EXH. DJL-12
DOCKETS UE-240004/UG-240005 et al.
2024 PSE GENERAL RATE CASE
WITNESS: DAVID J. LANDERS

BEFORE THE
WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION, Complainant, v. PUGET SOUND ENERGY, Respondent.	Docket UE-240004 Docket UG-240005 (*consolidated*)
In the Matter of the Petition of PUGET SOUND ENERGY For an Accounting Order Authorizing deferred accounting treatment of purchased power agreement expenses pursuant to RCW 80.28.410	Docket UE 230810 (*consolidated*)

SECOND EXHIBIT (NONCONFIDENTIAL) TO THE
PREFILED REBUTTAL TESTIMONY OF

DAVID J. LANDERS

ON BEHALF OF PUGET SOUND ENERGY

SEPTEMBER 18, 2024

BEFORE THE WASHINGTON UTILITIES AND TRANSPORTATION COMMISSION

Dockets UE-240004 & UG-240005
Puget Sound Energy
2024 General Rate Case

JEA DATA REQUEST NO. 027:

Re: Capital Planning.

Refer to DJL-6, Page 12 of 14. The Company provides Table 6.

a. Please provide documentation and business case documentation associated with the 2-4 demonstration projects that PSE plans to invest in during the rate plan.
b. Please indicate which end-use customers benefit from the alternative fuel readiness program.

Response:

a. Puget Sound Energy ("PSE") currently has two pilots identified for implementation during the rate plan. For the first pilot, PSE plans to purchase and place into service a small one megawatt hydrogen electrolyzer to support evaluation of the impact of natural gas-hydrogen fuel blends on the generation fleet, including impact to air quality and operational requirements, and to assess fuel blending considerations for PSE's natural gas customers. For the second pilot, PSE plans to evaluate hydrogen production through pyrolysis at one of PSE's industrial customer sites. Additionally, PSE will be continuing high level planning and research on hydrogen blending during the rate plan, including scoping a potential customer-facing pilot.

   The Fifth Exhibit to the Prefiled Direct Testimony of David J. Landers, Exh. DJL-6, Appendix C, pages 7-14, provides the Alternate Fuels Readiness Business Plan.

   Attachment A to PSE's Response to JEA Data Request No. 027 is the proposal for the first pilot that will install a green hydrogen electrolyzer at PSE's Fredrickson generation facility.

   Attachment B to PSE's Response to JEA Data Request No. 027 are Microsoft PowerPoint slides summarizing PSE's pilots underway and in development that are included in the rate plan.

   Attachment C to PSE's Response to JEA Data Request No. 027 provides a pyrolysis position paper.

b. All end use customers benefit from the Alternate Fuel Readiness Program.

ATTACHMENTS A – C
to PSE’s Response to
JEA Data Request No. 027

Project Proposal: Green Hydrogen Electrolyzer Pilot

Introduction: To advance PSE's understanding of renewable electrolytic hydrogen and lower the carbon footprint of existing natural gas and thermal plants using clean hydrogen, Energy Resources and Gas System Integrity are proposing to install, own, and operate a 1MW electrolyzer at the Frederickson Generating Station. The electrolyzer will provide a supply of approximately 300 kg of hydrogen per day that can be used for testing and validation on both generation and gas distribution assets. The project contemplates a 24 month total project timeline and $4M budget.

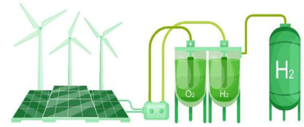
Background: Clean hydrogen has emerged as a promising low carbon energy source, with on-going financial and regulatory support at both the Federal and State level. By 2030, industrial scale supplies of clean hydrogen are expected to be commercially available in PSE's service territory at price points that may be equal to or cheaper than the effective price of natural gas. Hydrogen is set to have significant market penetration in long haul transportation, sustainable fuel refining, chemical processing, and industrial high heat applications. As a fuel source, it holds potential for PSE for system level decarbonization through direct blending into the natural gas system, as a fuel for peak power plants to ensure resource adequacy in a CETA compliant manner, and industrial decarbonization of commercial and industrial customers.

Objectives: This project aims to accomplish the following:

Power generation:

- Blend low levels of hydrogen into existing combustion turbine equipment to validate engineering analysis and modeling
- Work with OEMs and industry SMEs to study, understand and validate emissions profiles
- Provide a test bed for a collaborative regulatory approach to updating Air Operating Permits
- Create a source of low-carbon, company owned hydrogen that can be used for turbine cooling at other PSE owned generating sites
- Gain an understanding of the operational characteristics of manufacturing and storing electrolytic hydrogen

Natural Gas Distribution:



- Understand what is needed to blend low levels of hydrogen into the gas distribution system in the future.
- Validate system modeling and flow characteristics of blended gas
- Create a source of hydrogen that can be transported to customer sites and used in controlled testing of their equipment
- Understand the business opportunities and challenges of storing gaseous hydrogen

Other:

- Provides initial exposure to operations personnel to assist in developing training roadmaps for workforce development
- Publicly demonstrates PSE's commitment to a clean energy future while supporting the growth of the regional hydrogen economy
- Creates a tangible project for public engagement with local and state officials, interested parties, and community organizations
- Provides foundational knowledge into operational economics, reliability, permitting, and other factors that influence the development of potential lines of business

Scope of Work

- 0.5MW to 1.5MW PEM (proton-exchange membrane) or Alkaline electrolyzer, along with Balance-of-Plant equipment required to operate the unit
- Compressed hydrogen storage tanks for an initial capacity of 500 to 1,000 kg
- Blending skid and associated piping for existing CT turbine
- Blending skid and associated pipeline for natural gas blending at existing gate station
- Connection to existing on-site power, water supply, and wastewater systems

