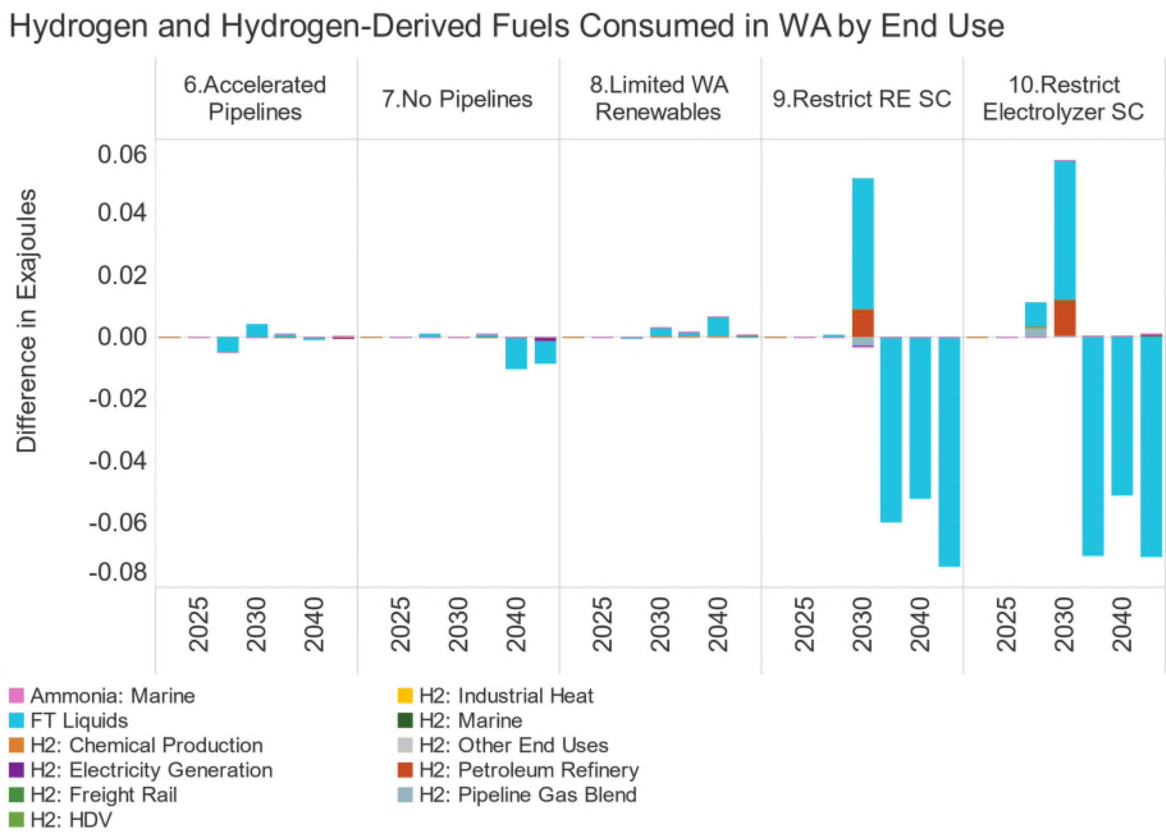
How does varying the rate or feasibility of adding new renewable generation, transmission lines, or pipelines impact hydrogen deployment in Washington? This section includes the following “what if” questions:

- **Scenario 6. Accelerated Pipelines:** What if pipeline builds are accelerated?
- **Scenario 7. No Pipelines:** What if no new pipelines can be constructed?
- **Scenario 8. Limited WA Renewables.** What if the rate of renewable resource expansion is limited in Washington?
- **Scenario 9. Restrict RE SC:** What if national or global supply chains for renewable energy limit the rate of renewable energy deployment?
- **Scenario 10. Restrict Electrolyzer SC:** What if national or global supply chains for electrolyzers limit the rate of renewable energy deployment?

The focus for sharing clean energy between regions in a decarbonizing world has often been on transmission lines, which are difficult to plan and take many years to develop but can be highly beneficial as intermittent and geographically variable renewable energy resources grow. Pipelines are another form of energy transport, one that may also be important in meeting emissions goals economically with the IRA tax credit for hydrogen. The Core Case restricts pipeline additions to 2035 and after. When pipeline additions become available, Washington becomes a net importer of hydrogen that is largely produced in Montana.

[66] Washington State Department of Commerce, “Washington 2021 State Energy Strategy,” (December 2020).

Figure 26. Difference to the Core Case of hydrogen and hydrogen-derived fuels consumed in WA by end use



Just as with transmission lines, whether and when pipelines can be built is uncertain, impacting where hydrogen infrastructure investments take place. If pipelines can be built in 2030 and onwards, as in **6. Accelerated Pipelines**, the cost of drop-in fuels declines in 2030, driving higher amounts of FT liquids consumption (shown in Figure 26). After 2030, accelerating pipelines has little effect because pipeline construction catches up in 2035 in the Core Case.

Figure 27. Difference to the Core Case of hydrogen gas usage in Washington

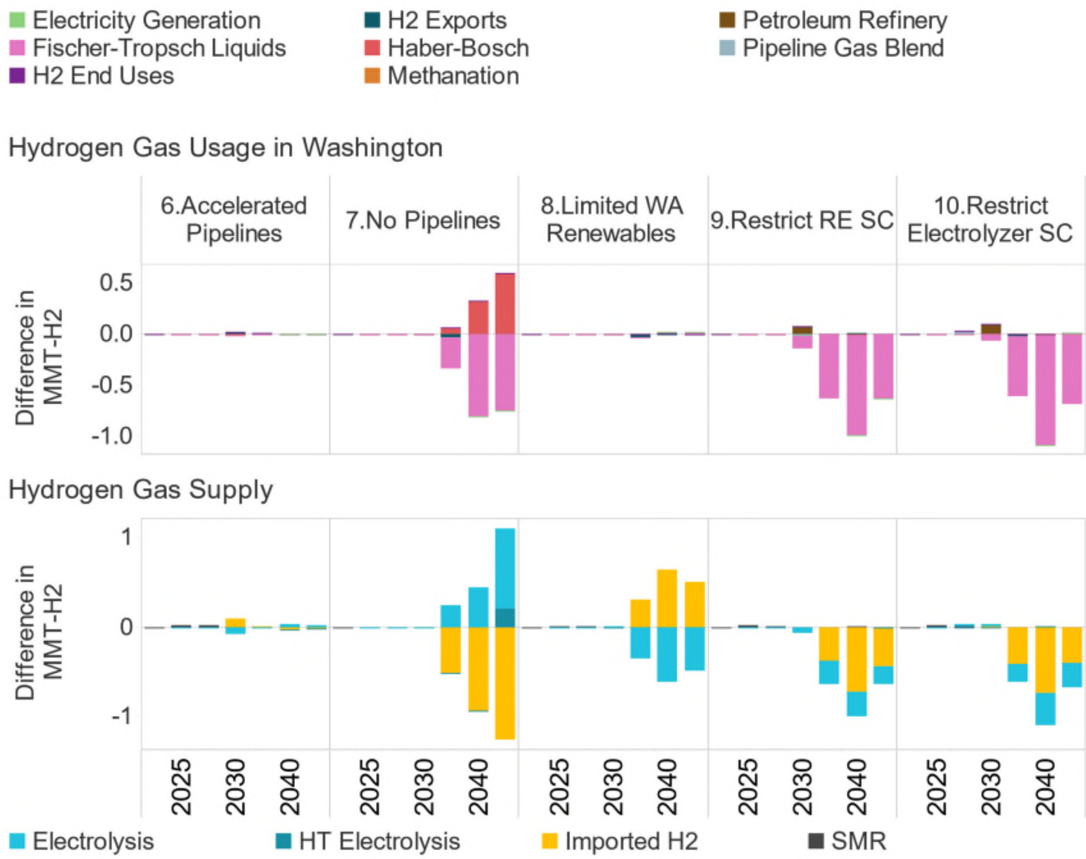


Figure 27 also shows minimal impact of accelerating pipelines on hydrogen gas supply and gas usage in Washington.

Finding: Lack of access to pipelines will shift electrolysis to Washington, increasing need to site new renewable electricity projects in the state

Not permitting pipeline construction in **7. No Pipelines** has much greater impact than accelerating pipelines. All imported hydrogen, most of the hydrogen supply in Washington in later years, is cut off from the state and is replaced by in-state electrolysis. In-state demand and production of Fisher-Tropsch liquids declines, but ammonia production, formerly imported entirely, is produced in state for marine usage.

Without permitting pipelines, hydrogen production in state is three times the production in the Core Case by 2050 (as Figure 20 shows), which impacts both electricity and water demand. Electricity demand for electrolysis increases by 6 average gigawatts over the Core Case (Figure 28), and water demand by an additional 13 million metric tons (Figure 29). Growth in electricity demand leads to a much larger electricity sector in the state. Imported electricity increases by 90% over the Core Case, and solar energy increases by 80%, as seen in Figure 17.

Figure 28. Difference to the Core Case of electricity demand for electrolysis in Washington

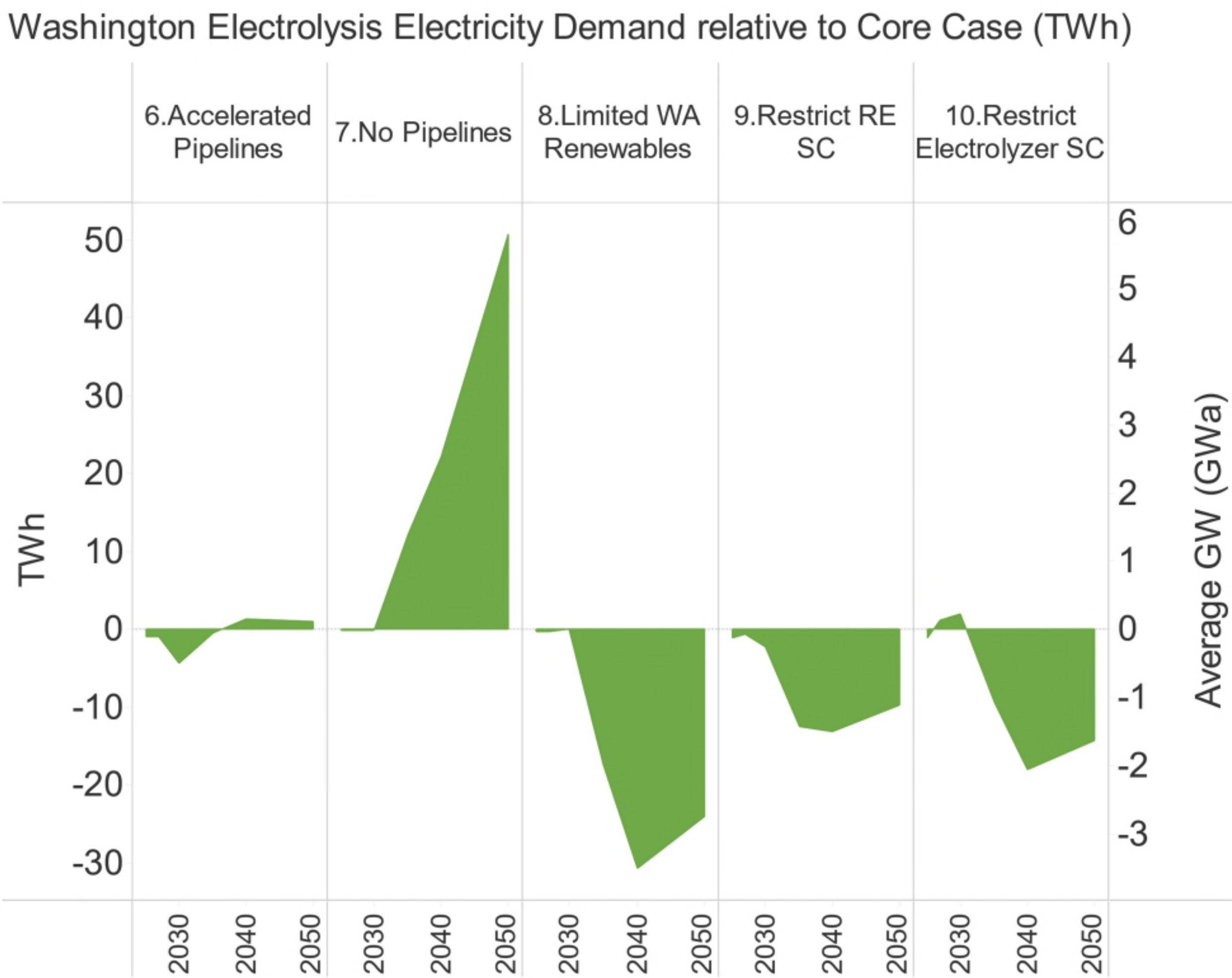
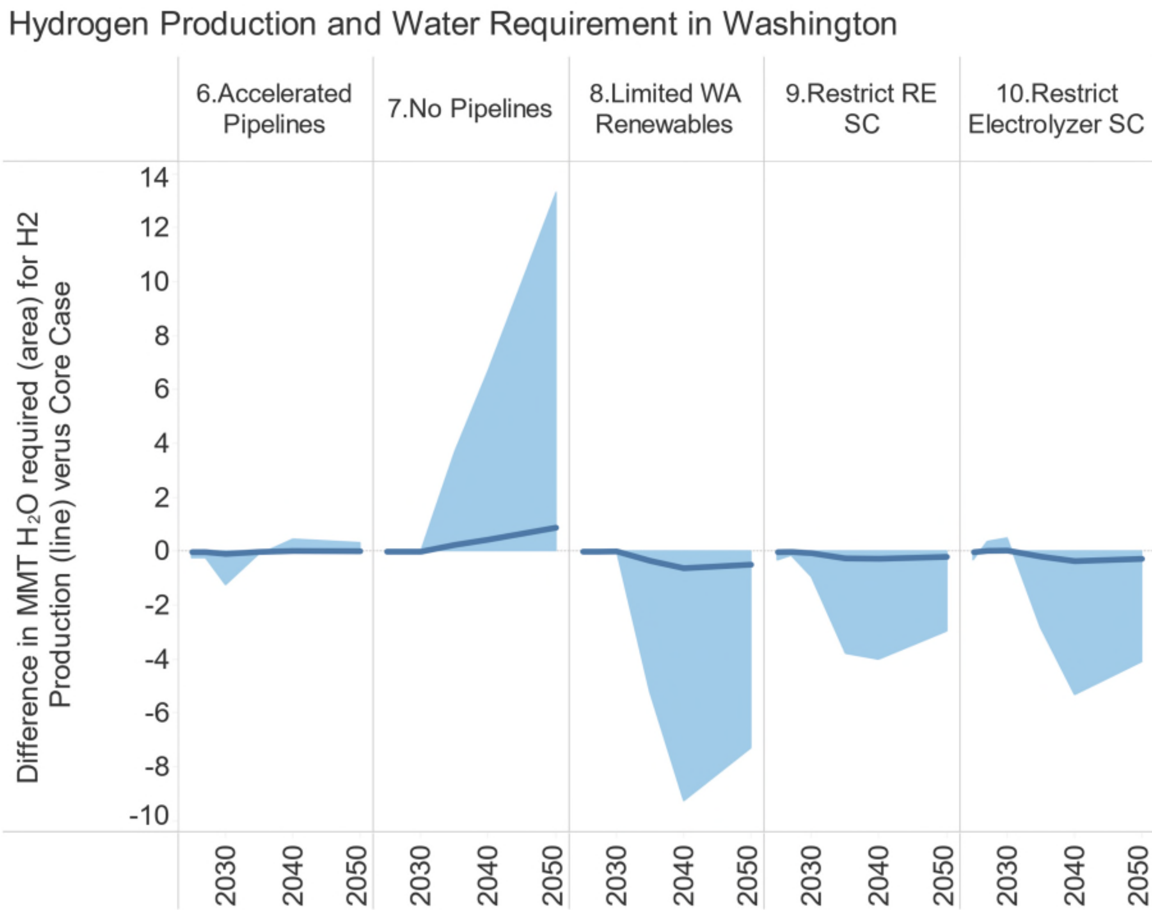


Figure 29. Difference to the Core Case of hydrogen production and water requirement in Washington



Scenario **7. No Pipelines** therefore puts extra stress on siting and permitting in-state renewable energy and building new transmission. Pipelines can take some of the burden off transmission lines in importing clean energy into the state, which gives Washington more options to reach net-zero. If siting and permitting renewables or transmission in-state is challenging, pipelines can be another form of clean energy import.

Finding: Limited renewable electricity capacity in Washington leads to importing hydrogen from other states

The Limited Renewables scenario (**8. Limited WA Renewables**) investigates the challenge of siting and permitting, examining a very limited scenario where building new renewables in the state are not possible. This has little impact on hydrogen and derived products consumed in state; however, almost all hydrogen must be produced out of state and imported in this scenario.

Washington retains the same amount of Fischer-Tropsch liquids production, using imported hydrogen to produce clean fuels, which takes advantage of the carbon captured from biomass power and uses it to produce drop-in fuels (shown in

Figure 18). At the same time, biomass power provides Washington with electricity, reducing the burden on imported electricity. However, imported electricity is still close to 50% by 2050, relying on transmission expansion to other states to meet clean electricity needs. While this is a bookend case, it shows the tight linkage between siting and permitting renewable energy in state and building electrolysis.

Finding: Limited renewable energy and electrolyzer supply chains decrease consumption of green hydrogen and hydrogen-derived fuels in Washington

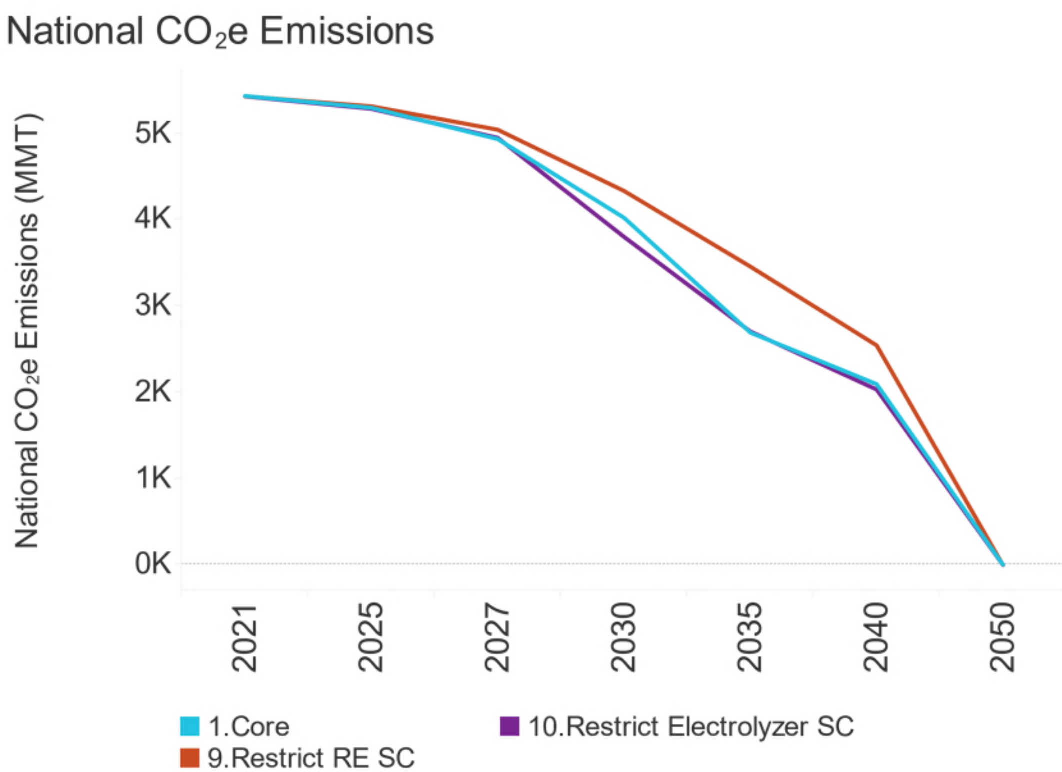
The final scenarios 9 and 10 restrict the national renewable energy supply chain, meaning that production of new renewables cannot keep up with the demand for new renewables across the country, and the national electrolyzer supply chain, meaning electrolyzer production, cannot keep up with demand.

When restricting the renewable energy supply chain (**9. Restrict RE SC**), scarce renewable resources are directed to the highest value locations across the country while still ensuring emissions targets are met. Renewables must be used for electric loads to meet clean electricity requirements and to decarbonize the electricity supply. Therefore, hydrogen production decreases relative to the Core Case. This is particularly pronounced in Washington in 2035, when hydrogen-derived fuels consumption drops significantly. Figure 21 shows Washington's greater reliance on biofuels from 2030 to 2050 in this scenario. Washington both imports less hydrogen and produces less hydrogen when the renewable supply chain is restricted.

Restricting the electrolyzer supply chain has very similar impacts on Washington hydrogen consumption and production (**10. Restrict Electrolyzer SC**). Fewer electrolyzers across the United States mean their usage is directed to the highest value locations. Washington is one of those locations, driven by its 2030 emissions target and the resulting need for clean fuels. The early clean fuels market in Washington draws limited electrolyzer capacity to production of clean fuels for Washington, though this increase happens out of state and not in Washington, taking advantage of the highest quality renewables. As electrolyzer production cannot keep pace with demand after 2030, hydrogen-derived fuel use in Washington drops, and biofuels play a larger role in the 2040s.

While the infrastructure outcomes for Washington are similar in these two restricted supply chain cases, the emissions outcomes for the country will differ. Restricted electrolyzers with no restrictions on renewables means that renewables will still be economically deployed to serve electric loads where it makes economic sense in regions without emissions policy. However, in **9. Restrict RE SC**, electrolyzers draw otherwise economic builds of renewable energy away from electric loads and fossil fuels fill in the gap in states without emissions policy.

