Alaska Hydrogen Opportunities Report

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Executive Summary

Hydrogen has recently received significant attention at the national and international levels due to its decarbonization potential in numerous economic sectors. As a piece of the clean energy solution puzzle, it offers spatial and temporal flexibility in the use of energy sources that might otherwise pose challenges in their locations and times of output. This inaugural report on Alaska's hydrogen energy opportunities introduces key themes for developing a hydrogen economy in Alaska, establishes a baseline understanding of Alaska's infrastructure and resources relevant to hydrogen, and contextualizes this baseline in terms of national and global initiatives focused on hydrogen. This report could be further developed into a hydrogen roadmap or a statewide hydrogen strategy in the future.

The driving group behind this report, the Alaska Hydrogen Working Group, was formed in 2022 to address the increasing interest in hydrogen energy opportunities in Alaska. As of December 2023, there were nearly 200 members representing industry, government, academia, communities, tribal entities, and interested citizens from both inside and outside Alaska. Since its inception, the group has met monthly to discuss issues of interest and to share insights and questions. One task is to synthesize Alaska's hydrogen energy opportunities and potential into a report. This task not only reflects grassroots interest but also responds to objectives outlined in *Alaska Statewide: Comprehensive Economic Development Strategy 2022–2027* (Alaska Department of Commerce, Community, and Economic Development, 2022), one of which is to develop and implement a hydrogen roadmap for Alaska.

The goals of this report are to enhance knowledge and information sharing, spur innovation and investment that could help transform Alaska's energy systems, and identify economic and workforce development opportunities across the state. Following the elements of the hydrogen economy outlined in the *U.S. National Clean Hydrogen Strategy and Roadmap*, published in June 2023, this report explores the production, storage/delivery, and end-use options in evolving markets for Alaska, both within and outside the state. It also outlines key opportunities to identify and develop infrastructure investments, policy and regulatory frameworks, future research and demonstration priorities, economic and investment considerations, and workforce programs. These goals and opportunities are intended to support a statewide hydrogen energy economy that is equitable, diverse, environmentally just, and supportive of Indigenous rights and value systems.

Alaska has the potential to make progress in a number of hydrogen ecosystem components, including hydrogen production from both vast renewable energy potential as well as natural gas resources combined with carbon capture; seasonal energy storage for Alaskan communities; and storage in depleted oil and gas reservoirs to enable affordable delivery of hydrogen at scale. Near-term demonstrations can show proof-of-concept as well as long-term benefits and challenges, establish early markets, and build social license for the growth of a hydrogen energy ecosystem. Determining the scope of work, timelines, and entities accountable for each effort is the next important action to realize these efforts. This report also details follow-on efforts in the categories of economic, financial, and policy considerations; research and infrastructure; workforce development; and social equity.

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Acronyms

45Q	Carbon Capture, Utilization and Storage Tax Credit
45V	Clean Hydrogen Production Tax Credit
AEL	alkaline electrolyzer
AKLNG	Alaska LNG Pipeline
ANC	Anchorage International Airport
ATR	autothermal reforming
BOEM	Bureau of Ocean Energy Management
CCS	carbon capture and sequestration
CO_2	carbon dioxide
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
GHG	greenhouse gas
LCOE	levelized cost of energy
LH_2	liquid hydrogen
PCE	Power Cost Equalitzation
PEM	polymer electrolyte membrane
PTC	production tax credit
SAF	sustainable aviation fuel
SHASTA	Subsurface Hydrogen Assessment, Storage, and Technology Acceleration
SMR	steam methane reforming
SOEL	solid oxide electrolyzer
USGS	U.S. Geological Survey

1 Why Hydrogen, Why Now, and Why Alaska?

1.1 Introduction to the Hydrogen Energy System

Clean hydrogen has long been discussed as a key element for tackling critical energy challenges, including the decarbonization of various sectors by displacing fossil fuels and providing energy security (IEA, 2019), but it has also been plagued by unfavorable production and infrastructure economics. Alongside international efforts, the U.S. Biden-Harris Administration has set ambitious goals to realize a carbon-free power sector by 2035 and a net-zero economy by 2050. Accompanied by tax credits and declining costs of renewable energy generation, there might be an economic path forward for clean hydrogen (IRENA, 2022).

Hydrogen, like fossil fuels, possesses two properties that are critical in a modern energy economy: (1) The energy can be stored until it is later needed, and (2) the stored energy can be transported and delivered where it is needed. Additionally, clean hydrogen can be an attractive contributor to the portfolio of decarbonization solutions for several reasons:

- Although the volumetric density of hydrogen is 2–6 times lower than conventional fuels, its specific energy by mass is up to 80% higher (Medwell et al., 2020). In other words, a hydrogen molecule contains a lot of energy, but it typically occupies large volumes. Compressing or liquefying hydrogen can reduce this volume, but doing so comes at a cost.

- Most interest in clean hydrogen production currently focuses on generation either from fossil fuels with carbon capture and sequestration (CCS) or through electrolysis powered by renewable electricity. Clean hydrogen can also be produced from nuclear energy, or directly from geologic sources.

- Hydrogen can be used for a variety of energy applications, including electricity (e.g., stored, combusted, or re-electrified in fuel cells), heat (e.g., in industrial processes, such as steel production), and transportation (e.g., fuel cell vehicles, ships, aviation).

- Hydrogen can also be transformed into fuels—such as methanol, ammonia, and synthetic hydrocarbons—that have wide applications worldwide and have higher energy densities by volume. Currently, most of the global hydrogen demand comes from refining and chemical industries i.e., approximately, 94 million metric tons (MMT) of fossil-based hydrogen which represents 99% of the hydrogen demand worldwide (IEA, 2023a).

- Hydrogen has immediate potential to help decarbonize difficult sectors, such as steel, cement, and chemical manufacturing (e.g., ammonia, methanol), which are significant contributors to global carbon dioxide equivalent (CO_2e) emissions. For instance, ammonia production contributes approximately 2% (The Royal Society, 2020), and the steelmaking industry represents 7%–9% of global greenhouse gas (GHG) emissions (Worldsteel, 2023).

The concept that hydrogen can be used in a wide range of sectors when it is deployed at scale is called H2@Scale and is illustrated in Figure 1. There are still questions about which sector will adopt hydrogen as a dominant fuel source and when, but it is clear that the energy sector expects the demand for hydrogen to increase.

1.2 The World Outlook

More than 50 economies around the world—including Germany, Australia, Canada, Chile, China, Japan, the United States, the United Kingdom, the European Commission, and others—have agreed that reducing fossil fuels in the global energy mix is a challenge and that hydrogen could play a key role in achieving GHG emissions neutrality. Several countries have already released dedicated hydrogen strategies, policies, guidelines, and roadmaps or have dedicated hydrogen components in their general decarbonization strategies. To provide context for the anticipated global hydrogen demand, Table 1 summarizes some projected hydrogen demands around the world.

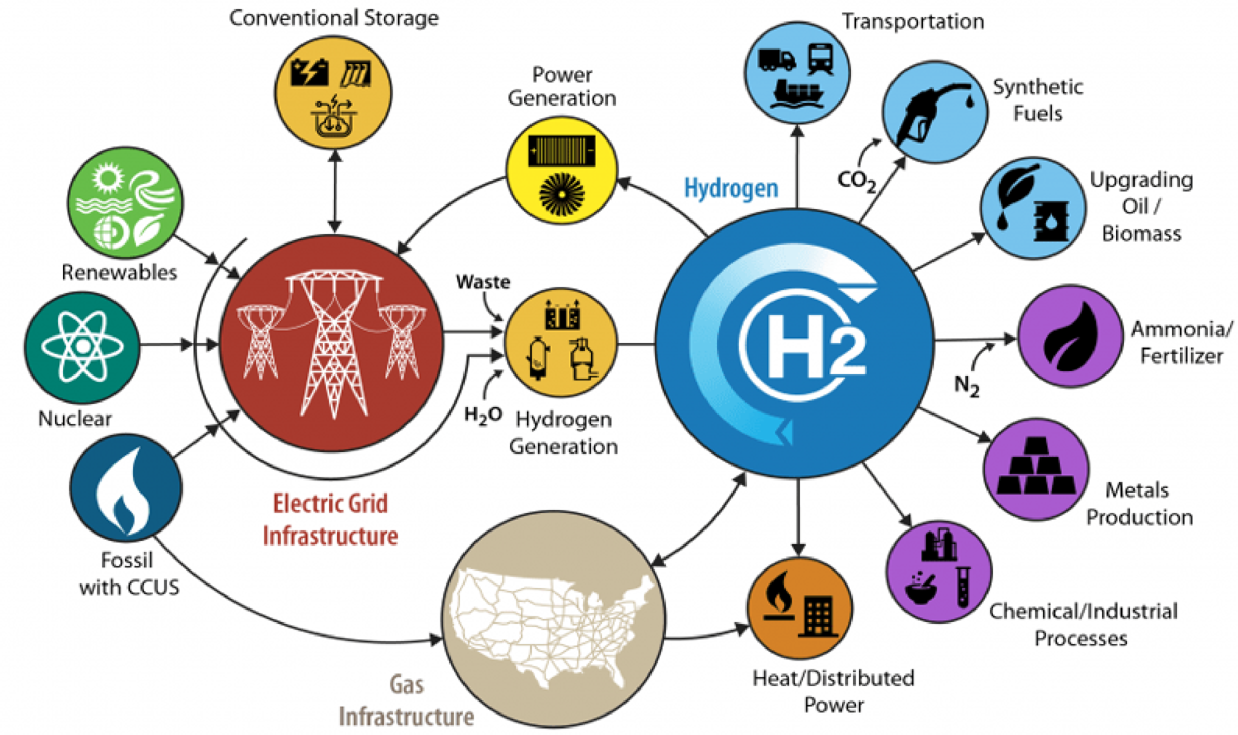

Figure 1. Illustration of the H2@Scale concept (DOE, 2021) — from hydrogen production using various sources, to storage for power generation when it is needed, to miscellaneous economic sectors where it can be used as a feedstock or fuel.

To support the realization of emissions reduction goals via clean hydrogen, many economies are incentivizing hydrogen production through regulatory and financial measures. Examples include renewable hydrogen mandates in the European Union's Renewable Energy Directive, contracts for difference in Europe (EMR Settlement Limited, 2024), production tax credits (PTCs) and financial support for hydrogen hubs in the United States, tax support expansions in South Korea, and loans to support investment in clean hydrogen in Chile, among others (Collins, 2023; McKinsey & Company, 2023; The World Bank, 2023).

As a result of these strategies and a favorable regulatory outlook, investment in hydrogen production and its carriers, such as methanol and ammonia, has skyrocketed worldwide. As of October 2023, operational electrolysis deployments reached 1.1 GW, and 12 GW of capacity have passed the final investment stage (McKinsey & Company, 2023). More than 1,400 projects have been announced to break ground through 2030, with equivalent investments of U.S. $570 billion and 45 MMT of clean hydrogen production per year. At least 25 projects are focused on the production of clean ammonia, methanol, steel, and synthetic fuels (McKinsey & Company, 2023).

Additionally, driven by the European Union's ambitious goal to generate clean hydrogen for less than €2/kg by 2030, the largest number of projects and investment in gigawatt-scaled renewable power plants for hydrogen production are of European origin (McKinsey & Company, 2023). Many of these investments are in North Africa, where there is plentiful land with abundant solar and wind resources.

Table 1. Selected countries and projected hydrogen demand

Country	**Hydrogen Demand by 2030**[*]	**Net Importer/Exporter**[*,†]	**Source**
Germany	3.4	-1.7	(Alkousaa et al., 2023)
Japan	3	-0.3	(Nakano, 2021)
South Korea	3.9	-1.96	(Oh, 2023)
United States	10	< 5	(DOE, 2023d)
United Kingdom	0.2 - 0.9	–	(HM Goverment, 2021)
Chile	1.0 - 2.3	0.6 - 1.3	(Government of Chile, 2020)

[*] All values for hydrogen demand and import/export are expressed in MMT.
[†] Net importers are denoted with negative values, and net exporters are denoted with positive values; if a country is neither an importer nor an exporter, it is denoted with "-".

1.3 National Significance

The United States has set ambitious goals for achieving a clean energy economy by 2050. In June 2023, the U.S. Department of Energy (DOE) released the *U.S. National Clean Hydrogen Strategy and Roadmap*, which sets a strategic framework for achieving clean hydrogen production at scale and unlocking its decarbonization potential over a range of economic sectors (DOE, 2023d). The roadmap aligns with the Biden-Harris Administration's goals to:

- Reduce U.S. GHG emissions by 50%–52% from 2005 levels by 2030
- Completely decarbonize the electricity sector by 2035
- Achieve net-zero GHG emissions by 2050
- Deliver 40% of the benefits of federal climate investments to disadvantaged communities

In November 2021, the U.S. Congress passed and President Joseph R. Biden, Jr. signed into law the Infrastructure Investment and Jobs Act (Public Law 117-58), also known as the Bipartisan Infrastructure Law. This historic, once-in-a-generation legislation authorizes and appropriates $62 billion for DOE, including $9.5 billion for clean hydrogen. In addition, in August 2022, President Biden signed the Inflation Reduction Act into law (Public Law 117-169), which provides additional policies and incentives for hydrogen, including a PTC, to further boost a U.S. market for clean hydrogen.

Clean Hydrogen Production Tax Credit (45V)

Clean Hydrogen Production Tax Credit (45V): Section 45V of the Inflation Reduction Act (Public Law 117-169) established a 10-year incentive for clean hydrogen production in the United States. The tax incentive program sets four tiers for the well-to-gate carbon intensity of produced hydrogen, capped at 4 kg of CO_2-equivalent (CO_2e) per kilogram of hydrogen to qualify for the credit. The incentive scales from $0.6 – $3/kg of clean hydrogen produced. Qualifying projects must begin construction by 2033. The 45V program cannot be stacked with the Carbon Capture and Sequestration Tax Credit (45Q).

