PACIFIC NORTHWEST

Renewable Hydrogen Action Plan

RHA
RENEWABLE HYDROGEN ALLIANCE

CSI

AUTHOR **Rhys Roth** *Executive Director*, CSI

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Photo of Downtown Portland Courtesy of David Mark

Center for Sustainable Infrastructure

Pacific Northwest Renewable Hydrogen Action Plan

The Pacific Northwest Renewable Hydrogen Action Plan is the first concerted, strategic effort to galvanize key partners and distill intelligence to develop a shared agenda for policy, project, and research action to scale up RH2 in the region, to benefit both our economy and environment.

The Center for Sustainable Infrastructure (CSI) and the Renewable Hydrogen Alliance (RHA) teamed with funding partners Bonneville Environmental Foundation, Bullitt Foundation, Toyota Motor North America, The Leighty Foundation, Oregon Department of Energy, Obsidian Renewables, and SoCalGas to produce this Pacific Northwest Renewable Hydrogen (PNW RH2) Action Plan.

Nearly 50 thought leaders and experts contributed generously to help develop the Action Plan, either sitting down for an hour-long interview or by providing review and comment for the draft of this document, and in many cases both.

Rhys Roth, Executive Director of CSI, served as primary author, responsible for synthesizing the insights and incorporating feedback from these sector experts, to distill a shared path forward with a set of action priorities to put the Northwest on a trajectory to build a powerhouse RH2 sector.

Designed as a concentrated 6-month effort, the purpose of the resulting PNW RH2 Action Plan is to provide an initial agenda for RH2 supporters to cohere around and collaborate to accomplish. We envision a diverse set of cross-sector organizations joining forces – project developers, big customers, utilities, public agencies, climate-focused NGOs, research teams, economic development groups – to accelerate the PNW's RH2 sector and realize the climate, economic, environmental and social benefits that RH2 offers the PNW and the planet.

Here's what you'll find in the following pages:

- Ken Dragoon, RHA's Founding Director, overviews the global trajectory for the RH2 sector and how that can translate to opportunity for the PNW.
- A two-page Executive Summary of the PNW Action Plan's two-part call to action.
- The bulk of the document fleshes out the Action Plan's two calls to action and sub-elements under each, offers a succinct case for why it is prioritized, and illustrates with validating quotes from interviews and discussions with thought leaders.
- In the closing pages we acknowledge the participating thought leaders and sector experts, whose countless contributions were instrumental to this PNW RH2 Action Plan*.

*Any shortcomings and errors that remain in the report are the sole responsibility of the author, and not the contributing experts.

PREFACE

GLOBAL TRAJECTORY, PNW OPPORTUNITY

Over the last few years, a clear and crucial role has emerged for hydrogen derived from renewable electricity. The long envisioned "hydrogen economy" could not be realized without a low-cost, low-carbon source of electricity to produce the hydrogen. Now the emergence of low-cost wind and solar power is unlocking the old vision. The US already produces and consumes billions of dollars' worth of hydrogen each year, mainly for refining oil and making fertilizer, and nearly all derived from fossil fuels with a big carbon footprint. Hydrogen from low-cost wind and solar can replace these uses and serve in others critically important to decarbonizing the energy economy.

The key challenge in depending on wind and solar power is that availability varies with the amount of wind and sunshine at a given moment. To rely on these sources for much of our electricity is to struggle with having more than enough power to meet demand at some times, not enough at other times. That's where hydrogen fits in.

Passing electric current through water in devices called electrolyzers splits the water into its constituents, hydrogen and oxygen. This process has been known for two centuries, and implemented at industrial scale since the 1920s! Until recently, deriving hydrogen from fossil fuels has been far less expensive than electrolysis, but that is changing. Increasing availability of clean, low-cost electricity, and rapidly falling cost of electrolyzers due to large-scale deployments abroad, are making "electrolytic fuels" (hydrogen and derivative fuels including ammonia, methane, and methanol) competitive.

Creating electrolytic fuels can soak up surplus renewable electricity when it is available, and the fuels can later be used in power plants to produce electricity when renewable production falls short of demand, thereby realizing a 100% renewable electricity system. Functionally this constitutes energy storage. Although batteries and other conventional forms of storage are more efficient and less costly for relatively small amounts of energy (i.e., hours of production), cost of storage as hydrogen and derivative fuels is far lower for large amounts of energy (days, weeks, or months of production).

The ability to make hydrogen and derivative fuels cost effectively brings a new understanding to the often-heard call to "electrify everything." Applications such as heavy-duty transportation and aircraft are inherently expensive or even impossible to electrify directly or with batteries, but substituting electrolytic fuels does so indirectly. Producing fuels from renewable electricity is truly a critical piece of a decarbonized economy, made possible by the energy revolution brought by low-cost wind and solar power.

Highlights of the hydrogen revolution underway include the first utility-owned electrolyzer under construction in Washington State, a new "electrofuels pilot tariff" offered by Tacoma Power, hydrogen transit buses available on a commercial basis with 60 already in service, 35,000 hydrogen forklifts and 3,800 hydrogen vehicles operating in the US today, a hydrogen ferry under construction in Bellingham, and heavy-duty trucks, transit trains, and aircraft in advanced stages of development. Renewable hydrogen is no longer the future, it is the present.

KEN DRAGOON
Founding Director, RHA

Go to RenewableH2.org/FAQ to see frequently asked questions about RH2

PACIFIC NORTHWEST

Renewable Hydrogen Action Plan

EXECUTIVE SUMMARY

This ***Pacific Northwest Renewable Hydrogen Action Plan*** features a **two-part call to action** to accelerate the region's renewable hydrogen (RH2) sector, and deliver significant economic and environmental benefits together for the Pacific Northwest (PNW).

The purpose of this Action Plan is to provide an initial agenda for RH2 supporters to cohere around and collaborate to accomplish. We envision a diverse set of cross-sector organizations coming together who want to accelerate the PNW's RH2 sector – project developers, big customers, utilities, public agencies, climate-focused NGOs, trade and economic development groups – using this Action Plan as its starting point agenda.

1. Lead with Projects: Invest in and Build RH2 Deployment Hubs

RH2 Deployment Hubs connect RH2 production with robust demand, supported by infrastructure to store and deliver RH2 to maximize customer convenience and satisfaction. To invest in and build Deployment Hubs, project initiators – which can be project developers, major customers, utilities, local economic development groups, corporations or cities – will assemble project development partnerships. These partnerships will facilitate clusters of RH2 projects that combine private, utility, and public dollars to deliver attractive investment returns in value for all participants. Key sub-elements of this call to action:

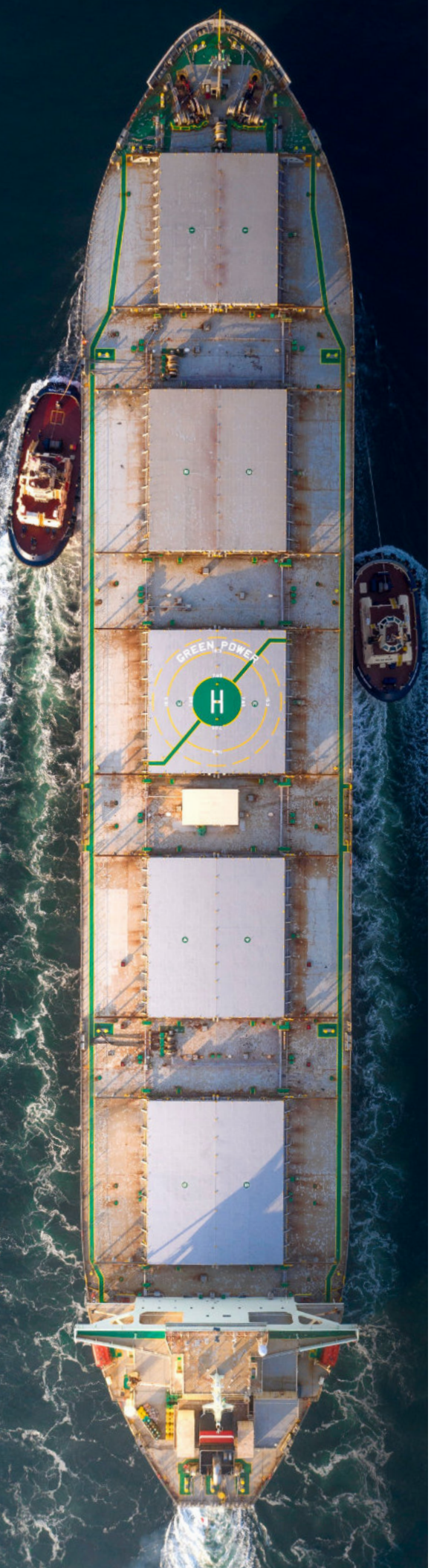
- **Project development partnerships** to plan, design, and finance clusters of projects at RH2 deployment hubs. Hub developers scale production to match demand from multiple types of customers, and deploy RH2 storage and delivery infrastructure to best serve the needs of specific customers.

- **Deployment hubs developed at priority locations** where multiple RH2 users can be concentrated, including at transport fueling stations, ports, and around select industrial facilities – including energy utility facilities. And deployment hubs initiated by PNW-based corporations and by cities with deep commitments to greening their operations and adding resiliency to supply chains.
- **Key policy incentives and standards** to stimulate diverse RH2 demand, that a coalition of RH2 advocates in the PNW can align behind and advocate together. The coalition also needs to develop performance criteria to help agencies rationalize and prioritize public investment in RH2 projects, especially with prospects growing for significant federal and state dollars for RH2 and other clean energy infrastructure.

2. Create the 10-year RH2 Roadmap

To realize the region's full, optimal potential for RH2, we need a long-range roadmap. This enables us to see where we're going and to better prioritize policies, projects, and performance metrics to get there. Ultimately, states should lead the roadmapping, ensuring that RH2 roadmaps are fully integrated into and harmonized with state energy and climate strategies. But the PNW RH2 coalition need not wait for state action – it can begin Roadmap work now. Key sub-elements of this call to action:

- Develop a vision for the role of RH2 in a fully realized zero-carbon energy-industry system for the PNW looking 10-20 years out, grounded in state-of-the-knowledge analysis of technology, markets and carbon performance.
- This vision for the longer-term role of RH2 and its derivatives in future zero-carbon scenarios will enable state RH2 roadmaps to nest properly into and optimize value of the larger state energy and climate strategies. PNW RH2 strategies should also consult and align with similar RH2 roadmaps in British Columbia, California, and the wider West, and draw lessons and adapt policy tools developed by leading RH2 regions globally.
- System-wide RH2 roadmapping is also the right venue for considering a variety of next-tier opportunities, and for prioritizing opportunities that can attract local, utility, and private investment into projects that fit well in the 10-year RH2 Roadmap. These projects will also offer a strong value proposition for federal and state funders, by demonstrating a clear business case for project investors and clear consistency with state energy and climate priorities.
- Roadmaps can also help surface the research, demonstration, and deployment (RD&D) initiatives that can strategically accelerate RH2 commercialization. RD&D initiatives can collaborate with deployment hub project developers to measure and evaluate performance and recommend innovations. And they can deploy pilot projects to test business models for the most promising and impactful next-tier opportunities.



Maritime applications will be a top near-term opportunity. *Photo Courtesy of Mudassir Ali*

A TWO-PART CALL TO ACTION

This section fleshes out the Action Plan's two-part call to action and represents the bulk of the document. The purpose of the ***Pacific Northwest Renewable Hydrogen Action Plan*** is to provide an initial agenda for RH2 supporters to cohere around and collaborate to accomplish.

1. **LEAD WITH PROJECTS**
   Invest in and Build RH2 Deployment Hubs

2. **CREATE THE 10-YEAR RH2 ROADMAP**
   Accelerating Long-term RH2 Deployment

These two calls to action reflect the overriding priorities that emerged from Action Plan conversations with thought leaders. The Action Plan aims to articulate a shared action agenda to steer efforts to accelerate growth of RH2 in the Northwest, for broad economic and environmental benefit.

For each of these two broad and immediate priorities, the Action Plan offers 3-4 sub-elements. Each Action Plan call-to-action and sub-element is explained in greater detail with a succinct case for why it was prioritized, and illustrated by validating quotes.

"A project-focused strategy is smart and appropriate to grow our nascent industry, at least for the first 2 to 5 years."

TIM SASSEEN
Market Development Manager | Ballard Power Systems

City skyline in Seattle, Washington. *Photo Courtesy of Garrett Morrow*

LEAD WITH PROJECTS
Invest in and Build RH2 Deployment Hubs

The first call to action is to invest in and build RH2 deployment hubs. The centerpiece of RH2 Deployment Hubs is connecting RH2 producers and users, supported by infrastructure to store and deliver RH2 to maximize customer convenience and satisfaction.

To invest in and build deployment hubs, project initiators – which can be project developers, major customers, utilities, local economic development groups, corporations or cities – will assemble project development partnerships. These partnerships will facilitate clusters of RH2 projects that combine private, utility, and public dollars to deliver attractive investment returns in value for all participants. Key sub-elements of this call to action:

- Project development partnerships to plan, design, and finance clusters of projects at RH2 deployment hubs. Hub developers scale production to match demand from multiple types of customers, and deploy RH2 storage and delivery infrastructure to best serve the needs of specific customers.
- Deployment hubs developed at priority locations where multiple RH2 users can be concentrated, including at transport fueling stations, ports, and around select industrial facilities – including energy utility facilities. Other deployment hubs will be initiated by PNW-based corporations and by cities with deep commitments to greening their operations and adding resiliency to supply chains.
- The PNW RH2 coalition needs to align behind and advocate some key policy incentives and standards to stimulate diverse RH2 demand. The coalition also needs to develop performance criteria to help agencies rationalize and prioritize public investment in RH2 projects, especially with prospects growing for significant federal and state dollars for RH2 and other clean energy infrastructure.

The Case for This Call to Action

The PNW RH2 Action Plan proposes that on-the-ground projects at deployment hubs, where RH2 production and demand are connected, are a top priority for near-term action. Getting more visible, operational projects working for all to see can propel the RH2 agenda and elevate the sector's viability in the PNW.

Why Lead with Projects?

- Builds public visibility – the pre-requisite to building public support and political will.
- Demonstrates that RH2 works – the best way to address lingering skepticism about hydrogen safety or economics based on past H2 pushes perceived to have fallen short.
- Centers on the most market-ready RH2 technologies and applications to target public dollars efficiently to fill gaps in the project finance stack.
- Leverages the "deployment-led innovation" model where simply deploying technology can be a great driver to reduce costs and increase experience that has been successful in solar, wind, and batteries.
- Grows the sector's field experience, fuels process improvements, and develops its supply chain, workforce, and track record of success.
- Expanding RH2 production and demand generates gravitational pull, attracting more market actors to explore and invest in the sector.
- Minimizes the immediate need for costly long-distance H2 transmission and distribution to improve the early business case for near-term RH2 project investments.
- Emphasizes success of the RH2 sector broadly, rather than just for individual companies, and maintains wide access to participation from small and large interests alike, as commercial markets mature.
- Hubs can fund expert third-party data collection and analysis to enhance credibility of performance.