Timeline and

Budget: 2023:

~ $1.5M May:

- Organization and alignment
- OEM review
- Evaluate WA CEF grant opportunity

June – July:

- Develop work plan
- Solicit bids from electrolyzer vendors
- Define EPC role, select company, and sign contract

August

- Review electrolyzer vendor bids, make selection, initiate procurement
- Finalize BoP requirements
- Initiate permitting planning and engagement

September – December

- Execute and finalize design work on blending skids

2024: ~

$2.5M Q1 –

Q4

- Finalize blending skid design, construct, and install
- Install control systems
- Finalize connections to power, water, and waste water

2025

Q1 – Q2

- Receive and install electrolyzer
- Commission, test, and adjust
- Move to steady state operations and initiate testing programs

H2 Pilot Goals

- 2023-2025: Blending H2 into generation facility (1st industrial customer) - Electrolyzer @ Frederickson Generation Plant
- 2024-2026: 2nd Industrial customer injection (pyrolysis)
  - Planning and preparing for residential customer facing pilot.
- 2026-2028: Residential Customer Pilot with up to ??% H2 Blend
- 2029/2030: System can handle up to ??% hydrogen blend by volume

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Current H2 Generation/Blending Pilot (#3)

- Electrolyzer for Frederickson generation facility
  - Gain Experience Operating an Electrolyzer
  - Gain Experience Operating a H2 Blending Skid
  - Deliver H2 Blend to Frederickson Generation Facility
  - Expose PSE Engineers to H2 Pilot to Gain Comfort Working with H2
- Determine PSE's requirements and tools needed to support H2 injection into the system:
  - External Training/Research Opportunities
  - Measurement – locations, factors, equipment
  - Gas quality – heat content, NOX/other gases
  - Odorization – how, where, type, up to what blends
  - Minimum skills, tools, qualifications, standards need to be in place for the pilot

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Pilots in Development

- Inject Hydrogen blends with an industrial customer (#4)
  - Candidate customers – Identify which customers would be good candidates for H2 blending test
  - Source of Hydrogen – would it be purchased, created (electrolyzer), pyrolysis
  - Delivery method
  - Minimum skills, tools, qualifications, standards need to be in place for the pilot
- Residential customer injection pilot (#5)
  - Determine where on the system to inject
    - Age of pipes
    - Impacted communities
    - Known integrity issues existing
  - Source and amount of Hydrogen
  - Design of the injection site
  - Minimum skills, tools, qualifications, standards need to be in place for the pilot
  - External communication/interested persons strategy developed (reference ATCO process)

PSE PUGET SOUND ENERGY

METHANE PYROLYSIS POSITION PAPER

SEP 2023

PUGET SOUND ENERGY

Executive Summary

Methane pyrolysis is an emerging technology solution that creates hydrogen gas from methane gas using a pyrolysis reaction. The process creates a continuous supply of hydrogen gas that can be used for decarbonization applications, while capturing all of the carbon in solid form. This technology can be installed upstream or downstream of the meter, and generally does not require new clean energy supplies or electrical system upgrades. Although natural gas consumption does increase to create the same energy in hydrogen form, the existing supplies of natural gas and robustness of the natural gas delivery system can facilitate widespread adoption with minimal system impacts.

Description / Purpose

The pyrolysis reaction separates the hydrogen atoms from the carbon atom in the methane molecule in a non-combustion process, allowing for the capture and collection of the carbon in solid form. The hydrogen is captured and can be used in a variety of applications, including high heat applications, direct blending in the natural gas system, retail sales, or stored and used for power generation applications such as peak power generation and distributed micro grids. The solid carbon is captured an can be used in productive industrial applications such as hot asphalt mixes, concrete, soil amendment, or deposited into a landfill for long term sequestration. There is on-going research to re-process and refine the solid carbon into higher grade materials such as carbon fiber and carbon nanotubes that can be sold for high value applications.

The process runs at an elevated temperate, so it is best suited for continuous end use applications such as steam loops, boiler units and high-heat processes. For this reason, pyrolysis is likely to play a small, but significant role in industrial applications. Within the natural gas distribution system, pyrolysis units can be installed near existing gate stations to decarbonize the gas stream prior to reaching customers. Similarly, pyrolysis units can be installed at power plants to remove the carbon from the fuel supply prior to being consumed in a combustion turbine. For distributed micro-grid applications, pyrolysis units can be coupled with hydrogen fuel cells, providing peak power when needed or grid resiliency when conditions dictate a public safety power shut off.

Business opportunities

Sourcing hydrogen from methane pyrolysis affords PSE the opportunity to develop applications and business cases in the following areas:

1. **Micro-Grids and Peak Power Generation:** Hydrogen from pyrolysis can be used in conjunction with fuel cells at substations to power micro-grids for peak shaving and grid resiliency applications. Hydrogen can also be consumed in combustion turbines to ensure resource adequacy in a CETA compliant manner.

2. **Industrial Decarbonization:** Pyrolysis units can be installed at commercial and industrial facilities, providing a carbon-free pathway without affecting the electric grid.
3. **Natural Gas Decarbonization:** Hydrogen from pyrolysis can be installed on the high-pressure distribution system, providing system level decarbonization benefitting all downstream customers.
4. **Retail Hydrogen Sales:** The hydrogen generated by pyrolysis can be sold to end users in a range of industries, including transportation electrification of long haul trucking and bus fleets.