In 2021, DOE launched Hydrogen Shot, which aims to reduce the cost of clean hydrogen production in the United States by 80% to become $1 for 1 kilogram of clean hydrogen within 1 decade. This cost target aims to help clean hydrogen reach cost parity with hydrogen produced by steam methane reforming (SMR) and establish the foundation of the H2@Scale economy (Figure 1).

In the *U.S. National Clean Hydrogen Strategy and Roadmap*, DOE identified demand scenarios and annual production targets of 10 MMT of clean hydrogen by 2030, 20 MMT by 2040, and 50 MMT by 2050. Further, DOE has prioritized three key strategies to ensure that clean hydrogen is developed as an effective decarbonization tool for maximum benefit to the United States:

1. **Target strategic, high-impact uses for clean hydrogen,** including industrial applications, transportation, and power systems. According to the roadmap, in the transportation sector, the willingness to pay ranges from \$4–\$7/kg H_2. This compares to approximately \$0.5–\$3/kg H_2 for chemicals, iron and steel, biofuels and synthetic fuels, seasonal storage, industrial heat and exports.

2. **Reduce the cost of clean hydrogen to \$1 per 1 kg within 1 decade** through technological innovation, deployment at scale, and fostering partnerships. This means that electrolysis costs will need to be reduced by more than 80% and those of SMR with carbon capture by 30%. This will require dramatically reducing capital and energy costs as well as improving the efficiency, durability, and reliability of hydrogen production technologies. That would mean reducing electrolyzer uninstalled capital costs from approximately \$1300/kW to \$150/kW and reducing energy costs from approximately \$50/MWh to \$20/MWh (Satyapal, 2023).

3. **Focus on regional networks (hydrogen hubs)** to achieve large-scale clean hydrogen deployment to supply increasing regional demand. By focusing investments in large-scale regional projects with co-located end uses, DOE seeks to establish the infrastructure that pushes the market toward the adoption of clean hydrogen and economies of scale to reduce costs. DOE has established a Regional Clean Hydrogen Hubs program with the intent and funding to establish seven hydrogen hubs across America (Office of Clean Energy Demonstrations, 2023).

The Clean Hydrogen PTC (federal, 45V) — created in the Inflation Reduction Act — introduced a tiered emissions-based tax credit that awards a maximum of \$0.6 – \$3/kg H_2 depending on the hydrogen production pathway. The incentive can be claimed in the first 10 years of projects as long as they begin construction by 2033. The PTC can be stacked with the renewable energy PTC and zero-emission nuclear credit, but it cannot be stacked with the Carbon Capture, Utilization, and Storage Tax Credit (45Q). The PTC tiers are provided in Table 2. The maximum credit is awarded by following prevailing wage standards and apprenticeship requirements (DOE, 2023b).

The Inflation Reduction Act contains a SAF tax credit of \$1.25 for each gallon of SAF in a qualified mixture. To qualify for the credit, the SAF must have a minimum reduction of 50% in life cycle GHG emissions, with a supplemental credit of \$.01 for each percentage that reduction exceeds 50% (IRS, 2023). The credit is valid for fuel mixtures that contain SAF sold or used before January 1, 2025.

The Carbon Capture, Utilization, and Storage Tax Credit (45Q) federal tax credit pays up to \$85 per every ton of CO_2 captured and stored permanently or used, i.e., it is subsequently used as feedstock to produce low-carbon fuels, chemicals, and building materials. The credit lasts for up to 12 years, and it is available for projects that begin construction before 2033. The 45Q tax credits cannot be used in combination with other credits and incentives (Cooper et al., 2022; IEA, 2023b).

Table 2. Clean hydrogen production tax credits (45V) tiers

Carbon Intensity (kg CO_2e per kg H_2)	Base Hydrogen PTC (\$/kg H_2)	Max Hydrogen PTC (\$/kg H_2)
4.00 - 2.50	0.12	0.60
2.50 - 1.50	0.15	0.75
1.50 - 0.45	0.20	1.00
0.45 - 0.00	0.60	3.00

1.4 Hydrogen in Alaska

In the context of global projections, Alaska is geographically positioned to serve emerging hydrogen markets in both developed and developing countries. Alaska is located between major demand centers in East Asia and the U.S. West Coast, and both Japan and South Korea have announced major commitments to clean hydrogen, ammonia, and methanol. On the supply side, Alaska has vast fossil fuel resources as well as renewable energy generation potential in offshore and land-based wind, geothermal, solar, and marine energy. Many of these resources, however, are "stranded," meaning they are located far from electric grids or other infrastructure that can use them.

Hydrogen has the potential to unlock these resources by storing their energy in a form that can be transported to local, domestic, and global markets. Alaska has significant geologic storage potential for hydrogen and CO_2, especially along the North Slope and in the Cook Inlet region. Developing these resources to produce and deliver clean hydrogen to global markets would be a paradigm shift—from fossil fuels to clean hydrogen—in the state's energy export economy. Such a change could be not only a model for the rest of the world to follow but also an engine for economic prosperity throughout the state.

Energy Resource or Asset?

An energy resource is a source of energy that can be identified, measured, and planned for future use. An energy asset is a resource that has been developed into production for current use.

To realize this transition, the state will need to work quickly to identify and develop the most promising projects. In the short term, this will mean technology demonstration projects that expose landowners, project developers, financiers, and the broader public to promising technologies. At the same time, the state must begin planning for larger-scale projects and infrastructure investments that can support economic growth. Doing so in a way that includes the perspectives and cultural values of all Alaskans will be critical. Building, operating, and maintaining these larger projects will create jobs and ensure that an affordable domestic supply of clean energy is available in future years for all Alaskans. Although Alaska is not currently participating in the DOE Regional Clean Hydrogen Hub program (Office of Clean Energy Demonstrations, 2023), the hub model remains an important potential pathway for helping to establish an Alaskan hydrogen energy economy.

2 Alaska’s Current Energy Production and Use

Understanding Alaska’s current energy production and use provides context for the scale of possible clean hydrogen opportunities in the state. Alaska is an energy-producing state (see Figures 2 and 3), and energy production is a major pillar of the state’s economy, alongside fishing, mining, and tourism. The state produces more than 1,300 trillion Btu (TBtu) of energy annually. The majority of the state’s produced energy (68% in 2021) is in the form of crude oil on the North Slope that is transported south via the Trans-Alaska Pipeline System. Natural gas production comprises another 29%, with the remaining 2% from coal, biomass, and renewables (EIA, 2023a).

Alaska consumed more than 675 TBtu of energy in 2021 (EIA, 2023a). More than half of the state’s energy consumption occurred in the industrial sector, of which 305 TBtu occurred in oil field operations (i.e., on the North Slope and in the Cook Inlet region). Statewide electricity generation consumed 49 TBtu (7% of the state’s total energy consumption) of energy to deliver 6,600 GWh (22 TBtu) of electricity.[1]

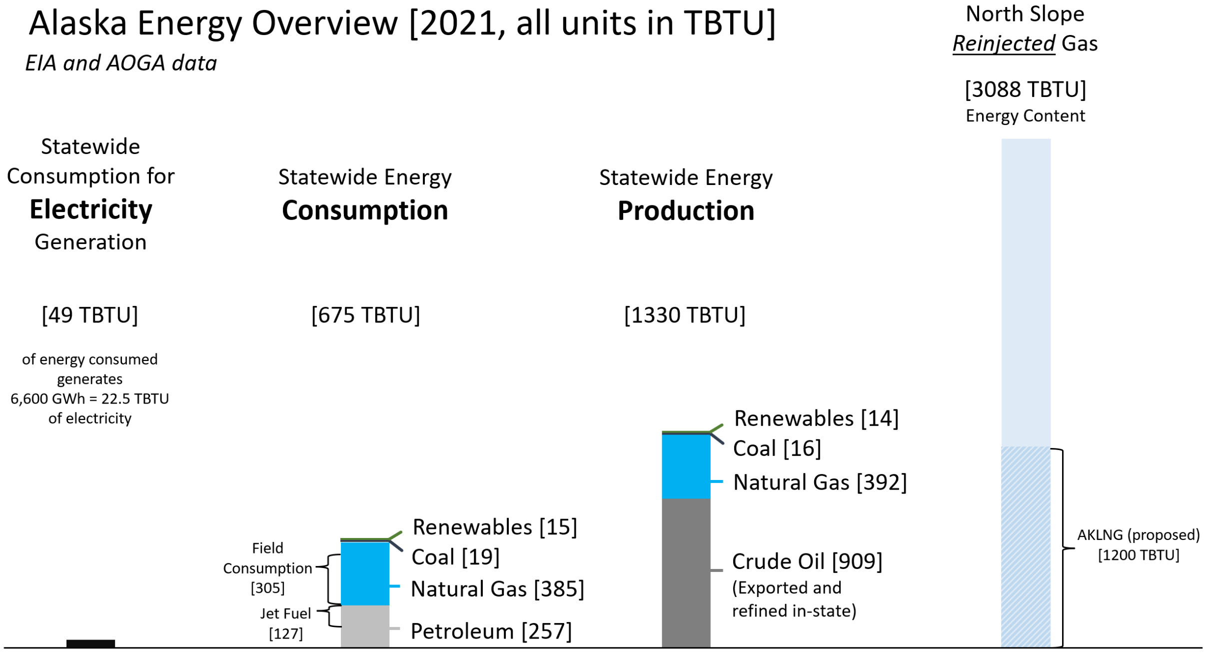

Figure 2. An overview of Alaska’s energy production and use. The north slope reinjected gas is not energy that is consumed, but it is gas that surfaces with produced oil and is reinjected for enhanced oil recovery, to avoid emissions, and to store it for later use. ‘Renewables’ includes biomass, hydropower, solar, and wind. A more detailed breakdown of this data is available in Figures 3 and 4.

Approximately 47% of the state’s electricity generation is derived from natural gas, 25% is from hydropower, 25% is from petroleum and coal, and the remainder (<3%) is from other renewable sources. Hydroelectric power is currently the dominant renewable energy source; however, as the cost of wind and solar have decreased in recent years, most of the new renewable projects that are being proposed and installed are wind and solar (Ellis, 2022). Geothermal projects are also seen as increasingly promising. The Makushin project is a proposed 36MW geothermal project on Unalaska Island, along the Aleutian chain, that has generated significant interest (Ounalashka Corporation and Chena Power, LLC, 2020). A feasibility study is also underway for a geothermal a project on Mount Augustine (Poux, 2022). Other technologies, such as nuclear energy, could also contribute to the net-zero economy while using the process

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[1] Note that the Consumption for Electricity Generation pie chart in Figure 4 is presented such that the inner circle indicates the amount of electricity generation from each source and the size of each wedge indicates how much total energy was consumed to generate that much electricity.

heat in high-temperature electrolyzers. Wave and tidal technologies are presently in the pre-commercial pilot and demonstration stages.

To meet the Biden-Harris Administration's goal of decarbonizing electricity by 2035, Alaska would need to decarbonize 72% of its electricity generation by either sequestering the carbon or by replacing it with renewable sources. Along these lines, discussions are ongoing about a renewable portfolio standard or a clean energy standard for the state's largest electric grid, also known as the Railbelt, which stretches from Fairbanks, in central Alaska, to Homer, in the south-central part of the state. The Railbelt accounts for 75% of the state's electricity generation, and it serves approximately 80% of the state's residents (Denholm et al., 2022).

In the rest of Alaska, 17% of the electricity generation is distributed across other smaller utility areas, including southeast Alaska, Kodiak, Copper Valley's service area, and the North Slope. The remaining 8% of electricity is generated in even smaller rural microgrids.

A large volume of natural gas comes to the surface as part of oil production on the North Slope. The equivalent of more than 3,000 TBtu are reinjected for enhanced oil recovery, stored for later potential production, and to avoid flaring emissions. The produced and non-reinjected gas on the North Slope is used to support oil field operations and communities in the region. In particular, North Slope gas is used to power the compressors that reinject gas for electricity and heat in the region and to power the transportation of crude oil along the pipeline. Across the state, including the North Slope and Cook Inlet, a total of 305 TBtu of gas was burned to support oil and gas operation, which is indicated in Figures 2 and 3 as "Field Consumption." This has a carbon footprint that is nine times that of the state's electricity generation. In other words, capturing and storing just half of the carbon emissions from the gas that powers field operations would be equivalent to more than four times the state's total carbon emissions for electricity generation.

The Alaska LNG Pipeline (AKLNG) project proposes to deliver a portion of the currently reinjected gas on the North Slope to market. It proposes producing 3.36 billion cubic feet (BCF) of gas per day, which would equate to an annual energy content of approximately 1,200 TBtu, and 25% of that energy would be used to process, transport, and liquefy the gas for export (DOE, 2023a). In a hypothetical scenario, if that energy were used to produce hydrogen with captured carbon emissions, it would produce approximately 10 MMT of hydrogen per year—which is equal to the 2035 national demand forecast and one-fifth the 2050 national demand forecast.[2]

Jet fuel is another major source of energy consumption in Alaska (127 TBtu, or 19% of the state's energy usage). Jet fuel is used at all the state's major airports and military bases. The Ted Stevens Anchorage International Airport (ANC) is the largest consumer of jet fuel because it is one of the largest cargo hubs in the United States (Fanelli, 2023). This is because cargo aircraft traveling between East Asia and North America frequently use the airport to refuel. By refueling midway in Anchorage, these aircraft can carry more cargo from their original departure point because they can carry less fuel, leading to more economic operations for cargo transport carriers.