"At Washington Maritime Blue, our process started with strategy, but then focuses on identifying and advancing demo projects and activities; not letting process stop actually doing the projects. We learn more from doing. So getting funding for projects is where we tend to elevate things. There is a lot of activity on RH2 happening in North America – to position the PNW as a leader in the space, we need to get projects going. And then we'll also need a roadmap, stakeholder alignment, etc."

JENNIFER STATES
Project Director
Washington Maritime Blue

"Projects that demonstrate RH2 viability will help answer questions about cost-effectiveness, regulation and logistics, and help us learn how to use this resource at scale. By learning from these projects, we can avoid the painful 'bleeding edge' and enjoy cutting-edge advantages from smart deployment of this renewable resource. I think the moment is near, if not already here."

DAVID DANNER | *Chairman* | Washington Utilities and Transportation Commission

Sub-elements of the First Call to Action
Invest in and Build RH2 Deployment Hubs

The three sub-elements include:

1. **Project development partnerships** to plan, design, and finance clusters of projects at RH2 deployment hubs that scale production to match demand from multiple types of customers, served by delivery and storage infrastructure.
2. **Deployment hubs developed at priority locations** where multiple RH2 users can be concentrated, including vehicle refueling stations, ports, industrial clusters and energy utility facilities. Deployment hubs will also be initiated by PNW-based corporations and by cities with deep commitments to greening their operations and adding resiliency to supply chains.
3. **Align on policy incentives and standards to accelerate demand**, and on performance criteria to help agencies rationalize and prioritize public investment in RH2 projects.

The potential for fuel cell-powered long-haul trucking is attracting significant market attention. *Photo Courtesy of 500photos.com*

Sub-Element 1
Project Development Partnerships

To invest in and build deployment hubs, project initiators – which can be project developers, major customers, utilities, local economic development groups, corporations or cities – will assemble project development partnerships.

These partnerships will facilitate clusters of RH2 projects that combine private, utility, and public dollars to deliver attractive investment returns in value for all participants. Project development partnerships provide the 'glue' and the vehicle by which partners can also fund essential project management and administration services.

RH2 deployment hub partnerships are organized to plan, design, and finance clusters of projects that scale production to match demand from multiple types of customers, and to deploy RH2 storage and delivery infrastructure to best serve the needs of specific customers.

Producing RH2 close to hubs of diverse demand minimizes the need for costly long distance hydrogen transmission and transport, which can be a barrier at this nascent stage where the RH2 industry lacks the transmission infrastructure that the power grid boasts.

Also, producing RH2 close to hubs of diverse demand, supplemented by storage and customer delivery infrastructure, connects companies specializing in each of these links in the RH2 supply chain in commercial relationships and partnerships. These commercial partners can go on to build experience and success to develop the next scale larger projects.

"Given the relatively high costs of transporting RH2 today, co-locating the supply and demand is really an ideal scenario. Whether that's a single large industrial off-taker or a diverse fleet of vehicles filling up, it overcomes a difficult business case in the early years for hydrogen infrastructure. Successfully producing and delivering RH2 to satisfied customers, with appropriate storage and delivery infrastructure – that's what people need to see in more and more places for the industry to ramp up."

EVAN RAMSEY
Senior Director, Bonneville Environmental Foundation

1ST CALL TO ACTION: RH2 Deployment Hubs

Project Development Partnerships

First-generation RH2 Deployment Hubs should center primarily on the most market-ready RH2 technologies and markets that offer a business case that can attract private, utility, and public investment, and demonstrate return in value for all participants. The centerpiece of deployment hubs is connecting RH2 producers and users:

- For RH2 Producers, electrolyzers powered by low-cost renewable electricity are increasingly market-ready, and because they can toggle on and off easily they offer the electric utility industry a valuable grid management tool – a flexible resource to absorb renewable power at times of surplus and rest when power is more scarce and prices are high. RH2 can also be produced from organic, bio-based resources, such as organic waste at dairies or sewage treatment plants. Though less scalable than renewable power, biomass-derived RH2 can be financially viable, particularly when capture of methane is rewarded.
- For RH2 Users, deployment hubs are places to concentrate robust, diverse demand. Transport customers are a top near-term opportunity, including heavy-duty vehicles like long haul trucking, cargo/materials handling, public transportation (especially transit buses), and maritime applications (harbor craft, to start), as well as lighter-duty vehicles at hubs in population centers.

Hubs will scale production capacity to customer demand, and provide the right storage and delivery infrastructure to maximize convenience and satisfaction of the hub's specific customers.

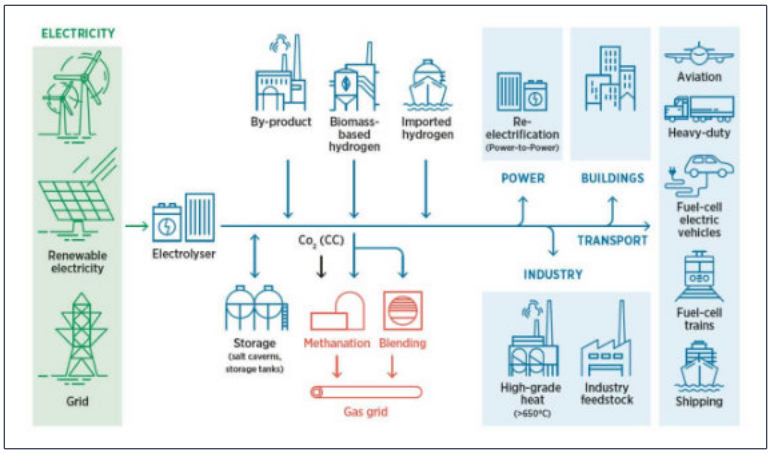
"I think the question is, is there a way you can multitask your hydrogen use in one plant/ place? I think the energy storage backup power that utilizes boil-off beats using other things."

KIRT CONRAD
Executive Director & CEO
Stark Area Regional Transit

RH2 Production

The cleanest, most rapidly-growing, and scalable technology for producing RH2 uses electrolyzers to convert electricity into carbon-free hydrogen. Electrolyzers use electricity to split water (H2O) into separate H2 and O streams, producing hydrogen that is renewable to the extent that the power utilized comes from wind, solar or hydropower resources.

The capital costs for electrolyzers are on a downward trajectory as economies-of-scale in manufacturing the units are achieved. They appear to be on a similar trajectory as wind and solar, where unit costs declined rapidly as global installed capacity grew exponentially year-by-year.



The Use of Hydrogen as an Energy Storage System. *Photo Courtesy of IRENA (2019), Innovation landscape brief: Renewable Power-to-Hydrogen, International Renewable Energy Agency, Abu Dhabi.*

First-generation RH2 Deployment Hubs will cluster electrolyzers close to RH2 customers, adding units incrementally as demand grows. Producing RH2 close to demand circumvents the immediate need for costly long-distance hydrogen transport to serve the needs of a diversity of nearby hydrogen customers. Hubs can also harness bio-based RH2 produced at dairies, sewage plants or other facilities that manage concentrated organic waste streams.

"The cost curve we see with electrolyzers is a lot like what we saw with wind and then solar – it's the economy-of-scale in manufacturing. The idea is that for every doubling in installed electrolyzer capacity, total costs should decline by about 20 percent. And what we saw in North America and Europe is that the cost of electrolyzers fell 40% between 2014 and 2019."

REBECCA SMITH
Senior Energy Policy Analyst
Oregon Department of Energy

"The sooner we can start investing in these kinds of projects at scale, the quicker the costs will come down. The quicker we build up the wind and solar fleets, the cheaper the electricity will be in the market for these kinds of projects. Let's open up the throttle and make it happen."