Figure 30. National CO2 emissions comparison between Core Case and supply chain scenarios



The economic benefits of receiving the PTC are higher than those of replacing fossil with renewable electricity in serving loads in many cases. This effect could increase emissions if renewable supply chains are limited. Figure 30 shows the comparison between emissions in the Core Case, **9. Restrict RE SC**, and **10. Restrict Electrolyzer SC**.

Chapter 2. Phases for advancing hydrogen

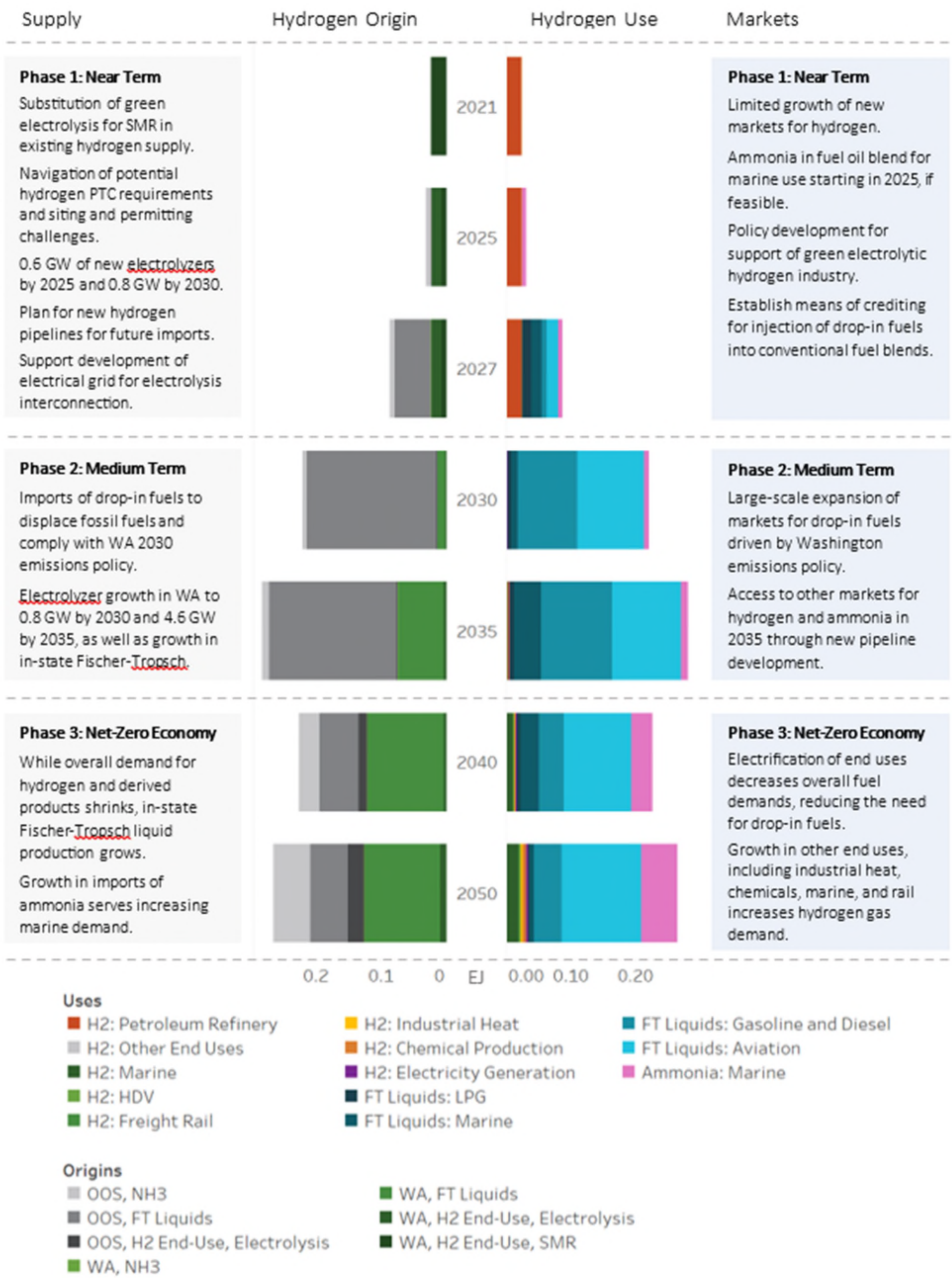
Chapter 2 lays out three phases of investments and actions, along with their associated risks, split up by time period, to establish a hydrogen economy in Washington. Figure 1 below graphically demonstrates the phases of development: one near-term phase, between now and 2030; a medium-term phase from 2030 to 2040, during which Washington's stringent emissions policy drives early demand for clean fuels; and a long-term phase from 2040 to 2050, when achieving a net-zero economy and decarbonizing the remaining fuel use are the primary drivers of hydrogen consumption.

Results shown in Figure 1 derive from the Core Case modeled for this analysis (See Chapter 1. Green electrolytic hydrogen requirement). Results from the additional nine scenarios help characterize the potential risks of each phase for advancing hydrogen.

The right side of Figure 1 shows various end uses for hydrogen, whether deployed directly or converted to another form of fuel, such as Fischer-Tropsch (FT) liquids or ammonia. The left side of the graphic indicates where those hydrogen products come from, whether they are produced in state (WA) or imported from out of state (OOS).

Note that the graphic shows hydrogen products only in the final form they are consumed in the economy. Hydrogen consumed in conversion processes such as Fischer-Tropsch or Haber-Bosch (i.e., to produce the final product for consumption) is not shown, but the graphic does include the resulting FT liquids or ammonia. Figure 1 in Chapter 1 provides more information on in-state and imported hydrogen production for end uses and production of other fuels.

Figure 1. Phases for advancing hydrogen



Please see List of Abbreviations at the end of this chapter for full names of the abbreviations used in Figure 1.

Phase 1: Near term (2023 to 2030)

In the near term, meeting Washington's 2030 emissions targets drives the need for investment in hydrogen and supporting infrastructure in the 2020s to decarbonize fuels by 2030. The modeling results show large-scale deployment of hydrogen-derived drop-in fuels by 2030, which requires infrastructure constructed in the 2020s to meet that need. This poses both risks and opportunities for Washington.

Early displacement of hydrogen from existing steam methane reforming.

In 2025, deployment of green electrolytic hydrogen — supplied by 0.6 GW of new in-state electrolyzer capacity — largely displaces steam methane reforming used in refining and chemicals production.

New markets for hydrogen developed in the second half of this decade.

New markets for hydrogen develop only later this decade, starting with ammonia production for blending in marine heavy fuel oil, and production of clean drop-in hydrocarbons using the Fischer-Tropsch process to displace gasoline, diesel, and aviation fuel. If the U.S. Department of Energy funds the Pacific Northwest Hydrogen Hub (PNWH2 Hub) at anticipated levels of up to $1 billion, there would likely be additional clean fuels consumption and investment in electrolyzer capacity in Washington. Since the final negotiated details and scope of a regional hydrogen hub and the benefits it could bring is not known at time of writing, this analysis investigated a generic 20% reduction in hydrogen infrastructure through 2032.

Preparation for large-scale hydrogen-derived drop-in fuel deployment by 2030.

Meeting Washington's 2030 emissions goals is contingent on displacing fossil fuels with clean drop-in fuels. Much of the clean fuel production occurs out of state where Fischer-Tropsch and Haber-Bosch processes can use hydrogen produced with the lowest-cost renewable resources. This analysis assumes relatively low-cost transportation of these clean fuels, either blending with fossil fuels or utilizing existing fossil fuel transportation networks. However, the state will need accounting mechanisms for out-of-state drop-in fuels production to ensure compliance with emissions standards. These mechanisms must be established in the near term, prior to the need for these fuels in Washington's economy.

Risks:

Due to the high volumes of fuel needed by 2030, Washington must rely on out-of-state development of hydrogen production and fuels conversion, over which the state has less control. If hydrogen infrastructure does not develop as expected in the modeling (due to supply chain barriers, challenges qualifying for the production tax credit, etc.), there is a risk the state may not meet the 2030 emissions target.

Biofuel use is an alternative pathway to comply with the 2030 emissions target, but biofuels infrastructure development also faces its own challenges and requires investment lead time. Washington should monitor the barriers to hydrogen deployment and assess these risks early so that there is time to adapt the strategy for meeting the 2030 emissions target.

Lastly, delivery of out-of-state drop-in fuels via existing transportation infrastructure requires accounting mechanisms to take credit for fuels produced in other states that are injected into existing fuels distribution networks. This mechanism should be established early to mitigate the risk of accounting challenges.

Navigating potential hydrogen production tax credit requirements to qualify for Inflation Reduction Act incentives.

At the time of writing, guidance for how to qualify for the full $3/kg hydrogen production tax credit (PTC) has not been released. Accounting for carbon content in electricity used to produce hydrogen could take several forms, two of which have been investigated in this report (the Core Case assumes a permissive version of Three Pillars and another scenario assumes accounting that does not require the Three Pillars — see Chapter 1. Green electrolytic hydrogen requirement). All electrolyzers built in this analysis qualify for the full $3/kg tax credit under the two accounting mechanisms modeled. Therefore, the quantity and pattern of hydrogen infrastructure deployment shown in this analysis depends on that valuable incentive.

Risks:

A tax credit that is difficult to qualify for may dampen the adoption of electrolyzers. If the PTC qualification requirements are difficult for hydrogen developers, the state may consider options to support them in navigating the process.

Siting and permitting hydrogen infrastructure and renewable energy.

Both electrolyzers and renewable energy experience rapid growth in our modeling to meet the energy needs of a decarbonizing economy. Chapter 3. Siting and permitting describes the challenges and options for reforms related to siting and permitting these resources in detail.

Risks:

Siting and permitting could become a bottleneck to renewable and hydrogen infrastructure deployment. Early preparation to handle the expected rate of development, while still maintaining a full review process for projects, will help mitigate the risk of falling short on infrastructure deployment.

Developing new hydrogen and ammonia pipelines.

The modeling underpinning this analysis did not permit new hydrogen or ammonia pipelines to be built until 2035. This is because building new interstate pipelines may be much like interstate transmission – difficult to plan and permit, with a long time between conception and use. Planning for new pipelines should start in the 2020s to ensure that construction and operation can happen in the 2030s.

Risks:

In addition to the Core Case, which assumes pipelines are available in 2035, the technical analysis modeled two scenarios modifying that assumption: One accelerated pipeline deployment to 2030 and the other did not permit pipeline development at any time. Accelerated pipeline deployment shows an increase in consumption of clean fuels in Washington met with increased imports of hydrogen, but not permitting pipeline build until 2035 in the Core Case still allowed development of an in-state clean fuels production industry in Washington using imported hydrogen.

The scenario without any pipeline development drove in-state electrolyzer deployment three times the size of that in the Core Case and a much larger electricity sector, increasing in-state wind generation by 9%, solar by 88%, and electricity imports by 61%. Increasing the growth rate of in-state renewables, hydrogen infrastructure, and interstate transmission lines comes with pressure to site these resources and may increase the risk of not achieving net-zero goals. Increased in-state generation in this scenario is primarily driven by the lack of access, via pipeline, to out-of-state ammonia production for assumed maritime shipping ammonia demands.

Phase 2: Medium term (2030 to 2040)

The second phase is the medium-term period from 2030 to 2040 when hydrogen strategy in Washington is governed by the requirement to meet the state's 2030 emissions target. There is not enough time between now and 2030 to roll over stocks of all fuel-consuming end uses to electricity. Fuel consumption in 2030 therefore remains high, despite high sales of electric vehicles and other electrified technologies of electrified technologies; as described in the Washington 2021 State Energy Strategy,[67] the emissions target will require decarbonization of liquid fuels used in the economy.

The emissions policy therefore establishes Washington as the earliest large-scale market for clean fuels in the United States. The modeling for this report shows that hydrogen-derived fuels are an important way to achieve the emissions policy by replacing fossil fuels in aviation, on-road transportation, and maritime shipping.

Large-scale hydrogen derived drop-in fuel deployment throughout the decade.

Figure 1 shows the scale of clean fuels production and consumption in 2030 and 2035. These clean fuels are largely imported from other states, as is the case in Phase 1: Near Term.

Risks:

It is possible that clean fuel supply will not scale with increased demand. The analysis investigated a version of this risk by modeling a restricted renewable energy supply chain scenario (i.e., the supply of new renewable technologies cannot keep pace with the demand for renewable energy). In this scenario, renewables are preferentially used for loads instead of for hydrogen production, reducing overall supply and consumption of hydrogen-derived fuels. Although Washington still has a substantial clean fuels market to achieve the 2030 emissions target, its scale is reduced. The state economy achieves emissions reductions in other ways, such as increased boiler electrification in industry, use of biogas, and measures to increase land sink and reduce non- CO2 emissions.

Growth of in-state hydrogen and derived fuels production.

There is in-state hydrogen production from 0.8 GW of electrolyzers in 2030, increasing to 4.6 GW in 2035. There is also pipeline development in 2035, allowing imported hydrogen to go to drop-in fuels production in Washington.

Risks:

As mentioned in Phase 1: Near Term, pipeline development must occur early to be operational in 2035. If pipelines cannot be developed, Washington will rely more on internal hydrogen production powered by a larger electricity sector.

Continued benefit from the Inflation Reduction Act PTC.

The PTC is set to expire in 2032. Electrolyzers built prior to expiry receive the PTC for the first 10 years of operation. Therefore, plants built in the early 2030s will continue to receive the tax credit through 2040, leading to a larger hydrogen industry relative to no PTC or a PTC expiring earlier than 2032.

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[67] Washington Department of Commerce, "Washington 2021 State Energy Strategy," (December 2020), https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

The modeling investigated a scenario where the PTC expired in 2026 rather than 2032. The earlier expiry leads to significantly lower consumption of hydrogen production in 2035 onward. Washington still requires clean fuels to meet its emissions goals, but there are lower volumes produced due to the increased cost of hydrogen products, with other measures taken to achieve emissions reductions instead. This scenario shows that through the 2030s, the hydrogen industry at the scale found in the Core Case is not sustainable without the hydrogen PTC.

Risks:

If the PTC expires earlier than expected, it will result in a smaller hydrogen industry, but Washington's emissions target would still drive the need for clean fuels. This could be costly for Washington, as the state would lose the benefit of the PTC incentive that drives hydrogen-derived fuel costs down.

Rapid growth of renewables and transformation of Montana and other high quality renewable states to energy exporters.

Washington relies upon energy coming from out of state to meet clean fuel requirements and clean electricity demand. The significant growth of wind generation in Montana may face a variety of feasibility challenges. If this is the case, hydrogen production may increase in other states and in Washington to meet the demand, albeit at a greater cost.

Risks:

This raises two important risks for Washington. The first, also mentioned in Phase 1, is that Washington has limited policy control over actions taken in other states yet relies on them for energy. The economics of renewable generation favor development outside Washington, providing an economic opportunity in other states to capture incentives that make renewable energy the cheapest form of energy, as well as the hydrogen PTC that removes economic obstacles to electrolyzer deployment. Furthermore, there is a large near-term market that hydrogen producers can participate in for hydrogen-derived fuels developing in Washington and later in other states that are pushing toward emissions reductions.

However, policy support in other states is likely necessary, particularly for building new transmission and pipelines, and for siting large quantities of renewable energy to support energy exports. Washington should monitor the development of clean energy infrastructure in other states under IRA incentives and strategize alternative ways of meeting emissions targets if development moves too slowly. While the modeling finds it more economic to import hydrogen-derived products from out of state in 2030, developing additional electrolyzers and Fischer-Tropsch plants by 2030 in Washington could mitigate the risk of relying so heavily on imports from other regions. Moreover, this risk is somewhat symmetrical: If developers elect to build renewable generation in Washington despite the higher cost, they face the risk of being underpriced if projects in other states are developed as the economic analysis suggests.

The second, related risk is the challenge of building so much infrastructure in a short time. The significant volumes of clean fuel required by 2030 in Washington rely on electrolyzer and conversion plant deployment across the country. The overall pace of scaling the hydrogen market may move more slowly if impacted by electrolyzer or renewable energy supply chain constraints, or other barriers that slow deployment. The scenarios that investigate supply chain constraints (**9. Restrict RE SC** and **10. Restrict Electrolyzer SC**) demonstrate the alternatives for Washington if the supply of either renewables or electrolyzers is constrained.

Emissions in states without emissions policy may increase with investments in electrolysis.

States that have no emissions policy will likely build significant quantities of renewable energy – with the IRA incentives for renewables, they are often the cheapest source of new electricity. However, under the IRA, producing hydrogen and claiming the PTC is often a more economic use of renewables than delivering to electric loads. If the rate of renewable additions is limited such that electrolyzer loads take renewables from electric loads, more fossil generation will be used in electricity, driving up emissions.

Risks:

Washington may want to consider emissions impacts of hydrogen and derived products imported from out of state if rates of renewable additions in those states are constrained.

Growth of renewables in Washington.

Out-of-state hydrogen-derived products are essential to meeting Washington's 2030 emissions target. However, in-state renewable growth is also necessary to both foster an in-state hydrogen industry and to reduce the reliance on new transmission development and out-of-state resources.

Risks:

If renewable growth in Washington is limited, as investigated in scenario **8. Limited WA Renewables**, 50% of the electricity Washington needs by 2050 must come from out of state and 100% of the hydrogen Washington uses must be imported. With a Pacific Northwest H2Hub, this could mean that more hydrogen is produced in Montana than may be currently anticipated. This places heavy reliance on the difficult and uncertain process of developing transmission lines and pipelines. Washington should ensure that economic build-out of renewables in the state can proceed without delays while also meeting all siting and permitting requirements.

Tapering of conventional oil refining activities.

Two cost-effective strategies to meet Washington's emissions targets reduce fossil fuel consumption in the 2030s. The first is electrification, dropping overall fuel demand as internal combustion engines are replaced with electric motors. The second is displacing the remaining fossil fuels with clean drop-in fuels. Both lead to significant drops in fossil fuel consumption, including refined products.

Starting in 2030, the modeling shows Washington's refined products replaced with those sourced from elsewhere. However, the actual decline may be more gradual, depending on the economics of the oil refining industry. If oil refining in Washington tapers more slowly, in-state demand for hydrogen in the 2030s may be higher to continue providing hydrogen needed for the refining process.

Risks:

The rate at which oil refining tapers in the state will depend on factors not fully captured in the modeling. Any oil refining activity that remains in the 2030s in Washington will drive additional hydrogen demand in the state.

Phase 3: Net-zero economy (2040 to 2050)

The final phase is the long-term period from 2040 to 2050, when the hydrogen PTC will expire for the fleet of electrolyzers built in the early 2030s. However, net-zero emissions policy, assumed across the United States in this modeling, requires decarbonization of most of the remaining fossil fuels in the economy. Despite the lack of the hydrogen PTC, existing hydrogen infrastructure is valuable for producing drop-in fuels for these remaining hard-to-decarbonize sectors.

In this phase, the volume of clean fuel consumption drops in Washington. By 2040, stocks of fuel-consuming technologies have rolled over sufficiently to electrify much of the vehicle fleets, dropping the need for clean fuels. By 2050, liquid fuel in Washington is fully decarbonized, but the volumes are low due to the level of electrification.

At the same time, there is higher direct hydrogen gas consumption in the state than in the 2030s, driven by decades of growth of direct hydrogen consumption in end uses, including industrial heat (such as for iron and steel production), chemical production (such as fertilizers), some electricity generation, freight rail, and marine use. Ammonia consumption also grows as it decarbonizes marine fuels. If fuel cells in long-haul trucking become cost effective, this will also add to hydrogen demand. Hydrogen will remain an important component of a net-zero energy economy in 2050 and the years beyond.

The actions and risks described in the previous two phases will have impacts on hydrogen deployment in 2040 and beyond as well. However, there are no specific recommendations or identified risks for this phase given how far in the future it is, as well as the number of uncertainties between present day and the 2040s that could shape the hydrogen economy. Washington should continue to update plans through an ongoing planning process to account for the latest developments in technical and political factors that may impact hydrogen deployment in each of the phases.

List of Abbreviations

FT: Fischer-Tropsch

H2: Hydrogen

NH3: Ammonia

OOS: Out of state

PTC: Production tax credit

SMR: Steam methane reforming

WA: Washington

Chapter 3. Siting and permitting

Background

The Inflation Reduction Act (IRA) clean hydrogen incentives and Washington's carbon emission reduction policies encourage rapid development of clean hydrogen use and our policymakers and government agencies seek the best methods to facilitate developing green electrolytic hydrogen.

More broadly, addressing the climate crisis will require a massive investment in clean energy infrastructure — not only green hydrogen — which in turn will need streamlined permitting and siting processes for decarbonization projects while maintaining important environmental and community protections along the way.

Many of the permitting and siting considerations that apply to renewable electricity and transmission projects are relevant to projects throughout the hydrogen economy (which includes production, distribution and storage, and end use), although some considerations are specific to only one stage in the hydrogen value chain. This chapter reviews key results from the modeling discussed in Chapter 1 to help inform hydrogen permitting and siting process in Washington.

This chapter also provides detail on the types of hydrogen infrastructure projects that are likely to be developed in Washington, with discussion of siting and safety considerations for each. This chapter reviews existing Washington permitting processes relevant to hydrogen projects and summarizes proposed and implemented United States and European Union permitting reforms.

This chapter concludes with recommendations for Washington's permitting processes and broader energy policies that can support increased production of and access to green electrolytic hydrogen in the state. Findings are summarized at a high level in this report; more detail is available in Framework for Siting and Permitting, Appendix C.