This perspective, combined with the illustrations in Figures 2-4, shows the degree to which Alaska's energy consumption is driven by its energy export economy. Field consumption of gas for producing oil and gas is nearly half (45%) the state's energy consumption. Jet fuel, much of which is consumed by aircraft that use Alaska as a refueling station, comprises 19% of the state's energy use. That is more than twice the energy consumed to generate the state's electricity, and it is more than all the energy used in the state's commercial and residential sectors combined.

During the last several decades, significant efforts and progress have been made toward reducing carbon emissions associated with electricity generation, both in rural Alaska and on the Railbelt. Although these efforts are certainly important and should continue, the perspective summarized in Figures 2-4 shows that the largest opportunities for carbon reduction might be found in changes to the state's energy production economy. This could happen by making the existing system more efficient, by adding renewable technologies to the energy generation mix (e.g., powering oil and gas operations or the pipeline with renewables), by capturing and storing or using the carbon emissions from the system, or by producing sustainable aviation fuels (SAFs).

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[2] Assuming 0.158 MMBtu HHV of natural gas per kilogram of hydrogen are needed and a 74% conversion efficiency. Conversion taken from H2A Lite, https://www.nrel.gov/hydrogen/h2a-lite.html.

In the longer term, there is also an opportunity to create a new—and larger—*clean* energy export economy. Hydrogen could be a key commodity in such an economy, and this report is designed to describe these opportunities in more detail. As the state's fossil fuel resources decline, the pipeline ages, and demand for low-carbon energy sources continues to increase, the opportunities described in this report might become increasingly relevant. The challenge lies in identifying the projects that are economically viable and politically palatable for industrial-scale development.

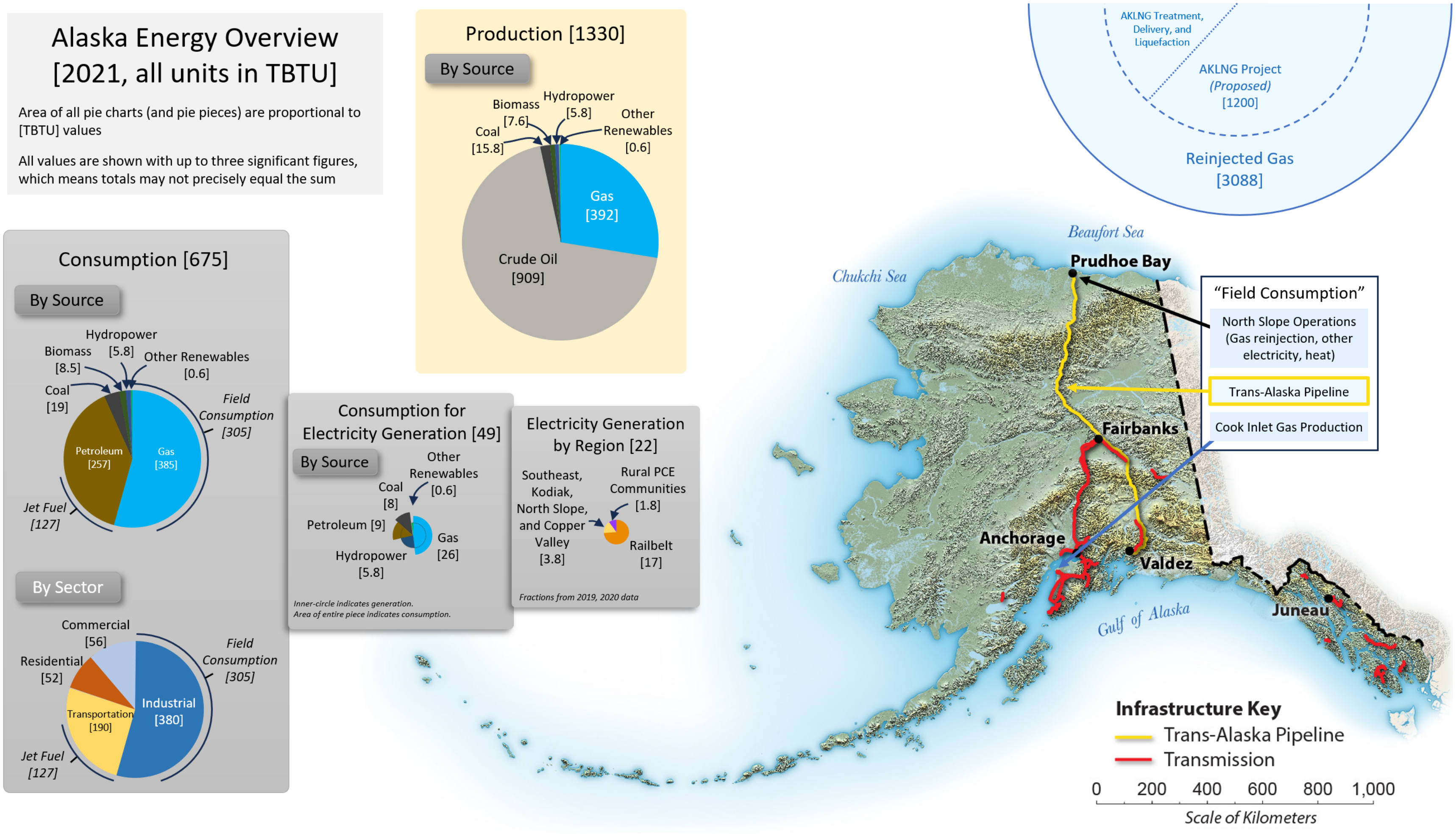
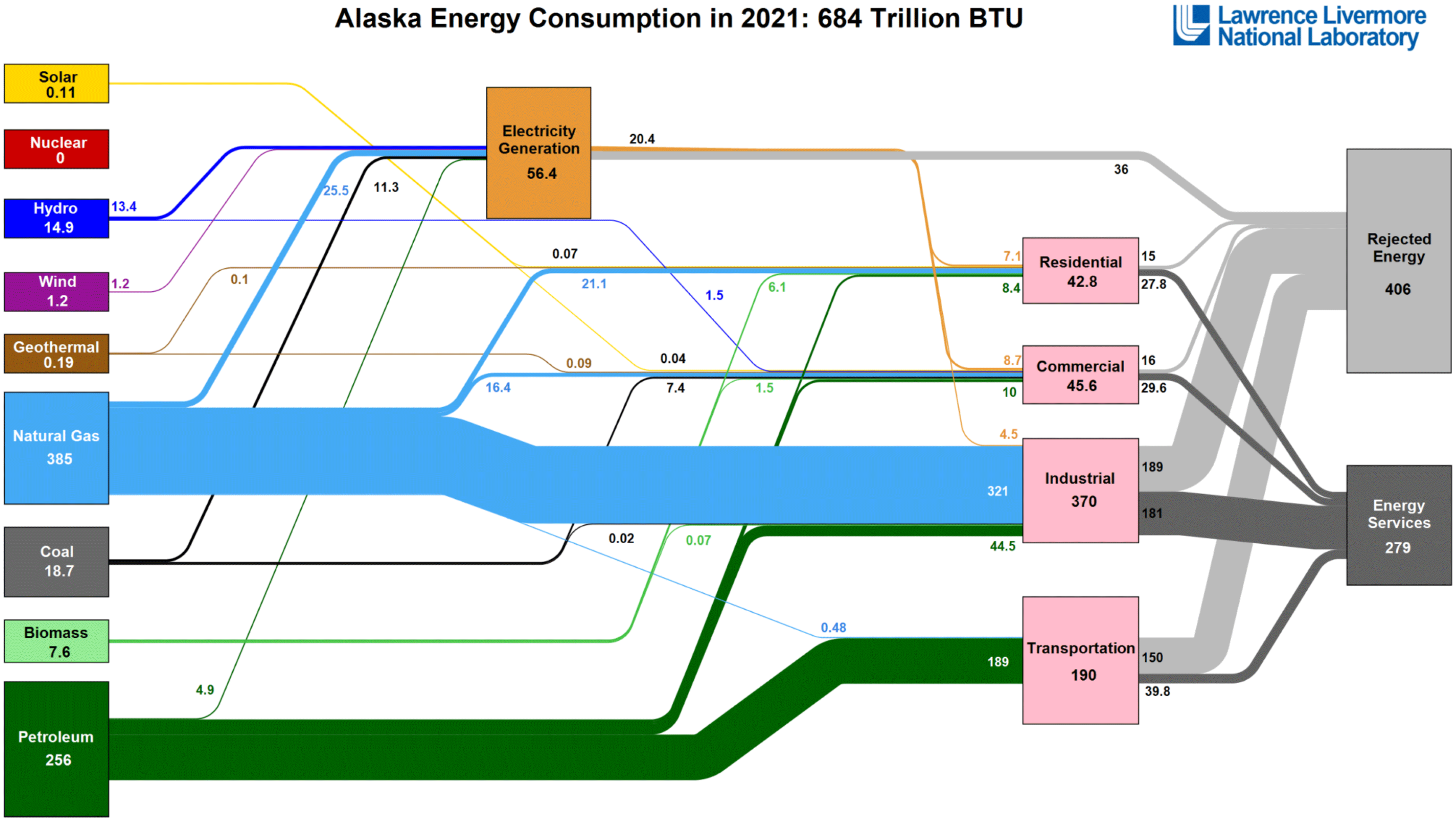


Figure 3. Overview of Alaska's energy production and use. Data updated from EIA, Dec. 21, 2023. Note that the values in this figure do not necessarily match those in Figure 4 because the EIA updated the dataset after Figure 4 was created. The map of Alaska was created by Billy Roberts at NREL.


Alaska Energy Consumption in 2021: 684 Trillion BTU

Source: LLNL July, 2023. Data is based on DOE/EIA SEDS (2021). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports consumption of renewable resources (i.e., hydro, wind, geothermal and solar) for electricity in BTU-equivalent values by assuming a typical fossil fuel plant heat rate. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 0.65% for the residential sector, 0.65% for the commercial sector, 0.49% for the industrial sector, and 0.21% for the transportation sector. Totals may not equal sum of components due to independent Rounding. LLNL-MI-410527

Figure 4. Flow diagram of Alaska's energy use in 2021 in TBtu (used with permission from Lawrence Livermore National Laboratory). Note that the values in this figure do not necessarily match those in Figure 3 because this figure was generated prior to corrections in the underlying EIA data.

3 Alaska’s Hydrogen Production Potential and Derivatives

There are two major mature technology methods for producing hydrogen: SMR and water electrolysis. When SMR is coupled with CCUS and electrolysis is powered by renewable energy, they can both generate clean hydrogen. Other production pathways such as methane pyrolysis, biomass gasification and direct water splitting could also produce hydrogen with low carbon emissions. However, they are in different stages of their development, and having not yet reached complete maturity, are not discussed in this document.

The total technical potential of Alaska’s renewable energy resources is comparable in scale to the nation’s current energy consumption (Figure 5). While Alaska’s North Slope natural gas resources are sizable, the state’s renewable energy potential far exceeds these natural gas resources. Note that some fraction of the energy potential of the resources would be consumed in producing hydrogen, which is discussed in more detail in the following sections.

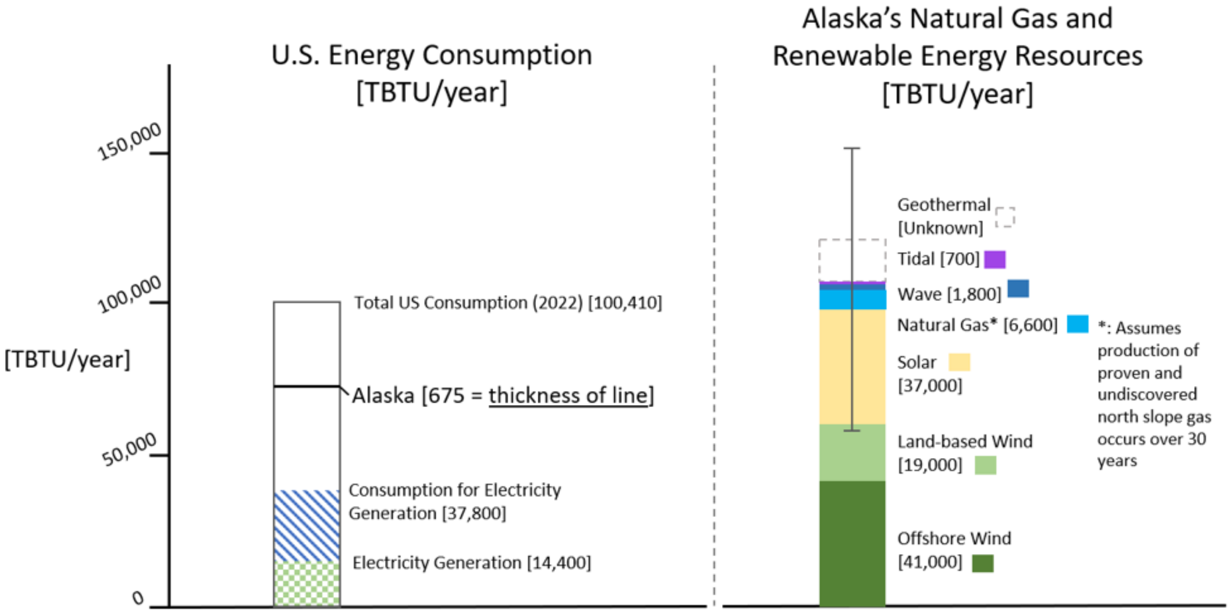


Figure 5. U.S. energy consumption (left) is comparable to the magnitude of Alaska’s renewable and natural gas resources (right). The uncertainty in resource potential (error bars at right—for the whole stack of resources) is due to uncertainty in the scale of projects that are politically and economically feasible.