Economics / Business case

Methane pyrolysis can deliver clean, low CO2e hydrogen at a produced price ranging from $1 to $6.50 per kg, or the equivalent of $8 to $50 per MMBtu. The range of pricing for the solid carbon spans -$100 per tonne (disposal cost), to over $1,000 per tonne (selling into plastic and asphalt markets). At a market price of $625 per tonne of carbon, the delivered price of hydrogen is equivalent to current price of natural gas, inclusive of CCA penalty.

Risks

Methane pyrolysis is a known and understood process, but has not been applied at an utility-level scale. The process requires approximately a 3x increase in natural gas consumption, exacerbating known challenges around methane leakage associated with production, transmission, and distribution. Business processes and market mechanisms would have to be developed to manage the disposal of the solid carbon. Furthermore, the economic value and impact to customers depends upon selling the carbon to offset the higher cost of the delivered energy. A flood of solid carbon into existing markets may depress prices, tempering the market penetration of this technology.

Recommendations

Based on this technology's utilization of the existing natural gas delivery system, as well as the looming limitations of electrolytic hydrogen due to electric system constraints, it is recommended that PSE continue to engage in technical, policy, and market activity beginning this year to ensure market liftoff and stabilization. The significance of using distributed pyrolysis units in conjunction with hydrogen fuel cells creates a pathway to distributed peak generation and grid resiliency, making this technology worth pursuing at this time. Adoption of this technology in the regional energy economy, and the related decarbonization benefits, will occur faster with PSE's leadership and engagement.

Timeline and actions

This technology appears poised to play a significant role in several decarbonization pathways due to its combination of low cost and adequate feedstock supply. To help ensure market adoption, the following actions are recommended:

- Short Term (0-18 months)
  - Work with suppliers, vendors, universities, and national labs to develop carbon management pathways
  - Join vendors and customers for Federal and State grant applications to develop, implement, scale and commercialize operations
  - Develop pathways and mechanisms to engage upstream gas suppliers and transmission companies to reduce their methane emissions
  - Analyze legal and policy implications, and, if warranted, initiate efforts to enhance adoption
  - Develop economic and operational model for natural gas blending and generation applications, including supply, RNG, storage, and products & services.
  - Evaluate costs, benefits, and risks of using this technology for electric micro-grids.
- Medium Term (18 to 36 months)
  - Conduct market and customer surveys to understand end-use applications and interest. Conduct analysis on system capacity to understand impacts of adoption
  - Solidify plans for carbon management pathways
  - Develop capability to offer customers decarbonized energy solutions, including conversion to hydrogen using pyrolysis
  - Refine internal business opportunities and develop implementation / transition pathways
  - Begin identifying core skill sets and training requirements to facilitate adoption, and engage with technology providers and customers about solutions
  - Refine hydrogen storage business model
- Long Term (36 months +)
  - Implement regulatory changes to the CCA to facilitate adoption
  - Finalize and implement a framework for beyond-the-meter applications
  - Offer tariff for clean hydrogen derived from methane pyrolysis
  - Provide ongoing support for development and stabilization of carbon pathways

Introduction

Background information

Methane pyrolysis, also known as methane cracking, methane decomposition, or auto-thermal reformation, is a process in which methane (CH4) is thermally decomposed into its constituent elements of hydrogen (H2) and solid carbon (C), typically in the form of carbon black. This process can be used to produce hydrogen, which is a valuable industrial feedstock and clean energy carrier, without emitting carbon dioxide (CO2) as a byproduct, unlike conventional methane reforming processes.

Pyrolysis can also be used to produce hydrogen from other sources such as biomass and waste. In addition, pyrolysis can be used to produce other valuable products such as carbon black. The technology is still in its early stages of development but has the potential to play an important role in the transition to a low-carbon economy.

Relevance to PSE

Methane pyrolysis relies on the gas infrastructure that PSE operates, and it offers a pathways to reduce emissions in the economy. Pyrolysis requires far less electricity than electrolysis, allowing for faster decarbonization pathways without impacting current electrical generation, transmission, or distribution infrastructure.

Relevance to local energy markets and industries

According to a report by the Department of Energy, the estimated total annual demand of hydrogen by 2045 is approximately 50 million tonnes per year, up from approximately 10 million tonnes today. In Washington state, hydrogen is currently utilized in refinery applications and is sourced from natural gas through the steam methane reformation process. Moving from SMR to electrolysis over the next 20 years would create in incremental electrical demand estimated to be between 2,500 MW and 4,000 MW. Other market demands for clean hydrogen are expected to increase the required electricity considerably higher. While some generation and transmission capacity will be dedicated to green hydrogen over the next 5 to 10 years, the region lacks the capacity to fully meet hydrogen demand solely through electrolytic hydrogen.

Methane pyrolysis produces both hydrogen and carbon black, both of which have an economic value. The hydrogen has value in the following applications:

1. **Transportation**: Clean hydrogen can be used as a fuel for hydrogen fuel cell vehicles (FCVs) and other forms of transportation, including buses, trucks, trains, and even ships. Hydrogen fuel cells offer zero-emission propulsion, making them attractive for decarbonizing the transportation sector.
2. **Industrial Processes**: Industries such as refineries, petrochemicals, steel, and ammonia production often use hydrogen as a feedstock or for various processes.

Clean hydrogen can replace fossil-derived hydrogen, reducing carbon emissions in these energy-intensive sectors.