KEN DRAGOON | *Founding Director* | Renewable Hydrogen Alliance

"As we're developing plans for the next 30 years, we need to be strategic more than tactical. That means building approaches that support future options (e.g. tree with branches) rather than a singular focus (e.g. stick). The concept is to put enough power at station hubs to be able to split it to either electrical charging, DC fast charging, or RH2 electrolyzing, and to shift the amount between those depending on who's showing up to get fuel. And to do it modularly to build up capacity for the market that arrives."

JOHN LECOMPTE
Senior Energy Management Analyst
Seattle City Light

While capital costs for electrolyzers are declining sharply, the other major component of total cost is the renewable power to operate the units. Because electrolyzers can be easily ramped on and off, RH2 producers can offer utilities valuable but affordable demand-flexibility services that help them keep power grid supply and demand in balance, and get more value from renewable power generation units when power prices plummet – in exchange for wholesale or deeply discounted power prices. Tacoma Power recently adopted a groundbreaking "Electrofuel Service Pilot" that does just this for RH2 producers.

Producing renewable hydrogen using electrolyzers powered by solar panels and wind turbines.

"[With our electrolyzer purchase] we're making a decision to take some of our electricity and turn it into gas, a power-to-gas option. There are times where the gas will be more viable than producing power because there's so much oversupply of renewables in the market that it's driving power prices down to the point where it's making it more difficult to make money even with a very low-cost renewable hydro-project like we have. We see it as soaking up some of that excess supply out there. Being a balancing authority, we're wasting a lot of energy with overgeneration to create reserves. There's a lot of wasted energy that we feel we can use better, so producing RH2 with that energy has a large value to an electric utility like DCPUD."

GARY IVORY | *General Manager* | Douglas County Public Utility District

Robust RH2 Customer Demand

Clustering RH2 Users in an ecosystem of different types of customer demand in proximity will create robust and resilient markets for RH2 producers, coupled to storage and delivery infrastructure designed end-to-end for customer convenience.

"Puget Sound is well positioned as a renewable fuel hub, combining low-cost renewable electricity, an active local maritime ecosystem, political will for environmental stewardship, and vessel operational profiles that in some cases are impractical for battery power. Local inland and coastal vessels can pioneer this technology in a controlled environment, while preparing the region to become a major renewable fuel bunkering hub as oceangoing vessels likely pivot toward ammonia long-term."

PETER BRYN
Technical Solutions Manager
ABB Marine & Ports

Promising customer segments that are most market-ready now include:

- **Heavy-duty Transport:** Fuel cell-powered transit buses are the most market-ready application, and long-haul trucking is attracting significant attention.
- **Cargo/Materials Handling:** Forklifts were the first segment to capture significant market share, but other cargo and material handling vehicles may not be far behind.
- **Select Industrial and Energy Facilities:** Energy utility facilities are a natural early-adopter customer for RH2, both electric and natural gas utilities. RH2 applications, including fuel cells for stationary power, offer valuable benefits to utilities, including backup power, resiliency, grid balancing and flexibility, and reducing carbon intensity. For industry, direct use of hydrogen is in demand, to the tune of $10-20 billion a year, 95% of which is supplied by fossil-derived H2. For producers seeking to reduce their carbon footprints, RH2 can supply industrial hydrogen, but which industrial markets are ripe for RH2 is not yet clear.
- **Maritime Harbor Craft:** The likely maritime transport early adopters will be the near-coast vessels that return to port on a regular basis.

"There's very strong synergy between duty sectors. You get the volume of fuel cell systems in the light-duty sector, which allows for improvements and cost reductions in storage. In the heavy-duty sector you have more hydrogen volume and that scale is why people always gravitate toward heavy-duty, but we need to think about both."

MICHAEL LORD | *Executive Engineer* | Toyota

- **Passenger Vehicles:** RH2-powered fuel cell vehicles can refuel at stations in 3-5 minutes and have long range (with all models over 300 miles). This makes them an attractive zero emission option for users (including rideshare cars and corporate fleets) without ready access to electric charging and where long distance and continuous usage is desired. These customers will cluster at hubs in population centers where convenient and reliable fueling infrastructure is in place.

Customer demand also depends on strong confidence, backed by solid data, in hydrogen safety. Strategies are needed to ensure that safety best practices are always integrated into projects.

Clustering RH2 users by customer demand can create resilient markets for RH2 producers.

"To gain public support it's important to get applications on the road. You're not going to get public adoption unless you have cars or buses running on hydrogen just because you get so hidden. The more you get people in seats, the more adoption will occur…To have a fleet of a 1,000 Uber cars would be a pretty big bang. Big companies like Microsoft can get all their employees driving to campus to be carbon neutral. Focus on creative ways of getting everyone to use this stuff. It's a matter of getting those players going."

COLIN ARMSTRONG
President and CEO
HTEC

"Safety issues can be a 'deal breaker' and must be addressed for successful hydrogen technology acceptance and deployment. Hydrogen can be used safely, indeed it has been for nearly a century by industry. However, hydrogen's use as a fuel is new to many who may lack experience or expertise for its safe use. Failing to address the safety knowledge gaps can result in delays to technology acceptance, impactful incidents, and industry setbacks."

NICK BARILO | *Executive Director* | Center for Hydrogen Safety

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Sub-Element 2
Priority Hub Locations and Convenors

Deployment hubs will be developed at priority locations where multiple RH2 users can be concentrated, including at transport fueling stations, ports, and around select industrial facilities – including energy utility facilities.

Deployment hubs will also be initiated by PNW-based corporations and by cities with deep commitments to greening their operations and supply chains.

"We also work on the fueling system infrastructure side for the RH2 tanks, mostly because in the scale that we're operating there really isn't anybody out there. You can't go down to the street corner and get your tank filled with liquid hydrogen. So we've had to provide a solution for that part of the problem in order for our customers to fill up."

ELIJAH SHOEMAKE
Chief Commercial Officer
The Protium Company

Fueling Stations

Establishing RH2 fueling stations for the long-haul trucking market along major highway corridors, like I-5, I-84, and I-90, is a priority because long-haul trucking is viewed as one of the most promising markets for hydrogen-powered transport. RH2 Truck Stops can be positioned as RH2 Deployment Hubs by co-locating RH2 production and storage at refueling stations designed for rapid fill-up for truckers.

Because major highways link our biggest cities and towns, many Hydrogen Highway fueling stations will be in metropolitan areas. These should be designed to accommodate transit buses, the most mature market for H2 fuel cell transport.

"It's our transportation sector that needs help [because it's the] biggest carbon input. I-5 running up and down Vancouver to San Diego could be a hydrogen highway for large truck hauling. There is one fueling station in Sacramento, one in BC, and probably nothing in between. Serving the heavy truck industry is the biggest bang for your buck in the PNW. I would like to use electrolyzers for capacity and then set up a fueling station to sell the excess."

MIKE MCCANN | *Electric Generation Manager* | Eugene Water and Electric Board

Fueling stations in metro areas should serve passenger vehicles too, for three main reasons: first, fuel cell electric vehicles offer important benefits for customers that value longer range and fast refueling time. Second, fuel cell electric vehicles are an excellent zero emission option for customers who do not have convenient access to electric charging, especially those in multi-unit dwellings such as apartment complexes. Finally, passenger vehicle fueling in population centers offers exceptional public visibility for RH2, and so is especially valuable to accelerating PNW RH2 sector growth.

A hydrogen filling station in the center of Hamburg supplies the fuel cell buses of the Hamburger Hochbahn and fuel cell cars with hydrogen produced on site from green electricity.