3.1 Hydrogen from Alaska’s Fossil Fuel Resources

Hydrogen production via SMR is currently the most typical pathway for hydrogen production worldwide. SMR is used in 95% of global hydrogen production, with an emissions intensity of approximately 9.5 kg CO_2e/kg H_2 (Lewis et al., 2022).[3] When combined with carbon capture and storage, hydrogen generated from fossil fuels can have carbon emissions of less than 4 kg CO_2e/kg H_2 (depending on capture rates and fugitive emissions), and can be a stepping stone in the transition to a clean energy economy (Lewis et al., 2022). Alternative fossil fuel hydrogen production methods include methane pyrolysis as well as coal and biomass gasification, which also need to be coupled with CCS to reduce CO_2 emissions. A detailed investigation of the potential for producing hydrogen from these pathways, however, is beyond the scope of this report.

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[3] CO_2 emissions are emissions that are related only to carbon dioxide, whereas CO_2e emissions pertain to total greenhouse gas emissions expressed in CO_2 equivalent terms.

Steam Methane Reforming

Steam methane reforming (SMR) involves heating methane in natural gas using steam and a catalyst, which produces a mixture of carbon monoxide (CO), hydrogen (H_2), and a small amount of CO_2. The process is endothermic, meaning it requires heat. For SMR, the reactionary heat source is supplied via steam at 700℃ – 1,000℃. SMR is a mature process and is widely used globally—it currently accounts for approximately 95% of the hydrogen produced worldwide.

Whereas oil shale producers in the contiguous United States are in the early stages of fugitive emissions control, Alaska's industry has employed best practices for capturing fugitive emissions since operations began in 1977. A recent survey conducted by National Oceanic and Atmospheric Association aircraft found that fugitive emissions from North Slope petroleum activity were 1/50th to 1/200th the U.S. national average and the lowest among major U.S. energy basins (Floerchinger et al., 2019). In Alaska, hydrogen development from natural gas and biomass could alleviate and unlock currently stranded assets across the energy landscape. For instance, the North Slope's natural gas has remained one of the world's largest stranded energy assets. The U.S. Geological Survey (USGS) reports a total of approximately 117,000 TBtu of natural gas. This is composed of approximately 35,000 TBtu of 'known natural gas reserves', 65,000 TBtu of 'undiscovered non-associated' gas resources, and 17,000 TBtu of 'associated gas resources' (Houseknecht, 2004). There is also an estimated 96,000 TBtu of undiscovered gas resources in the Beaufort and Chukchi seas in federal offshore planning areas, which brings the total estimate to more than 200,000 TBtu (i.e., 6,600 TBtu/year over 30 years, Figure 5). Thus, if this optimistic estimate of the North Slope's natural gas reserves were converted to hydrogen via SMR, they would produce approximately 1,000 MMT H_2. This is certainly enough to meet projected national hydrogen demands for 2030 (10 MMT), 2040 (20 MMT), and 2050 (50 MMT). This production could happen over a period of time—for example, 33 MMT/year over 30 years (Velazquez Abad et al., 2017).[4]

3.2 Renewable Electrolytic Hydrogen Production

Another mature pathway for producing clean hydrogen is via water electrolysis. There are three major electrolyzer technology types that are predominantly characterized by their electrolyte material: polymer electrolyte membrane (PEM), alkaline (AEL), and solid oxide (SOEL) (DOE, 2023c). PEM electrolyzers are currently the most promising type due to their technical capabilities and decreasing cost potential (Bulgarian Hydrogen Institute, 2018).

Electrolyzers can be powered by the electric grid, directly by off-grid renewables, or both. The carbon intensity of the produced hydrogen primarily depends on the emissions associated with the electricity production. When the electricity comes from 100% renewable sources, the emissions can approach 0 kg CO_2e/kg H_2, but when the electricity comes from the grid, the emissions depend on the technology used to meet the electrolyzer demand; therefore, to reduce emissions, it is important that electrolyzers do not increase carbon-intense electricity generation.

Water Electrolysis

Water electrolysis is the process of splitting water into hydrogen and oxygen. The reaction takes place in electrolyzers, which can range from small, appliance-sized units to large-scale production facility units due to their modularity. Although there are different types and sizes of electrolyzers, they all consist of an anode and a cathode separated by an electrolyte, which transfers ions between the anode and the cathode. The three primary types of electrolyzers are polymer electrolyte membrane (PEM), alkaline (AEL), and solid oxide (SOEL).

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[4] Assuming 74% SMR efficiency and 95% operating plant.

Alaska has vast renewable energy resources that could be developed to power electrolysis, including offshore wind [>12,000 TWh/yr, or 41,000 TBtu/yr] (Doubrawa Moreira et al., 2018), land-based wind [5,400 TWh/yr, or 19,000 TBtu/yr] (EIA, 2023b; Lopez et al., 2021),[5] geothermal (technical potential unknown), solar [11,000 TWh/yr, or 37,000 TBtu/yr] (Schwabe, 2016),[6] tidal [210 TWh/yr, or 700 TBtu/yr], hydropower [>21 TWh/yr, or 72 TBtu/yr], and wave energy [540 TWh/yr, or 1,800 TBtu/yr] (Kilcher et al., 2021). In another hypothetical scenario, if all this energy were used to produce hydrogen, it would yield more than 500 MMT,[7] which is 10 times the projected U.S. hydrogen demand in 2050 (DOE, 2023d).

These resource numbers are estimates of the limit of what is possible (Figure 5). The geographic scale of the projects that would generate this amount of energy is immense. For example, developing the land-based wind resource would require building wind projects across roughly 30% of the state's land (Figure 8)—an area equal to the size of California and Maine combined. There would also be other impacts associated with projects of this scale, including mining natural resources for building and installing the projects. On the other hand, the potential value to Alaska and the global economy of producing hundreds of million metric tons of clean hydrogen is also immense.

Maps of Alaska's renewable energy resources show that different locations have varying degrees of resource intensity. Note, however, that these resource intensity maps are only one of many data sources that determine project feasibility. Ultimately, project feasibility is determined by a range of factors, including economics, social license, and regulatory approval. The economics of a project certainly depend on resource intensity as well as the costs of developing a project at a particular site. These costs, in turn, depend on a wide range of factors, including components, materials, transportation and labor costs, regulatory requirements, and the physical complexity of the terrain.

Some of the most important drivers of clean hydrogen cost are the levelized cost of electricity and the energy source capacity factor. Alaska locations that have combined wind and solar capacity factors greater than 50% (e.g., generating power at least half the time) include the Aleutian Islands, Cook Inlet, Kusilvak-Bethel, and the North Slope Borough from Point Hope to Wainwright. Optimized power mixes for these regions indicate a heavy reliance on wind over solar photovoltaics due to moderate solar irradiance. By 2030, the total combined LCOE, dominated by wind, has the potential to reach approximately \$57–\$63/MWh for land-based wind and approximately \$83–\$136/MWh for offshore wind, depending on the exact location and the type of turbine structural form (Meadows et al., 2023). For perspective, the LCOE compares to approximately \$20/MWh in 2030 for places such as Western Australia and Chile, which are considered leaders in affordable clean hydrogen (Graham et al., 2023; Henze, 2022). Adding wave and tidal power to the mix in Alaska could increase the competitiveness of the Aleutians and Cook Inlet as clean hydrogen producers by increasing utilization for electrolyzer operation.

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[5] Assuming it is technically feasible to cover 30% of Alaska with wind projects that have a packing density of 3 MW/km^2 and a capacity factor of 40%. This approach follows that of Lopez et al. (2021).

[6] Assuming it is technically feasible to cover 5% of Alaska with solar panels that have an efficiency of 15% and using a value of 3.5 kWh/m^2/day as the annual-average solar insolation in Alaska, as in Schwabe (2016)

[7] Assuming an average electrolyzer system energy efficiency of 55 kWh/kg H_2, which is the current state of the PEM electrolyzer technology, according to the DOE Hydrogen Fuel Cell Technologies Office (DOE HFTO, 2022)

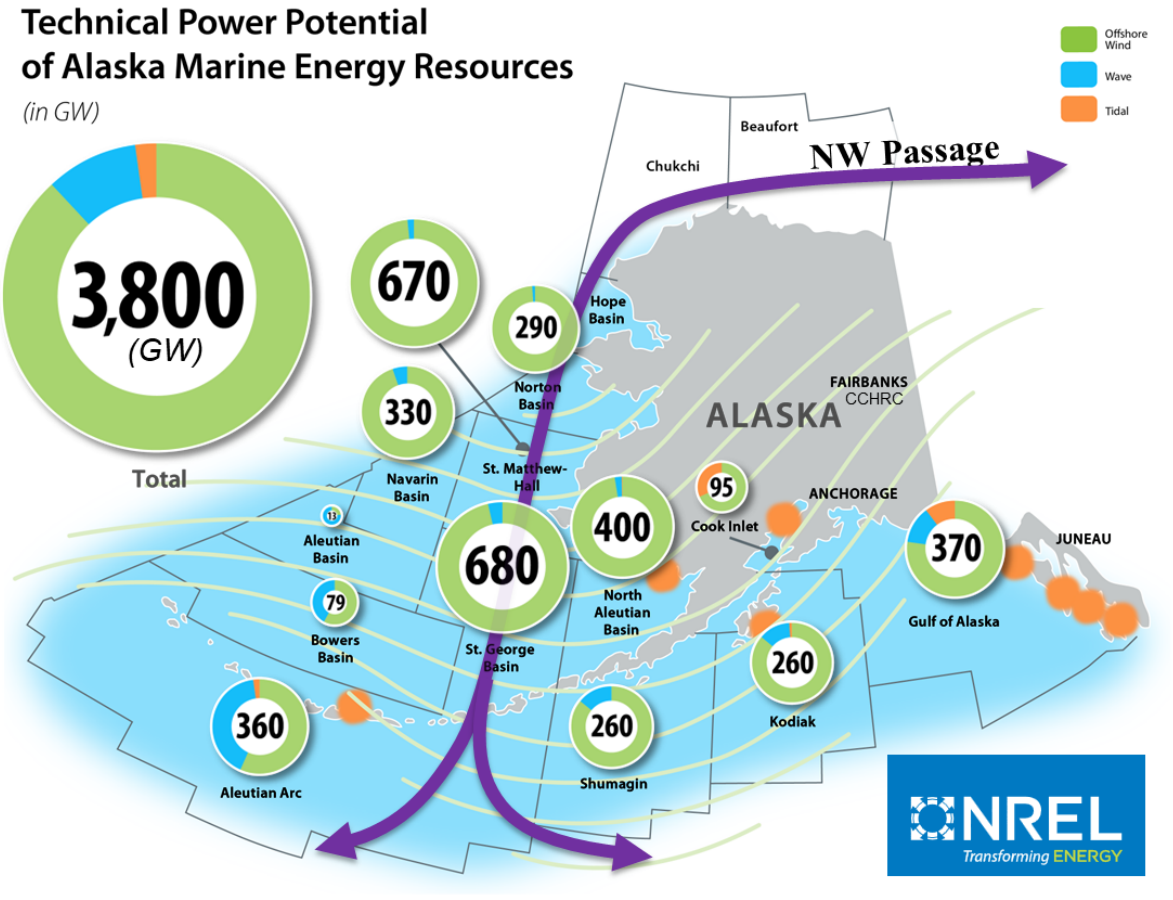

Figure 6. Alaska marine energy resource potential for offshore wind, wave energy, and tidal energy, broken down by Bureau of Ocean Energy Management (BOEM) planning area. This does not include land-based renewable production potential. Adapted with permission from Meadows et al. (2023).

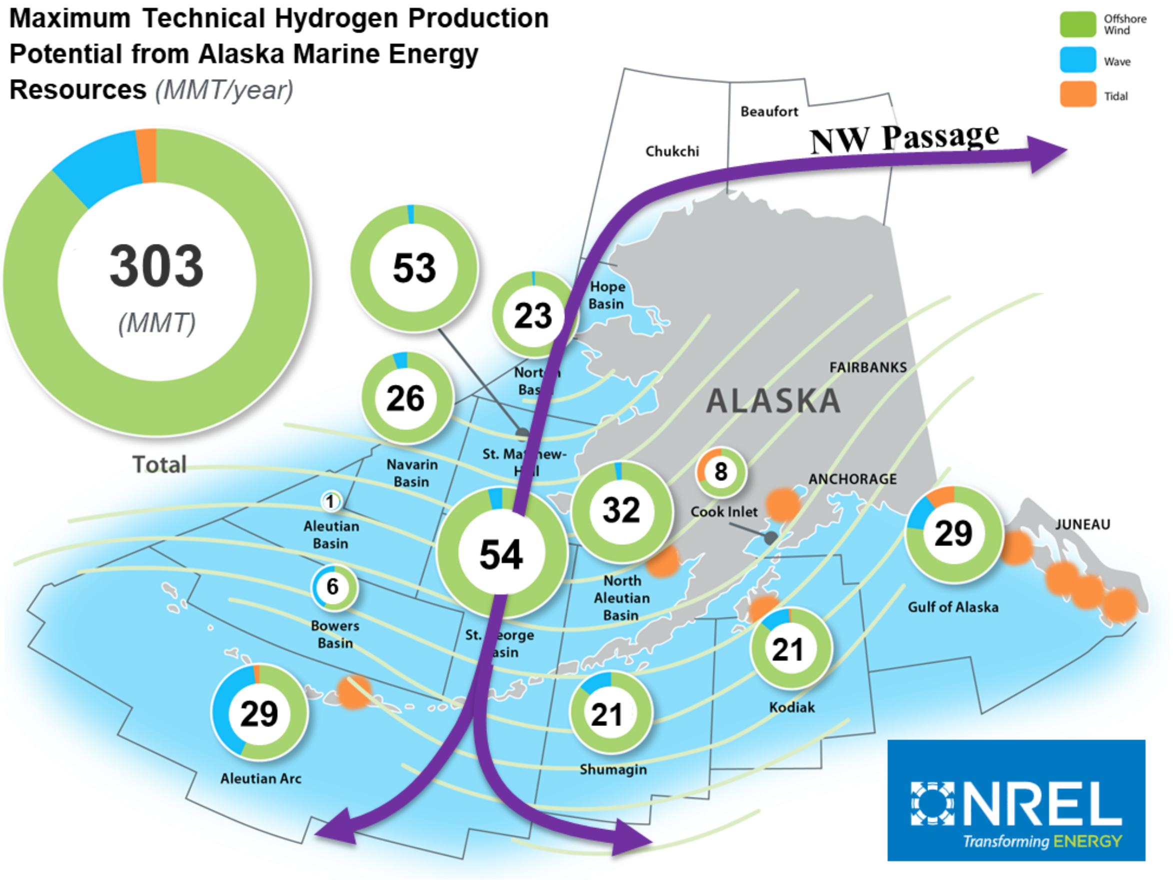

Figure 7. Alaska's ocean energy (offshore wind, tidal, and wave energy) resource technical potential expressed in terms of hydrogen production potential (MMT per year) broken down by BOEM planning area. This does not include land-based renewable production. Adapted with permission from Meadows et al. (2023).