Key model results

The technical analysis supporting this report generates insights into how Washington's hydrogen economy could evolve under different policy and technology availability assumptions. The full set of analytical results are available in Chapter 1. Green electrolytic hydrogen requirement; the results highlighted here focus on a subset of the modeled scenarios to illustrate the range of hydrogen production capacity, end uses, and supporting infrastructure that could develop in Washington under different conditions.

Figure 1. below shows how hydrogen is supplied and consumed in Washington under three different modeled scenarios (Core Case, **6. No Pipelines**, and **8. Limited WA Renewables**). Across scenarios, in-state hydrogen electrolysis and out-of-state hydrogen imports are the primary sources of hydrogen supply in the long-term. Steam methane reforming, which supplies all hydrogen in 2021, is largely replaced with electrolysis by 2025.

In the Core Case, in-state electrolyzers begin producing significant quantities of hydrogen in 2025, scaling up production to around 0.5 MMT of hydrogen by 2035 and maintaining that approximate production level through 2050. Comparing the Core Case to other modeled scenarios demonstrates that the balance of in-state production versus imports is heavily dependent on the ability to construct pipelines to other states and the ability to site renewable electricity generation in Washington.

Figure 1. Washington hydrogen supply and demand through 2050 under three modeled scenarios

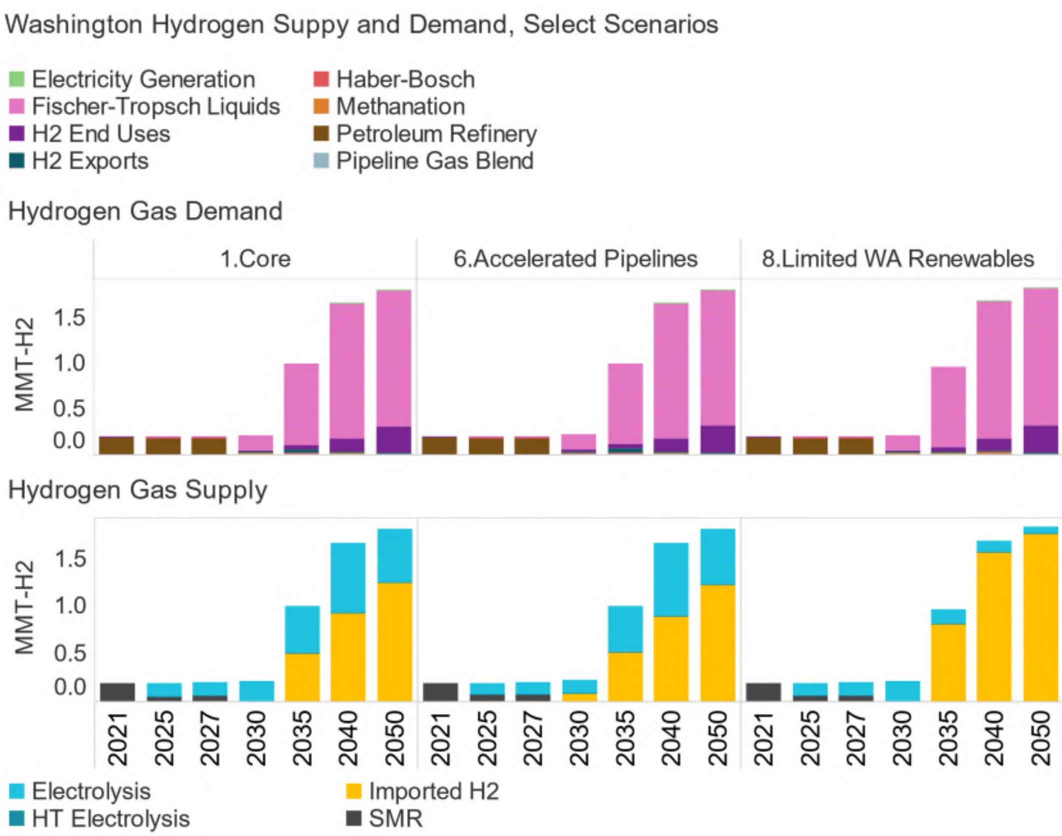


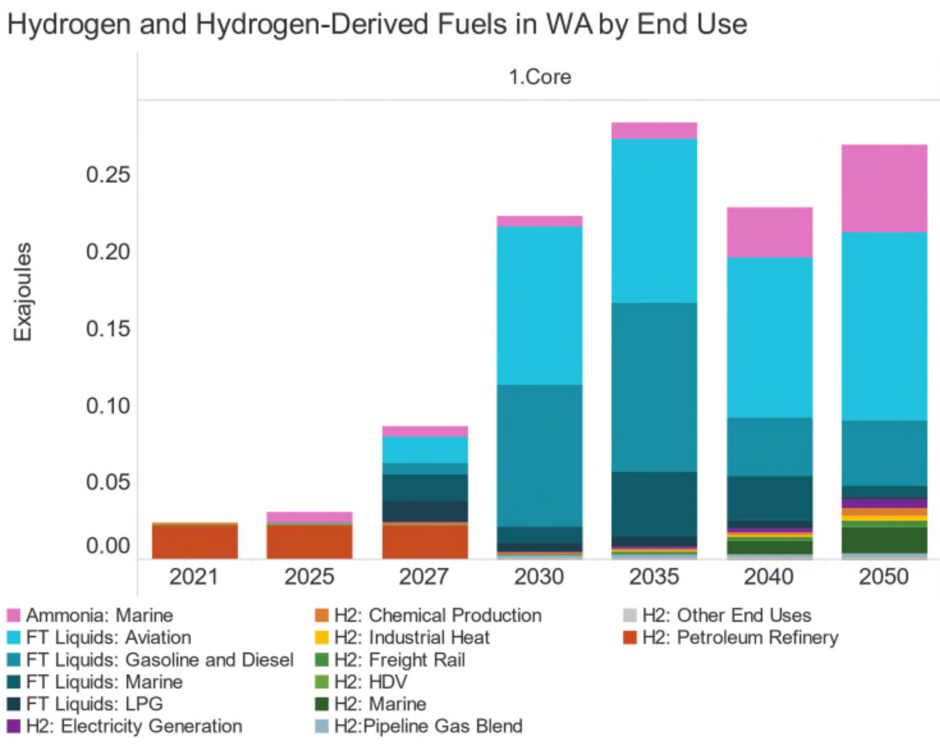
Figure 1. also shows the hydrogen end uses adopted in Washington under different scenario assumptions. In all scenarios, petroleum refining is the primary source of demand for hydrogen through 2027, suggesting that refining could be an important early market for green hydrogen producers.

Beginning in 2030, Fischer-Tropsch (FT) fuel production becomes a growing source of hydrogen demand. FT fuel production combines hydrogen with captured carbon to produce synthetic hydrocarbon fuels. FT fuels production is a new industry that these modeling results suggest will play a significant role in Washington under a variety of scenarios. Under select conditions (the absence of interstate ammonia pipelines in the No Pipelines scenario), Washington also sees development of in-state ammonia production capacity, an industry similar to FT fuel production in that it converts hydrogen into a synthetic fuel.

Compared to hydrogen demand for fuel production, the modeling shows that demand for direct hydrogen makes up a smaller but still significant share of total hydrogen demand in Washington. Figure 2 below provides a more detailed view of Washington demand for hydrogen and hydrogen-derived fuels in the Core Case. Industrial and transportation demand for direct hydrogen grows slowly through 2035 and then scales up in 2040 and 2050. Converting to hydrogen as an energy carrier in those sectors requires upfront investment and takes time to scale.

Some potential hydrogen end uses do not appear in these modeling results or appear only in small quantities. Hydrogen power generation is present in Washington, but represents a small amount of hydrogen demand, because gas blend and hydrogen power plants operate as electric reliability resources in the model and therefore operate in a small number of hours each year. Hydrogen is both blended into natural gas pipelines up to the modeled limit of 20% by volume and delivered directly to power plants. The H2: Electric Generation category also includes conversion of construction site power from diesel to hydrogen by 2050. By 2050, pipeline gas delivered to buildings and industry contains 20% by volume hydrogen gas.

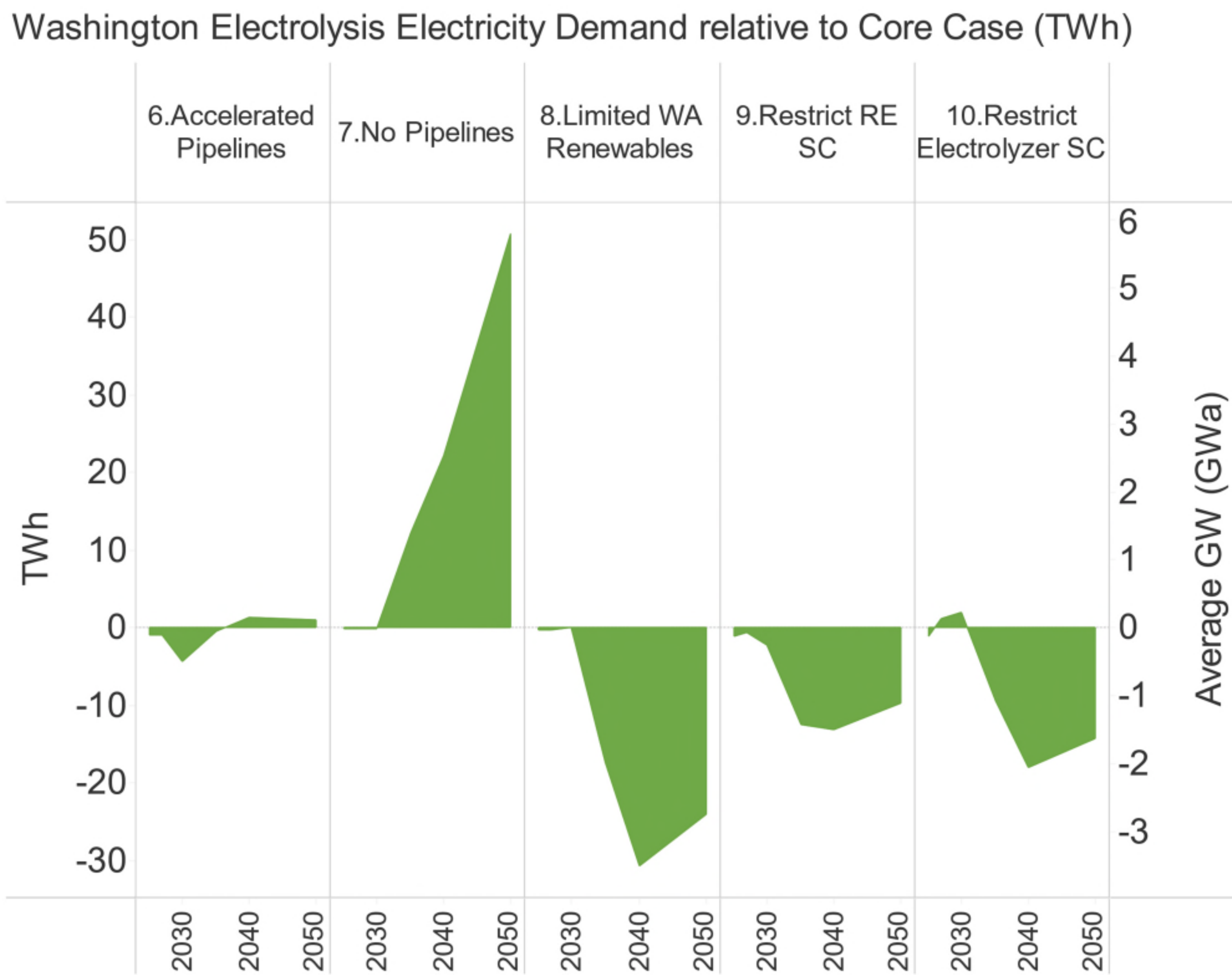
Figure 2. Washington demand for hydrogen and hydrogen derived fuels in the Core Case



These modeling results indicate that a significant expansion of renewable electricity generation capacity is needed in Washington to meet state policy goals. Renewable electricity demand from electrolysis peaks at 35 TWh in the Core Case in 2040, equivalent to 4 average gigawatts. Translating this to gigawatts of renewables installed in Washington is difficult because energy comes from multiple sources, and some is sold back to the grid when electrolyzers cannot use it. As a reference point, 4 GWa is equivalent to 10 GW of wind at a 40% capacity factor, if all GWh produced were to go to electrolysis and none were sold back to the grid.

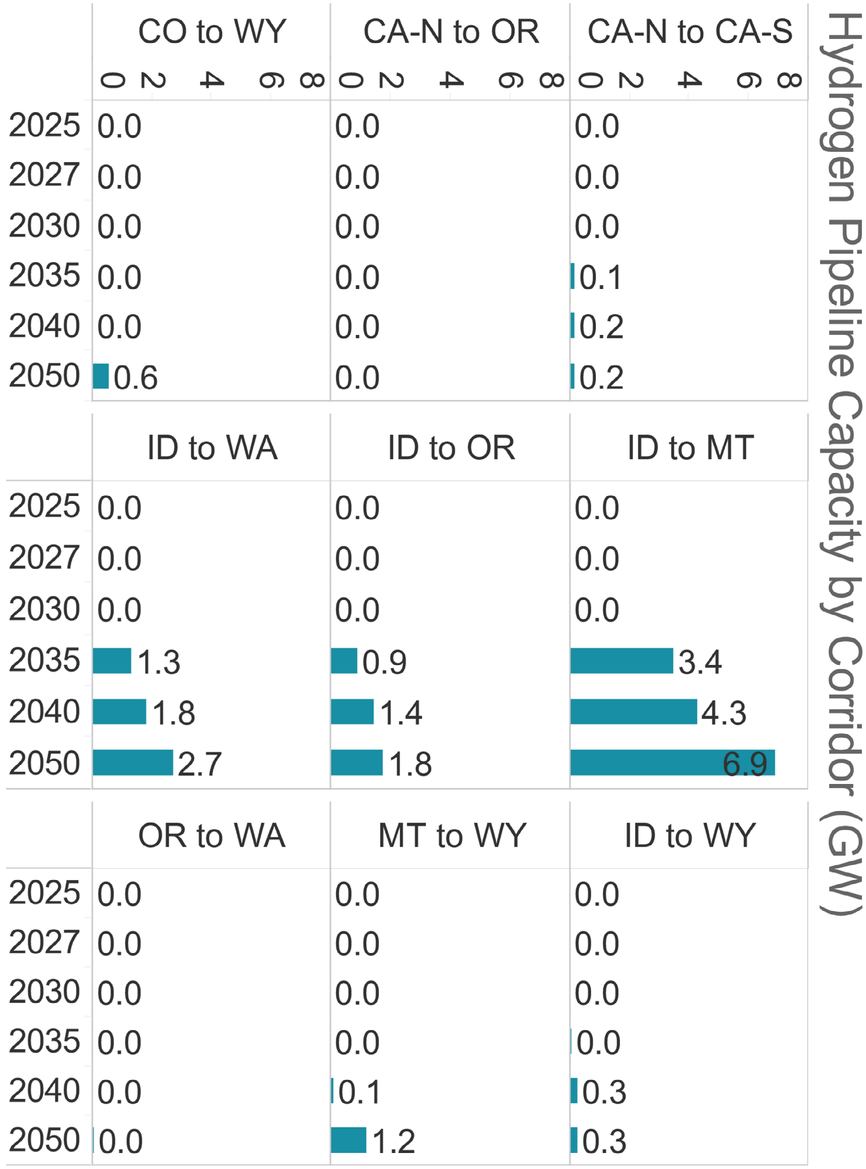
Electrolyzer electricity demand varies by scenario, driving different siting and permitting challenges in Washington depending on future system conditions. Figure 3 shows how electrolysis electricity demand in Washington varies between the scenarios described in Chapter 1 that limit the availability of energy resources. Limiting Washington renewable energy growth (**8. Limited WA Renewables**) drops electricity demand to 4 TWh, whereas preventing hydrogen and ammonia pipeline build (**7. No Pipelines**) peaks it at 77 TWh in 2050.

Figure 3. Change in modeled Washington electrolysis electricity demand relative to the Core Case



While large-scale renewable electricity generation supports in-state hydrogen production in Washington, interstate pipelines are needed to support imports from out of state. Figure 4 shows the expansion of interstate hydrogen pipeline capacity modeled in the Core Case. Pipelines connecting Washington to Montana hydrogen supplies, through Idaho, are an important component of Washington's hydrogen economy in this analysis.

Figure 4. Core Case hydrogen pipeline capacity by corridor



These analytical results help us understand the types of hydrogen projects that might be proposed in Washington, both in the near term in immediate response to IRA incentives, and in the longer term as the state's emissions policies drive deeper decarbonization. The nature of the modeling performed in support of this report primarily demonstrates the infrastructure requirements of a hydrogen economy at a large-scale, interstate level because the model represents each Northwest state as one zone and represents energy flows between zones.

While not reflected in the model results, extensive hydrogen storage and transport infrastructure will also be required within Washington's borders to connect hydrogen supply and demand. Although smaller scale than the large renewable generation buildout and interstate transmission lines and pipelines depicted in the analysis, these intrastate infrastructure assets will be an important component of Washington's permitting and siting efforts.

Hydrogen siting along the value chain

We can divide a hydrogen economy into three segments: 1. Production (Upstream), 2. Distribution and Storage (Midstream), and 3. End Use Applications (Downstream). Each segment is represented by different technologies, and each technology has different resource needs or other characteristics that dictate siting and permitting requirements. Understanding these dynamics can help policymakers anticipate the types of hydrogen project applications likely to be submitted in Washington in both the near term and longer term. Siting dynamics also inform which parts of the state are best suited to host different types of hydrogen facilities.

Production

This report focuses exclusively on green hydrogen production, which uses renewable electricity to convert water to hydrogen using an electrolyzer. Siting electrolysis projects in Washington will depend on access to these inputs as well as access to hydrogen transportation networks required to deliver hydrogen from a production site to end users. Given the high cost and feasibility challenges of expanding electric transmission, hydrogen electrolysis projects are likely to seek sites where they can access the existing transmission network, or sites that are co-located with clean electricity generation such that the need for electricity transmission is minimized.

This could create potential to develop electrolysis projects at retired coal power plants or petroleum refinery sites, as those facilities require large transmission connections. Simultaneously, electrolysis developers are likely to seek to minimize hydrogen transport costs by finding sites that are geographically close to sources of hydrogen demand. The most attractive locations for hydrogen production will be those that can limit both electricity delivery and hydrogen transport costs.

The type of electricity generation that will be used to power hydrogen electrolysis in Washington depends to some extent on how IRA incentives are implemented. The United States Department of the Treasury has yet to define how green hydrogen projects seeking to qualify for IRA incentives will be required to demonstrate use of clean electricity; Treasury is considering requiring hydrogen producers to demonstrate that they are using "additional" renewable resources — meaning renewables that are constructed for the hydrogen production they support.

If this additionality provision is implemented, electrolysis projects will need to be powered by new renewable electricity generation. In Washington, that primarily means large ground-mount solar and on-shore wind projects. If additionality is not required, electrolysis projects will have the option of using zero-carbon power from existing resources in Washington, especially hydropower. Hydropower is more likely to be available to serve electrolysis demand in the near term; in the longer term, Washington's existing zero-carbon electricity sources will be insufficient to meet the state's climate targets, and significant buildout of new renewable capacity will be required to power expanding hydrogen production.

Given the importance of large-scale renewable electricity generation to produce in-state green electrolytic hydrogen, renewable electricity, land use, and grid interconnection are key considerations for Washington's hydrogen economy. The solar and wind resources required to power electrolysis use much more land than an electrolyzer facility does (the difference is multiple orders of magnitude),[68] which may make siting the new renewable power required to produce hydrogen more difficult than siting electrolyzers.

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[68] See Framework for Siting and Permitting, Slide 10 (Appendix C) for more detail on land requirements.

The solar and wind resources will also require interconnection to the electric transmission grid: in the immediate term, IRA incentives for hydrogen production may be significant enough to support off-grid renewables that are used entirely for producing hydrogen, but in the longer term, renewable electricity projects will be most profitable if they can alternate between delivering electricity to the grid and producing hydrogen based on time-varying electricity price signals. However, there are long delays to interconnect renewable electricity generation across the U.S., including in the Northwest.[69]

Transmission connection timelines will need to be accelerated to match the desired pace of hydrogen production expansion. Where projects are stuck in long interconnection queues in the immediate term, however, the IRA incentive may make it profitable for a renewable energy project to produce hydrogen off grid while waiting for interconnection later.

A final requirement for electrolysis siting is access to water. While the Northwest currently has freshwater resources sufficient to meet electrolysis requirements, electrolysis projects will nonetheless need to procure water for the planned duration of their operations.

Distribution and storage

Like any fuel, hydrogen must be transported from where it is produced to where it will be consumed, and it must be stored at either end of transport to be provided on demand. Green electrolytic hydrogen has especially large storage needs to smooth out mismatched patterns of hydrogen production and demand since intermittent and seasonally varying renewable electricity availability dictates its production.