"Commercial transportation/ trucking sectors are very viable in the PNW. I envision hydrogen generation and storage facilities of all scales strategically located so semis can make trips across the US exclusively using hydrogen fuel. These facilities can be operated with energy from conventional utilities, or energy generated remotely in areas with abundant renewable resources and water – RH2 can be made and stored pretty much anywhere."

PATRICK MILLS
Chemical Engineer
Confederated Tribes of the Umatilla Indian Reservation

Ports

Ports are natural commercial intermodal transport hubs, with significant cargo flows, concentrated energy consumption, and a mandate to promote economic development.

Ports are hubs serving key transport industries like shipping, aircraft, trucks, and rail. A variety of cargo and material handling equipment can operate in and around ports on a near-continuous basis. Trains and trucks deliver this cargo for broader distribution, and cranes, forklifts, and drayage vehicles move cargo and materials on site. Waterfront ports are also hubs for a variety of maritime vessels from small to very large. RH2 is a viable competitor to supply green fuel for many of these heavy-duty transport sectors.

"As the Port of Seattle develops strategies for eliminating all emissions from port operations by 2050, we need to keep our eyes open to a full range of clean energy sources and technologies to power the maritime industry. It will be critical to pair the right renewable fuels with the requirements of a wide range of vehicles, vessels and equipment. The Northwest's clean, renewable electricity is a strategic opportunity and we are eager to see the evolution of other clean alternatives such as fuel cells, green hydrogen and its derivatives as important tools in the toolbox to decarbonize the working waterfront."

DAVID FUJIMOTO
Senior Environmental Program Manager
Port of Seattle

Diesel-powered vehicles dominate port heavy-duty transport applications today. Electric battery-powered vehicles can work well for some applications, but for a growing number of applications RH2 fuel cell vehicles can match performance of diesel incumbents in the 24-7, around-the clock operating environment that prevails at ports.

Converting diesel vehicles at ports to electric or fuel cell vehicles can also benefit environmental justice. Heavy reliance on diesel vehicles make ports among the most significant contributors to criteria air pollutants. Generally lower land values around ports mean that lower-income communities tend to be sited in their vicinity, putting the health of their residents at disproportionate risk.

Ports have a mandate and significant flexibility to invest public resources and deploy port assets to foster locally-beneficial economic development. That's why ports make ideal places to host RH2 Deployment Hubs.

And ports often host or neighbor industrial lands. Industrial centers can themselves serve as excellent RH2 Deployment Hubs (see next sub-element).

"People need to see the success in the ports, then drive past enough refueling stations on the roads to realize this is viable. Then it will take off… And you're going to see big RH2 liquifiers go in at some of our ports, and a hub and spoke model start to take off in those ports."

JACOB LEACHMAN | *Associate Professor* | School of Mechanical & Materials Engineering WSU

Select Industrial and Energy Facilities

Energy utilities, both electric and natural gas, are natural early adopter customers for RH2 and initiators of Deployment hubs because RH2 applications can provide valuable operations benefits at utility facilities and for operations.

Electric utilities can expand demand for their product by electrifying transportation markets now served by fossil fuels. Some transport applications can best be served by RH2-powered fuel cell technologies, using fuel derived from renewable electricity. Electricity demand is stagnant for many utilities, so expanding into new markets offers opportunities for growth that also deliver environmental and climate benefits for the broader region.

RH2 applications, including fuel cells for stationary combined heat and power, offer other valuable benefits to utilities, including backup power, resiliency, grid balancing and flexibility, and low carbon intensity.

For example, electric utilities can forge agreements with RH2 generators to take advantage of electrolyzers' capacity to be ramped off and on, providing utilities with a new, affordable, flexible resource to help them keep power grid supply and demand in balance, and to get more value from renewable power generation units when power prices plummet. RH2-powered stationary fuel cells can also offer utilities valuable resiliency and backup power capacities. In exchange for these services, utilities can deliver RH2 producers power at wholesale or deeply discounted prices, as Tacoma Power's Electrofuels tariff does.

Natural gas utilities, too, can benefit from RH2. Some natural gas power plants and pipeline injection points are located in industrial areas, and the gas utilities that operate them are under growing pressure to reduce carbon intensity – which can make blending RH2 into their fuel mix at up to 20% an attractive proposition.

"Including green hydrogen options in regional, integrated energy and transportation planning processes could provide the context critical for understanding the way hydrogen fits best into the region's future energy picture. That work feels critical both for understanding a broad regional hydrogen strategy and to understand the next critical moves with this fuel."

BILL EDMONDS | *Executive Director* | Northwest Power & Conservation Council

"Our green renewable hydrogen will hopefully replace brown or blue hydrogen that industrial gas companies buy to supply markets for industrial uses of hydrogen. Our intent as a power company is not to displace some of those gas suppliers; our niche in the market is to be a wholesaler of RH2 industrial gas to those suppliers."

GARY IVORY
General Manager
Douglas County
Public Utility District

The large and reliable market demand for hydrogen for direct use by industry, replacing fossil-derived H2 with renewable could provide a significant economic opportunity. These industrial applications range from fertilizer production to semiconductor manufacture, alloying metals, chemical processing, flat glass production, and oil refining. For industrial producers seeking to reduce their carbon footprints, RH2 can supply a carbon-free feedstock, but which industrial markets are ripe for RH2 is not yet clear. Industrial centers also concentrate a number of businesses that often require large volumes of high-reliability heat and power, which in some cases can be supplied in part by carbon-free RH2.

Utilizing fertilizer derived from hydrogen can help decarbonize an existing market in a hard to abate industry. *Photo Courtesy of pixabay.com*

"Natural gas power plants can burn up to 30% hydrogen without modification, and they are under pressure to reduce their carbon intensity. Although the economics of hydrogen are a lot closer to competing with gasoline and diesel, the market potential in the gas system and in power plants is orders of magnitude larger."

KEN DRAGOON | *Founding Director* | Renewable Hydrogen Alliance

Initiated by Green Corporations and Cities

Many PNW corporations, including giants like Microsoft, Starbucks, Intel and Amazon, are making serious commitments to reducing the carbon footprint of their operations and products. Similarly, cities big and small – from Spokane, Portland, Eugene, and Tacoma to Olympia and Walla Walla, are committed to climate and clean energy leadership and innovation.

Corporations committed to decarbonizing their operations and products are reimagining energy flows at their campuses where employees are concentrated, at production facilities and data centers that use large volumes of energy and have a high need for consistent reliable heat and power, and at operations hubs including fulfillment and distribution centers. At Microsoft, for example, "we have these aggressive company goals around sustainability that we think green hydrogen will contribute to quite a bit," says Mark Monroe.

An employee checking on a data center. *Photo Courtesy of Christina Morillo*

"The datacenter or digital industry is a small part of the hydrogen marketplace in the long-run, but I believe it can provide a very short-term drive of components for green hydrogen in a way that other industries can't. Most of the companies that had a vested interest in hydrogen were talking about 2050 timelines, and I said, "Look, internet years are like dog years, there's 7 for every regular one." So, 2030 is already 70 internet years away from us, and we just have to go faster than that. We're looking at being able to push manufacturers in ways that they're not prepared to respond to."

MARK MONROE
Datacenter Advanced Development
Microsoft

"Spokane Public Works absolutely has a role to play in the clean hydrogen revolution. As consumers of huge quantities of energy, and providers of life-impacting municipal services, we owe it to our citizens to power our infrastructure with the cleanest, most affordable and resilient energy we can find. Partnering and piloting renewable hydrogen solutions is in our future."

CADIE OLSEN
Sustainability Director
Department of Public Works at the City of Spokane

Likewise, many PNW cities are also committed to clean energy leadership. These cities are pursuing innovative strategies to transform their operations and infrastructure and slash climate and other pollution in ways that benefit the community economically, environmentally, and socially.