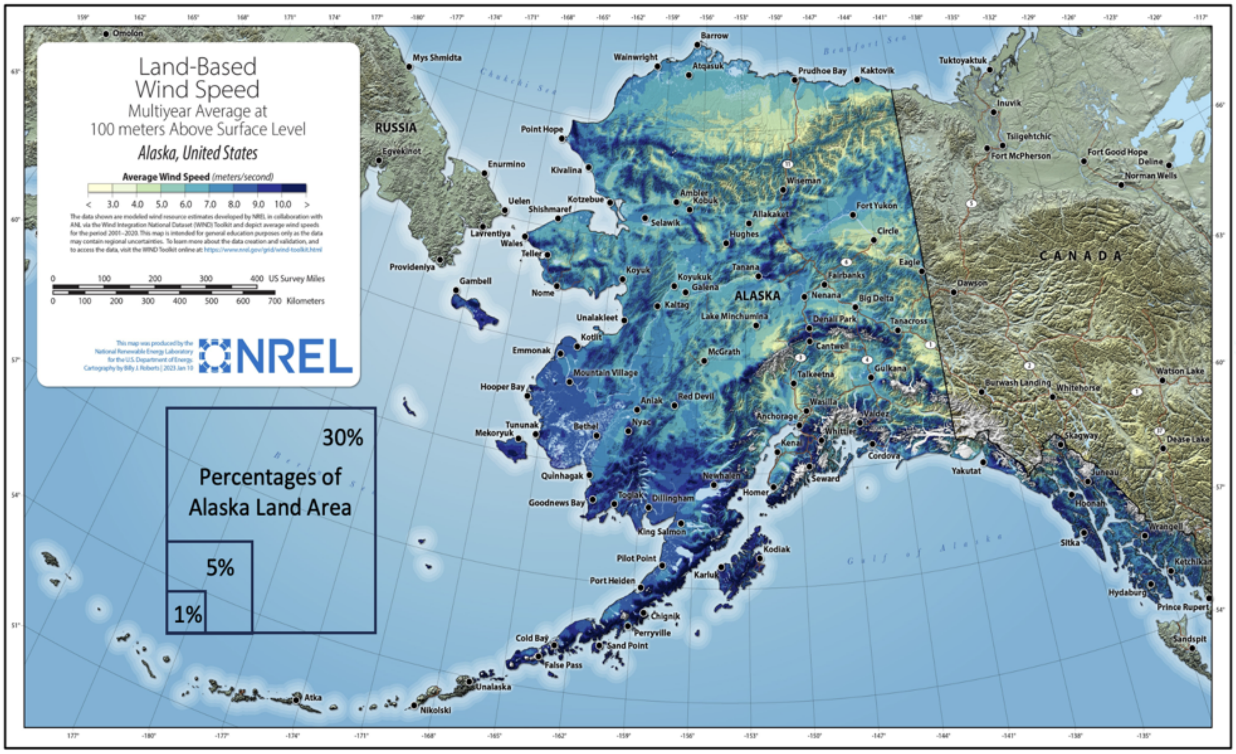

Figure 8. Alaska's land-based wind resources. Disclaimer: This map was produced by DOE's National Renewable Energy Laboratory (NREL) using modeled wind resource estimates developed by NREL via the Wind Integration National Dataset (WIND) Toolkit and is intended for general educational purposes only. While these 100-meter wind speed maps can provide a general indication of good or poor wind resources, they do not provide a resolution high enough to identify local site features such as complex terrain, ground cover, and data needed prior to siting a wind project. Adapted with permission from the DOE Wind Energy Technologies Office (2023).

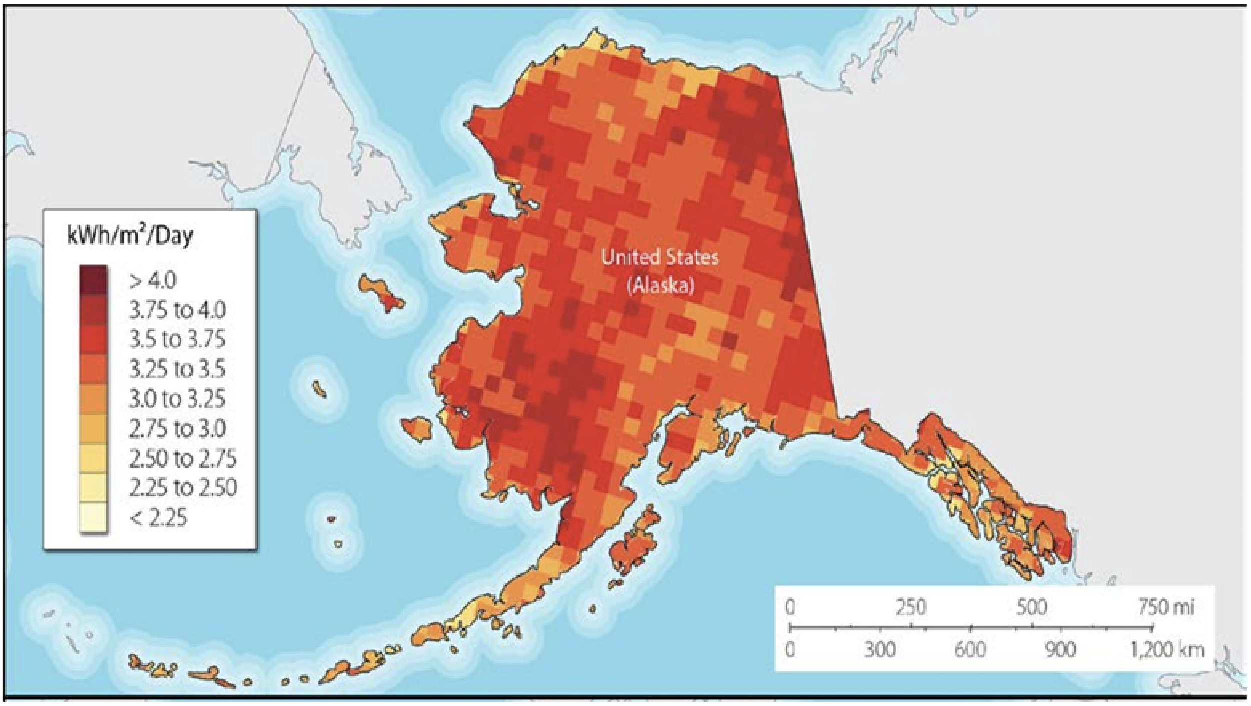

Figure 9. Alaska's solar energy resources. Adapted with permission from Schwabe (2016).

3.3 Clean Hydrogen Derivatives

With its world-class renewable potential, limited population, and position along major worldwide transportation routes, one of Alaska's biggest opportunities to develop a hydrogen ecosystem is to focus on the production and export of not only hydrogen but also its derivatives, such as methanol and ammonia. The source of energy for these derivatives is the same energy that produces hydrogen. It can be hydropower, wind, solar, tidal, wave, or fossil fuels with carbon capture.

Hydrogen Derivatives Versus Hydrogen Carriers

Hydrogen derivatives are products of processes in which hydrogen is a feedstock and could as well be used as a feedstock for industrial processes, in agriculture, or as a way of transporting energy over long distances. Such derivatives include clean ammonia, methanol, other fuels, etc. ***Hydrogen carriers***, on the other hand, are hydrogen-rich liquid or solid-phase materials from which hydrogen can be liberated on demand. Examples include metal hydrides, carbon and other nanostructures, and reversible hydrocarbons, among others; thus, ammonia and methanol are hydrogen derivatives, which are also proposed as carriers.

Ammonia is synthesized through the Haber-Bosch process (ScienceDirect, 2023), reacting hydrogen with nitrogen, where the nitrogen is typically obtained through air separation. As ammonia synthesis already uses hydrogen as a feedstock, it is a low-hanging fruit for decarbonization if clean hydrogen is supplied to the process. Ammonia is predominantly used as a fertilizer in agriculture, but other applications include refrigerant gas, plastics, explosives, textiles, and other chemicals for manufacturing (New York State Department of Health, 2005).

In addition to the common ammonia applications in the agriculture and chemical industries, it can serve as a hydrogen derivative energy carrier or a hydrogen carrier. In the former case, the ammonia can be consumed where it is needed for energy, and in the latter case, it can be converted back into hydrogen where that specific molecule is needed.

One advantage of ammonia compared to hydrogen is that its volumetric energy density is much higher at standard temperatures and pressures, and it can be liquified more easily (Thyssenkrupp, 2023). It also does not leak at the same rate that hydrogen often does. This means that storage tanks and pipes do not need to be as large, technologically advanced, and therefore costly. Ammonia does not contain carbon and might be less challenging to produce if there are a lack of industrial carbon sources. Also, it does not lead to CO_2 emissions, but it does contribute to nitrogen oxide emissions (Poore, 2023).

Methanol also finds numerous applications in industry (e.g., as an antifreeze, solvent, building material, and in synthetic fuels). Methanol is currently extensively used in Alaska for freeze protection and natural gas processing. Clean methanol (e-methanol) can be synthesized by reacting clean hydrogen with CO_2 and water vapor (Iberdrola, 2023). Similar to ammonia, methanol is a rapidly emerging alternative fuel, especially in the maritime industry, and because of its liquid state at ambient temperature and pressure, it could be a good candidate for a hydrogen derivative (Methanol Institute, 2023); thus, Alaska could leverage its position near the North Pacific shipping lanes to sell methanol as fuel. Additionally, methanol engines can provide a convenient clean alternative to diesel engines in remote areas, and a transition to using methanol would require storage; however, although methanol engines exist in Europe and China, Environmental Protection Agency (EPA) certification rules are a barrier to importing them into Alaska.

Alaska does not currently have any operational ammonia or methanol plants, but there is a formerly operational ammonia plant in Nikiski. There have been discussions about bringing the plant back online as well as building a methanol plant in northern Alaska from Alyeschem (Cashman, 2022). The Alyeschem plant project plans to produce hydrogen and would have the potential to produce clean methanol by capturing carbon from existing emissions on the North Slope.

Although it is not yet clear which of these fuels will reach widespread adoption globally, it would still be worthwhile to investigate the infrastructure requirements for producing these products in Alaska. For example, it would probably be worthwhile to investigate the feasibility of retrofitting the Nikiski ammonia plant (owned by Nutrien) to use hydrogen as a feedstock rather than natural gas. Such a study could also investigate the market opportunity for green ammonia and ammonia-based products, such as urea.

4 Alaska's Storage, Transmission, and Distribution Potential

4.1 Hydrogen Storage

The clean hydrogen production pathways described in the previous section would most likely require long-term or seasonal hydrogen storage to balance any intermittent power supplies, if powered by renewables, and maintain relatively steady demand (this requirement, however, would not be needed for a geothermal energy source). Further, there would be a need for permanent CO_2 storage for any hydrogen derived from fossil fuel sources with CCS.

Storage is an essential piece of a hydrogen production and delivery system. For small and distributed applications, buffer storage in pressurized vessels at 350–700 bar[8] could be sufficient. In medium-scale facilities and for seasonal storage, underground pipes at up to 90 bar could be a viable option. For bulk applications, cryogenic storage in spherical tanks has so far been the standard method. Material-based storage in metal organic frameworks, metal or chemical hydrides, liquid organics, etc., are also promising affordable ways of aboveground hydrogen storage. Underground geologic storage is considered to be the most economic solution for storing large amounts of hydrogen (Papadias et al., 2021), with installed capital costs as low as $\sim$\$35–38/kg H_2 stored,[9] compared to aboveground compressed gas storage costs of $\sim$\$400-700/kg H_2 (Shin et al., 2023).

Economically and physically, the most suitable storage for both hydrogen and CO_2 is in geologic formations. In particular, hydrogen storage suitability for salt caverns, lined rock caverns, and depleted oil and gas fields has been evaluated at some length (Lysyy et al., 2021; Papadias et al., 2021). Sequestering carbon in deep geologic formations to prevent its release into the atmosphere could occur in permeable and porous geologic strata with an overlain impermeable rock layer (Duncan et al., 2011).