Storage

There are three primary options for storing hydrogen with different cost dynamics that make each suited to different applications: geologic storage, compressed gas tank storage, and liquid tank storage. Geologic storage is the lowest cost option on a levelized basis and is appropriate for large volume applications.[70] Storing hydrogen in tanks, either as liquid or gas, is better suited to smaller-scale applications and on-site storage for hydrogen users. Compressed gas storage is comparatively more expensive than liquid storage on a levelized basis, but it has a lower upfront capital cost and so is useful in low-volume operations.[71]

Of the various types of geologic hydrogen storage under investigation, salt caverns are the most technologically mature. Washington does not have salt cavern formations, suggesting that gas and liquid tank storage will be the primary in-state storage options in the near term. In the longer term, hardrock outcroppings are another potential type of geologic storage formation — they are less mature than salt caverns but are available at large scale in northern Washington. Figure 5below shows the location of geologic storage formations[72] in the United States, as determined by a joint research effort between several national labs.[73]

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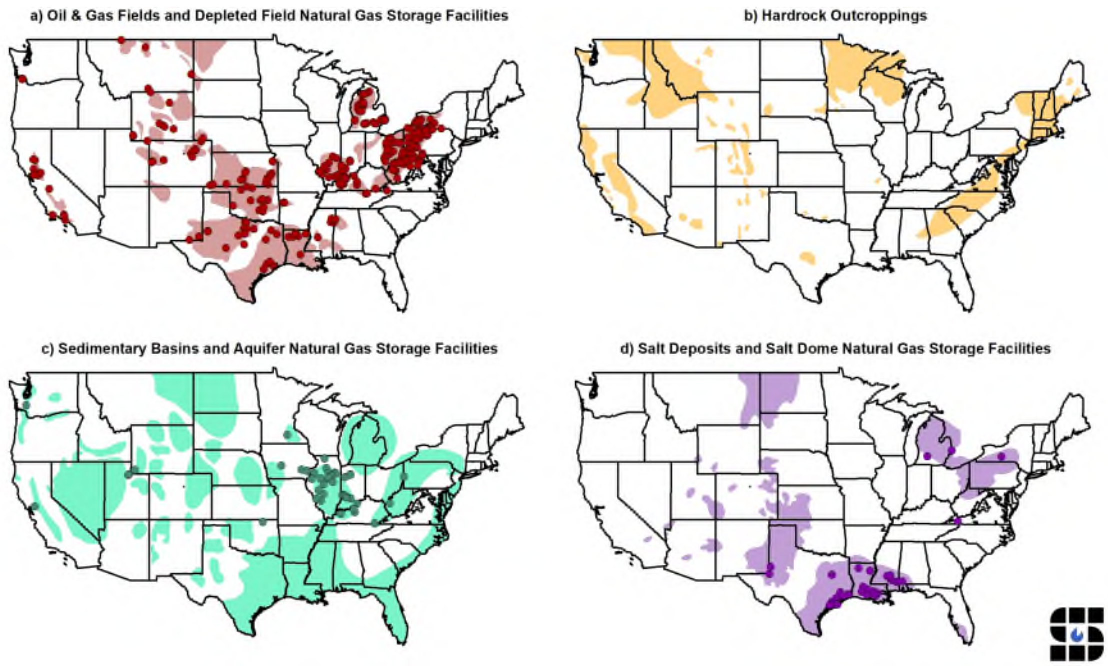
[69] Joseph Rand et al., Lawrence Berkeley National Laboratory, "Queued Up: Characteristics of Power Plants Seeking Transmission Interconnection As of the End of 2022," (2023), https://emp.lbl.gov/sites/default/files/queued_up_2022_04-06-2023.pdf, see especially p. 9.
[70] A levelized basis means the cost across the useable lifetime - in this case of a large volume storage facility.
[71] US Department of Energy, "Pathways to Commercial Liftoff: Clean Hydrogen," (2023), https://liftoff.energy.gov/wp-content/uploads/2023/03/20230320-Liftoff-Clean-H2-vPUB.pdf
[72] Hardrock outcroppings (b) and salt deposits (d) are the most mature formations for hydrogen storage.
[73] Department of Energy National Laboratories, "Subsurface Hydrogen Assessment, Storage and Technology Acceleration," (accessed August 30, 2023), https://edx.netl.doe.gov/shasta/

Hydrogen may also be converted and stored in other forms of fuel including liquids from the Fischer-Tropsch or Haber-Bosch processes. When storing energy in large volumes or over long periods of time, such as across seasons, storage as a liquid fuel may be more cost effective than storing as a hydrogen gas.

Figure 5. Geologic storage locations in the United States



Distribution

The options for hydrogen transport are pipelines or trucking; as with hydrogen storage, hydrogen can be trucked either as a liquid or a gas. Pipelines are significantly lower cost than trucking at high volumes and are likely to be a major component of a mature hydrogen economy. Trucking is a more likely form of transport in the near term, when volumes of hydrogen demand are small and insufficient to support investment in pipelines. Over long distances, trucking hydrogen as a liquid is more economical than trucking it as a gas: liquid trucking has higher capital costs, but more energy can be transported per trip, reducing labor costs.[74]

A final consideration for transporting hydrogen is leveraging the existing natural gas transmission and distribution network. Natural gas transmission and distribution pipelines are an appealing option for transporting hydrogen because they avoid the need for new infrastructure investment. However, the materials used for natural gas pipelines limit the amount of hydrogen they can safely carry: most economic assessments assume blends above 7% hydrogen by energy (20% by volume) will require costly infrastructure upgrades.[75] The feasibility and safety of blending hydrogen in natural gas pipelines is an area of ongoing research. Exact blend limits are uncertain and likely vary from one gas pipeline network to another.

Natural gas pipelines could theoretically be used to deliver a blend of hydrogen and natural gas, or they could transport a blend of the two fuels but deliver pure hydrogen to end users by incorporating separation equipment that removes hydrogen from blended natural gas and hydrogen at the point of delivery. Given the high cost of this separation equipment, end uses requiring 100% hydrogen are expected to use dedicated

[74] US Department of Energy, "Pathways to Commercial Liftoff: Clean Hydrogen," (2023).
[75] National Renewable Energy Laboratory, "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues," (2013), https://www.nrel.gov/docs/fy13osti/51995.pdf

hydrogen delivery infrastructure. Existing natural gas end uses that can convert to a blend of hydrogen and natural gas, such as power generation and building heating, may be able to use the existing natural gas network.

End uses

The Department of Energy provides the following categories for hydrogen end uses:[76] industrial use, natural gas replacement, and transportation. The technical analysis underlying *Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Deployment in Washington* (see Chapter 1. Green electrolytic hydrogen requirement) indicates that some of these use cases are more economic than others because Washington seeks to achieve its carbon emission reduction targets at lowest cost. Nonetheless, state agencies should expect to see individual project applications across the full spectrum of potential end uses, as individual project economics can support end uses that may not be economic in system-wide analyses.

Industry

Many of the primary industrial applications for green hydrogen are already consumers of hydrogen produced by steam methane reforming (SMR): ammonia production, petroleum refining, steel production, and bulk chemicals all use methane-derived hydrogen today and are likely to convert to green or renewable hydrogen sources in response to IRA incentives and other climate policies.

For end users already consuming SMR hydrogen, converting to green hydrogen requires minimal infrastructure changes. This is especially true for hydrogen users who are simply taking delivery of hydrogen and not producing it themselves: such users should be able to use the same storage and transport infrastructure for green hydrogen and SMR hydrogen. If users are using natural gas to produce hydrogen on-site, as is often the practice at petroleum refineries, larger infrastructure investments are required.

Those users can either take direct delivery of hydrogen, which would require new on-site hydrogen transport and storage investments, or they can add electrolysis production on-site. The relative cost of those two approaches will be highly site- and application-specific, as adding on-site electrolysis requires access to electric transmission and sufficient space for the electrolysis facility.

A new likely source of industrial hydrogen demand is FT (Fischer-Tropsch) fuel production, which combines hydrogen and captured carbon to produce synthetic hydrocarbon fuels. FT fuel production is incentivized by IRA incentives for hydrogen and carbon capture and is further encouraged by Washington's emissions reduction targets, which in previous analyses[77,78] have been shown to drive economic adoption of decarbonized liquid fuels in the transportation sector to reduce emissions.

FT facility siting will be driven by access to hydrogen and captured carbon, likely via pipeline for FT fuel production at scale. FT facilities using electrolytic hydrogen may be co-sited with renewables and hydrogen production to avoid the cost of hydrogen pipelines. In the analysis supporting this report, FT fuel production is economically sited in Washington in the 2030-2035 timeframe and continues to scale up through 2050.

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[76] US Department of Energy, "Pathways to Commercial Liftoff: Clean Hydrogen," (2023).
[77] Washington Department of Commerce, "Washington 2021 State Energy Strategy," (2020*),* https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/
[78] Clean Energy Transition Institute, "Net-Zero Northwest: Technical and Economic Pathways to 2050," (2023), https://www.nznw.org/

Natural gas replacement

The three primary opportunities for hydrogen to replace natural gas are in natural gas pipeline blending, power generation, and industrial heat production.

As previously discussed, pipeline blending is limited by safety considerations. Hydrogen is a smaller and more flammable molecule than methane, introducing greater leak and explosion risk.[79] Hydrogen also has varying degrees of compatibility with different materials used in the natural gas pipeline network,[80] which is a patchwork of assets of different ages and designs.

Natural gas utilities across the US are piloting and testing hydrogen blending as a means of decarbonizing pipeline gas supply, particularly to commercial and residential buildings. The commercial viability of this approach remains to be determined, not only because of safety considerations, but also because the tolerance of household appliances to hydrogen blend levels is uncertain.[81]

In the power generation sector, technical modeling indicates that hydrogen combustion turbines (CTs) can be a useful electric reliability resource when policy constraints prevent natural gas electricity generation. CTs are relatively low capital cost compared to other reliability resources like long-duration energy storage. However, because of hydrogen's high fuel cost, we expect hydrogen CTs to operate only a small number of hours per year, when renewable electricity supply is most constrained.

In the modeling, hydrogen CTs burn pure hydrogen, which is delivered via dedicated infrastructure. However, projects have been proposed in the West[82] that would use a blend of hydrogen and natural gas to produce electricity to operate at higher capacity factors than those indicated in the technical modeling for this project. Some proposals would use existing natural gas pipeline infrastructure to deliver blended fuel. In the long-term, these proposed facilities would convert from a blend to pure hydrogen fuel.

Hydrogen CTs pose potential impacts to air quality: hydrogen burns at a higher temperature than natural gas, potentially producing greater nitrogen oxides (NOx).[83] These NOx emissions are particularly impactful if the hydrogen power generator is operating at a high capacity and sited close to population centers.

High-temperature industrial process heat applications that can't be electrified are suited to conversion from natural gas to hydrogen as a means of decarbonization. Like other industrial uses, industrial heat production requires hydrogen transport and on-site storage. Because hydrogen is combusted to produce heat, these applications also introduce NOx air quality considerations.

Transportation

Hydrogen use has been considered as a decarbonization strategy across a range of different transportation applications, particularly those that are difficult to electrify. Aviation, marine, and medium- and heavy-duty on-

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[79] Pipeline Safety Trust, "Report: Safety of Hydrogen Transportation by Gas Pipelines, Summary for Policymakers", (2023), https://pstrust.org/wp-content/uploads/2023/01/hydrogen_pipeline_safety_summary_1_18_23.pdf

[80] Exponent, "Can your Natural Gas Pipelines Handle Hydrogen Blends?", (2022), https://www.exponent.com/article/can-your-natural-gas-pipelines-handle-hydrogen-blends

[81] National Renewable Energy Laboratory, "Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues," (2013), https://www.nrel.gov/docs/fy13osti/51995.pdf

[82] Scattergood (L.A. Department of Water and Power), https://www.latimes.com/business/story/2023-02-08/l-a-is-shutting-down-a-coastal-gas-plant-and-replacing-it-with-hydrogen; Intermountain Power Project Renewed (Utah), https://www.ipautah.com/ipp-renewed/

[83] Georgia Tech Strategic Energy Institute, "NOx Emissions from Hydrogen-Methane Fuel Blends", (2022), https://research.gatech.edu/sites/default/files/inline-files/gt_epri_nox_emission_h2_short_paper.pdf

road vehicles are transportation subsectors where battery applications are currently limited and hydrogen may be a successful alternative.

In the technical modeling, on-road medium- and heavy-duty trucks are the most appropriate application for hydrogen fuel cells. Supplying hydrogen for transport requires delivery and storage infrastructure, as well as hydrogen fueling stations. Light-duty cars and trucks could convert to hydrogen, also requiring fueling station infrastructure, but thus far, battery electric vehicles have dominated that sector. Aviation and marine applications are more likely to use hydrogen-derived fuels like synthetic jet fuel, ammonia, and methanol than they are to convert to direct hydrogen, due in part to the relative ease of transporting and storing those fuels as liquids.

Current permitting processes in Washington

Washington's State Environmental Policy Act (SEPA) dictates the state's environmental review processes. Both SEPA and the analogous National Environmental Policy Act (NEPA) require proposed projects to prepare an Environmental Impact Statement (EIS), detailing project-specific environmental impacts.

Washington's Energy Facility Site Evaluation Council (EFSEC) was created in 1970 as a licensing agency for non-hydro energy projects.[84] Projects involving alternative energy electricity generators, pipelines, and certain electric transmission lines have the option to apply for permits through EFSEC instead of local permitting authorities.

In 2023, the Washington Legislature passed Chapter 230, Laws of 2023, which establishes new processes for clean energy project permitting.[85] The provisions relevant to the hydrogen industry are the Coordinated Permit Process for Clean Energy Projects and the Programmatic EIS. In the Coordinated Permit Process, project developers can request that Washington's Department of Ecology convene a fully coordinated permit process, in which Ecology serves as the primary point of contact for the project applicant and any other participating agencies.

Chapter 230, Laws of 2023's Programmatic EIS component instructs Ecology to develop a programmatic EIS for green electrolytic and renewable hydrogen projects by June 30, 2025. A programmatic EIS is a concept that also exists under NEPA: it is an alternative to a project-specific EIS that details anticipated environmental impacts and potential mitigations for a category of development projects. Proposed projects can seek to comply with the requirements of a PEIS which will help developers avoid and minimize potential impacts as they work to site and develop specific proposed projects. There is precedent for using PEISs at the federal level to streamline permitting for renewable energy projects.[86]

Proposed and implemented permitting reforms

The scale of clean energy infrastructure required to meet climate goals in the U.S. and the European Union (EU) has prompted debate about whether existing permitting practices should be reformed. In the U.S., federal permitting reform proposals have focused on NEPA and electric transmission expansion practices. The IRA provides significant incentives for renewable electricity generation but does not address how to build the long-distance transmission lines needed to connect the country's best renewable resources to load. Proposed

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[84] State of Washington Energy Facility Site Evaluation Council, (accessed August 30, 2023), https://www.efsec.wa.gov/
[85] Washington State Legislature, Chapter 230, Laws of 2023 "Clean Energy Project Siting," (accessed August 30, 2023)
[86] The Bureau of Land Management's 2012 Solar PEIS is an example of a federal programmatic EIS. Detail available at https://blmsolar.anl.gov/solar-peis/

NEPA reforms are primarily concerned with accelerating NEPA timelines and have introduced controversy over whether those reforms should apply to renewable energy projects only or to oil and gas investments as well.

The Fiscal Responsibility Act passed in June 2023[87] to raise the US debt limit included some changes to NEPA requirements, which the Council on Environmental Quality (CEQ) began implementing in July 2023. Primary NEPA changes include: instituting page limits for documentation and timelines on application review, allowing federal agencies to adopt each other's categorical exclusions (categories of projects that are exempt from NEPA review), and encouraging the use of programmatic EISs. The NEPA changes do not address transmission expansion other than to require its study. Expanding transmission interties between sections of the U.S. grid is an ongoing area of debate and proposed federal reforms.

States throughout the U.S. are also revisiting permitting practices with the aim of accelerating renewable energy deployment. California and New York recently passed permitting reform legislation[88] that share certain characteristics: they identify a dedicated lead agency for renewable energy project permitting, impose maximum timelines on environmental impacts statements and reviews, and require projects to deliver benefits directly to impacted communities.

The EU similarly imposed permitting time limits for renewable energy projects in 2023.[89] The EU policy (a revision to the 2017 Renewable Energy Directive) notably also includes grid connection for renewable projects in its scope and requires EU member states to designate preferred geographic areas for deployment of renewables, where accelerated permitting time limits apply.

The U.S. and EU permitting reforms proposed and enacted indicate best practices for other jurisdictions seeking to accelerate renewable energy deployment. A primary opportunity lies in identifying preferred geographic areas for siting new infrastructure, as the EU is doing and as the U.S. federal government has done on federally managed lands in some cases. Preferred development areas should be selected based on availability of natural resources required for specific types of energy projects, while limiting impact on the environment and local communities.

Non-governmental organizations have recently begun undertaking these kinds of renewable energy siting studies, which include significant mapping efforts among other analysis.[90] Designating preferred development areas then allows permitting agencies to accelerate approvals for projects in their areas, which is likely more achievable than accelerating reviews for all proposed projects, given that staffing and budget limitations are often the reasons for long review timelines.

Other best practices for renewable energy permitting include prioritizing brownfield or urban infill sites, adding grid interconnection and transmission expansion into the scope of reforms, providing agency support necessary to achieve accelerated timelines, encouraging coordination between state agencies and with federal agencies, identifying a lead agency to oversee coordination, and providing state agencies authority to override local agencies for projects deemed to be in the public interest.

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[87] "Fiscal Responsibility Act of 2023," Pub. L. No. 118-5 (2023), https://www.congress.gov/118/plaws/publ5/PLAW-118publ5.pdf
[88] World Resources Institute, "US Clean Energy Goals Hinge on Faster Permitting", (2023), https://www.wri.org/insights/clean-energy-permitting-reform-us
[89] Reuters, "Europe on verge of permitting leap for wind, solar farms," (2023), https://www.reuters.com/business/energy/europe-verge-permitting-leap-wind-solar-farms-2023-06-01/
[90] The Nature Conservancy, "Power of Place," (2023), https://www.nature.org/en-us/what-we-do/our-priorities/tackle-climate-change/climate-change-stories/power-of-place/; Mass Audubon, "New Report Shows We Can Build Solar Energy While Conserving Nature," (2023), https://www.massaudubon.org/news/latest/new-report-shows-we-can-build-solar-energy-while-conserving-nature

These reforms — especially those that strengthen state authority over local authority — intended to accelerate renewable energy deployment must be balanced against protecting vulnerable communities and environmental resources. See Chapter 4. Addressing environmental and energy justice considerations on incorporating environmental and energy justice considerations.

Considerations regarding tribal lands and resources

Importantly, both mapping exercises and siting and permitting processes must take into account specific considerations with regard to tribes. Mapping exercises to identify landscapes that are higher or lower priorities can be complex when there is a state desire to include geographic information about tribal lands and resources. For example, tribal governments may not wish to publicly disclose the locations of archaeological and cultural resources for use on public maps, though may still wish to ensure that project proposals seek out and utilize such data directly from tribes. Care and consideration must be taken to involve tribes in developing any mapping tools or using tribal data to inform siting and permitting of proposed projects, in the ways that tribes require that their data be used. Any efforts undertaken to collaborate on these projects cannot replace established processes for tribal consultation.

Additionally, tribes may wish to encourage the siting and permitting of hydrogen projects on tribal lands, either independently or in coordination with private sector entities or others. Tribal land development codes may be different for tribal lands (either reservation or non-reservation trust lands) than on non-tribal lands. Developers seeking to site and permit hydrogen and renewable fuels projects on tribal lands should seek to understand relevant development codes and legal authorities available to tribal governments. Additionally, developers should actively work with tribes to collaboratively identify and agree development sites.

Conclusions for green hydrogen in Washington

Several of the permitting best practices identified here are already in place in Washington, especially with the passage of Chapter 230, Laws of 2023. Washington's SEPA allows applicants to use NEPA documents, creating some coordination between state and federal policy. Chapter 230, Laws of 2023 establishes a choice of lead agency for most hydrogen projects, encourages coordination between state agencies, and creates a programmatic EIS for hydrogen projects.

Washington should take further steps to facilitate green hydrogen siting and permitting through advance planning efforts. The state should define geographic areas that are preferred sites for hydrogen production, transport, and use. These areas should include land for renewable electricity generation required to support electrolysis. They should identify preferred corridors for hydrogen pipelines, both for intrastate hydrogen transport and for accessing hydrogen imports from Montana and Wyoming.

Geographically detailed mapping can be very helpful to define preferred development areas that minimize impacts to sensitive environments and local communities. This must be done with appropriate input and guidance from tribes as described previously. Washington can limit the environmental and community impact of the hydrogen economy by seeking opportunities to geographically concentrate demand or co-site demand with supply. Sectors likely to demand hydrogen that may be appropriate for co-locating could include high-heat industrial processes, transportation fleets, petroleum refineries in the short term, and synthetic fuel refineries in the longer term. Proposed hydrogen projects along any point of the hydrogen value chain should qualify for expedited review timelines when sited in state-designated geographic areas.

Washington should also take into account that while renewable electricity may be available for short-term purchase for hydrogen projects in the near term, competition for renewable electricity supply is likely to heighten in the next decade as Washington's emissions caps become more difficult to achieve. Hydrogen production projects that can demonstrate procurement of renewable electricity for the intended duration of their operations should be prioritized over those relying on short-term electricity purchases. The same approach could be applied to procurement of water.

Washington should streamline processes for existing hydrogen users to convert from methane-derived hydrogen to green hydrogen. The IRA supports these conversions economically, which are an opportunity for green and renewable hydrogen projects to secure early sources of demand, as other demand sectors mature more slowly (for example, transportation, where large equipment investments are required to convert to hydrogen).

Washington can consider additional policy changes that could facilitate growth of the state's hydrogen industry and clarify guidelines for hydrogen project developers. As discussed in this report, grid interconnection of large-scale renewables is critical to support an in-state hydrogen economy at scale. The state can pursue policies that implement cost-sharing for electric grid upgrades required to interconnect renewables in preferred development areas. The state can also increase transparency in the interconnection process, helping renewable generation projects select sites that take advantage of existing grid capacity rather than requiring upgrades.

Chapter 4. Addressing environmental and energy justice considerations

Introduction

Defining environmental and energy justice

Through the Healthy Environment for All (HEAL) Act,[91] Washington defines environmental justice as:

> "[T]he fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, rules, and policies. Environmental justice includes addressing disproportionate environmental and health impacts in all laws, rules, and policies with environmental impacts by prioritizing vulnerable populations and overburdened communities, the equitable distribution of resources and benefits, and eliminating harm."