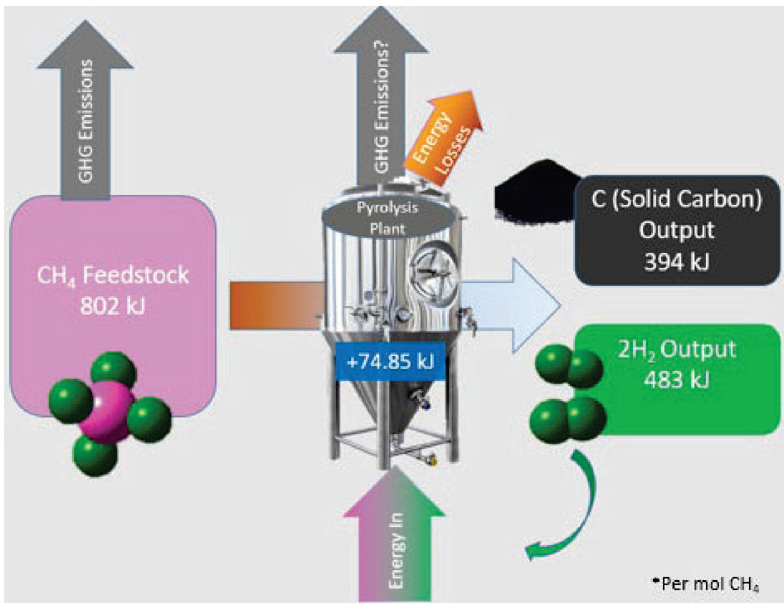
3. **Power Generation**: Hydrogen can be used in gas turbines or fuel cells to generate electricity. It can also contribute to the flexibility and stability of the electricity grid by serving as a storage medium or backup power source.
4. **Heating and Cooling**: Hydrogen can be used in heating applications, such as residential and commercial space heating, as well as in industrial processes that require high-temperature heat. It can also be utilized in cooling applications, such as in absorption chillers.
5. **Chemical and Petrochemical Industry**: Clean hydrogen can serve as a feedstock for producing chemicals, such as methanol, ammonia, and other synthesized products, without contributing to carbon emissions.
6. **Energy Storage**: Hydrogen can be stored and later converted back to electricity or heat as needed, providing a means of storing excess renewable energy for times of high demand or low generation.
7. **Hydrogen Refueling Infrastructure**: Developing a network of hydrogen refueling stations is crucial to support the growth of hydrogen-powered vehicles. Clean hydrogen from methane pyrolysis can contribute to expanding this infrastructure.
8. **Hydrogen Exports**: Regions with excess clean hydrogen production capacity can explore exporting hydrogen to other regions with high demand but limited production capabilities.
9. **Remote and Off-Grid Applications**: In remote areas or off-grid locations, clean hydrogen can provide a reliable source of energy for power generation and other applications.
10. **Aviation**: The aviation industry is exploring the use of hydrogen as a clean fuel for aircraft. Clean hydrogen produced from methane pyrolysis can contribute to this emerging market. Sustainable aviation fuel (SAF) is expected to be on the largest markets for clean hydrogen in the coming decades.
11. **Hydrogen Blending**: Clean hydrogen can be blended with natural gas in existing natural gas pipelines, reducing the carbon intensity of the gas and helping to lower emissions in the natural gas sector.
12. **Research and Development**: Clean hydrogen can also be used for research purposes, including the development of new hydrogen-related technologies and applications.
13.

The solid carbon produced in this process can be used in a number of aftermarket applications. While the carbon byproduct may not be the primary focus of methane pyrolysis, finding beneficial applications for it can contribute to the overall economic viability and environmental sustainability of the process. If used in a beneficial manner, there is a significant downstream decarbonization impact in multiple industries. Here are some potential uses for the carbon produced by methane pyrolysis:

1. **Carbon Black Production**: Carbon black is a widely used industrial material with applications in the production of rubber products (tires, belts, hoses), ink, paint, plastics, and more. The carbon produced from methane pyrolysis can be a feedstock for high-quality carbon black production, offering an alternative to carbon black derived from fossil fuels.
2. **Concrete and Pavement Additives**: Research efforts indicate that an addition of a low percentage of solid carbon into cold patch materials and hot asphalt emulsions generate an increase in mechanical properties. Adding solid carbon that is generated from pyrolysis also lower the carbon footprint of the material.
3. **Battery Electrodes**: Carbon materials are used as electrode materials in lithium-ion batteries and other energy storage devices. The carbon byproduct can be processed and incorporated into battery electrode formulations to enhance performance and reduce costs.
4. **Supercapacitors**: Carbon materials are also used in supercapacitors, which are energy storage devices with high power density and rapid charging capabilities. The carbon byproduct could find applications in supercapacitor manufacturing.
5. **Catalyst Support**: Carbon materials can serve as supports for catalysts used in various chemical processes, such as hydrogenation, oxidation, and more. The carbon byproduct can provide a stable and high-surface-area support for catalytic reactions.
6. **Water Purification**: Activated carbon is widely used in water purification and wastewater treatment to remove contaminants, odors, and colors. The carbon byproduct could be activated and used in water treatment processes.
7. **Carbon Composites**: Carbon fibers and composites are used in aerospace, automotive, and construction industries due to their lightweight and high-strength properties. The carbon byproduct could be processed and incorporated into carbon fiber composites.
8. **Construction Materials**: Carbon materials can be used to enhance the properties of construction materials like concrete, making them more durable and resistant to corrosion.
9. **Agriculture and Soil Amendment**: Carbon black can be used as a soil amendment to improve soil quality, retain moisture, and enhance nutrient retention in agricultural applications.
10. **Energy Storage and Conversion**: Carbon materials can be utilized in various energy storage and conversion technologies, such as in fuel cells and as electrode materials for capacitive deionization.
11. **Additive Manufacturing (3D Printing)**: Carbon materials can be used in 3D printing processes, allowing for the production of lightweight and high-strength parts in industries like aerospace and automotive.
12. **Carbon Capture and Storage (CCS)**: The carbon byproduct can be captured and stored or sequestered in a lanfdill, contributing to carbon capture efforts and potentially earning carbon credits.
13. **Research and Development**: Carbon materials can be used in research for exploring new applications and technologies, including those not listed here.