Alaska does not have any known salt caverns or lined rock caverns, but its depleted oil and gas fields could provide a viable economic alternative. Moreover, depleted oil and gas reservoirs have well-defined geologic structures, good reservoir quality, and some existing infrastructure that could make this type of storage economic (Sambo et al., 2022). A downside is that each reservoir should be studied to understand its compatibility for storing hydrogen. The first step toward a feasibility assessment of a depleted reservoir for a particular project in Alaska started in 2023, with modeling analysis performed by the Subsurface Hydrogen Assessment, Storage, and Technology Acceleration (SHASTA) effort (NETL, 2023).

Current comprehensive data on depleted oil and gas reservoir storage potential in Alaska are scarce. A proxy could be the estimated current North Slope's total gas and oil storage potential, which exceeds approximately 200,000 TBtu (Houseknecht, 2004), which would translate to a maximum potential of at least approximately 460 MMT hydrogen storage if all storage were to be used for hydrogen when the reserves are depleted.[10] Note that converting a depleted oil reservoir to hydrogen storage would necessitate a comprehensive study on the suitability along with an investigation of potential leaks, side reactions, and other complicating factors.

4.2 Carbon Dioxide Storage and Sequestration

The EPA's GHG facility-level data for 2021 for Alaska include cumulative GHG emissions of 14 MMT CO_2e from 61 reporting sites (EPA, 2021). Today, there is limited manufacturing activity in Alaska, and these emissions, though small on a national scale, are mainly from oil operations. Historically, Alaska's economy has been dominated by crude oil exports to refinery centers located in California and Puget Sound, Washington. Because Alaska will never be able to fill its large CCS potential with its own CO_2 emissions, there is an opportunity to backhaul CO_2 collected from industrial point sources on the U.S. West Coast or in East Asia for sequestration in Cook Inlet. Developing a clean energy manufacturing economy and international CO_2 storage hub in Alaska is a vital prospect of national interest to the United States. The Alaska Carbon Capture, Use, and Storage (CCUS) Workgroup and other stakeholders are advancing efforts to determine the feasibility of CCUS across Alaska, with an initial focus on the North Slope and south-central (Cook Inlet) regions (Paskvan et al., 2023).

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[8] One bar is approximately equal to 1 atmosphere—or the pressure at sea level.

[9] The cost applies for salt caverns underground storage.

[10] Not considering any cushion gas.

According to the USGS, sequestration formations include any “deep saline formation, unmineable coal seam, or oil and gas reservoir that is capable of accommodating a volume of industrial carbon dioxide” (Brennan et al., 2010). In Alaska, there are multiple identified areas with sedimentary basins where CO_2 sequestration could potentially take place with different probabilities (Figure 10), including the North Slope, Cook Inlet, Kandik Basin, and North Aleutian Bristol Bay, among others (Shellenbaum et al., 2010) . The coal basins with low to high potential for CO_2 storage are located in the Northern Alaska Province, the Nenana Basin, and Cook Inlet, as illustrated in Figure 11.

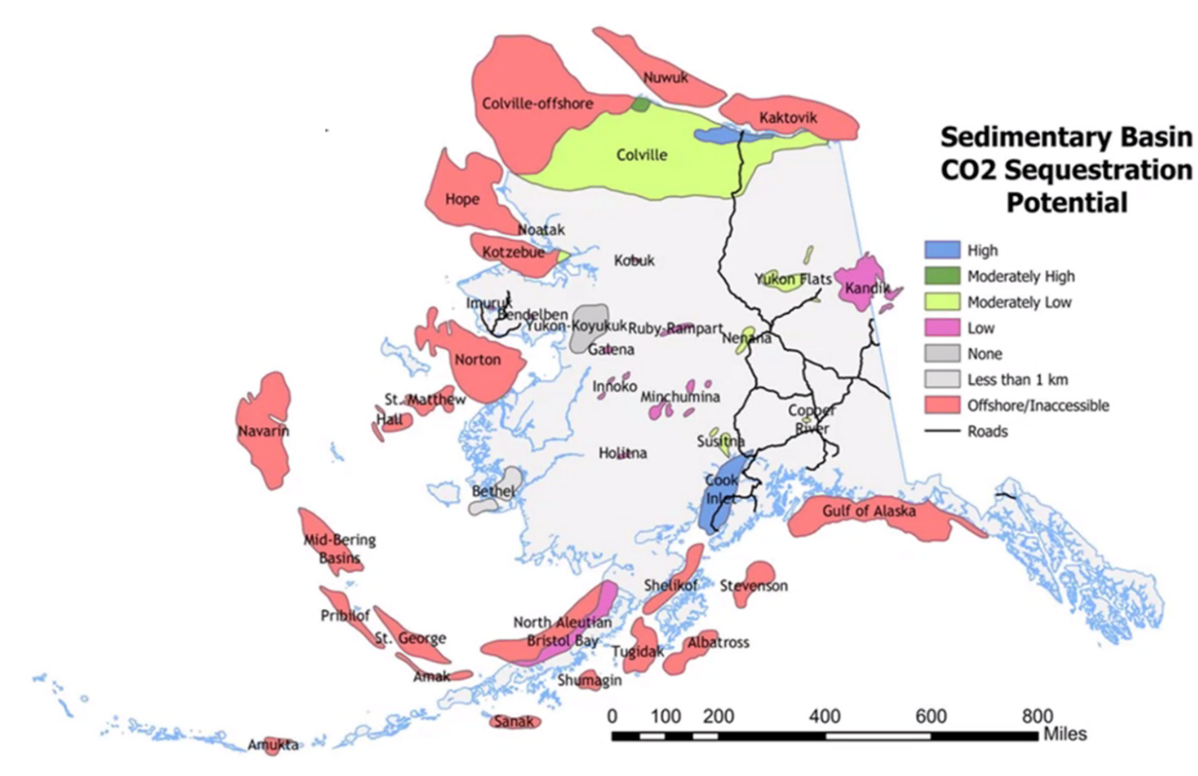

Figure 10. Alaska sedimentary basin CO_2 sequestration potential. Adapted with permission from Shellenbaum et al. (2010).

Technical reports by DOE have estimated that the total storage for saline basins and coal seam with potential for sequestration could be approximately 5,700,000 MMT and approximately 50,000 MMT, respectively (Shellenbaum et al., 2010). The assessed technically accessible sequestration capacities by the USGS amount to approximately 270,000 MMT CO_2 in the North Slope and 1,500 MMT CO_2 in the Kandik Basin (USGS, 2023). This is equivalent to approximately 42 years of storage of the nation’s annual emissions, estimated at 6,340 MMT in 2021 (EPA, 2024).

In the Lower Cook Inlet, the oil and gas reservoir capacity for sequestration is calculated at 4,330 MMT CO_2 within the Hemlock Formation (Pantaleone et al., 2020).[11] For context, provided that all targeted national clean hydrogen by 2050 was produced in Alaska and via SMR with CCS, approximately 200 MMT CO_2 of storage would be required. This approximated amount is orders of magnitude less than the CO_2 storage potential or the technically accessible sequestration capacity per basin. Based on current estimates, the generic cost for storing CO_2 could vary from approximately \$5/ton CO_2 in depleted land-based oil and gas reservoirs to approximately \$18/ton CO_2 in offshore saline reservoirs (Schmelz et al., 2020).[12]

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[11] Assumed 50% probability.

[12] These costs pertain to the northeastern and midwestern United States, so for more accurate representation, they need to be adjusted for Alaska’s economic landscape and specific reservoir.

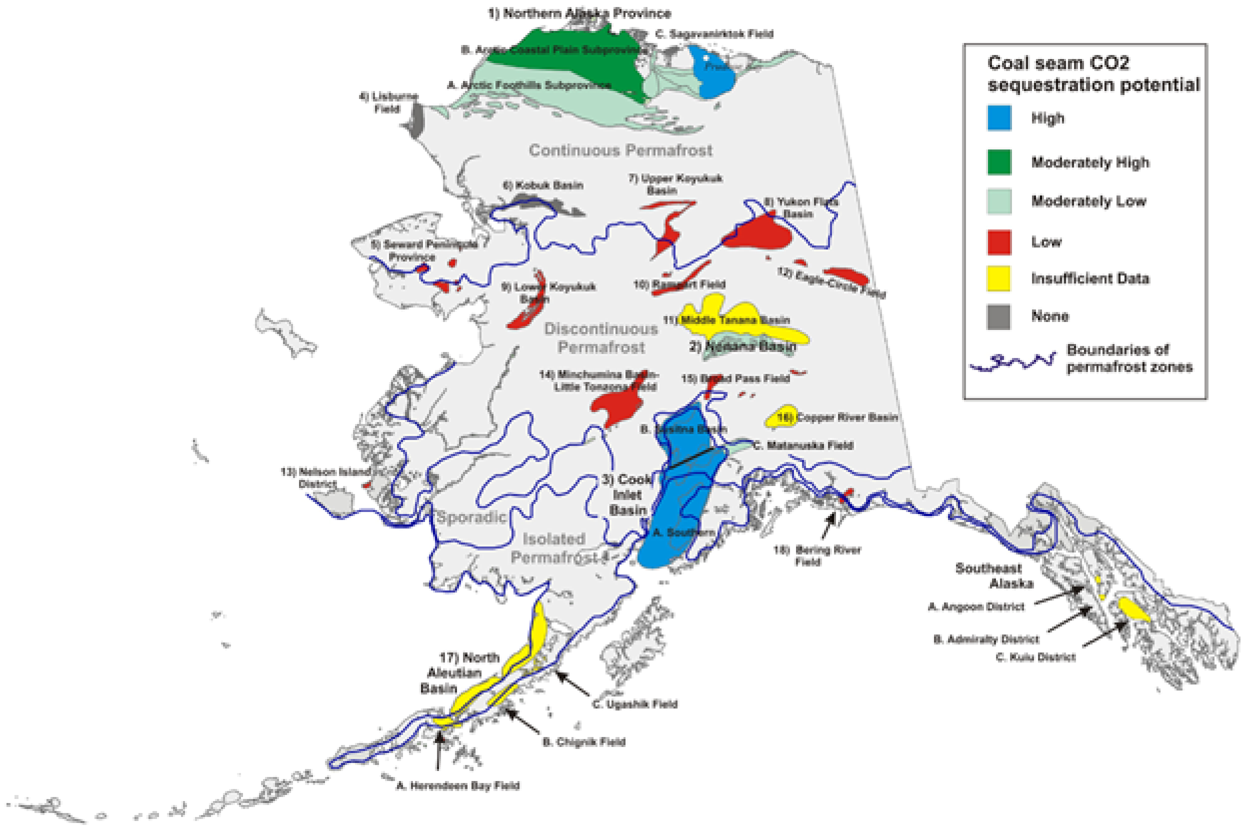

Figure 11. Alaska coal basin CO_2 sequestration potential. Adapted with permission from Shellenbaum et al. (2010).

4.3 Hydrogen Transmission and Distribution

Hydrogen transmission and distribution from central production areas to the final point of use is a critical piece of a hydrogen energy system. There are four major ways of transporting hydrogen: gaseous tube trailers, liquid tankers, pipelines, and hydrogen carriers (discussed in Section 5.4). All of these can support all the end uses (DOE, 2020). Due to its low energy density, difficult containment, and highly explosive nature, hydrogen is challenging to transport over significant distances. These challenges motivate the use of hydrogen derivatives—especially ammonia and methanol—for long-distance transportation.

Although it is investment intensive (i.e., on the order of several million dollars per mile), pipelines are the most energy-efficient way to transport bulk hydrogen or its derivatives (Chen, 2010). Currently, the United States has 1,600 miles (∼2,500 km) of pipelines dedicated to hydrogen. These are primarily located along the Gulf Coast because of the demand for hydrogen in the region's refineries (DOE, 2020). Although the economy continues to build hydrogen demand, blending H_2 (∼5 vol %–20 vol %) into existing natural gas infrastructure to use as a mixture or to be separated at the point of use is a possible solution (DOE, 2020). For context, Alaska's gas transmission and distribution pipeline systems are approximately 833 miles long and 2,929 miles long, respectively (National Conference of State Legislatures, 2011).[13] The literature reports that fugitive hydrogen emissions from pipelines could occur at a rate of 0.02%–0.05% per 1,000 km per year (Miao et al., 2021; Boothroyd et al., 2018). Energy-wise, compared to producing hydrogen by electrolysis, compressing the gas transport requires a relatively low amount of energy, estimated at roughly 1.05 kWh/kg H_2 from 20 bar to 350 bar (Gardiner, 2009).[14]

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[13] Lines connecting distribution lines to end users are excluded from the estimate.

[14] For reference, the energy to liquefy hydrogen from ambient conditions is approximately 3.9 kWh/kg liquid hydrogen (Gardiner, 2009).

One possible area of future studies and research is the assessment of the Alaska-specific pipeline infrastructure and estimate of the extent to which it can be used for hydrogen transmission and distribution. Such studies would ideally focus on infrastructure embrittlement and hydrogen leakage in the state's climatic conditions. A study that focused on the extent to which infrastructure could be converted for hydrogen and the optimal timing of that conversion would also be valuable. Leveraging the outcomes and findings of the HyBlend™ initiative could inform the state's specific assessment of blending opportunities (DOE, 2022).

5 Alaska's Potential Hydrogen Markets and End-Use Applications

Hydrogen end-use capabilities depend not only on the resource availability but also, importantly, on the demands (and offtakers) for those applications or the potential for exports to serve the demand elsewhere. Therefore, assessing the potential of developing such demands for Alaska-generated hydrogen, both inside and outside the state, is an essential step toward creating the state's hydrogen economy and driving broader economic growth within the state. Some sectors that could transition to using hydrogen are outlined here, with no specific timeline for demand realization unless otherwise stated.