Energy justice concerns energy production and consumption and aims to achieve "equity in both the social and economic participation in the energy system, while also remediating social, economic, and health burdens on those disproportionately harmed by the energy system."[92]

While environmental and energy justice frameworks overlap, leading energy justice scholar Kirsten Jenkins argues that energy justice is a more strategically impactful framework because it is "(1) more targeted in its topic of concern and systems focus, and therefore has increased potential for policy uptake, (2) unlike environmental and climate justice, is not the outcome of anti-establishment social movements, and (3) is backed by a strong methodological tradition which shows a range of both academic and policy-relevant applications."[93]

This chapter focuses on energy justice considerations as they relate to developing electrolytic hydrogen projects in Washington.

Policy context

Justice40 Initiative

For the first time in the history of the United States, the Federal Government, as directed by the Biden Administration, has set forth a goal with the Justice40 Initiative that "40 percent of the overall benefits of certain Federal investments must flow to disadvantaged communities that are marginalized, underserved, and overburdened by pollution."[94]

Investments covered by the Justice40 Initiative that relate to this report include climate change, clean energy, and workforce development, as well as potentially the reduction of legacy pollution. Electrolytic hydrogen and

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[91] RCW 70A.02.010(8), https://app.leg.wa.gov/RCW/default.aspx?cite=70A.02. This builds on the definition from the Environmental Protection Agency: https://www.epa.gov/environmentaljustice
[92] Shalanda Baker et al., Initiative for Energy Justice, "The Energy Justice Workbook," (2019), https://iejusa.org/wp-content/uploads/2019/12/The-Energy-Justice-Workbook-2019-web.pdf
[93] Kirsten Jenkins, "Setting energy justice apart from the crowd: Lessons from environmental and climate justice," (2018), https://doi.org/10.1016/j.erss.2017.11.015
[94] The White House, "What is the Justice40 Initiative?" (accessed February 26, 2023) https://www.whitehouse.gov/environmentaljustice/justice40/

other clean fuels would replace the polluting fossil fuels that have largely been sited precisely in communities that the Justice40 Initiative aims to address. DOE funding that would be allocated[95] through the Bipartisan Infrastructure Law (BIL)[96] for regional clean hydrogen hubs is also covered under the Justice40 Initiative.

DOE has identified eight policy priorities[97] to guide implementation of Justice40:

1. Decrease energy burden in disadvantaged communities (DACs).
2. Decrease environmental exposure and burdens for DACs
3. Increase parity in clean energy technology (e.g., solar, storage) access and adoption in DACs.
4. Increase access to low-cost capital in DACs.
5. Increase clean energy enterprise creation and contracting (MBE/DBE) in DACs.
6. Increase clean energy jobs, job pipeline, and job training for individuals from DACs.
7. Increase energy resiliency in DACs.
8. Increase energy democracy in DACs.

Additionally, for all BIL and Inflation Reduction Act (IRA) funding opportunity announcements, DOE requires Community Benefits Plans[98] based on the following four priorities:

1. Engaging communities and labor;
2. Investing in America's workforce;
3. Advancing diversity, equity, inclusion, and accessibility; and
4. Implementing the Justice40 Initiative.

Together, these priorities can help guide more equitable green electrolytic hydrogen development. For example, the Justice40 policy Priority #2 (Decrease environmental exposure and burdens for DACs), is critical to ensure that development and use of green hydrogen does not add to — and in fact, decreases — potential environmental exposures, such as those described in detail later in this chapter. Additionally, Priority #6 (Increase clean energy jobs, job pipeline, and job training for individuals from DACs) could help funnel potential economic benefits from hydrogen development into disadvantaged communities.

Washington policies

In addition, Washington has incorporated justice and equity into recent environmental and clean energy policies. The Washington 2021 State Energy Strategy[99] opens with a chapter on equity and provides five key directives to guide how the state must build an "equitable, inclusive, resilient clean energy economy" from 2021-2030, two of which are particularly relevant: #3 — Ensure public participation and inclusion of historically marginalized voices and #5 — Embed equity in the design of clean energy policies and programs.

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[95] U.S. Department of Energy, "DOE Justice40 Covered Programs," (accessed on February 27, 2023), https://www.energy.gov/diversity/doe-justice40-covered-programs
[96] The White House, "Building a Better America," (accessed on February 27, 2023), https://www.whitehouse.gov/build/
[97] U.S. Department of Energy, "Justice40 Initiative," (accessed September 15, 2023), https://www.energy.gov/diversity/justice40-initiative
[98] U.S. Department of Energy, "About Community Benefits Plans," (accessed September 15, 2023), https://www.energy.gov/infrastructure/about-community-benefits-plans
[99] Washington Department of Commerce, "Washington 2021 State Energy Strategy," (2020), https://www.commerce.wa.gov/growing-the-economy/energy/2021-state-energy-strategy/

In 2021, Washington passed the HEAL Act, “a historic step toward eliminating environmental and health disparities among communities of color and low-income households [and] the first statewide law in Washington to create a coordinated state agency approach to environmental justice.”[100]

The HEAL Act requires Washington agencies to incorporate environmental justice when drafting agency strategic plans; developing community engagement plans and Tribal consultation frameworks; promoting equitable sharing of environmental benefits; and investing in communities that have experienced the greatest environmental and health burdens, among other provisions. Like the Justice40 Initiative, the HEAL Act sets the goal that 40% of expenditures be made in these communities.

Washington’s 100% clean electricity law, the Clean Energy Transformation Act (CETA), requires Washington electric utilities ensure an affordable, reliable, and equitable transition to an electricity supply free of greenhouse gas emissions.[101] This includes an equitable distribution of the benefits of clean energy, and reductions in burdens to vulnerable populations and highly impacted communities.

Electric utilities that produce or use hydrogen assets need to consider the equity impacts of producing and using hydrogen. The clean energy implementation plan (CEIP) is the primary planning document where utilities will explain how they consider equity when developing hydrogen assets. In addition to showing how specific generation and use of hydrogen assets will meet the law’s 2030 greenhouse gas-neutral standard and 100% clean electricity standard in 2045, utilities will need to:

- Assess the distribution of energy and non-energy costs and benefits of using hydrogen for vulnerable populations and highly impacted communities
- Assess risks to highly impacted communities and vulnerable populations
- Mitigate risks to those communities and populations
- Use a public input process to inform each of the above evaluations and the utility’s decision to generate and produce hydrogen

Starting in 2026, utilities will need to assess their plans at the end of each four-year planning window. The plans and assessments provide an opportunity for utilities to ensure their hydrogen programs and projects benefit and do not burden vulnerable and overburdened communities. Preliminary findings of challenges implementing CETA’s equity mandates include, but are not limited to:

- Inconsistent use of equity indicators and metrics across utilities, reflecting the absence of a shared understanding of equity terms and measures
- Many utility public input processes remaining limited to governing board hearings with limited opportunity for input from low-income households, vulnerable populations, and highly impacted communities

CETA's clean energy and equity requirements remain a work in progress. Utilities, state agencies, and the public must realize equitable outcomes for low-income households and highly impacted communities. Ensuring effective and consistent implementation of the equity requirements in CETA will be one tool for ensuring the energy and non-energy benefits of hydrogen flow to these communities, and that these

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[100] Washington State Department of Health, "Environmental Justice," (accessed on February 26, 2023), https://doh.wa.gov/community-and-environment/health-equity/environmental-justice
[101] RCW 19.405, https://app.leg.wa.gov/rcw/default.aspx?cite=19.405

communities are protected from potential risks and burdens of hydrogen generation and deployment in the state by electric utilities.

Energy infrastructure legacy impacts

Energy project siting has historically occurred at sites in and around disadvantaged and underserved communities, especially Black, Brown, Indigenous, and low-income communities.[102,103] Energy development in low-income communities in the United States has resulted in "energy sacrifice zones" that bear a disproportionate burden of generating energy to meet the nation's demands.[104,105]

Research suggests that historical red-lining housing policies led to siting fossil fuel power plants in low-income communities where people of color lived, which resulted in present-day emissions and a concentration of unhealthy criteria air pollutants.[106] Fossil fuels extraction, particularly from oil and gas wells, has been linked to historical redlining with disproportionate impacts on marginalized communities.[107]

Addressing environmental and energy justice at the start of energy projects

Environmental and energy justice concerns must be addressed from the outset of any energy project, renewable or not. While renewable energy projects produce fewer lifecycle emissions than other power sources,[108] siting renewable energy projects has the same potential as fossil fuel projects to perpetuate historical energy injustices and burden communities.[109]

A 2022 study that investigated sources of opposition to more than 50 utility-scale renewable energy projects revealed concerns about environmental and wildlife impacts; financial and revenue challenges; perceptions of unfair participation processes; failure to respect Tribal rights; health and safety issues; intergovernmental disputes; and potential impacts on land and property value.[110]

Renewable energy projects can also be a tool to further energy justice[111,112] by channeling economic benefits of project development to local communities, adding value to otherwise under-utilized land,[113] and furthering

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102 Timothy Q. Donaghy et al., "Fossil Fuel Racism in the United States: How Phasing Out Coal, oil, and Gas can Protect Communities," (2023), https://doi.org/10.1016/j.erss.2023.103104

103 Benjamin K. Sovacool and Michale H. Dworkin, "Global Energy Justice: Problems, Principles, and Practices," (2014), https://doi.org/10.1017/CBO9781107323605

104 Diana Hernández, "Sacrifice Along the Energy Continuum: A Call for Energy Justice," (2015), https://doi.org/10.1089%2Fenv.2015.0015

105 Michele Morrone and Geoffrey L. Buckley, "Mountains of Injustice: Social and Environmental Justice in Appalachia," (2011), https://muse.jhu.edu/book/12495

106 Lara J. Cushing et al., "Historical Red-Lining is Associated with Fossil Fuel Power Plant Siting and Present-Day Inequalities In Air Pollutant Emissions," (2023), https://doi.org/10.1038/s41560-022-01162-y

107 David J. X. Gonzalez et. al., "Historic Redlining and the Siting of Oil and Gas Wells in the United States," (2023), https://doi.org/10.1038/s41370-022-00434-9

108 National Renewable Energy Laboratory, "Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update," (2021), https://www.nrel.gov/docs/fy21osti/80580.pdf

109 Eric O'Shaughnessy et al., "Drivers and Energy Justice Implications of Renewable Energy Project Siting in the United States," (2023), https://doi.org/10.1080/1523908X.2022.2099365

110 Lawrence Susskind et al., "Sources of Opposition to Renewable Energy Projects in the United States," (2022), https://doi.org/10.1016/j.enpol.2022.112922

111 Florian Hanke et al., "Do Renewable Energy Communities Deliver Energy Justice? Exploring Insights From 71 European Cases," (2021), https://doi.org/10.1016/j.erss.2021.102244

112 Vasco Brummer, "Community Energy – Benefits And Barriers: A Comparative Literature Review of Community Energy in the UK, Germany and the USA, the Benefits it Provides for Society and the Barriers it Faces," (2018), https://doi.org/10.1016/j.rser.2018.06.013

113 Alexis S. Pascaris et al., "Integrating Solar Energy with Agriculture: Industry Perspectives on the Market, Community, and Socio-political Dimensions of Agrivoltaics," (2021), https://doi.org/10.1016/j.erss.2021.102023

community empowerment.[114] However, ensuring these positive outcomes requires active and early community engagement.

Green electrolytic hydrogen considerations

The primary concerns with transitioning to green electrolytic hydrogen[115] can be thought of in the context of three aspects of the hydrogen economy as described in Chapter 3. Siting and permitting:

- **Upstream: Production** — Use of water and electricity, placement of facilities with respect to communities and sites of sacred, cultural, or other importance to tribes
- **Midstream: Distribution and Storage** – Environmental, safety, and aesthetic impacts of pipelines and storage facilities, safety of on-road hydrogen transport
- **Downstream: End Uses** — Nitrogen oxides (NOx) emissions/health impacts and other safety concerns around consumer use, and economic burden in the case of potential energy cost increases

Below are four theoretical frameworks that incorporate environmental and energy justice into project development, followed by a discussion of how each could be applied to specific concerns relating to green electrolytic hydrogen.

Interdisciplinary theoretical frameworks

Four interdisciplinary theoretical frameworks can be used to evaluate social justice and equity in project development and integrate environmental and energy justice considerations into the clean fuels industry. The first three approaches propose distinct methods for equitable development, while the fourth synthesizes the three approaches into a single framework. This section outlines each process individually, then considers their commonalities and how they demonstrate what makes a successful, effective environmental and energy justice framework. Table 4.1 summarizes the four frameworks. For a more detailed discussion, see Appendix D.

1. Social Life Cycle Assessment (S-LCA)[116]

- Seeks to optimize social sustainability in every life cycle phase of an energy system, considering social impacts that occur during (1) raw material extraction and processing, (2) manufacturing, (3) electrical power generation, (4) transportation and distribution, and (5) waste management. S-LCA organizes each phase around four groups of stakeholders (workers, electricity consumers, local communities, and society) and then asks questions of each stakeholder category at each lifecycle stage to assess energy justice considerations.

2. Social Framework for Projects[117]

- Offers a holistic, straightforward approach for addressing social issues arising from large projects, especially projects sited in disadvantaged areas that have historically led to population displacement.

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[114] Aparajita Banerjee et al., “Renewable, Ethical? Assessing the Energy Justice Potential of Renewable Electricity,” (2017), https://doi.org/10.3934/energy.2017.5.768

[115] Clean Energy Group, “Hydrogen Areas of Concern,” (accessed August 10, 2023), https://www.cleanegroup.org/initiatives/hydrogen/areas-of-concern/

[116] Marie-Odile P. Fortier et al., Applied Energy, “Introduction to evaluating energy justice across the life cycle: A social life cycle assessment approach,” (2019), https://doi.org/10.1016/j.apenergy.2018.11.022

[117] Eddie Smyth and Frank Vanclay, Impact Assessment and Project Appraisal, “The Social Framework for Projects: a conceptual but practical model to assist in assessing, planning and managing the social impacts of projects,” (2017), https://doi.org/10.1080/14615517.2016.1271539

- Organized, easy-to-understand model enables clear communication with stakeholders and centers “people’s wellbeing,” a term that comprises access to basic human needs, good mental and physical health, the ability to pursue goals and thrive, connection to local community, and general satisfaction with life.
- Can be applied at local, regional, national, and international levels and at all stages of the project cycle.
- Considers both the positive and negative impacts of projects.

3. Three Tenets of Energy Justice[118]

- Incorporates distributional, recognition, and procedural justice to identify where energy injustices occur and develop processes for avoidance and remediation.
- Distributional justice investigates where energy injustices emerge, recognizing injustice in both the physical distribution of impacts, as well as the unequal allocation of the responsibilities for these impacts.
- Recognition justice seeks to understand which sections of society are ignored or misrepresented and promotes fair representation of individuals, equal and complete political rights, and protection from physical threats.
- Lastly, procedural justice considers the ways in which decision-makers engage with communities and promotes the equitable and holistic engagement of stakeholders throughout the development process.

4. Meaningful Energy Development (MED) Framework[119]

- Combines and builds on the three prior frameworks, considering four tenets of energy justice in four social categories across a four-stage life cycle of renewable energy development, providing a comprehensive framework to help developers and policymakers decide which justice concerns to focus on for each stakeholder at each life cycle stage.
- Breaks down an energy system’s life cycle into four stages: (1) design, (2) installation, (3) operations and maintenance, and (4) decommissioning.
- Summarizes the Social Framework chart into four social categories: (1) people, housing and livelihood, (2) community engagement, (3) culture, land and water, and (4) infrastructure and environmental impact.
- Expands the Three Tenets of Energy Justice to include a fourth tenet: restorative justice to assess the environmental or social harm caused by energy projects and consider the costs and responsibility for restoration.

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[118] Kirsten Jenkins et al., Energy Research and Social Science, “Energy justice a conceptual review,” (2016), https://doi.org/10.1016/j.erss.2015.10.004
[119] Mariah D. Caballero et al., Renewable and Sustainable Energy Reviews, “Energy justice & coastal communities: The case for Meaningful Marine Renewable Energy Development,” (2023), https://doi.org/10.1016/j.rser.2023.113491

Table 1. Summary of four interdisciplinary justice-centered frameworks

Framework	Definition	Stakeholders/categories
Social Life Cycle Assessment (S-LCA)	S-LCA reduces environmental and social burdens of energy projects by holistically considering impacts throughout the life cycle of an energy system.	Stakeholders 1. Workers 2. Local Communities 3. Electricity Consumers 4. Society Life Cycle 1. Design 2. Installation 3. Operations & Maintenance 4. Decommissioning
Social Framework for Projects	The Social Framework is a holistic, straightforward model that can guide effective communication with stakeholders (especially impacted communities) and make project planning easier. It focuses on "people's wellbeing" and comprises eight key categories.	1. People's capacities, abilities, and freedoms to achieve their goals 2. Community/social supports and political context 3. Livelihood assets and activities 4. Culture and religion 5. Infrastructure and services 6. Housing and business structures 7. Land and natural resources 8. Living environment
Energy Justice	Energy Justice provides a framework for recognizing where energy injustices occur, developing new processes for avoidance and remediation, and bridging existing and future research on energy production and consumption.	1. Distributional 2. Recognition 3. Procedural

Framework	Definition	Stakeholders/categories
Meaningful Energy Development (MED) framework	MED builds on the three above frameworks, holistically considering four tenets of energy justice in four social categories across the four-stage life cycle of development.	Energy Justice Tenets 1. Recognitional 2. Procedural 3. Distributional 4. Restorative Social Categories 1. People, Housing & Livelihood 2. Community Engagement 3. Culture, Land & Water 4. Infrastructure & Environmental Impact Life Cycle 1. Design 2. Installation 3. Operations & Maintenance 4. Decommissioning

Similarities and best practices

The best practices for incorporating environmental and energy justice into developing renewable energy projects lie in the intersections of these frameworks. No single framework can suffice, as effectiveness could differ based on the project, and one framework could be limiting. The process of incorporating energy justice in project development is challenging, complex, and iterative, and therefore will draw upon different aspects of the frameworks.

Understanding commonalities across the four frameworks reveals the fundamental aspects of an impactful environmental and energy justice framework — effective frameworks rely on whole systems thinking, transparent communication, and meaningful community engagement:

- **Whole systems thinking:** Successful frameworks take a whole systems approach, recognizing that each stage of developing energy projects is interconnected and that justice concerns are ever evolving. A whole systems framework designates potential stakeholders at each stage of the process, from raw material extraction or design to waste management or decommissioning, then outlines and plans for justice considerations at every stage.
- **Transparent communication:** Transparency is at the heart of an effective environmental and energy justice framework and could include straightforward framework presentation; clear and honest communication; and having dedicated personnel available to discuss concerns, risks, and benefits with community members in an effective manner at each stage of the project. Presenting the clearest information possible will be particularly important in the case of hydrogen projects, as hydrogen-based energy is a new concept that can be met with skepticism. Transparency regarding hydrogen projects needs to include communicating risks as well as protection measures. Visually orienting key information about a project or policy around a framework can act as an important foundation for effective stakeholder engagement. Using these kinds of tools, managers can articulate their goals, objectives, and ideas in an understandable, digestible way. In turn, stakeholders are better positioned to ask questions, provide feedback, and work with managers to align priorities. Ensuring that there are knowledgeable and authoritative personnel assigned to answer community questions transparently

through the project's development is as important as having a co-created diagram. These tools are important for empowering stakeholders to participate in engagement opportunities, which can lead to better projects and policies with greater community support and trust.

- **Meaningful community engagement:** Engaging with potentially impacted communities means looking to community members as experts of their own environments and meaningfully involving them in whole-systems decision-making early in the project's life cycle. The Washington 2021 State Energy Strategy emphasizes the critical importance of public and community participation in development and review of energy policy. What community involvement looks like will differ from place to place. It is essential to engage different communities in the ways they find most meaningful. This ensures issues are heard, understood, and addressed before they arise and could potentially avoid the need for remediation further on. However, it can be challenging to engage with communities in meaningful ways that support two-way engagement. As the Washington 2021 State Energy Strategy notes, "Equity is not in and of itself assured through fair and open public meetings. Fair and open public comment sessions do not invite comments from those historically excluded. These voices must be intentionally sought out, respected, empowered and privileged."[120] Meaningful community engagement means not only soliciting tribal citizens' and local community members' input, concerns, and desires from the outset, but also making it as easy as possible for tribes and stakeholders to share their ideas. While workshops and information sessions provide an opportunity for discourse, forums alone do not always result in meaningful engagement, and additional strategies could include: lowering participation barriers by paying individuals to participate; covering transportation or childcare costs during the events; assembling an advisory board that includes local youths, small-business owners, community organizations, and other concerned citizens; or engaging in knowledge exchange through storytelling.

Limitations

All frameworks come with limitations and challenges to consider when applying them, especially when used in tandem. While these theoretical frameworks are a helpful starting point, there are likely aspects of energy project development processes that require unique treatment depending on the community and location. Potential challenges include effectively tracking social, environmental, economic, and other impacts on tribes and stakeholders throughout various stages of the project or policy development process and marrying context-appropriate quantitative and qualitative success metrics for the three pillars of energy justice. Putting these frameworks into practice is inherently complex and requires flexibility, creativity, and close collaboration with tribes, stakeholders and communities.

Applications to green electrolytic hydrogen

The primary environmental and energy justice concerns with the transition to green electrolytic hydrogen can be grouped into the following segments of the hydrogen economy: Production, Distribution and Storage, and End Uses.