Technology description

How it works



Methane pyrolysis occurs when methane is heated to over 1,000 deg F and exposed to a catalyst in an oxygen free environment. When this occurs, the molecular bonds between the hydrogen and the carbon molecule in methane are broken. The hydrogen gas is collected, captured, compressed and stored, while the solid carbon leaves the unit in a powder form, with a consistency of flour or fine sand.

Listed below are some of the key technologies and approaches being used or explored in methane pyrolysis:

1. **Catalytic Pyrolysis**: Catalysts are used to facilitate the methane decomposition process at lower temperatures and reduce the energy input required. Various types of catalysts, including transition metals and metal oxides, are being studied to improve the efficiency of methane pyrolysis.
2. **Plasma Pyrolysis**: Plasma, which is a high-energy ionized gas, can be used to create the conditions needed for methane decomposition at lower temperatures. Plasma pyrolysis has the potential to enhance reaction rates and reduce energy consumption.

3. **Microwave and Radiofrequency Heating**: Microwave and radiofrequency heating can selectively heat the methane molecules, leading to more efficient decomposition. These methods have the advantage of precise and rapid heating, which can improve reaction kinetics.
4. **Electromagnetic Induction Heating**: Induction heating uses electromagnetic fields to generate heat within a material. This technology can offer localized and controlled heating for methane pyrolysis reactions.
5. **Innovative Reactor Designs**: Engineers are exploring novel reactor designs to improve heat transfer, optimize residence time, and enhance the distribution of reactants. These designs can lead to more efficient and cost-effective methane pyrolysis processes.
6. **Solid-State Electrolysis**: Solid-state electrolysis involves using a solid electrolyte to facilitate the dissociation of methane into hydrogen and solid carbon. This approach aims to improve energy efficiency and reduce thermal losses.
7. **Membrane Reactors**: Membrane reactors combine the reaction process with a separation membrane, allowing for the selective removal of hydrogen from the reaction mixture. This can improve reaction kinetics and yield.
8. **Advanced Materials and Coatings**: Researchers are exploring advanced materials and coatings that can enhance the stability and performance of reactor components exposed to high temperatures and reactive gases.
9. **Integrated Carbon Capture**: Some research focuses on capturing and utilizing the carbon produced during methane pyrolysis, reducing emissions and creating value-added products.
10. **Hybrid Processes**: Combining methane pyrolysis with other processes, such as steam reforming or carbon capture, can enhance overall efficiency and improve the economics of hydrogen production.
11. **Scale-Up and Commercialization Efforts**: Developing technologies that are scalable and economically viable for large-scale hydrogen production is a significant focus of ongoing research and development.

Technology development in this field is rapid, and new innovations are currently in development. The choice of technology depends on factors such as efficiency, cost-effectiveness, scalability, and compatibility with specific applications and industries.

Technology vendors

Listed below are a few companies that are involved in methane pyrolysis research and development at this time:

1. **Modern Hydrogen:** Modern Hydrogen, based in Bothell, WA, is a start-up backed by Breakthrough Energy that is developing small modular pyrolysis units. Their system relies on a catalytic reaction, and is powered by siphoning a small stream of the produced hydrogen to sustain the heat required for the reaction.

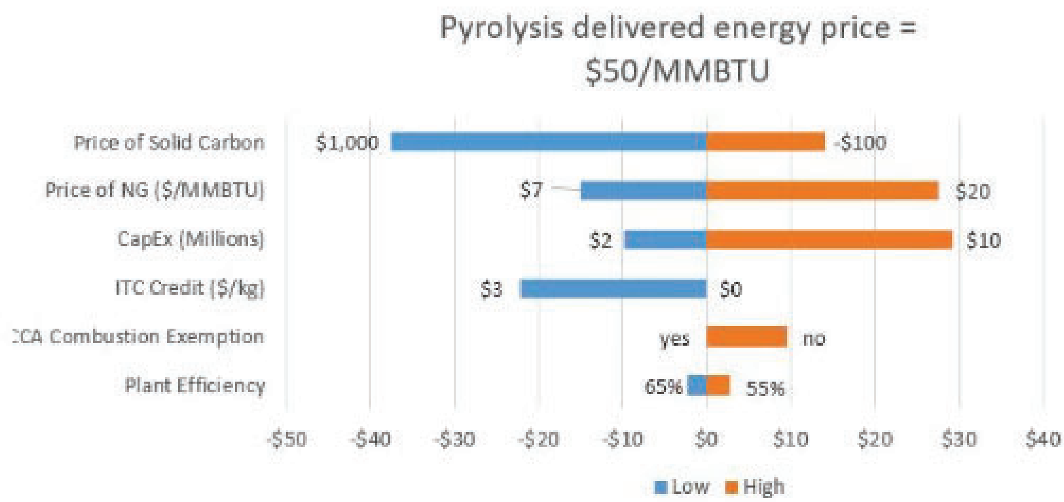
2. **Pacific Northwest National Laboratories:** PNNL has ongoing research efforts dedicated to reprocessing the solid carbon into higher grade forms, yielding enhanced market value.
3. **H2Pro**: H2Pro, an Israeli startup, is focused on developing an innovative methane pyrolysis technology that utilizes an oxygen-ion-conducting membrane to enhance the efficiency of the process.
4. **H Quest**: Is a start up based in Pittsburgh, PA, and is developing a microwave plasma process that uses less energy than thermal decomposition processes.
5. **C-Zero**: C-Zero, based in the United States, is developing methane pyrolysis technology to produce hydrogen and solid carbon materials. Their approach aims to provide a low-carbon and economically competitive method for hydrogen production.
6. **Monolith Materials**: Monolith Materials is working on methane pyrolysis technology for hydrogen and carbon black production. They are exploring the use of plasma-based processes to achieve efficient methane decomposition. Monolith currently has one operational plant in Nebraska.
7. **Starfire Energy**: Starfire Energy is developing a methane pyrolysis technology that combines solid oxide electrolysis cells with hydrocarbon pyrolysis to produce hydrogen and solid carbon.