5.1 Heat

Industrial sectors requiring high-temperature heat (above 550°C) could gradually see a shift from natural gas to clean hydrogen. Blending hydrogen in natural gas is perceived as a transition strategy to reduce emissions while dedicated hydrogen infrastructure is built out. Blending approximately 5 vol %–20 vol % H_2 in natural gas are the recommended percentages without imposing major safety or infrastructure risks (Raju et al., 2022; Topolski et al., 2022).[15] Blending at these levels into natural gas used for industrial processes would translate to approximately 0.3–1.4 MMT H_2.[16] Using higher blends of 20 vol %–50 vol % H_2, as suggested by the *U.S. National Clean Hydrogen Strategy and Roadmap*, would result in a demand of approximately 1.4–3.4 MMT H_2 in Alaska.

5.2 Power

Hydrogen can be used for long-duration or seasonal energy storage for large and small grids in Alaska, combusted directly, or blended into other fuels in low percentages. Considerations include whether it is economically and technically favorable compared to other storage/capacity solutions and physical storage infrastructure e.g., man-made versus natural, leaking risks, round-trip efficiencies (~40% based on electrolysis and fuel cell systems), and whether it could be made off-site versus on-site (Headley et al., 2020). Hydrogen could become an important buffer in balancing renewable supply with Railbelt and rural energy demands. Further analysis is required to quantify the storage size and duration of centralized and distributed projects.

If Alaska were to produce 100% carbon pollution-free electricity from renewables such as hydropower and geothermal, which could be assumed to be baseload, and solar and wind, which are diurnally and seasonally intermittent, the storage capacity would be geographically dependent to balance the intermittent sources and the loads of interest. Deriving the storage duration and capacity would be a useful research effort and will depend on the system boundary.

Considering only the current Railbelt residential load to start, hydrogen would need to cost approximately ~\$0.20/kWh – \$0.23/kWh, equivalent to \$11–\$13/kg H_2 using electrolyzer system efficiency of 55 kWh/kg H_2, to be competitive with Railbelt electricity costs (EIA, 2023a).[17] For context, the current levelized cost of clean delivered hydrogen (including production, storage, and fixed distance transmission) in the contiguous United States is estimated to range from \$4/kg H_2–\$14/kg H_2, depending on the renewable resource, underground storage availability, etc (King et al., 2023; Ramadan et al., 2022).

5.3 Transportation

Hydrogen fuel cell vehicles are being considered for hostlers at the Port of Alaska. Hostlers are the vehicles that load and unload containers from ships at the port. Port hostlers, though used only a few days per week when ships are in port, need to be able to run around the clock and hence are unsuitable for battery power given the time required to recharge. Future research in the area could determine the optimum demand of hydrogen for hostlers at the Port of Alaska or other ports given specific scheduling.

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[15] The percentage needs to be determined based on the condition of the pipeline infrastructure and its operating conditions with blends.

[16] Based on the assumption that 358.5 TBtu of natural gas are used for heat.

[17] Hydrogen cost includes production, storage, delivery, and re-electrification.

Hydrogen is one possible feedstock for aviation fuel, including SAF. SAF is chemically indistinguishable from kerosene produced from fossil fuel sources, and therefore it can be used as a drop-in fuel for aircraft without requiring any modifications to existing engines. Because SAF is identical to conventional aviation fuels, however, when it is produced with hydrogen, it also requires a source of carbon. This carbon could potentially come from biomass, fish waste, or CO_2 capture that happens locally or is brought into Alaska from other sources. A study focused on the opportunities, challenges, and market potential for SAF production within the state is needed, and the infrastructure required to facilitate its manufacture needs to move into the planning phase soon. Alaska has tremendous potential demand for SAF at ANC, which is one of the world's largest freight airports, and for military air bases, e.g., Joint Base Elmendorf-Richardson and others in Alaska. ANC alone consumes approximately 2 million gallons per day of kerosene, or jet fuel. To replace 100% of this volume with hydrogen would require approximately 0.4 MMT clean H_2 per year.[18] To replace 100% of this volume would require approximately four standard-size SAF production plants. Many passenger and freight airlines operating out of ANC already have aggressive targets for SAF use over the next several decades. For instance, Alaska Airlines plans to offset 85 millions gallons of SAF starting in 2026 (Alaska Airlines, 2022).

ZeroAvia and Universal Hydrogen have designed, built, and tested aircraft that use hydrogen directly. If these technologies gain market share, it will be necessary to provide hydrogen for them to refuel.

Hydrogen or hydrogen derivatives could be supplied to Alaska's major ports to help decarbonize shipping (Valdez, Nome, and the Port of Alaska). More detailed analysis is required to identify projected demand for these fuels and to begin building the infrastructure needed to deliver the fuels to the ports. Aleutian Island ports have an estimated total liquid hydrogen (LH_2) potential demand of 0.01–0.37 MMT LH_2 by 2035. That includes container ships, bulk, vehicle refrigerated and general cargo carriers, and oil tankers (Georgeff et al., 2022). In southeast Alaska, the potential to decarbonize cruise ships could create a hydrogen demand of 0.18 MMT LH_2 for the 4.5 months of seasonal demand in the area.[19]

There are also potential opportunities for using hydrogen in other surface transportation applications, such as rail and medium- and long-haul trucking. Given that medium- and heavy-duty vehicles only represent approximately 7% of the transportation sector (EPA, 2015a), if all of them were converted to hydrogen, approximately 0.03 MMT H_2 would be required in Alaska. According to the market segmentation report, medium-duty/heavy-duty fuel cell electric vehicles will represent 2% by 2030 and 17% by 2050 (Ledna et al., 2022), which translates to approximately 0.001 MMT and 0.005 MMT of hydrogen per year, respectively (FHA, 2022; Marcinkoski et al., 2019).[20]

5.4 Industry

In the industrial sector, hydrogen could be used to curb Scope 3 (extraction and capital expenditure emissions) and Scope 2 (power) emissions in oil production (EPA, 2015b). Other end uses include:

- **Ammonia:** The existing mothballed Nutrien ammonia plant in Nikiski represents an opportunity to resurrect one of Alaska's industrial facilities and, if retrofitted to accept clean hydrogen as a feedstock, generate low-carbon ammonia or downstream products, such as urea. If Nutrien comes back online at its original capacity of 600,000 tons of ammonia per year, that would require approximately 0.15 MMT H_2 per year (Redlinger et al., 2018). The products produced by this facility could be sold for export and/or locally to meet local energy or fertilizer needs.

- **Methanol:** Alyeschem's methanol plant on the North Slope—which is currently in the planning stage—could be designed for future expansion to meet demand growth.

- **Cement:** Hydrogen could also be used in local Portland cement production, which currently comes from Washington. (Clinker, a key ingredient in cement production, is responsible for a significant portion of CO_2 emissions in the industry. Hydrogen can be used to reduce the amount of clinker needed in cement production.)

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[18] Based on 0.49 kg H_2 required per 1 gallon of SAF.

[19] Personal communication with Alaska Marine Power, 2023.

[20] Values have been rounded and are based on approximately 4,100 million miles annual vehicle-miles traveled in Alaska and a hydrogen fuel economy of $\sim$9.5 miles/kgH_2.

- **Export:** It is projected that the largest demand for hydrogen would be driven by exports, either in its liquid form, in a material-based storage, or as a derivative. Japan and South Korea have published a combined projected demand for hydrogen of approximately 2.3 MMT H_2 per year by 2035 (Obayashi et al., 2020; Australian Trade and Investment Commission, 2022).[21] Thorough research should be performed to investigate these markets in more detail and to identify probabilities and portions of demand that could be served by Alaska.

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[21] Based on projected imported hydrogen demand of 0.3 MMT from Japan and approximately 2 MMT from South Korea.

6 Factors Affecting Hydrogen Opportunities in Alaska

Beyond the physical components of the hydrogen economy discussed above (production, storage, transmission, distribution, and end-use applications), we present four additional categories that are likely to affect the development of Alaska's hydrogen economy:

- Economic, financial, and policy considerations
- Technical, research, and infrastructure considerations
- Workforce development considerations
- Equity and social considerations

Demonstration projects in Alaska will be critical to making the items described in these categories tangible and practical. These demonstration projects will inform our understanding of the economic opportunities hydrogen can bring (i.e., costs and profitability), and the need to adjust policy and regulation. They will also reveal technical challenges that represent new research opportunities as well as provide real-world, hands-on training opportunities for the workforce. Finally, they will provide opportunities for forming new partnerships that ensure that the benefits of Alaska's hydrogen future flow back to all Alaskans.

It will be important to continue to convene a hydrogen working group to track progress across these action items. The working group should also seek out expertise from successful hydrogen projects and companies outside of Alaska so that lessons learned elsewhere can be leveraged expeditiously in the Alaskan context. Future development of a hydrogen roadmap or other strategic plans could expand on these items and would benefit from the inclusion of timelines, prioritization, and identification of specific collaborating organizations.

6.1 Economic, Financial, and Policy Considerations

Economic conditions, financial constraints, and policy directives (including regulation) have the potential to accelerate or slow the development of hydrogen in Alaska. The following considerations could help the state realize different components of a hydrogen economy on a timeline that helps Alaska achieve this goal. The items described in this subsection are organized into three jurisdictions (audiences): (i) state and local, (ii) federal, and (iii) the private sector.

6.1.1 State and Local

- **Create a renewable portfolio or clean energy standard:** Alaskans need affordable, low-carbon energy sources. The creation of a state renewable portfolio or clean energy standard could support low-carbon energy production that would benefit a future hydrogen ecosystem.
- **Streamline permitting for renewable energy projects:** More efficient state permitting of renewable energy projects could reduce potential project development timelines.
- **Expand the purview of the Regulatory Commission of Alaska:** This will enable the commission to better support the various sectors impacted by a hydrogen economy.
- **Implement economic policy actions:** Economic policy actions, such as the development of state royalty structures and tax breaks for clean hydrogen production, might accelerate hydrogen development relative to other fuels. There are currently no state incentives for hydrogen, and questions remain about whether federal incentives are sufficient for widespread uptake of hydrogen technologies. It would be prudent to explore the need for state incentives. Legislative action might be needed to help support investor and project developer confidence and stabilize early market economics. Alaska has an established policy and tax system framework developed from decades of oil and gas production and state constitutional advantages of resource ownership for the benefit of all Alaskans. For example, an Alaska state ammonia production tax credit might be needed.

- **Apply the strength of Alaska's Permanent Fund:** As one of the largest sovereign wealth funds in the world and top of mind for most Alaskans, the Alaska Permanent Fund could potentially incentivize public participation and interest if it is structurally linked to Alaska's hydrogen production market. With new North Slope oil projects viewed by many as favorably bolstering the Alaska Permanent Fund, this effect could be replicated in parallel or extended to amplify the value of hydrogen production to all Alaskans.

- **Obtain state primacy for CO_2 injection:** The state's ability to permit CO_2 injections is critical for clean hydrogen production from fossil fuel sources such as natural gas. This permitting authority currently resides with the EPA. State primacy of Class VI well programs is anticipated to result in significantly faster permitting of underground CO_2 injection. State primacy for Class VI well underground injection has been achieved in other states, including Wyoming and North Dakota.

- **Explore the need for regulation of new materials:** Additional regulations might be needed for materials scaled for hydrogen production, such as liquid hydrogen, ammonia or other fuels.

6.1.2 Federal

- **Allow the import of methanol engines:** The EPA currently does not allow for the import and sale of engines without precertification. This is a lengthy and expensive process that is preventing alternative fuel engines from being sold in the United States, and manufacturers cannot justify the expense for a market that does not yet exist. Methanol engines are, however, a mature technology that are being manufactured in China and Europe. Because methanol is a key hydrogen derivative, reducing domestic policy restrictions on these engines comprises a key enabling strategy to boost the hydrogen ecosystem. Hydrogen and ammonia engines will face similar challenges.

- **Synergize federal land use policy and leasing actions to align with tax credits:** Land use policy directives and leasing actions could be aligned specifically to support the development of clean, renewable power projects on federal lands. This would help to bolster the economic measures (such as tax credits) that are already in place.

- **Optimize federal tax policy**: The 45Q, 45V, and SAF tax credit systems are good starts to accelerating the energy transition, but they also create a landscape of competing incentives. Capital investments will flow to projects that create the most profits from these incentives, which may leave out other projects that would be economical in a unified policy.

- **Reform federal permitting systems:** The Federal Energy Regulatory Commission permitting process for grid-connected projects provides a structural pathway for federal review and approvals. New exemptions or alternative regulatory processes, such as the Verdant exemption for tidal projects less than 5 MW (Wright, 2010), might enable faster scaling of small hydrogen demonstration and commercialization projects.

- **Revise existing and implement new fuel standards:** Implementing fuel standards revisions and creating new fuel standards that align with low-carbon intensity could be beneficial. For example, new standards that drive higher percentages of lower-carbon methanol in transportation fuels might have a positive effect on the use of methanol as a hydrogen carrier.

- **Expand research, development, and deployment of CO_2 injection:** Federal investment in research, development, and demonstration has the potential to anchor and accelerate the scaling of CO_2 injection for carbon injection and storage because injection currently requires both technical and regulatory vetting.

- **Enable CO_2 storage markets that support energy transition:** Costs to dispose of and store carbon will be a large factor in any analysis. CO_2 storage markets can enable or discourage energy transition project development.

6.1.3 Private Sector

- **Support hydrogen demonstration projects in Alaska:** Private capital support for hydrogen pilot and demonstration projects is critical for getting these projects off the ground. Not only is private capital typically required to match federal and state funding, but a private partner is also frequently the party who is ultimately responsible for ensuring the project happens at all.