Upstream: Production

This report investigates the role of green electrolytic hydrogen in Washington, meaning hydrogen produced through electrolysis powered by renewable energy. The process of electrolysis requires 15 kg of purified water per kg of hydrogen produced.[121] Because clean water is a precious resource with many competing demands, there are concerns about diverting water to produce hydrogen and intensifying water stress in areas where

[120] Washington State 2021 Energy Strategy "A. Build an Equitable, Inclusive, Resilient Clean Energy Economy" WA_2021SES_Chapter-A-Equity.pdf
[121] Philip Woods et al., "The Hydrogen Economy – Where is the Water?" (2022), https://doi.org/10.1016/j.nexus.2022.100123

hydrogen facilities are sited.[122] These concerns about water availability could be addressed with early planning and additional infrastructure, such as reverse osmosis plants to purify water.[123]

Electrolysis is also electricity-intensive, and there are concerns about diverting renewable energy to electrolyzers rather than to direct uses that would offset fossil fuel emissions. These concerns may be less relevant if the IRA hydrogen production tax credit requires additionality by demonstrating the use of "additional" new renewable resources to power electrolysis, as discussed elsewhere in this report (Chapter 1. Green electrolytic hydrogen requirement; Chapter 3. Siting and permitting).

As noted in Chapter 3. Siting and permitting, the solar and wind resources needed to power green electrolysis require a much larger land footprint than the electrolyzers themselves. Therefore, concerns about the production of hydrogen could also include the potential community impacts of siting the renewable energy generation needed. This points to the value of frameworks, such as those described in the previous section, that take into account impacts from the full life cycle of energy project development.

As with any energy project, there are also concerns about siting hydrogen production facilities close to communities that have already experienced disproportionate industrial pollution, especially when considering retrofitting existing fossil hydrogen plants or fossil fuel facilities such as oil refineries. It is therefore important to be aware of and address potential community concerns about continuing legacies of harmful siting of fossil fuel infrastructure.

Tribes also hold unique perspectives and concerns around the upstream aspects of the hydrogen economy. Tribal governments may have concerns about how water diversion for electrolytic hydrogen production impacts legally-protected water rights within and outside of reservation land. Further, tribes may raise questions about how site-specific water use effects ground and surface-water resources they hold environmentally, culturally, and spiritually valuable. For the siting of new hydrogen projects and the renewables that power them, tribes expect to engage in government-to-government relations with state permitting agencies to ensure project placement does not degrade sacred lands. Proactive, sincere, and reciprocal consultation with sovereign tribal nations is important to develop hydrogen projects and policies that address concerns from the start, actively benefit interested tribes, and strengthen relationships.

These concerns point to a general question from many environmental justice groups about whether hydrogen is the right solution, given its cost and resource needs. This sentiment was described in an August 2023 letter urging the U.S. Department of Energy to reject applications for hydrogen hub funding because large-scale hydrogen development, regardless of its power source or end use, would "further exacerbate the climate crisis and disproportionately harm people of color, low-income communities, and Indigenous peoples."[124]

Midstream: Distribution and storage

After producing hydrogen, it must be transported and/or stored, which brings up infrastructure-related safety concerns. Options for transporting hydrogen include pipelines (either hydrogen-specific pipelines, or blending with natural gas; generally for higher volumes) or trucks (for lower volumes).

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[122] K&L Gates LLP, "Water Resource Considerations for the Hydrogen Economy," (2020), https://www.jdsupra.com/legalnews/water-resource-considerations-for-the-84603/

[123] Philip Woods et al., "The Hydrogen Economy – Where is the Water?", (2022).

[124] "Re: Don't believe the "Hydrogen Hype" - Reject all applications for Department of Energy Regional Clean Hydrogen Hubs (H2Hubs) funding (DE- FOA-0002779)," (2023), https://www.biologicaldiversity.org/programs/climate_law_institute/pdfs/National-Hydrogen-Letter-8_22_23.pdf

There are safety risks to consider with the use of pipelines, especially when blending hydrogen into existing natural gas infrastructure above safe limits. For analysis purposes, the modeling in *Green Electrolytic Hydrogen and Renewable Fuels: Recommendations for Deployment in Washington* uses an industry assumption of 20% by volume/7% by energy.[125] However, because the gas system is made up of many different assets of various materials and vintages, individual segments of the gas system may have different capabilities. There is ongoing research and development in this area; regardless, there is a clear relationship between higher blends of hydrogen in the pipeline and increased risk.[126,127] Risks include hydrogen embrittlement, which occurs when hydrogen that is pumped through steel pipeline diffuses through the steel alloy and causes cracks.[128,129]

Existing natural gas pipeline infrastructure is therefore largely unsuitable for transporting and storing hydrogen without costly upgrades. Additionally, hydrogen leaks can add to the risk of explosion, as hydrogen is a highly flammable gas.[130] To mitigate risk and transport hydrogen safely, existing steel gas pipeline infrastructure would need to be replaced, at significant cost. Even in new pipelines designed for hydrogen, developers and policymakers need to be careful to ensure safety, employing leak detection technology and ongoing monitoring.[131]

Since hydrogen blending is relatively new, it raises significant concerns about safety and cost for local communities. Last year, after local opposition from environmental groups, Oregon gas utility Northwest Natural withdrew its application for a renewable hydrogen pilot project that would have involved injecting the resulting hydrogen into its gas supply lines.[132] One of the opposing groups called out the company for being potentially willing to treat residents as "guinea pigs" for the emerging technology. This position represents a common concern of local communities.[133]

In addition to safety risks with hydrogen blending, there are concerns about extending the lifetime of fossil fuel infrastructure and systems if continuing to use the existing natural gas distribution network. Further, communities may hold generalized, negative associations between hydrogen infrastructure and that which is reminiscent of the fossil fuel industry, pipelines in particular. The over-arching perception that this kind of distribution infrastructure is tied to negative environmental and social impacts is a challenge the hydrogen industry will have to overcome as it grows.

Safety concerns apply to hydrogen storage, as well. While salt caverns may be a safer option for hydrogen storage, these only exist in certain parts of the country (and not in Washington).[134] Therefore, gas and liquid tank storage will likely be the main in-state options for storing hydrogen, especially in the near term. This may

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125 M.W. Melaina et al., "Blending Hydrogen into Natural Gas Pipeline networks: A Review of Key Issues," (2013), https://www.nrel.gov/docs/fy13osti/51995.pdf
126 The California Public Utilities Commission, prepared by University of California Riverside, "Hydrogen Blending Impacts Study," (2022), https://docs.cpuc.ca.gov/PublishedDocs/Efile/G000/M493/K760/493760600.PDF
127 Pipeline Safety Trust, "Report: Safety of Hydrogen Transportation by Gas Pipelines, Summary for Policymakers," (2023), https://pstrust.org/wp-content/uploads/2023/01/hydrogen_pipeline_safety_summary_1_18_23.pdf
128 Yukitaka Murakami, "Hydrogen Embrittlement," (2019), https://doi.org/10.1016/B978-0-12-813876-2.00021-2
129 Mariano A. Kappes and Teresa E. Perez, "Blending hydrogen in existing natural gas pipelines: integrity consequences from a fitness for service perspective," (2023), https://doi.org/10.1016/j.jpse.2023.100141
130 Pipeline Safety Trust, "Report: Safety of Hydrogen Transportation by Gas Pipelines, Summary for Policymakers," (2023).
131 Ibid.
132 Steve Ernst, Clearing Up, "NW Natural Pulls Plug on Hydrogen Pilot Over Local Objections," (2022), https://www.newsdata.com/clearing_up/supply_and_demand/nw-natural-pulls-plug-on-hydrogen-pilot-over-local-objections/article_e187c8b4-5c73-11ed-8bd6-8fecc3d278e8.html
133 Adam Duvernay, The Register Guard, "NW Natural cancels west Eugene hydrogen blending project," (2022), https://www.registerguard.com/story/news/2022/11/02/nw-natural-cancels-west-eugene-hydrogen-blending-project/69612987007/
134 Dilara Gulcin Caglayan et. al., "Technical potential of salt caverns for hydrogen storage in Europe," (2020). International Journal of Hydrogen Energy, Volume 45, Issue 11.

bring up concerns about the risk of explosions, which can potentially be addressed with proper safety measures, protocols, and monitoring.

Downstream: End uses

Hydrogen can be used for many different end uses, some of which bring up serious health, safety, and environmental/energy justice concerns.

Nitrogen oxides (NOx) are at the forefront of environmental justice concerns for frontline communities. When hydrogen is used in a fuel cell, its only products are electricity, water, and heat.[135] However, the combustion of hydrogen in a gas turbine can lead to NOx emissions up to six times more than methane combustion.[136] NOx emissions can increase vulnerability to respiratory infections, asthma, and lead to environmental effects such as acid rain, hazy air, and nutrient pollution in coastal waters.[137] There are existing air pollution controls to limit NOx emissions in gas turbines, but there are still questions and additional research needed on applying this technology to control NOx emissions in hydrogen-powered combustion turbines.

While concerns about NOx emissions from hydrogen combustion are serious and should be addressed when considering the role of hydrogen, the modeling for this analysis (see Chapter 1. Green electrolytic hydrogen requirement) does not show significant use of hydrogen combustion for electricity generation, although that does not mean that there will not be any in Washington.

Hydrogen boilers for industrial uses are another use of hydrogen that involves combustion and may produce harmful NOx emissions. The modeling for this analysis does not find this to be an economic use of hydrogen (see Chapter 1. Green electrolytic hydrogen requirement). However, as noted in Chapter 3. Siting and permitting, individual project economics can support end uses that may not be economic in system-wide analyses, and it will be important to address the health concerns connected to NOx emissions in any project applications, particularly if the combustion is sited close to population centers.

The modeling in this report assumes that hydrogen boilers will use 100% hydrogen delivered with new dedicated infrastructure (either pipelines or trucks), as opposed to blended hydrogen and natural gas delivered via the existing natural gas pipeline networks. Additional uses of hydrogen in the modeling performed for this report largely do not involve combustion, such as conversion processes to produce clean fuels or direct use in fuel cell vehicles.

Another justice concern about end uses is the disproportionate economic burden that a switch to renewable energy will create for low-income communities. As higher-income households that can afford clean energy make the transition, utility companies will shift upkeep costs to the remaining low-income customers.[138] This concern is not unique to green electrolytic hydrogen, but it could arise if hydrogen is used as a substitute for natural gas. Without energy affordability protections, low-income households will experience the highest burdens on top of the elevated energy burden they already face: In Washington, communities with more

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[135] U.S. Department of Energy Office of Energy Efficiency & Renewable Energy, "Fuel Cells," (accessed August 31, 2023), https://www.energy.gov/eere/fuelcells/fuel-cells

[136] Mehmet Salih Cellek and Ali Pinarbasi, "Investigations on performance and emission characteristics of an industrial low swirl burner while burning natural gas, methane, hydrogen-enriched natural gas and hydrogen as fuels," (2017), https://doi.org/10.1016/j.ijhydene.2017.05.107

[137] U.S. Environmental Protection Agency, "Basic Information about NO_2," (accessed August 31, 2023), https://www.epa.gov/no2-pollution/basic-information-about-no2

[138] Climate and Clean Energy Equity Fund, "Hydrogen Gas: A False Promise," (2022), https://static1.squarespace.com/static/5fb58e0bd182a42ba80eabdd/t/62ed51f3fe9eba2d0507795b/1665523209054/CCEEF_Hydrogen+Gas+Policy+Brief_April+2022.pdf

individuals living in poverty have a median energy burden three times higher than communities with fewer individuals living in poverty.[139]

Appliances would also need to be replaced if hydrogen is used instead of natural gas, as appliances built to run on natural gas would not be able to run on hydrogen.[140] As mentioned previously, there is also the risk of explosions, both along pipelines and in homes, if hydrogen were to be used for heating a home. The modeling in the report assumes hydrogen can be blended with natural gas in the existing natural gas pipeline network up to 7% by energy or 20% by volume but does not allow dedicated hydrogen appliances in buildings. In addition to the health and safety risks, research shows that using hydrogen for residential heating is less economical, less efficient, more resource intensive, and associated with larger environmental impacts than other clean energy heating methods such as heat pumps.[141]

Consumers may also have concerns related to the cost of ownership and convenience of owning a hydrogen fuel-cell passenger vehicles. Hydrogen powered light-duty cars are in the very early stages of adoption in the United States. As of 2022, there are zero fuel cell electric vehicles registered in Washington and no publicly-available hydrogen refueling stations.[142] California has fifty-nine of the sixty publicly-available hydrogen fueling stations in the US (the other being in Hawaii) and, therefore, represents the most developed domestic FCEV market.[143] There, light-duty FCEV owners have experienced challenges around fluctuating fuel costs and both the accessibility and availability of refueling stations.[144,145] The California case study highlights potential consumer-facing energy justice issues in the FCEV market, which may cause concern for future zero-emission vehicle buyers.

Decommissioning

In addition to the areas listed above, there may also be environmental and energy justice concerns around the decommissioning of hydrogen production facilities and related infrastructure. Current permitting processes already require plans for decommissioning, and any environmental/energy justice community engagement process should address concerns around this life cycle stage as well.

While it may seem appropriate to look to lessons from decommissioning natural gas infrastructure, the challenges there largely revolve around the distributed nature of the natural gas network, which will not be as much of a concern with dedicated hydrogen infrastructure, assuming that a dedicated hydrogen distribution network is not built to serve residential and commercial buildings. It will be important to define responsibility for decommissioning hydrogen projects from the outset to mitigate negative impacts down the road. The lens

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139 U.S. Department of Energy, "Low-income Energy Affordability Data Tool," (2018), https://www.energy.gov/scep/slsc/lead-tool
140 Frazer-Nash Consultancy, "Appraisal of Domestic Hydrogen Appliances," (2018), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/699685/Hydrogen_Appliances-For_Publication-14-02-2018-PDF.pdf.
141 Jan Rosenow, "Is heating homes with hydrogen all but a pipe dream? An evidence review," (2022), http://dx.doi.org/10.1016/j.joule.2022.08.015.
142 U.S. Department of Energy, "Washington Transportation Data for Alternative Fuels and Vehicles", (2023), https://afdc.energy.gov/states/wa
143 Hydrogen Fuel Cell Partnership, "By the Numbers: FCEV Sales, FCEB, & Hydrogen Station Data", (2023), https://h2fcp.org/by_the_numbers
144 Hydrogen Insight, "Analysis: It is now almost 14 times more expensive to drive a Toyota hydrogen car in California than a comparable Tesla EV", (2023), https://www.hydrogeninsight.com/transport/analysis-it-is-now-almost-14-times-more-expensive-to-drive-a-toyota-hydrogen-car-in-california-than-a-comparable-tesla-ev/2-1-1519315
145 Hydrogen Insight, "Almost half of California's hydrogen filling stations offline after H2 supply 'disruption'", (2023), https://www.hydrogeninsight.com/transport/almost-half-of-california-s-hydrogen-filling-stations-offline-after-h2-supply-disruption/2-1-1526923

of restorative justice, which considers a project's potential harm to people and environments as well as the associated costs and reparations, can be helpful here.

Applying frameworks

To recognize and remediate the past and present social and environmental impacts of both non-renewable and renewable energy production and to avoid future inequality, it is necessary to use a whole system environmental and energy justice framework, such as those suggested in this chapter. It is crucial to acknowledge and embrace the interdependence of ecosystems, living beings, and infrastructure. To navigate this complexity, using one or more of the frameworks to engage tribes and stakeholders and address issues of environmental and energy justice.

The S-LCA framework can help provide a framework for considering the perspectives of different tribes and stakeholders across the upstream, midstream, and downstream phases of the hydrogen energy system. For example, S-LCA could be used to organize tribes and stakeholders from hydrogen project design through decommissioning around specific questions, including ones about social or environmental impacts at each life cycle stage. Additionally, the S-LCA framework can provide an organizational structure around which energy governance agencies can plan, implement, and assess new policies and programs.

The Social Framework for Projects offers a model for developer collaboration with tribal citizens and community stakeholders, ideally in a workshop setting, that could take place before the production phase even begins. The developers would present the model to the community, facilitating discussion while making it transparent to tribes and stakeholders that they intend to understand and address the potential impacts raised. The Social Framework helps clarify priorities and fosters positive developer-community relationships, making environmental and energy justice participatory and accessible.

Recognitional justice can be applied to hydrogen siting by recognizing and addressing the concerns of affected communities, such as those in close proximity to proposed hydrogen facilities, rather than ignoring or fighting against dissenters. Working directly with tribes and stakeholders, especially from the outset and during the decision-making process, could ensure tribal and community members' voices are heard and respected. Procedural justice, which considers the ways in which decision-makers engage with communities, would promote equitable engagement of tribes and stakeholders from the very beginning and throughout the development process.

Distributional justice investigates where energy injustices emerge, recognizing injustice in both physical distribution of impacts, as well as unequal allocation of responsibilities for these impacts. In the case of hydrogen siting, distributional injustice could concern the proximity of disadvantaged communities to harmful NOx emissions or risky hydrogen embrittlement. Alternatively, it could involve the inequitable economic burden a hydrogen transition could place on lower-income households in an impacted community.

Lastly, the addition of restorative justice in the MED framework would consider a hydrogen project's potential environmental and social harms (such as the health and safety concerns listed above), as well as associated costs, from the outset of the development through the midstream and downstream phases. Restorative justice would aim to both mitigate harm and bring benefits, such as economic development, along with proposed hydrogen projects. The MED framework would consider the various social categories impacted across the life cycle phases and promote justice throughout each life cycle stage.

For a list of community engagement topics/questions to consider throughout the life cycle of a project, see the list of guiding questions from the MED framework (Appendix F), which can be adapted from marine renewable energy to apply to green electrolytic hydrogen. The MED guiding questions should not be used as a simple checklist; rather, as the MED framework authors state, "the list of questions is intended to facilitate conversation and support delving further into each project's nuances to help developers, researchers, regulators, community members, and other stakeholders identify shared priorities."[146]

Conclusion

Demand for clean energy is expected to rise precipitously in the coming decades to decarbonize economies as required to address the climate crisis. However, the need for rapid development of clean energy should not result in replicating past and present injustices from prior energy development.

While cleaner than fossil fuel, green electrolytic hydrogen development poses unique dangers to humans and the environment, including the health and safety risks of NOx emissions and hydrogen embrittlement, depending on its application. It also carries justice concerns associated with all energy development, such as unequal economic burden and harm to people's wellbeing. To ensure the equitable distribution of the burdens and benefits of green hydrogen production, developers and policymakers must organize and assess all justice concerns for all tribes and stakeholders at all development stages.

Using environmental and energy justice frameworks such as the Social Life Cycle Assessment, the Social Framework for Projects, the Three Tenets of Energy Justice, or the MED Framework, will help decision-makers determine considerations, priorities, and plans for ensuring equitable development. Next steps for incorporating environmental/energy justice into green electrolytic hydrogen development in Washington should include creating a community engagement topic/question list, such as the example shown in Appendix F, focused on potential impacts of hydrogen and drawing from these four frameworks.

The best practices for incorporating environmental and energy justice into developing clean fuels industries, as determined by the intersection of these four frameworks, include whole systems thinking, transparent communication, and meaningful community engagement. Equitable development must begin with and maintain a holistic, straightforward, and authentic approach through the entire life cycle of a project.

[146] Mariah D. Caballero et al., Renewable and Sustainable Energy Reviews, "Energy justice & coastal communities: The case for Meaningful Marine Renewable Energy Development," (2023).

Chapter 5. Recommendations

Contextualizing Commerce's recommendations

In order to approach hydrogen advancement strategically and support a robust market for green electrolytic hydrogen and renewable fuels, there should be a strategic approach building off the Phases of Advancing Hydrogen described in Chapter 2, which should include supportive actions and investments from the state as well as other actors.

It is important to note that the analysis and associated recommendations in this report do not propose a single pathway toward green hydrogen deployment. Our modeling does not provide specificity on the exact locations or scale of green hydrogen and renewable fuel deployment needed, or suggest that large centralized production processes and transportation systems are the primary path forward. The findings do suggest that hydrogen production and use should be developed in coordination to align supply and demand in key sectors and renewable electricity systems, and this will likely involve numerous localized production opportunities, some serving on-site demand and other operations providing fuels for more distributed use. The pathway to a net-zero economy supported by green hydrogen and renewable fuels will continue to evolve as new actors come to the table, technologies evolve, costs reduce, and communities contribute to siting and permitting as well as community benefits planning, to ensure the green hydrogen economy helps to advance community priorities.

As Washington, tribal nations, the Legislature, and other stakeholders work to advance a green hydrogen economy, several factors should be considered including:

- Federal funding - what resources are known to be coming to Washington projects and what resources projects in this state may be a strong candidate to receive. The recent announcement of DOE's intention to negotiate and, ideally, fund a Pacific Northwest Hydrogen Hub will change the funding and infrastructure landscape in the state. Final project and budget details should be carefully evaluated to determine how they will support state priorities and what gaps remain.
- State funding - where there are gaps in federal incentives and grants for Washington's hydrogen economy that the state should seek to fill. This should be considered strategically based on production and end uses that align well with the anticipated strategic end uses identified in this report, the DOE National Hydrogen Strategy and Roadmap, and related analysis.
- State policy and planning landscape - opportunities to amend existing or add new state policies that can support the goals outlined in this report. Several are discussed below.
- Regional partnerships - identifying opportunities to work collaboratively to advance hydrogen and renewable fuels partnerships with neighboring jurisdictions, including Oregon, Idaho, Montana, British Columbia, and other areas through Clean Hydrogen Hubs efforts, coordinated regional transportation, storage, or use of hydrogen, regional power and clean fuel planning efforts such as the Northwest Power and Conservation Council (NWPCC), Pacific Coast Collaborative (PCC), Western Green Hydrogen Initiative (WGHI), and others.
- Equity and environmental justice and an equitable distribution of benefits, including opportunities to direct benefits to tribes, overburdened communities, rural communities and more.
- Local stakeholder perspectives and opportunities to create multiple benefits, with an emphasis on opportunities that help to advance local climate and clean energy strategies, economic development strategies, tribal energy priorities, and related goals.