PSE has on-going engagement with Modern Hydrogen to understand the technology, business model, and development of carbon management pathways.

Economic analysis

Hydrogen is less energetic than methane, requiring a higher volume to deliver the same energy content as yielded by the combustion of natural gas. For purposes of this discussion, the baseline model assumes that there is a 3:1 ratio in natural gas consumed as a feedstock for pyrolysis, compared to combustion of the gas. In addition, for every one kilogram of hydrogen that is produced, four kilograms of solid carbon are created. In the current regulatory design, the increased consumption of natural gas will effectively triple the incoming gas bill, while also incurring a proportional increase in the carbon charge due to the Climate Commitment Act.

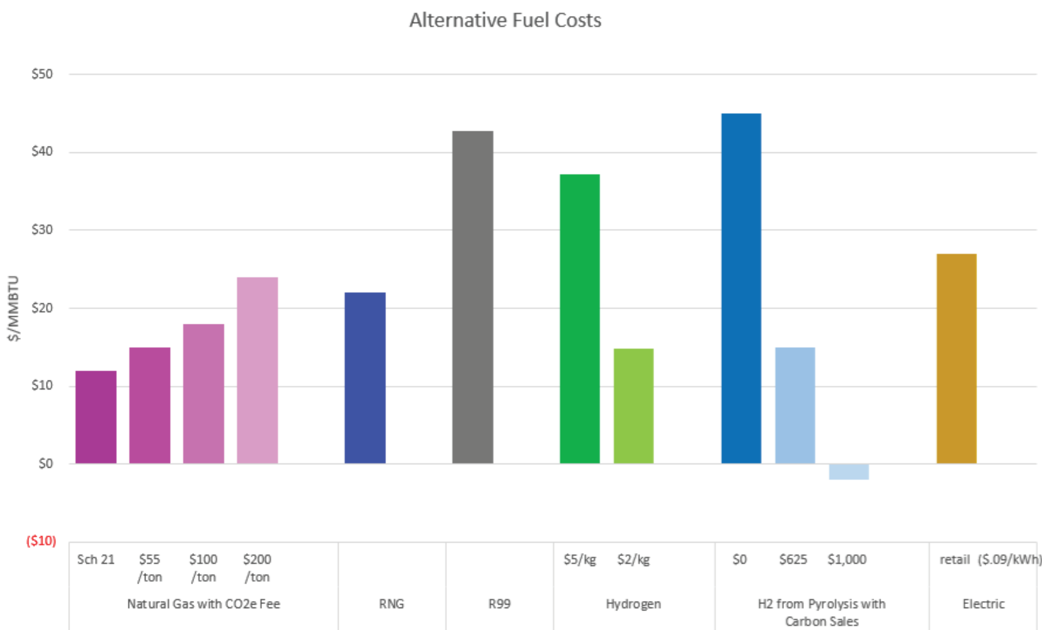
Methane pyrolysis can deliver clean, low CO2e hydrogen at a produced price ranging from $1 to $6.50 per kg, or the equivalent of $8 to $50 per MMBtu. The table below shows the economic components and base case.



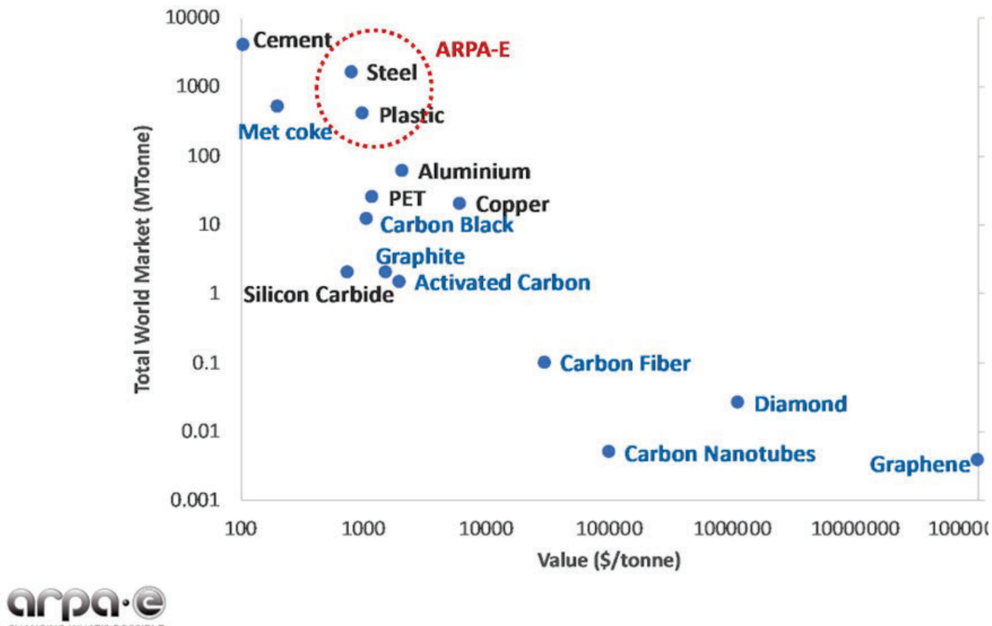
What separates pyrolysis from other energy solutions is the ability to sell the solid carbon into various industrial markets. Different markets are willing to pay differently, from a low point of $100 per tonne for cement, to a high of $1,000,000 per tonne for industrial diamond applications. At a price of $625 per tonne, the revenue from the sale of the carbon off-sets the price of the hydrogen to the point where hydrogen and natural gas (inclusive of CCA) are equal on an energy content basis. Any market price for carbon above $625 per tonne results in operating profit for the owner / producer of the carbon.