In both cases, RH2 can become an important component in the portfolio of solutions of green corporations and clean cities, which means these organizations can initiate RH2 deployment hubs that engage other private, public, utility and NGO project development partners.

Northwest Tribes, too, can initiate RH2 deployment hubs. A number of tribes are considering RH2 projects. The Confederated Tribes of the Umatilla Indian Reservation, which is exploring a RH2 hub that combines solar-powered electrolysis to produce RH2, a fueling station for commercial trucks traveling on I-84, and storage and delivery infrastructure.

The Ántukš-Tińqapapt or "sun trap" solar array recently installed by the Confederated Tribes of the Umatilla Indian Reservation in Oregon. *Photo Courtesy of U.S. Department of Energy*

"Companies like Plug Power, whose West Coast office is in Spokane, are basically replacing many of the Walmart battery recharging infrastructures for running fulfillment centers (with RH2 fuel cell solutions). Look at Amazon, Krogers – 30% of the groceries in the US right now are moved by a hydrogen fuel cell forklift, where that hydrogen was brought there by a liquid tanker-truck.

JACOB LEACHMAN | *Associate Professor* |
School of Mechanical & Materials Engineering at Washington State University

Sub-Element 3
Align on Key Policy Levers and Criteria for Public Investment

The PNW RH2 coalition needs to align behind, and advocate for, key policy incentives and standards to stimulate diverse RH2 demand. The coalition also needs to develop performance criteria to help agencies rationalize and prioritize public investment in RH2 projects, especially with prospects growing for significant federal and state dollars for RH2 and other clean energy infrastructure.

Policymakers can incentivize development of vibrant and diverse markets for RH2 that reduce carbon intensity, in close proximity to production facilities, reducing risk and increasing confidence for project investors.

Increasing RH2 demand will also grow demand for renewable electricity, which policymakers have encouraged through a variety of incentives and mandates. But even with these incentives, for the economics of investment in new PNW solar and wind farms to pencil out for utilities and developers, new demand for renewable power is essential.

Key policy levers to fuel RH2 demand for the coalition to align on in the near-term include:

- Zero-emission vehicles requirements (ZEV) and low-carbon fuel standards (LCFS).
- Renewable/carbon-free portfolio standards for electric and gas utilities that treat RH2-derived system benefits on a level playing field.
- Utility tariffs and regulatory mechanisms to better reward the real benefits that RH2 offers to utilities, including resilience, energy storage, system flexibility resources, carbon-free fuels, and more.
- Tax incentives, appropriate to each state, to attract private investment into RH2 equipment and projects.
- Education initiatives for stakeholders, code officials and first responders on hydrogen safety to accelerate the acceptance and approval of hydrogen technologies.

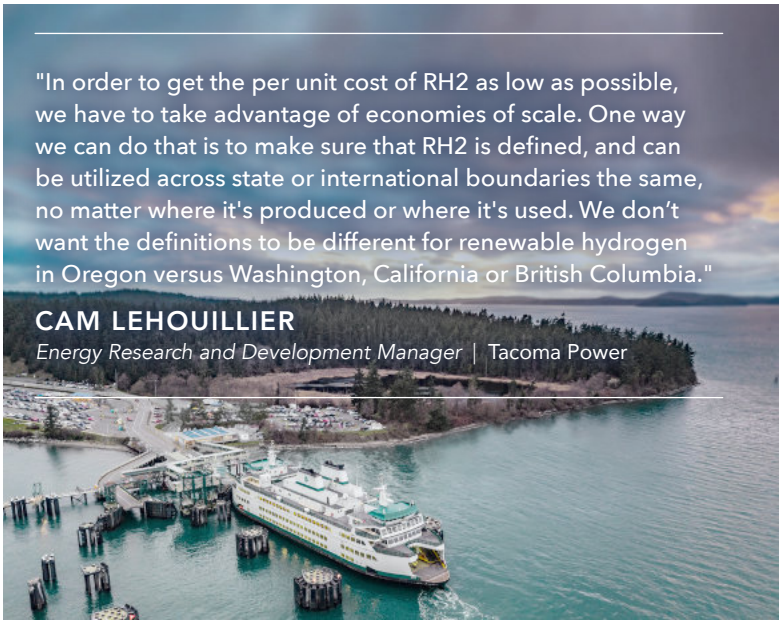
"Our Council has adopted a first-of-its-kind electrofuels rate (tariff) that offers RH2 producers a deeply discounted demand charge on our already competitive power rate, but in exchange they accept a moderate degree of interruptibility."

CLAY NORRIS
Power Management Officer
Tacoma Power

"Consumers buying one small sedan after another doesn't send a very large market signal to suppliers to make/produce RH2. But in CA there's a zero-emission vehicle standard that's now being applied to heavy duty trucks. What that will do is dramatically ramp up demand for clean vehicles and clean fuel, and that's where hydrogen and fuel cell vehicles really start to scale."

EVAN RAMSEY | *Senior Director* | Bonneville Environmental Foundation

In addition, at a time when prospects are growing for significant federal and state dollars for RH2 and other clean energy infrastructure, the coalition also needs to propose performance criteria to help agencies rationalize and prioritize public investment in RH2 projects. This is important to mitigate risk for private capital investment and to ensure that public dollars maximize leverage of other investments and get significant economic and environmental bang for the public buck.



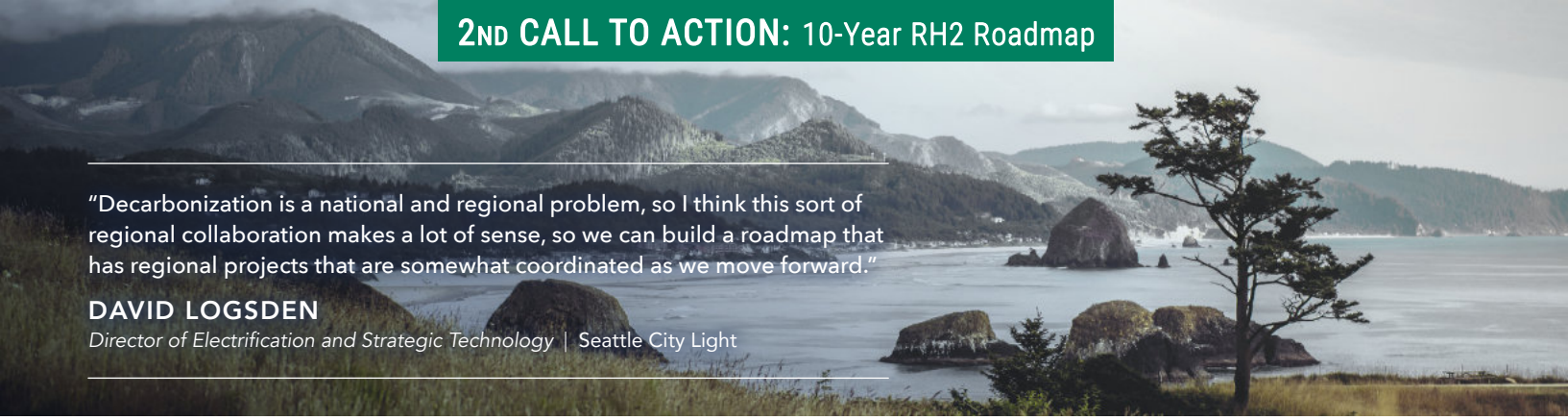
A Washington State ferry docks at the Anacortes ferry terminal in Washington.