The modeling and recommendations in this report need to be disseminated widely and incorporated in discussions and planning processes with many stakeholders, including the Legislature, hydrogen industry representatives, utilities, tribes, unions, and community organizations among others. Commerce recommends that a robust review and planning process follow the submission of this report, to support the development of a comprehensive policy and funding package for consideration in 2025 legislative session. If advanced as agency request legislation, an Environmental Justice Assessment will also be conducted.

Policy and funding recommendations

While a longer-term planning process will be needed to fully refine a list of relevant state investments, the following actions and opportunities are recommended for consideration. There are seven high level recommendations, each followed by specific sub-recommendations. Those items that are planned for inclusion in Commerce's 2024 Decision Package are noted.

Additional recommendations will be refined with input from the legislature, partners, and the public after submission of this report. We expect to refine and introduce additional policy and budget recommendations in the 2025 legislative session.

1. Support and seek to accelerate in-state green electrolytic hydrogen production

- **1.1 Set a state target for in-state green electrolytic hydrogen production of 4.5 GW by 2035 with a stretch goal of 4.5 GW by 2030.**
- **1.2 Help green hydrogen producers access the 45V Production Tax Credit.**
- **1.3 Use existing and consider new incentives to support electrolyzer production and use in Washington.**
- **1.4 Evaluate and promote safe and efficient hydrogen storage, including evaluating underground storage opportunities.**

Context: This report demonstrates that electrolyzer deployment must advance rapidly from a near-zero baseline to significant levels of in-state production of green electrolytic hydrogen. The following sub-recommendations will help to achieve this aim.

- **1.1 Set a state target for in-state green electrolytic hydrogen production of 4.5 GW by 2035 with a stretch goal of 4.5 GW by 2030.**

Washington needs to rapidly advance from close-to-zero production of green electrolytic hydrogen to significant levels in the coming decades. The modeling in this report finds Washington should deploy install 0.8 gigawatts (GW) of electrolysis capacity and produce 200,000 metric tons (MT) per year of hydrogen by 2030, and 4.5 GW of electrolysis and 700,000 MT per year of hydrogen by 2035. In order to use this modeling to set clear market direction, the state could establish a target in statute to deploy 2.5 GW of electrolyzer capacity by 2035 with a stretch goal of accelerating this to 2030.

Accelerating deployment to 2030 would be an optimistic policy and could be difficult to achieve; however, it would take advantage of the IRA incentives that are available now and anticipated H2Hub funding. Building electrolyzers earlier could help prevent against the policy risk that the incentives are removed with a change in administration or for other reasons. The state can work with partners to promote relevant incentives already established in state law to support manufacturing of electrolyzers, such as the tax deferrals and incentives (which increase in value when certain labor standards are achieved).[147] Consideration of additional incentives,

[147] These tax deferrals and incentives are established in Chapter 185, Laws of 2022.

such as for research, development, and deployment of new and improved electrolyzers may be appropriate. The state should consider the need to strike a balance in cost-effectiveness alongside the speed at which Washington can develop a competitive hydrogen economy.

- **1.2 Help green hydrogen producers access the 45V Production Tax Credit.**

One of the most critical factors making production of green hydrogen cost-effective is the new 45V Production Tax Credit (PTC), included in the IRA. The final rules from the US Treasury are pending at the time of publication, and prospective producers are watching closely to see the final guidelines, especially in relation to how issues such as additionality, regionality, and hourly matching are included, if at all. Regardless of details, accessing the highest credit levels will likely require demonstration of environmental attributes of electricity and navigating electricity and utility planning, distribution, and related systems. State bodies including the state Energy Office at the Department of Commerce can provide assistance to understand and navigate these systems. Commerce is also seeking funding and authorization from the legislature to build out broader programs to help Washington-based entities access tax credits that align with the State Energy Strategy, and 45V access can be included in these efforts. This may include tax guidance, legal support, and other approaches, with a focus on supporting access in underserved communities.

- **1.3 Use existing and consider new incentives to support electrolyzer production and use in Washington.**

The state has already passed important incentives for the manufacturing of certain clean energy infrastructure including electrolyzers. Critical sales and use tax deferrals and incentives were established in Chapter 185, Laws of 2022. Working to raise awareness of these incentives with electrolyzer manufacturers considering establishing operations in Washington may help to accelerate progress. For projects where the incentivized labor standards are achieved, procurement from and contracts with women, minority, or veteran-owned businesses, or apprenticeship utilization standards, will also help to advance good, family-wage jobs in the clean energy economy.

- **1.4 Evaluate and promote safe and efficient hydrogen storage, including evaluating underground storage opportunities.**

Production of hydrogen at scale will rely on safe and cost-effective storage opportunities. Studying and providing recommendations about these topics will be important to help support green hydrogen production and use. Some regions in the US have access to salt caverns, which provide safe and cost-effective storage at scale, but there are no such salt caverns in Washington. The state can support a better understanding of what large-scale storage options are available by conducting a feasibility study investigating underground hydrogen storage in Washington. This may involve collaboration with Washington State Department of Natural Resources and the Washington Geological Survey to evaluate hard rock formations and other geologic regions that might be candidates for storage. This analysis would require a strong community engagement component and seek to advance storage projects that align with environmental justice priorities with community support.

2. Provide targeted state support for green hydrogen in strategic end uses

- **2.1 Clearly identify and direct state and federal investments and incentives to strategic end use sectors.**
- **2.2 Fund pilot and demonstration projects.**
- **2.3 Provide technical assistance to support market development in strategic sectors.**
- **2.4 Support access to DOE H2Hubs Demand-side Initiative as part of H2Hubs implementation.**
- **2.5 Work with refineries to replace in-state fossil-derived hydrogen with green electrolytic hydrogen.**

- **2.6 Evaluate policy options that will accelerate production and use of renewable Fischer-Tropsch liquid fuels and reduce statewide transportation emissions.**
- **2.7 Direct hydrogen initiatives and investments for on-road hydrogen use to the most strategic vehicle types and corridors.**
- **2.8 Support efforts to deploy hydrogen, ammonia, and other renewable fuels as part of decarbonizing maritime fuels and operations.**

Context: State resources will be used most effectively when they are targeted to advance hydrogen use in strategic sectors of the economy that will provide opportunities for the highest and best use of both hydrogen and the renewable resources used to produce it. While, as discussed in recommendation 2.1 below, additional discussion will be valuable to refine an articulation of the most strategic hydrogen end uses in Washington, the following information is offered for consideration based on modeling data and staff analysis.

Transportation sector: The modeling in this report demonstrates significant demand for hydrogen in certain transportation uses, particularly maritime, aviation, and on-road transportation. The vast majority of the demand is anticipated to be in the form of Fischer-Tropsch liquid fuels and ammonia, with smaller levels of demand for hydrogen gas used in fuel cell vehicles. For example, in 2030, the modeling suggests over 90% of Washington's demand for hydrogen products will be for liquid fuels (FT liquids and ammonia), compared to use of hydrogen gas. Identifying the best fuels for such transportation types and routes, and how to supply the hydrogen-derived liquid fuels and ammonia will be an important task for stakeholders and the state to tackle. Many public-private partnerships exist to help with planning and market development, including the Alternative Jet Fuels Work Group for sustainable aviation fuel, and Washington Maritime Blue for sustainable marine fuels.

Regarding on-road vehicle and hydrogen fuel, the modeling and projections made in the Transportation Electrification Strategy (2023) that contributed to the analysis in this report, shows low expected uptake in hydrogen fuel cell light- and medium-duty passenger vehicles. However, more significant opportunities in transit buses and heavy-duty vehicles are expected, starting in 2029 but especially in the 2035-2050 timeframe. There are additional opportunities to explore where green hydrogen could play a valuable role in decarbonizing heavy-duty transportation, such as hydrogen internal combustion engine (ICE) vehicles. Entities like US DOE are advancing research around these vehicles.[148] Some local companies such as Westport have prototype hydrogen ICE vehicles, and others are under development. Hydrogen ICE trucks have a potential market due to having very low carbon emissions at the tailpipe[149], but the lifecycle emissions are this low only if the hydrogen is produced and transported without using fossil fuels. Such vehicles can be produced through retrofitting existing diesel vehicles rather than needing to be purchased new, and can provide lower operating costs. However, hydrogen ICE vehicles are not classified as zero-emission vehicles under standards such as California's Advanced Clean Trucks program, which may limit their uptake in the market.

Chemical processes: The primary sector where hydrogen is used today in Washington as is a chemical feedstock in certain industrial process, especially in the five refineries in Washington. Replacing gray, fossil-derived hydrogen with green hydrogen will make a direct reduction in Washington's current GHG emissions and is a no-regrets opportunity for green hydrogen use. We discuss this further in 2.5 below.

Additionally, hydrogen is a feedstock in other industrial processes such as fertilizer production. The modeling in this report does not highlight extensive opportunities for green ammonia for use in green fertilizer

[148] US DOE, February 2023. "Overview of Hydrogen Internal Combustion Engine (H2ICE) Technologies." https://www.energy.gov/eere/fuelcells/february-h2iq-hour-overview-hydrogen-internal-combustion-engine-h2ice-technologies.
[149] Ales Crna, Sandia National Lab (2023). Are H2ICEs Viable for Medium and Heavy-Duty Trucks. https://www.hydrogen-expo.com/2023-agenda/hice-viable-medium-heavy-duty-trucks. Accessed 10/6/2023.

production in Washington, though it does identify demand for ammonia production for maritime fuels. However, there are presently companies proposing to produce green fertilizer in Washington, which may indicate that certain circumstances on the ground in Washington provide even greater opportunities than the modeling has identified.[150] These types of uses to help decarbonize existing fertilizer production and use, especially in a state like Washington with a strong agricultural sector, hold promise.

High heat industrial processes: Opportunities for high-heat industrial processes that cannot readily be electrified should be encouraged to explore use of hydrogen as a fuel, as part of a broad and technology-neutral exploration of the best decarbonization opportunities. This could be valuable especially for the state's industrial facilities that are classified as Emissions-Intensive, Trade-Exposed (EITE) industries under the state's Climate Commitment Act, which are covered entities with emission reduction requirements though receive no-cost allowances for the majority of their emissions at present to help avoid displacing these facilities to other regions and simply moving emissions and jobs to other jurisdictions. The state will be working with these industries to help identify reduction and allowance pathways for future years, through efforts such as an Ecology-convened EITE work group (forthcoming). It would be valuable for agencies like Commerce's Office of Renewable Fuels to work in coordination with these EITEs and with Ecology, to support studies and potentially capital grants or other activities that could help lead to cost-effective use of renewable fuels in these high-heat processes.

Power sector: Opportunities to use hydrogen to support a reliable power sector supported by renewable electricity are important considerations for Washington, especially in the context of requirements under the Clean Energy Transformation Act. The modeling in this report demonstrates limited but important power generation uses emerging in the coming decades (2040-2050) These small levels of hydrogen could have significant impacts on supporting a clean and reliable grid and avoiding the need for natural gas-fired peaking capacity (power plants that are run only in periods of peak electricity demand). Ideally this would focus on generation of electricity using a hydrogen fuel cell or using a combustion turbine operating no more than 500 hours per year, with the hydrogen produced earlier using surplus renewable generation. A demonstration project related to peak shaving, or hydrogen use to reduce demands on the grid at peak power use hours which could reduce demand for gas-fired production of electricity, in the Okanogan region may provide useful lessons and further demonstration projects of this type may prove valuable.[151] The feasibility and environmental impacts of using hydrogen in combustion turbines will require further technical developments, tests, and demonstrations. In particular, the ability to abate NOx emissions associated with hydrogen combustion is key. It would be valuable for Commerce and other partners including utilities, national labs, communities and others to further research and support testing and demonstration of strategic power sector uses.

- **2.1 Clearly identify and direct state and federal investments and incentives to strategic end use sectors.**

The initial step to support these recommendations is to more formally articulate the most strategic end use sectors for green hydrogen and renewable fuels in Washington as part of efficient decarbonization pathways. The end use demand sectors identified in this report provide a valuable starting point for consideration, and they largely mirror the "strategic, high impact uses" identified in documents such as the US Clean Hydrogen Strategy and Roadmap, including industrial processes and high-heat industrial needs, key transportation

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[150] "WA Gov. Jay Inslee praises 1st-of-a-king 'green' fertilizer plant in Richland." Annette Cary and Wendy Culverwell, Tri-City Herald, 12/12/2023. https://www.tri-cityherald.com/news/local/article282843718.html Accessed 12/19/2023.
[151] Washington State Capital Budget SB 5200, section 1035. https://lawfilesext.leg.wa.gov/biennium/2023-24/Pdf/Bills/Session%20Laws/Senate/5200-S.SL.pdf

sectors, and energy storage and electricity generation.[152] With further input from stakeholders, strategic sectors can be articulated clearly in policy or statute, which should inform state funding decisions.

- **2.2 Fund pilot and demonstration projects.**

Many proposed uses for hydrogen have sufficiently advanced technology to be ready to move to demonstration, but additional testing to refine operations or to help generate public awareness and trust in these opportunities may be valuable. The state should consider funding pilot and demonstration projects particularly in areas identified in this report as likely end uses. Examples include hydrogen storage for use in backup power generation, which can replace diesel backup generators, or demonstrations of hydrogen and renewable fuel use in maritime vessels.

- **2.3 Provide technical assistance to support market development in strategic sectors.**

Several sectors that may be defined as strategic end uses are not expected to come to scale until the 2040-50 timeframe based on this modeling. However, it may take many years to conduct the analysis and identify the resources needed to invest in hydrogen and renewable fuels.

- **2.4 Support access to DOE H2Hubs Demand-side Initiative as part of H2Hubs implementation.**

DOE announced that $1 billion will be made available for demand-side initiative to support the H2Hubs program. The initiative will work to ensure that both producers and end users in the H2Hubs have sufficient market certainty during the early years of production to access private investment and achieve commercial liftoff.[153] The state can work with the PNWH2 and potential demand-side actors identified as priorities for the state, and provide match funding through in-kind support or direct funding to help access these resources.

- **2.5 Work with refineries to replace in-state fossil-derived hydrogen with green electrolytic hydrogen.**

The primary sector where hydrogen is used today in Washington as is a chemical feedstock in certain industrial process, especially in the five refineries in Washington. Results from the analysis in this report show that there is a near-term opportunity to displace fossil-generated hydrogen produced through steam methane reforming (SMR) in Washington with green electrolytic hydrogen. Displacing existing hydrogen SMR production with electrolysis is expected to be cost-effective by 2025. Washington should aim to replace all the existing fossil-derived hydrogen with green hydrogen in the near term, especially to take advantage of the IRA incentives while they are in place.

This recommendation to replace fossil-derived hydrogen is particularly applicable to the extent that refineries are currently producing hydrogen through steam methane reforming. However, in some cases hydrogen is produced as a by-product of other processes within a refinery, such as naphtha production. In these cases, it will be more costly to choose to produce or buy green hydrogen when hydrogen is already available on site, albeit from fossil-generated processes. The state should work closely with refineries to identify those circumstances and consider ways to support the decarbonization of the on-site hydrogen production and use.

While working with refineries to transition to use of green electrolytic and renewable hydrogen, the state can also support the assessment of related opportunities at existing refinery sites or other industrial lands. This could include assessing opportunities to repurpose existing refineries for Fischer-Tropsch (liquid fuels

[152] US DOE (2023), US Clean Hydrogen Strategy and Roadmap, pg 29-35.
[153] Biden-Harris Administration to Jumpstart Clean Hydrogen Economy with New Initiative to Provide Market Certainty And Unlock Private Investment | Department of Energy. Accessed 10/20/2023.

including alternative jet fuel) or Haber-Bosch (ammonia production) process and production, if delivery of hydrogen to the site is not cost prohibitive.

- **2.6 Evaluate policy options that will accelerate production and use of renewable Fischer-Tropsch liquid fuels and reduce statewide transportation emissions.**

There is still much uncertainty around hydrogen production, including the cost of production, the feasibility of building out the infrastructure, the mechanism of receiving IRA incentives, and the availability of IRA incentives. However, Washington must decarbonize fuels in transportation to meet the 2030 emissions targets. This makes the market size for Fischer-Tropsch liquids relatively consistent across scenarios, providing generalized support for target setting.

A target that encourages off-takers - or customers and users of these fuels - to use hydrogen-derived fuels (Fischer-Tropsch liquids) could help develop a market for hydrogen. Washington should consider establishing a target for clean fuel procurement by 2030. By setting demand-side targets for carbon content in fuels, Washington remains agnostic to the geographic origins and agnostic to technology as long as it qualifies for the Clean Fuel Standard (CFS). This provides producers with certainty that an off-taker will exist.

Additional policy options should be evaluated with further input from the Washington State Department of Ecology's CFS program and other stakeholders to assess opportunities that could support these aims.

- **2.7 Direct hydrogen initiatives and investments for on-road hydrogen use to the most strategic vehicle types and corridors**

In terms of on-road transportation uses, the modeling and projections made in the TES which were included in and built upon in this report to extend analysis to 2050, show that demand for hydrogen fuel cell transit buses and heavy-duty vehicles is anticipated to be a moderate demand sector, especially after 2035, which was modeled as part of this report. With this in mind, the state should only direct further subsidies for fueling stations to vehicle classes and/or routes where hydrogen is clearly the superior form of clean energy carrier, and in the years leading up to when this economic viability is expected. This will enable state resources to be directed to more strategic uses where demand is expected. Transit agency investments are expected to demonstrate value in key routes where agency analysis shows hydrogen buses will support efficient and reliable zero-emission operations. WSDOT is slated to receive roughly $40 million per biennium to fund zero-emission transit buses, which already includes hydrogen fueling infrastructure and fuel cell buses. For example, Thurston County's Intercity Transit is receiving $6.9 million through the program for a green hydrogen fuel cell electric bus demonstration project.

Where specific opportunities for hydrogen fuel cell vehicles are identified in the heavy-duty and transit spaces, it could be beneficial for the state to explore opportunities to support regional planning and strategic H2 fueling strategies that focus on key travel corridors for these vehicle types. The Washington State Department of Transportation has already registered a few state highways as "hydrogen corridors", including I-90 and I-5. Additionally, other local jurisdictions such as British Columbia, Canada are working with partners like HTEC to establish innovative leasing programs to help key fleets access and incorporate some heavy-duty hydrogen vehicles into their fleets. This approach should be explored in Washington as well where key heavy-duty vehicle routes and relevant partnership opportunities with fleet are identified, although it will be important to consider the final costs and ways that any public funding could ensure equitable distribution of benefits. Partnerships with tribes and tribal-led organizations to support tribal zero-emission vehicle strategies and projects should be a focus where these align with the State Energy Strategy and recommendations in this report.

In addition, it may be worth Washington analyzing the potential benefits of hydrogen ICE vehicles as a bridge product while heavy-duty EV and hydrogen truck development, access and infrastructure advance in the state.

- **2.8 Support efforts to deploy hydrogen, ammonia, and other renewable fuels as part of decarbonizing maritime fuels and operations.**

As the modeling in this report identifies, the maritime sector and the need for sustainable maritime fuels is a critical area that likely requires a significant amount of focus and investment. Deeper analysis of opportunities to use green hydrogen and renewable fuels in the maritime sector will be important, to ensure that evaluation of alternative fueling options, siting decisions, and other factors are made strategically to support the decarbonization of the maritime sector. An initial step is the completion of a Sustainable Maritime Fuels study, being led by Washington Maritime Blue and supported by RMI, in coordination with Commerce and other partners. The legislature should consider recommendations resulting from this study regarding the most appropriate sustainable fuels for key maritime vessel types and priority corridors. State support for and investment in public-private partnerships related to advancing sustainable maritime fuels, similar to the state-supported Alternative Jet Fuel Work Group, may be advisable.

It is important to note that, especially for shipping, cruises, and other domestic and international maritime operations, the use of alternative fuels including hydrogen-derived fuels is not a policy area controlled by the state. Entities such as the Coast Guard and American Bureau of Shipping will review and need to approve of new fuels and fueling systems.

Additionally, it is also important to recognize that the use of new renewable or sustainable maritime fuels should be based on input from other impacted stakeholders, such as vessel and port workers, and neighboring communities. This is particularly important when considering health or safety considerations, such as how to safely handle ammonia which is toxic to humans when mishandled. Various non-energy considerations will need to be evaluated and addressed to ensure positive impacts on the environment as well as human wellbeing.

3. Ensure that Washington's green hydrogen economy is consistent with GHG reduction requirements and a net-zero economy

- **3.1 Support increased renewable electricity capacity and transmission infrastructure to supply hydrogen and economy-wide loads.**
- **3.2 Address and control GHGs from imported hydrogen in the context of state carbon cap.**
- **3.3 Monitor and reduce leakage of hydrogen to minimize indirect greenhouse gas impacts.**

Context: State and local policies already provide strong incentives driving hydrogen and renewable fuels production toward the lowest possible lifecycle carbon intensity. However, additional actions and policy changes may be needed to ensure that sufficient renewable power is available to support a production of low- or zero-carbon hydrogen, and to ensure the carbon footprint of hydrogen across the full lifecycle is known and accounted for.