Production tax credits in the Inflation Reduction Act stipulate a per-kg rebate based upon the amount of equivalent CO2 produced during the manufacturing process. If sourcing conventional fossil fuel for pyrolysis, lower tiers of the tax credit would be applied, as the carbon footprint is too high due to upstream emissions. If sourcing RNG, the upstream emissions are negated, allowing for a full application of the production tax credit. The $3 / kg tax credit is approximately equivalent of $24/MMBtu natural gas.

The market value of the carbon produced from pyrolysis varies by the grade and process used to create it. Recent market surveys show a value of $1 to $2 per kg, which further offsets the increased costs of incoming natural gas. The table below shows the relative costs of different energy sources, including different sensitivities for CCA carbon price and market price of solid carbon, as well as electrification.



The graph below illustrates the market prices for solid carbon in various industries and applications.



A successful economic business model would entail the following attributes:

- Substantial reduction of upstream methane emissions associated with production and transportation
- Elimination of the CCA penalty from the increased natural gas consumption
- Business model and revenue stream from carbon sales, including recognition of the carbon as a decarbonization benefit to downstream industries
- Continued growth in hydrogen demand

Use cases / Target markets / Benefits

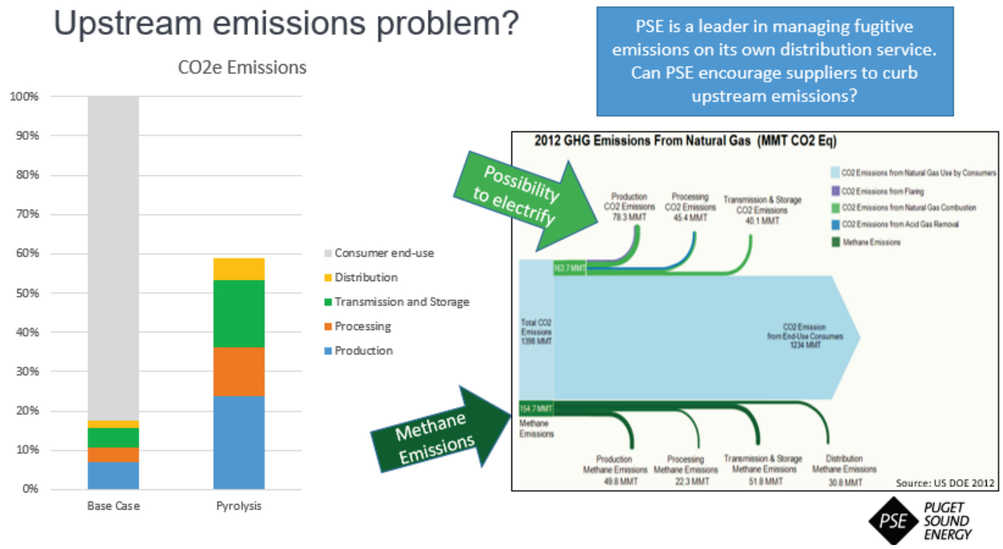
Methane pyrolysis is a process that has several benefits over other methods of hydrogen production. Some of the primary benefits:

- It does not require extensive investment in electric infrastructure or procurement of new renewable electricity.
- It requires less infrastructure to be built than steam methane reformation, with none of the carbon emissions associated with SMR.
- The marginal cost of operation is closely tied to the relatively stable wholesale price of natural gas as opposed to the more volatile price of renewable electricity.

The target customers for methane pyrolysis are those that want to decarbonize and have a high demand for hydrogen or require high-temperature processes. For example, most of today's hydrogen is used for petroleum refining, treating metals, producing fertilizer and processing foods. Many studies also indicate that hydrogen for transportation will be a new market .

In addition to these primary markets, there are other markets for methane pyrolysis. One such market is for high-temperature processes including district heat systems. In locations where electricity expansion is constrained, methane pyrolysis offers a pathway to decarbonize that does not rely on grid investments and upgrades. Another market is for the production of solid carbon that might be used as an additive in concrete and asphalt production.

Lifecycle analysis



Using the hydrogen produced by pyrolysis lowers the CO2e footprint by 42% when compared to the production, distribution, and combustion of natural gas for the same energy content. However, the potential benefit is limited by the increase in upstream emissions due to the increased consumption as a feedstock. In addition, hydrogen from methane pyrolysis is not currently eligible for the highest tiers of clean hydrogen production tax credits through the Inflation Reduction Act due to the high CO2e values associated with producing the hydrogen.

If upstream emissions were eliminated or greatly reduced, the net reduction in CO2e emissions could approach 100%. Using renewable natural gas as a feedstock results in a carbon negative process, although at a delivered energy price per MMBtu that is likely higher than nearly every other decarbonization option.

Engaging in responsibly sourced gas (RSG) may offer a better pathway towards carbon reduction and economic sustainability. RSG focuses on methane reductions through the production and transmission of natural gas. Although there is an economic premium with RSG, it is considerably lower than the retail price of RNG, and the premium may be more than offset by eligibility to claim the $24 MMBtu PTC in the IRA.