"We see a strong future for renewable hydrogen in the Pacific Northwest. California's mix of carrots and sticks and evolution toward market-based mechanisms creates an environment for accelerating and scaling renewable and decarbonized hydrogen. This becomes a virtuous cycle enabling improvements in cost and performance that open up opportunities for further acceleration and scale. The carrots include vehicle purchase incentives and 'capacity credits' in their LCFS that encourage early adopters and actors. The sticks include ZEV and LCFS mandates. These experiences along with the progress from industry in California may provide a strong starting point for success with renewable hydrogen in the PNW."

WAYNE LEIGHTY
Hydrogen Commercial Head, North America
Shell New Energies

"For the marine sector, a strong but achievable standard would be that all harbor craft operating in the state (e.g. ferries, tugs) must be zero emission. For example, phase in the requirement for all new builds that go under contract on or after 1/1/2022, and all operating vessels by 2035 to allow for repowerings and fleet planning. Also, fund pilot programs for early adopters."

PETER BRYN | *Technical Solutions Manager* | ABB Marine & Ports



"Decarbonization is a national and regional problem, so I think this sort of regional collaboration makes a lot of sense, so we can build a roadmap that has regional projects that are somewhat coordinated as we move forward."

DAVID LOGSDEN
Director of Electrification and Strategic Technology | Seattle City Light

Coastline along Cannon Beach, Oregon. *Photo Courtesy of Tim Mossholder*

CREATE THE 10-YEAR RH2 ROADMAP

The PNW's RH2 Action Plan's second call to action is to create a 10-year RH2 Roadmap for the Pacific Northwest. To realize the region's optimal potential for RH2, we need a long-range roadmap. This enables us to see where we want to go and better prioritize policies, projects, and performance metrics to get there.

Ultimately, states should lead the roadmapping to ensure that RH2 roadmaps are fully integrated into and harmonized with state energy and climate strategies. But the PNW RH2 coalition need not wait for state action; it can begin roadmap work now.

Key sub-elements of this call to action:

- Develop a vision for the role of RH2 in a fully realized PNW zero-carbon energy-industry system.
- Consider a variety of next-tier opportunities in the context of long-range system-wide RH2 roadmapping, and launch strategic deployment projects for the most commercially viable.
- Surface the research, development, and deployment (RD&D) initiatives that can strategically accelerate RH2 commercialization.

"The idea is you take excess renewable capacity to convert green electrons into green molecules, and utilize that molecule when you need it. That's specifically for power, but it unlocks other industries along the way. As we look at large-scale projects for power-to-hydrogen that bring costs down, we can also help unlock transportation and industry, which are baseload uses of hydrogen. We're very utility-focused, but anything we can do at the state level to get more of this cross-sector talk going will greatly benefit the industry as a whole."

PETER SAWICKI
Regional Director of Sales and Marketing, Mitsubishi Power Americas, Inc.

The Case for This Call to Action

The PNW RH2 Action Plan's second call to action proposes that we create 10-year RH2 Roadmaps that are ultimately formalized and adopted by states, to ensure they are fully integrated into and harmonized with state energy and climate strategies.

The benefits of this strategy:

- The RH2 sector is a nascent and increasingly dynamic sector. Projects in the near-term will target markets that are closest to commercialization. But the scale and breadth of RH2 applications in a fully-realized zero-carbon future is not widely understood. State RH2 Roadmaps can provide the market intel to fully integrate RH2 into state energy and climate plans.
- The Pacific Northwest is not the only region building a strategy to accelerate the RH2 sector. Collaborating with California, British Columbia, and the wider West on RH2 planning and policy can yield dividends for broad RH2 market development and acceleration. Drawing lessons and adapting policy tools developed by leading RH2 regions globally will improve PNW roadmapping and policymaking.
- There are a range of next-tier RH2 opportunities that are exciting, but they need to be considered in the context of larger, holistic RH2 Roadmaps. Projects that can not only demonstrate a clear business case for project investors, but also clear consistency with state energy and climate priorities, will face fewer barriers to successful development.
- By securing investment commitments from local, utility, and private sources for projects that fit well with the state RH2 Roadmap, these projects will offer an attractive value proposition for federal and state funders.

"It does feel like hydrogen is the place where everyone lines up and agrees and is excited about driving it forward. All of this is going to be hard, so having more players that are in agreement on a solution, even if we don't know how we're getting there yet, is helpful."

HOLLY BRAUN
Energy Innovation & Policy Manager
Northwest Natural

"The big takeaway from the PNW region [is an] integrated energy discussion. Integration of markets has a lot of value for the PNW, but physical energy delivery in the PNW without carbon means you have to solve for heat and for integration."

BEN FARROW | *Manager of New Product Development* | Puget Sound Energy

Sub-Element 1
Develop a Long-Range RH2 Vision

To create a 10-year RH2 Roadmap for the PNW, a first order of business is to develop a broadly-shared vision for the role of RH2 in a fully realized zero-carbon energy-industry system looking 10-20 years out, grounded in state-of-the-knowledge analysis of technology, markets and carbon performance.

This vision for the longer-term role of RH2 and its derivatives in future zero-carbon scenarios will enable state RH2 roadmaps to nest properly into and optimize value of the larger state energy and climate strategies. PNW RH2 strategies should also consult and align with similar RH2 roadmaps in British Columbia, California, and the wider West, and draw lessons and adapt policy tools developed by leading RH2 regions globally.

"I am concerned we could short-change hydrogen and not realize its full potential until it gets to scale. Hydrogen is not just an adjunct to the grid and for car fuel. The longer-term wicked problem will be to allocate capital, markets and policy between grid, hydrogen, and perhaps other energy systems without assuming that the grid is the only and the default way we're going to decarbonize the entire human enterprise."

BILL LEIGHTY
Director
The Leighty Foundation

"Comprehensive policy with a combination of incentives, procurement policy, and R&D funding will be helpful for development of the hydrogen industry. That will help address the cross-sectoral issues so, for example, you can have a flexible energy storage policy where there's not a requirement to put electricity back on the grid in the same place that it was taken off."

TANYA PEACOCK
Public Policy & Planning Manager
SoCalGas

"It's very important to think through the rollout of stations, how to coordinate that activity with everyone who's involved (states, fuel providers, OEMs, etc). The reason we were able to launch in California is because that's done. The next place is the Pacific Northwest. You've got the green mentality, the potential hydrogen source, and a lot of policies here or coming on board."

MICHAEL LORD
Executive Engineer
Toyota

"In a lot of ways, hydrogen as a storage medium is a great opportunity because it allows for electric airplanes and allows us to build in significant redundancy and backup safety features that will help us get to a safety case story that the FAA will eventually accept. If things are happening in other industries, then there are opportunities to build off of those successes. This is a great place for us to understand how government, rule-making groups and committees, and sustainability groups are moving forward."

JEFF KNAPP | *Chief Engineer* | Insitu

Sub-Element 2
Consider Next-Tier Opportunities

System-wide RH2 roadmapping is also the right venue for considering a variety of next-tier opportunities, and for prioritizing next-generation projects that can attract local, utility, and private investment and that fit well in the 10-year RH2 Roadmap.

These projects will also offer a strong value proposition for private, local and utility investors, as well as for federal and state funders, by demonstrating a clear business case for all project investors and clear consistency with state energy and climate priorities.

"Maritime and aviation fuels are very large potential markets for hydrogen or ammonia possibly, in contrast with trucking and personal vehicles. The front runner for long hauls is ammonia, which translates to a lot of demand. Same with marine bunkers."

THOMAS KOCH BLANK
Senior Principal
Rocky Mountain Institute

"When it comes to longer-duration storage, hydrogen becomes more cost effective. While the current chemistries of batteries (lithium-ion and others) are useful for discharging stored electricity over the course of hours, they are much less cost effective for events lasting days or weeks. RH2 is on the short list of candidate technologies that could provide cost-effective long-duration and seasonal storage."