- **3.1 Support increased renewable electricity capacity and transmission infrastructure to supply hydrogen and economy-wide loads.**

For hydrogen to contribute to the state’s energy and climate transformation, it must be produced without emitting significant greenhouse gases, which will require significant build-out of renewable electricity and transmission systems. The state can support this in many ways, including sharing the results of this study and the significant indications that Washington's hydrogen economy is reliant on being able to increase renewable capacity and transmission in this region. Related support will be advanced through recommendation 2.1, as the state seeks to help hydrogen producers access the 45V credit which will likely include helping them to navigate and access new and existing renewable resources, as well as in recommendation 4.3, as the state seeks to expedite and improve siting and permitting for renewable electricity and transmission infrastructure.

- **3.2 Address and control GHGs from imported hydrogen in the context of state carbon cap.**

The state should assess opportunities to include the lifecycle carbon emissions of imported hydrogen in key policies such as the Climate Commitment Act (CCA). There are already provisions that support including emissions from imported electricity under the state's carbon cap; it may be wise to expand these provisions to include imported hydrogen and renewable fuels. Discussions with Ecology and other partners to explore policy recommendations is advisable in the near term. Additionally it may be advisable to formalize requirements for the documentation of the environmental attributes of hydrogen sold in Washington.

- **3.3 Monitor and reduce leakage of hydrogen to minimize indirect greenhouse gas impacts.**

Hydrogen is an indirect greenhouse gas, and the leakage of hydrogen into the atmosphere can prolong the life of other gases such as methane and thereby contribute to global warming impacts. While other GHGs have a greater global warming potential and should remain a primary focus in reducing GHGs, it is valuable to continue to study hydrogen's global warming potential and seek ways to reduce risk of and actual events of leakage. Investing in leakage detection equipment as well as broader monitoring and reporting regimes would be valuable. Entities such as the Greenhous Gas Institute may be able to partner with the state to determine recommendations.

4. Promote expedited and equitable siting and permitting practices for hydrogen and renewable electricity systems

- **4.1 Work with the Washington State Department of Ecology to develop an effective and equitable PEIS for green hydrogen.**
- **4.2 Develop a process to evaluate preferred geographic locations for hydrogen infrastructure.**
- **4.3 Promote local or on-site hydrogen and renewable fuel production where appropriate.**
- **4.4 Conduct additional activities that support efficient and effective siting and permitting for green hydrogen production and use.**
- **4.5 Support efforts to site and permit renewable electricity and transmission infrastructure.**
- **4.6 Ensure robust tribal input and community engagement informs state and regional approach to hydrogen and ammonia pipelines.**

Context: The need for hydrogen derived fuels in 2030 to meet Washington’s emissions target places an imperative on the pace of development of the hydrogen industry. Ensuring permitting processes can keep pace with expansion of the industry is one way to reduce the risk that Washington falls short of the 2030 targets.

Hydrogen-derived fuels can come from Washington or out of state. However, Washington only has control over permitting processes within Washington, and it may be a less risky strategy for Washington to pursue in-state production of hydrogen derived fuels to reduce the need for imports, even when this is a more expensive option. Doing so can reduce the dependence on economic hydrogen development in other states that may not be as supportive an environment as Washington from a permitting perspective.

Permitting reform is one way of preparing for rapid in-state growth.

- **4.1 Work with the Washington State Department of Ecology to develop an effective and equitable PEIS for green hydrogen.**

Several of the permitting best practices identified here are already in place and being supported by the state of Washington. For example, the SEPA process allows for NEPA to be adopted or referenced, and identifies lead agencies for green hydrogen projects.[154] Additionally, Chapter 230, Laws of 2023 provides an important structure, through creating optional coordination process between agencies, and directing Ecology to prepare a programmatic EIS for green electrolytic hydrogen. The work of this report has been developed in coordination with Ecology with the intention that the siting and permitting recommendations can contribute to an efficient and productive final PEIS for green hydrogen. Commerce should continue to direct staff time and support analysis and planning to support Ecology's work in this area in the coming years.

- **4.2 Develop a process to evaluate preferred geographic locations for hydrogen infrastructure.**

Washington should consider taking further steps to facilitate green hydrogen siting and permitting through advance planning efforts. One important step would be for the state to define designated geographic areas in Washington that are preferred sites and corridors for green hydrogen production and transport. This could be a similar process to the multi-stakeholder Least-Conflict Solar Siting process coordinated by Washington State University.

The state could focus resources to expedite permitting process for projects sited in those designated areas, ideally with maximum timelines. The process could also prioritize hydrogen production projects with long-term input supply contracts for renewable electricity generation and water rights, to help ensure state resources and efforts align with projects likely to be successful over the long term.

It is important to note that this work is outside the scope for Ecology's PEIS and siting and permitting processes. Any such planning efforts would likely require additional planning and funding support to implement.

Additionally, any mapping exercises must take into account specific considerations with regard to tribes. This includes the need to consult with tribes about treaty rights, archaeological and cultural resources, and other topics. Tribes may or may not wish for geographic data to be included on public maps, but may still wish to see that such information is sought out and used to inform siting and planning of proposed projects. Land development codes and other tribal authorities may differ on tribal lands. This is discussed in more detail in Chapter 3.

- **4.3 Promote local or on-site hydrogen and renewable fuel production where appropriate.**

It is likely that production of green hydrogen and renewable fuels may occur in centralized locations in Washington and the region, and transported to end uses. The opportunities from federal funding for an H2Hub in the Pacific Northwest is expected to help to advance numerous regional production locations, located in relatively close proximity to off-takers who will use these fuels. This will help to reduce the costs, energy use, and environmental disturbance from transporting hydrogen over long distances. While pipelines are often the most cost-effective way to transport hydrogen over longer distances, and more regional plan with localized production locations is beneficial where cost-effective to do so.

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[154] For a facility storing one million gallons of liquid fuel, if the project is not under EFSEC jurisdiction, Ecology is the lead agency (WAC 197-11-938(9))

In addition, it may be appropriate to support the siting of smaller electrolyzers for on-site hydrogen production and use in some circumstances. For example, rural or remote locations where hydrogen is needed for industrial process heat, backup power, or a small number of heavy-duty trucking or transit fueling stations. There are numerous enterprises that have developed smaller, modular electrolyzers that may be able to help meet these needs.

- **4.4 Conduct additional activities that support efficient and effective siting and permitting for green hydrogen production and use.**

Another valuable opportunity in the near term could be to streamline process for existing steam methane reformation (SMR) hydrogen users to convert to green or renewable hydrogen. This would help to direct low-carbon hydrogen to displace existing fossil-generated hydrogen in Washington's refineries and other sectors, which would drive down existing GHG emissions from state industries.

Additionally, the state should consider ways to support hydrogen and grid interconnection of renewables. This could include reforms that expedite renewable interconnection, when hydrogen production facilities have a surplus of renewable power and can sell that power back to the grid. This type of support could be particularly beneficial to support in-state green hydrogen production, especially if IRA incentives require additionality.

Another important siting and permitting consideration is whether — or under what conditions — the state should permit hydrogen blending in natural gas pipeline. SB 5910 asks Commerce to provide guidance to the UTC on this topic (section 6: Gas Company Notice). Overall, Washington policies require moving to net zero economy and do not favor continued use of natural gas in home heating and other uses, where there are more efficient and cost-effective options such as heat pumps. Blending green hydrogen at the low levels (approximately 20% by volume or 7% by energy content) that current pipeline systems will accommodate are unlikely to provide cost-effective decarbonization opportunities in the long term, and air quality impacts such as NOx emissions must be studied carefully.

However, to the extent that the UTC will consider blending proposals, it will be critical to define permitting blending levels, monitoring requirements, and R&D/pilot thresholds that must be met before blending at scale is allowed. A complete set of recommendations on the topic of blending is beyond the scope of this report. As such, we recommend that the state to complete a separate analysis that specifically provides guidance to the UTC and natural gas utilities on hydrogen blending.

Finally, there are relevant recommendations related to opportunities to use hydrogen in power generation, discussed in part above. Siting and permitting processes should define allowed air quality impacts from NOx emissions (especially in relation to NOx generation levels in or adjacent to overburdened communities) and translate those impacts into allowed operational profiles. Permissions could vary based on degree of natural gas blending vs. pure hydrogen use (as replacing natural gas has other air quality benefits). These conditions should be informed by the planning and testing systems Commerce is interested in advancing in Washington as well as related state, regional, and national data and analysis.

- **4.5 Support efforts to site and permit renewable electricity and transmission infrastructure.**

The analysis in this report demonstrates that, as important as the siting and permitting of hydrogen production, transportation, storage and use will be, the challenges are even greater for the siting and permitting of the electricity and transmission required to develop a green hydrogen economy at scale. This is largely due to the larger geographic footprint for renewable generation and the high levels of electricity required for hydrogen production. As is currently underway led by the Washington State Department of Ecology, efforts to improve and expedite siting and permitting processes for clean electricity will be critical. The state will also need to work in partnership with utilities, local governments, tribes, and many other stakeholders to advance new transmission capacity to meet the needs of hydrogen and as part of broader requirements and efforts to increase renewable electricity supply.

- **4.6 Ensure robust tribal input and community engagement informs state and regional approach to hydrogen and ammonia pipelines.**

This report suggests that a cost-effective pathway to supply green hydrogen and renewable fuels, including green ammonia, to end users in Washington is likely to include transportation of these fuels by intra- and inter-state pipelines. While some blending of green hydrogen intro existing natural gas pipelines may occur in the short term, the most critical next step will be to evaluate needs for significant retrofits or entirely new pipeline infrastructure, as in most cases existing pipelines are not able to carry high concentrations of hydrogen without problems including corrosion and leakage of hydrogen gas. The Core Case recognizes that siting and permitting pipelines is not a simple process, and does not assume new pipelines would be feasible until 2035. This is in part due to a recognition that significant planning and engagement with tribal nations, communities and others would be required to determine appropriate locations and specifications. The state should anticipate and plan for these significant community engagement needs, and should seek to ensure that relevant tribes and communities are at the table from the beginning of any planning process.

5. Promote equity and environmental justice in all green hydrogen projects and activities

- **5.1 Develop environmental justice tool for hydrogen projects.**
- **5.2 Support implementation and oversight of PNWH2 Community Benefits Plan.**
- **5.3 Support analysis and recommendations regarding hydrogen combustion and NOx generation, to avoid air quality and health burdens.**

Context: Environmental justice and meaningful community engagement must be a central focus of deploying green hydrogen and renewable fuels in Washington, in order to contribute to an equitable distribution of the benefits of these new projects and opportunities. Washington is already committed to environmental justice in significant agency actions under the HEAL Act**.** At the federal level**,** the Justice40 Initiative directs benefits of certain environmental programs to overburdened or disadvantaged communities; the H2Hubs program is included in the Justice40 Initiative. However there are additional actions the state should consider to increase the likelihood that environmental justice is advanced through all hydrogen projects implemented in or impacting Washington, whether part of our outside the PNWH2 projects.

- **5.1 Develop environmental justice tool for hydrogen projects.**

Even with these policy incentives, it is important to note that hydrogen project developers and stakeholders will have different levels of understanding and use different practices when engaging with communities. The state should provide guidance and tools that can help entities across the hydrogen supply chain to understand likely concerns or questions across the supply chain, processes to work with communities to work toward shared priorities, and methods of mitigating or eliminating environmental harms. Commerce's recently developed Environmental Justice Assessment tool is a strong model for addressing EJ considerations in significant projects, but it is not specific to hydrogen nor is it a tool that private sector entities are expected to use. Commerce can use this to develop a tool that draws on the valuable work and planning that has led to the EJ Assessment tool, while adapting the recommendations to make them relevant to hydrogen projects specifically. The work would also seek to draw on any such tools or checklists developed in other areas, such as an expected tool from the Just Solutions Collective.[155]

The final product would be a toolkit checklist that can recommend processes and decision-support tools for hydrogen projects to advance EJ benefits. In future, this tool could be one that the state may choose to use in specific ways, such as incentivizing the use of this tool when seeking state funding or access to expedited permitting processes.

- **5.2 Support implementation and oversight of PNWH2 Community Benefits Plan.**

As part of the development of an H2Hubs proposal in the Pacific Northwest, the PNWH2 and its board and partners developed a Community Benefits Plan (CBP), a requirement of the funding opportunity. There are four components:

- Supporting meaningful community and labor engagement;
- Investing in America's workforce;
- Advancing diversity, equity, inclusion, and accessibility; and
- Contributing to the Justice40 Initiative.

The state was able to contribute to a strong plan for the PNWH2, including by helping to incorporate the strong policy context from the HEAL Act. If final H2Hub negotiations with DOE are successful in leading to an award, Commerce will also contribute to the implementation of the CBP, including through strategic oversight of plan implementation, and direct support for the community engagement in communities in and adjacent to planned projects. Commerce recently created a new position in the Energy Division, a Public Engagement Specialist for Hydrogen and Renewable Fuels. This position will help support robust engagement activities around PNWH2 and other hydrogen and renewable fuels projects in the states, helping to reach especially tribes, labor unions, and community organizations, and ensure their voices help to shape the implementation of hydrogen projects developed as part of the PNWH2 hub.

- **5.3 Support analysis and recommendations regarding hydrogen combustion and NOx generation, to avoid air quality and health burdens.**

A key concern area that has been articulated in some communities is the issue of hydrogen combustion and NOx emissions. It is critical that the design and permitting of any hydrogen combustion activities in Washington do not increase air pollution including increasing NOx emissions, and avoid disproportionate environmental health burdens. Research by the US DOE indicates that technologies to manage and abate NOx are advancing rapidly and are expected to progress alongside new proposed uses including 100% hydrogen combustion.[156] However, publically available data on testing results is scarce, and often is conducted by industry actors without public involvement. Increasing trust in test results by involving state agencies, national labs, universities, and environmental health groups will help ensure data is robust, transparent, and can increase public trust and support for hydrogen combustion projects where they are proposed.

Research and planning for projects and data collection are included in Commerce's 2024 Decision Package. Further implementation of these activities will require private sector funding, and can benefit from additional public sector funding from the state and likely federal sources. This is because a thorough understanding of both technical and health impacts is in the public interest. Additionally, conducting such tests in partnership

[155] Just Solutions Collective: https://justsolutionscollective.org/. Accessed 10/22/2023.
[156] US DOE, December 2022. "DOE Low NOx Targets and State-of-the-Art Technology for Hydrogen Fueled Gas Turbines." https://www.energy.gov/sites/default/files/2022-12/h2iqhour-09152022.pdf.

with natural parties such as state agencies or national labs can help increase public trust in the results of such tests and demonstrations. While data on hydrogen combustion and NOx will be relevant across the country, Washington can be a partner and even a national leader in advancing understanding in this area.

6. Support positive and equitable economic impacts from a green hydrogen economy

- **6.1 Evaluate workforce impacts and opportunities related to hydrogen and renewable fuels.**
- **6.2 Increase resources for workforce development opportunities with equitable benefits.**
- **6.3 Evaluate tax and fiscal impacts of hydrogen deployment.**

Context: The workforce development opportunities and considerations are significant, as hydrogen and renewable fuels production, transportation, storage and use all provide opportunities to create and support good jobs in a clean energy economy. We can make efforts to model and invest in these career pathways and direct benefits equitably across our communities, and can support development of new hydrogen credentials to support workforce development. Overall economic and tax considerations should also be reviewed and advanced.

- **6.1 Evaluate workforce impacts and opportunities related to hydrogen and renewable fuels.**

One important activity related to hydrogen workforce is to help map out career opportunities, skills need for specific positions, and pathways for Washington's workforce to access these careers. It will be valuable to identify where these skills already exist in our economy and where workers can transition from related careers including in the fossil fuel industry to new hydrogen-related careers, as well as where additional or expanded training and workforce development programs may be needed. This work should be conducted in coordination with relevant partners including labor unions, tribes, community, technical and tribal colleges, the Center of Excellence for Clean Energy, national labs and others to assess opportunities and gaps.

This assessment and planning should provide analysis specific to the hydrogen and renewable fuels sector, though it should also be included in relevant state clean energy workforce planning processes to situate these needs in a broader context. The Clean Energy Technology Workforce Advisory Committee recently established through Chapter 231, Laws of 2023, convened by the State Workforce and Training Board, and on which Commerce will participate, will provide a valuable opportunity to weave hydrogen workforce considerations and skills assessments into a broader statewide analysis and planning process.[157]

It is critical that training and workforce opportunities are available and accessible for all, including those living in overburdened communities.

- **6.2 Increase resources for workforce development opportunities with equitable benefits.**

Washington should commit to investing in these workforce development opportunities to ensure our workforce is ready to deliver on the hydrogen and renewable fuels opportunities discussed in this report or that may arise in later years. This should include support for the development of new credentials that will support access to well-paying careers in a clean hydrogen economy. Additionally, the state should provide funding for relevant workforce development programs that help meet the needs anticipated in future years. The state should seek to prioritize opportunities whereby these programs will deploy investments and benefits equitably. Partnerships with tribes, support for apprenticeship and pre-apprenticeship programs that demonstrate they

[157] Chapter 231, Laws of 2023

are training a workforce at least as diverse as the state's population, and other efforts to bring benefits to overburdened communities will be particularly valuable.

Additionally, Washington agencies and hydrogen project developers should engage with and build relationships with labor unions, workers, and educational and training institutes. The voice of relevant workers and unions can help ensure hydrogen deployment creates and supports good jobs.

It will also be critical to use tools such as Community Workforce Agreements to ensure that hydrogen projects promote well-paying jobs and support apprenticeship utilization and local job opportunities. Permanent hydrogen jobs should be family-wage jobs.

- **6.3 Evaluate tax and fiscal impacts of hydrogen deployment.**

This report envisions a significant role for hydrogen and synthetic fuels in the state's economy over the long run. An important element in preparing for this transition should be an examination of the state's system of taxing various energy forms, including the application of existing taxes and exemptions on the consumption, sale, or use of natural gas and motor fuels compared to hydrogen, and synthetic fuels. This review should also look at the taxes on the sale or use of electricity to produce hydrogen and if the application of taxes differs depending on whether the electrolyzer is operated by an electric utility or the customer of an electric utility and whether the electricity was procured from an electric utility or a non-utility provider. A careful examination of hydrogen's place in this system of taxes will preserve the state's tax base and the government services that are funded by taxes on energy. It will also provide greater transparency and certainty to potential project developers.

Engagement and contributions to this report

The work of this report is only possible with input from various partners such as tribes and tribal leaders, as well as stakeholders of various types from across and outside of Washington. Commerce has prioritized public and stakeholder engagement in numerous ways, both generally across the agency, and specifically in relation to hydrogen. We have worked with our Tribal Liaison to engage in numerous conversations with tribal leaders on the topic of hydrogen, and engaged with the diverse array of partners on the board of the PNWH2 in assessing hydrogen policy and project opportunities in the state. Recently, we have increased our capacity to engage with a broad array of partners specifically in our hydrogen policy work, by hiring a Public Engagement Specialist for Hydrogen and Renewable Fuels.

In the process of developing this report, while the statute did not explicitly call for this, Commerce recognized the importance of working with partners to help inform the work of this report and recommendations. Therefore, we convened an Advisory Committee with representatives from across the hydrogen supply chain, as well as tribal, labor, environmental and other partners. Explicit conversations to inform the environmental justice section, especially with leaders at Front and Centered, helped to inform the content of the report and determine key next steps.

Advisory Committee Members

Name	Affiliation	Role in Committee
Stephanie Celt	Washington State Department of Commerce	COM staff/project lead

Glenn Blackmon	Washington State Department of Commerce	COM staff/project lead
Austin Scharff	Washington State Department of Commerce	Member
Steven Polunsky	Washington State Department of Commerce	Member
Brian Young	Washington State Department of Commerce	Member
Diane Butorac	Washington State Department of Ecology	Member
Jonathan Olds	Washington State Department of Transportation	Member
Rob Corwin	Fortescue Future Industries	Member
Sebastien David	Air Liquide	Member
Jon Goldsmith	Par Pacific	Member
Cam LeHoullier	Tacoma Power	Member
Michelle Detwiler	Renewable Hydrogen Alliance	Member
Scott Campbell	United Steelworkers 12-591	Member
Kelly Hall	Climate Solutions	Member
Mariel Thuraisingham	Front and Centered	Invited member (Provided environmental justice input)
Donald Williams	Confederated Tribes of the Umatilla Indian Reservation, From the Light Consulting, Affiliated Tribes of Northwest Indians Energy Committee	Member
Kent Caputo	Cowlitz Indian Tribe	Member

With these important steps already underway and feedback infused in this report, Commerce is committed to a detailed tribal and stakeholder engagement process as our work on hydrogen and renewable fuels continues. This will include thorough discussion of the report contents and recommendations with many partners after the report is submitted to the Legislature, beyond what time allowed during the writing of the report. We will also conduct an Environmental Justice Assessment for legislative and funding recommendations advanced by the agency in future years.

While tribal nations are sovereign governments and not considered stakeholders, it is critical that we continue deep partnerships with tribes, tribal leaders, staff and educators on topics of green hydrogen, a modern workforce, and renewable fuel deployment in this region. Commerce is committed to supporting multiple pathways for tribal engagement on hydrogen and the many issues with which we work with tribal leaders.

Conclusion

This report demonstrates that Washington will have a robust demand market for green electrolytic hydrogen and renewable fuels, including Fischer-Tropsch liquid fuels and ammonia. Our state's strong climate and clean energy policy context, combined with the funding opportunities provided as part of the federal IIJA and IRA programs, mean that this is a particularly critical time to seek to advance and deploy a green hydrogen economy. The state should focus on producing these fuels in-state where possible while some regional imports may also be a cost-effective approach. With a strong focus on directing these fuels toward the most strategic end use sectors, advancing new renewable electricity and transmission infrastructure, it will be possible to provide the supply of green hydrogen and renewable fuels to sectors most in need of these fuels as they decarbonize. With a consistent and persistent focus on environmental justice and developing benefits for workers, tribal nations, and communities, Washington's green hydrogen economy can be part of an efficient and equitable pathway to a net zero economy.