- **Collaborate with organizations such as the First Movers Coalition:** Organizations such as the First Movers Coalition are working to enable advanced market conditions by leveraging their collective purchasing power. The First Movers Coalition might directly or indirectly impact hydrogen economy development in Alaska across the hydrogen value chain from production (e.g., hydrogen fuel price guarantees), to application, to end use (e.g., enabling hydrogen fueling infrastructure for the transportation sector). Swift action is needed to ensure Alaska is not left behind first market movers.

- **Develop market solutions that enable commercial viability for rural, remote locations:** Energy conversion systems for clean methanol and ammonia are not yet available to support end-use applications at the small community scale. Alaska's rural communities need market solutions scaled for infrastructure deployment. Prior experience suggests that deploying experimental technologies without full life-cycle engineering support from launch to decommissioning leaves disadvantaged communities with burdensome technical and financial liabilities.

- **Assess timelines and requirements for offtake agreements:** Large and industrial-scale hydrogen consumers and their offtake agreements will play a key role in underpinning the stability of large projects. Further consideration is warranted to assess when buyers will enter the market looking to establish long-term sales contracts.

- **Identify storage use case thresholds fit for Alaska:** Minimization of capital investment for storage depends on the use case. For example, retail fuel storage depends on the hub and frequency of offtake, but remote locations might need long-term storage to account for seasonality and variability.

6.2 Research and Infrastructure Considerations

Transitions to a hydrogen economy will be smoothed through dedicated approaches to resolving myriad technical uncertainties. Research and development are critical components of proving up hydrogen opportunities in Alaska, requiring collaboration across the public/university, private industry, and government sectors.

There is a broad area of research needed to better understand the technical challenges, economic constraints, and market potential of hydrogen production in Alaska. Such analysis should be specific to Alaskan markets and costs. Viability of end-use applications, such as the delivery and use of power, should be measured against what is currently available. Key areas of investigation include the following.

- **Prove geologic storage and retrieval:** Where can successful geologic storage and retrieval of hydrogen gas occur in Alaska?

- **Techno-economic analysis and market research needs:** There are several research questions that should be addressed to understand the techno-economic feasibility, and market potential of hydrogen production in Alaska. Some of these questions are:

  - What are the costs and benefits of hydrogen versus electric heat options?

  - What new industries could Alaska attract to help drive hydrogen?

  - What are the trade-offs between industrial hydrogen production and distribution vs. a range of other options to meet local needs, including: building more renewables (increasing generation capacity), other types of storage (such as pumped hydro), and transmission upgrades? What factors should be considered in an Alaska evaluation of the economics and efficiency of making, storing, and distributing hydrogen versus using the primary energy source itself?

  - Continue to study and monitor the market to identify which hydrogen derivatives will be in demand (ammonia, SAF, methanol, eDiesel and eGasoline). What are the trade-offs of different hydrogen carriers? Are ammonia and methanol safer in Alaska than in other locations? What are the pros and cons of ammonia and methanol compared to each other, hydrogen, and other hydrogen carriers? What are the geographic and climate advantages of fuel production in Alaska? Are there benefits from less evaporation and fewer contributions to fugitive emissions than in warmer locations?

  - What are the different applications for high-temperature versus low-temperature electrolysis, and how do those align with Alaska's different energy sources?

- **Research and development needs for renewable electrolytic hydrogen production:** There are several research questions specific to renewable hydrogen that need to be addressed, including:

  - Evaluating the potential reduction in electrolyzer costs, which constitute an important factor in the levelized cost of hydrogen.

  - What are the water quality needs for electrolysis relative to availability in Alaska, and what are the prospects for economic seawater electrolysis?

- **Research needs for fossil-fuel based hydrogen production in Alaska:** There are several research questions about CCUS technologies that are critical to understanding the potential for fossil-fuel based hydrogen production in Alaska, including:

  - What is the potential for SMR, or autothermal reforming (ATR), for North Slope natural gas?

  - Can Alaska become a CO_2 import and storage market for international customers? Does this improve the economics of hydrogen production in the state? What is the sequestration potential in the state's basins, and how permanent is the storage for CO_2?

  - What are the geologic parameters for CO_2 injection? What characteristics of geologic features must be understood and targeted for Class VI permitting primacy? Can storage in new features such as coal seams and hydrates be used in Alaska, and how much additional storage capacity might this add to traditional sources, such as enhanced oil recovery, depleted oil and gas reservoirs, and saline storage?

  - What can be done with the byproducts of hydrogen production (e.g. black carbon for methane pyrolysis)?

- **Assess the suitability of the existing natural gas distribution system for hydrogen:** Related to the repurposing of infrastructure for storage and delivery, what is the current status of existing piping, and are there pipe linings that would hold hydrogen? How does Alaska repurpose its infrastructure? For example, one key infrastructure component to evaluate is the pipeline from the Port of Alaska to the airport.

- **Study the feasibility of hydrogen research and an industrial park:** What are the prospects for the establishment of a research/industrial park or a hydrogen hub? What locations are most suitable? What would it take to build a more versatile hydrogen feedstock plant (industrial park or hub) in the state? For offshore components, there is a need for a collaborative test site in marine environments, bridging gaps between applied research and demonstration. Repurposing vessels or offshore platforms could aid this effort.

- **Complete a feasibility study for SAF production:** What are the success factors and challenges of SAF production in Alaska?

6.3 Workforce Development Considerations

A hydrogen energy economy within Alaska will require a robust supply of trained workers across multiple disciplines and job fields. Leveraging the strong workforce, expertise, and training programs that already exist in Alaska's oil and gas sector will be critical to building a workforce for a hydrogen sector. Some of the specific job sectors and training programs that will need to be expanded or developed include:

- **Expand the oil and gas support sector to hydrogen:** The oil and gas workforce has most of the skills and knowledge necessary to support a hydrogen economy in the state. Some training programs will need to be created or updated to educate this workforce about the details of working with hydrogen and hydrogen derivatives. A few of the specific areas where these programs likely need updating include:
    - Control room operators and instrument technicians will be needed to keep plants running smoothly.
    - Operations and maintenance support will be essential to the operation of hydrogen infrastructure, similar to what has been developed to support the oil and gas industry in Alaska.
    - Process safety and training standardization is needed to support the safe operation of hydrogen facilities across the United States.
    - Safety cultures must be fostered at both the individual company and industry-wide levels.
    - Emergency personnel training will be needed for hydrogen, ammonia, methanol, and other chemicals that are a part of the system.
- **Establish monitoring, permitting, and compliance programs:** Environmental permitting, monitoring, measurement, and compliance oversight of hydrogen is needed by state and local regulatory agencies. This will be important for hydrogen production, distribution and storage infrastructure, and hydrogen end-use cases.
- **Support rural-industrial training and development:** Within rural environments, state and local support of organized workforce programs will be needed, including safe handlers within communities, training programs for small locations, and nontraditional remote education programs (e.g., farmers handling anhydrous ammonia in other locations). The Alaska Vocational Technical Center is a model to build from. Transitional and compatible workforce opportunities within the oil and gas sector might present workforce advantages across the state.
- **Enable higher education to support hydrogen research:** There are currently no in-state chemical engineering programs. Higher education federal programs that drive interest in degrees including chemical engineering and process engineering might prompt universities to start or expand degree programs in Alaska.

6.4 Equity and Social Considerations

A myriad of opportunities exists to build a hydrogen future for Alaska that provides access and benefits to all Alaskans. The following equity and social factors are important to consider as we take actions toward this future.

- **Consult indigenous groups:** Indigenous groups need to be consulted, involved, and informed throughout the process of creating a hydrogen future for Alaska.
- **Develop guidance for land ownership:** Land ownership issues need to be resolved for all aspects of hydrogen production, storage, and distribution.
- **Support rural Alaska in addition to the Railbelt:** Rural Alaska needs support, in addition to Railbelt communities. The PCE program is structured so that reductions in Railbelt energy costs should result in lower costs in rural Alaska, and the understanding that Railbelt improvements might also directly impact PCE subsidies.
- **Establish PCE incentives for renewable energies and hydrogen:** Restructuring the PCE program to better support renewable energy and hydrogen projects could help increase energy equity within the state. Such

changes could help rural Alaskan communities take part in the energy transition using existing program funding. Modifying the PCE to encourage hydrogen production, storage, and/or usage would encourage the adoption of hydrogen ecosystems in remote communities. Convening a summit to discuss changes to the PCE program could be an important first step.

- **Identify low-carbon fuels for rural Alaska:** Identifying which low-carbon fuel (liquid/compressed hydrogen, eDiesel, methanol, or ammonia) is best suited for remote communities is an important first step toward bringing the benefits of the energy transition to residents of these areas. The fuel choice process should consider criteria such as:
  - System reconfiguration capital cost, unit cost per energy, safety and operational considerations, and transportation and storage logistics.
  - Transportation safety – demonstration and oversight may be needed to build confidence in the fuel.
  - Siting decisions for storage facilities should be community-led, and the sites should be designed to improve community well-being.
- **Project benefits should flow to indigenous groups and the broader community:** Project benefits must come back to indigenous groups and should be directed to the broader population as well. Directing benefits back to these communities can encourage broader buy-in, which has the potential to accelerate project development.
- **Enable tribal loan guarantees and create tribal bonding mechanisms:** Tribal loan guarantees should be enabled. Tribal bonding mechanisms could also be developed (*Community Development Financial Institutions Fund* 2024).

7 Alaska’s Key Opportunities and Next Steps

In the broader process of hydrogen development, opportunity identification is a preliminary step. Follow-on work is required to evaluate feasibility, to test and refine concepts, to engage communities and other stakeholders, and to determine which opportunities should be further pursued. From strategic planning to specific and applied research, there is much to do on Alaska’s journey toward a future hydrogen economy.

Alaska has the potential to make progress on a number of the components of a hydrogen ecosystem. They are listed here, followed by suggested actions toward their realization.

- Hydrogen production technologies can be demonstrated in Alaska now, which will help prove the technology in the Alaskan climate, begin building social license for the growth of the technology, expose Alaskan investors and project developers to the economics of hydrogen, and establish early markets for hydrogen and its derivatives (e.g., port hostlers, blending with gas, hydrogen electric vehicles, local industrial uses).
- Hydrogen can be an energy storage and/or energy supply fuel for rural Alaskan communities. Projects that demonstrate hydrogen technologies (electrolyzers and fuel cells) in rural communities could help to show the long-term benefits and reveal potential challenges of using hydrogen in these communities.
- Some or all of Alaska’s vast natural gas resources—most notably on the North Slope—could be converted to hydrogen, and the carbon could be captured locally. This combination could deliver a low-carbon hydrogen source to global markets that are seeking this fuel in the midterm (5–10 years). The following questions should be considered for such an undertaking:
  - Can hydrogen be produced and exported from the North Slope directly, or should it be created at the end of the proposed AKLNG project? How do the economics of those two approaches compare?
  - In either scenario, where exactly can/will hydrogen be stored?
  - How do the economics and technical feasibilities of low-carbon hydrogen (“blue” hydrogen) compare to other options, such as exporting gas and backhauling the CO_2 versus converting hydrogen to ammonia and shipping it instead or the production of hydrogen from renewable energy via electrolysis.
- Alaska possesses vast renewable energy potential that could be developed to produce clean hydrogen at scale. Solar and wind technologies are proven to be robust, reliable, and economic in some markets. Other technologies are still being researched and demonstrated. The economics of proven technologies are rapidly improving, and emerging technologies will soon reach economic viability. Alaska should be prepared for project construction (feasibility studies, permitting, social license) when these technologies mature.
- Alaska has ample storage resources in the form of depleted oil and gas reservoirs, which are one of the cheapest storage options. Cheap storage proves crucial for the affordable delivery of hydrogen at scale. The maximum storage potential in the North Slope is estimated to be approximately 460 MMT H_2 when reserves are depleted.[22] Techno-economic feasibility studies for each considered reservoir for potential hydrogen storage must be considered early on.

Representative follow-on efforts for consideration are listed here. Determining the scope of work, the timelines, and the entities that are accountable for each effort is the next important action for the realization of these efforts.

- Develop an Alaska hydrogen strategy and roadmap supported by hydrogen production and demand potential across the state.
- Evaluate policy opportunities to create state-level incentives for hydrogen production, transmission, storage, distribution, and use.

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[22] The estimate is an absolute maximum if all the depleted oil and gas reservoirs were to store hydrogen, which will likely not be the case due to technical, economic, or programmatic infeasibilities.

- Create a database with planned clean hydrogen projects in Alaska.
- Connect offtakers, producers, and stakeholders in the state for information and know-how exchange and contract agreements possibilities.
- Establish public and private-sector working groups to identify and initiate workforce development, establish permitting programs, create supply chains, create markets, integrate producers and end users, and study resources.
- Create a pipeline ecosystem for demonstration projects to establish proofs of concept.
- Enable feasibility studies and pilot project demonstrations at the local/rural and grid/Railbelt scales. The projects could involve different power sources, storage options, and even derivatives e.g., ammonia and methanol.
- Complete a techno-economic analysis for establishing an industrial park concept.
- Identify sites where ample renewable resources coincide with geologic storage for hydrogen, and perform site assessments and economic feasibility analyses.
- Advance state-level programs required to support key elements of the clean hydrogen value chain, including CCS.
- Pursue federal funding and private-sector financing opportunities.
- Align Alaska's energy goals and strategic assets to meet global market demand through competitive lower-carbon solutions, including, but not limited to, hydrogen production from natural gas resources.
- Fund research, development, and demonstration through the University of Alaska system.
- Create strategic alliances and partnerships with Western states and provinces.
- Develop in-state workforce capabilities associated with the energy transition and hydrogen ecosystem skills.

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