REBECCA SMITH
Senior Energy Policy Analyst
Oregon Department of Energy

"I see opportunities for fuel cells powered by RH2 to produce clean electricity for resilient microgrids and backup generation to replace diesel gen-sets, while harvesting the waste heat to feed into district thermal loops. This is what the Goldendale Energy Exchange aims to do."

DAVE WARREN
Principal
The Warren Group

"I don't see a one-fits-all solution for the goal of sustainable aviation. RH2 is one significant piece in a multi-pronged approach, along with other sustainable fuels, electrified aircraft, etc. It's important to understand how hydrogen fits into the overall strategy, and into the renewable/sustainable industry more generally. Then we can identify ways to fit it in, and identify synergies with adjacent industries that will bolster the RH2 sector as well."

HUBERT WONG | *Aeronautics & Configuration Design Engineer* | Boeing

Next-tier RH2 opportunities are markets where RH2 is not quite ready to carve open market share, but that can realistically scale with targeted policies, technology refinement and economies of scale.

These promising applications and markets for RH2 include:

- Long-term energy storage for utilities and grid operators
- Green hydrogen to replace fossil gas as feedstock to produce fertilizer for agriculture
- Green fuel to replace fossil fuels for long-haul shipping, rail, and aviation
- RH2 pipeline infrastructure to inexpensively transport renewable energy long distances
- Conversion of RH2 to methane, ammonia, formic acid, or other energy-intensive products for applicable markets
- RH2 to replace fossil-derived hydrogen for targeted industrial applications
- RH2-powered fuel cells to provide heat to district thermal systems and industry, and electricity to microgrids
- Carbon-negative H2 generated from gasification facilities at wastewater treatment plants and other waste biomass processing centers, as one of multiple product streams
- PNW manufacturing of RH2 equipment
- Export of RH2 and derivative fuels

"A huge use of natural gas hydrogen is fertilizer – it's the second biggest use of hydrogen today. If we can get a modestly sized fertilizer plant to make ammonia from green hydrogen rather than natural gas, that would attract a huge amount of attention. There's an opportunity to make the RH2 equipment and infrastructure here in the PNW (electrolyzers, trucks, motors, etc.). That should be a big part of our RH2 strategy: trying to be a hydrogen advanced state so that manufacturing companies want to come here and make the stuff a hydrogen economy needs."

DAVID BROWN
Senior Principal and Co-Founder
Obsidian Renewables

"Everyone is building gigafactories these days – the major electrolyzer manufacturers have 8-10 in the works now. Each one built will effectively double global capacity, which is now only 1 gigawatt. The market is going toward 25GW by 2025, and 100GW by 2035. A handful of these electrolyzer gigafactories will be built in the US. How do you ensure one or more are built in the PNW? The idea of joint ventures with European companies is an interesting one."

THOMAS KOCH BLANK | *Senior Principal* | Rocky Mountain Institute

Sub-Element 3
RD&D to Accelerate Commercialization

Roadmaps can also help surface the research, demonstration, and deployment (RD&D) initiatives that can strategically accelerate RH2 commercialization. RD&D initiatives can collaborate with deployment hub project developers to measure and evaluate performance and recommend innovations. And they can deploy pilot projects to test business models for the most promising and impactful next-tier opportunities.

"RD&D in general has super tiny budgets. There is no Oregon state-level funding; we don't even have a clean energy fund like Washington. Oregon could be putting a lot more into this."

ANNA CHITTUM
Director of Renewable Resources
Northwest Natural

To accelerate the growth of the RH2 sector in the PNW, investment is needed in programs to advance industry knowledge and commercialization through research, demonstration and deployment (RD&D). These programs should be co-designed by leading PNW research institutions, government agencies, and industry to align public and private dollars for multi-institution, high-priority research initiatives, proof-of-concept demonstration projects, and deployment of scalable applications.

Students with Washington State University's HYPER lab test fly Genii, the first liquid hydrogen fueled drone built by a university team. *Photo Courtesy of the Hydrogen Properties for Energy Research (HYPER) Laboratory*

"What's so exciting in the PNW is there are now multiple developers looking at building major hydrogen liquefiers in the ports along the I-5 corridor. And as soon as we get a hydrogen liquefier here, that's going to open the flood gates to everyone being able to more cost effectively site and build liquid hydrogen infrastructure in the region."

JACOB LEACHMAN | *Associate Professor*
School of Mechanical & Materials Engineering at Washington State University

One example is CHARGE – Washington State University's new Consortium for Hydrogen and Renewably Generated Electrofuels.

- **Research**: A wide variety of research is warranted to help solve key commercialization challenges. But to gain political support and buy-in from the environmental community, research is also needed to develop objective, transparent accounting for the full end-to-end life cycle environmental impacts of RH2 applications (versus incumbents and alternatives), especially for carbon and for water consumption by electrolyzers in arid regions.
- **Demonstration**: Proof-of-concept demonstration projects provide field experience with new technologies and configurations, generating performance data that can be harvested to improve processes and develop next generation business cases.
- **Deployment**: RH2 applications that demonstrate a strong business case, or that are clearly poised to break through with economies-of-scale, are good candidates for deployment initiatives to bring down costs by scaling up the number and/or size of projects.

"I'm thinking about it from a conversion efficiency perspective. There's no question that making RH2 from curtailed energy makes sense for overall system efficiency. If we create new markets for RH2 and they're depending on that renewable power resource, do we create pressure to use that resource for hydrogen rather than producing electricity? Maybe that's not a real tension or conflict, but we need good research that evaluates these kinds of questions."

NANCY HIRSH
Executive Director
Northwest Energy Coalition

"From a PNW perspective, bringing in multiple entities will be a valuable way to create a system where we're using the best of each entity. Teaming with UW researchers, we step in for deployment and scale, which creates opportunities to build the whole chain here. R&D plus deployment is a good consortium strategy."

BEN FARROW | *Manager of New Product Development* | Puget Sound Energy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Thank You

Thought Leaders who Contributed to the PNW RH2 Action Plan

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HUBERT WONG *Aeronautics & Configuration Design Engineer*, Boeing

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KEN DRAGOON *Former Executive Director*, Renewable Hydrogen Alliance

MARTINA STEINKUSZ *Interim Executive Director*, Renewable Hydrogen Alliance

NICOLE HUGHES *Executive Director*, Renewable Northwest

SASHWAT ROY *Technology & Policy Analyst*, Renewable Northwest

THOMAS KOCH BLANK *Senior Principal*, Rocky Mountain Institute

JOHN LECOMPTE *Senior Energy Management Analyst for Emerging Technologies*, Seattle City Light

DAVID LOGSDEN *Director of Electrification and Strategic Technology*, Seattle City Light

WAYNE LEIGHTY *Hydrogen Commercial Head, North America*, Shell New Energies

TANYA PEACOCK *Public Policy & Planning Manager*, SoCalGas

KIRT CONRAD *Executive Director & CEO*, Stark Area Regional Transit

KELLY ECHOLS *Partner*, Stoel Rives LLP

CLAY NORRIS *Power Management Officer*, Tacoma Power

CAM LEHOUILLIER *Manager of Energy Research & Development*, Tacoma Power

BILL LEIGHTY *Director*, The Leighty Foundation

DAVE WARREN *Principal*, The Warren Group

MICHAEL LORD *Executive Engineer*, Toyota Motor North America

JASON SEKHON *Advanced Technology Research Consultant*, Toyota Motor North America

JACOB LEACHMAN *Associate Professor at the School of Mechanical & Materials Engineering*, Washington State University

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