Qualitative / Cumulative risk assessment

Regulatory risk

There is no current mechanism to facilitate retail sales of hydrogen to customers within PSE's regulatory framework. If PSE were to pursue this path, a new tariff design would have to be proposed and adopted through a regulatory filing. The biggest hurdle to this path is the general resistance to natural gas and natural gas infrastructure within the State political leadership, and interested parties who hold influence with regulatory bodies. This technology, by its very nature, extends the lifespan of fossil fuel infrastructure, unless all incoming sources of methane in the future can be sourced through a combination of RNG and RSG.

There are no known regulatory or legal limitations if a customer installs this equipment downstream of their meter. PSE would not be impacted by their actions, other than to see a 3x increase in gas consumption at the demand point.

Technology risk

The technology is sound, and the family of technologies using thermal decomposition has been around for several decades. Most of the emerging technologies are in the R&D phase, or early stages of scaling and deployment. It is not yet clear if this technology will scale up to utility application, but there is reason to be optimistic that there will be multiple vendors in this space by 2030.

Market and commercial risk

The adoption of this technology relies on a combination of:

- Continued policy support through the application of PTCs and ITCs
- Low natural gas, RSG, and RNG prices
- Sustainable and profitable market for solid carbon
- Ideal customer use case and application

At a local level, industrial companies and processes that lack low-carbon options or electrification may find this solution appealing. Nationally, there is already one large-scale plant operating in Hallam, NE, by Monolith Corporation. Monolith recently commissioned the pyrolysis plant to supply Goodyear Tire and Rubber Company with 14,000 tonnes of carbon black per year for use in tire manufacturing.

The general market risks to adoption include:

- Lack of industrialization and scaling by vendors
- Inadequate after-market and ongoing operational support
- Inadequate development of carbon offtake and re-selling

- Expiration of PTCs and ITCs before market critical mass has been developed
- Policy implementation prohibiting or limiting the use of this technology

As with any new technology and new market, there will likely be several years of upheaval due to innovation, consolidation, economic forces, and policy evolution. However, the underlying technology is sound, it utilizes the strength of the existing natural gas infrastructure, and the objectives of decarbonization to reduce climate change are likely here to stay. The overall market risk of methane pyrolysis is considered to be low.

Energy Equity

Impacted / Named communities

Utilization of methane pyrolysis holds potential to improve the lives and living conditions of people in impacted and named communities. Industrial factories and commercial facilities are often located next to low-income neighborhoods, who in turn have historically suffered from poor air quality and higher incidences of respiratory disease. When hydrogen is used in high heat applications, there are no airborne particulates or carbon emissions produced. Methane pyrolysis units can be installed upstream or downstream of the meter to provide a point-source clean energy supply in these communities. In addition, new business models would have to be developed around the collection and distribution of the solid carbon, potentially creating new employment opportunities for people who live in and near these facilities.

A further benefit of using clean hydrogen and methane pyrolysis is potentially the avoidance of the CCA penalty. As energy-intensive companies contemplate their compliance options, one option will be to move out of the region to areas with lower cost energy. If hydrogen is competitively priced, they will likely remain in the area and adapt their operations, continuing to employ people who live in the community.

Energy burden

Methane pyrolysis takes full advantage of the existing natural gas system, which has been continually invested in and upgrade throughout its 130 year existence. It is likely that the existing system could withstand high rates of penetration without needing significant upgrades. Contrast this to the looming challenge of electrification and sourcing over 13,000 MW over the next 20 years. Investments in electricity will drive customer bills higher, while natural gas rates are likely to increase at a lower rate for the foreseeable future.

If this technology can be deployed for micro-grid peaking and resiliency applications, it may reduce the need for investments in electric transmission and resource capacity projects, potentially resulting in lower rate increases in the future.

Workforce transition

Methane pyrolysis offers a clear and distinct pathway to utilize and augment the skill set of the natural gas workforce. Discussions with equipment vendors have shown a market need to maintain and operate the equipment, a requirement that will be an economic drag to the vendor, yet is uniquely suited to the utility business model. It is easy to envision a service contract model where PSE offers routine maintenance on pyrolysis units, working with both the customer and the equipment vendor to ensure safe and reliable operation.

By utilizing the existing gas delivery infrastructure, there will continue to be a need for the existing natural gas workforce to operate and maintain the system in accordance with Federal and State pipeline safety regulations.

Business Opportunities

Using methane pyrolysis presents several business opportunities for PSE, especially as we innovate and transition towards cleaner energy solutions. Some potential business opportunities leveraging methane pyrolysis include:

1. **Clean Hydrogen Production**: Methane pyrolysis can produce hydrogen without emitting carbon dioxide. PSE can capitalize on the growing demand for clean hydrogen as a fuel and feedstock for various industries, including transportation, manufacturing, and power generation.
2. **Carbon Reduction and Sustainability**: As governments and industries strive to reduce carbon emissions, we can position ourselves as environmentally responsible by adopting low-carbon technologies like methane pyrolysis.
3. **Resilience and Energy Security**: Hydrogen produced through methane pyrolysis can serve as a backup energy source or contribute to energy storage solutions, enhancing grid resilience and energy security.
4. **Diversification of Energy Portfolio**: Incorporating methane pyrolysis into our energy mix allows us to diversify our portfolio with a technology that aligns with decarbonization goals. This can reduce dependence on traditional fossil fuels and increase resilience to changing energy market dynamics.
5. **Repurposing Fossil Infrastructure**: The natural gas delivery system that our customers have invested in can be re-purposed and rebranded as a hydrogen delivery system, leading to economic savings for all customers.
6. **Workforce Transition**: PSE can work with vendors and customers to lease and maintain pyrolysis equipment, leading to faster adoption and market scaling. The existing natural gas workforce can be retrained with new skill sets to maintain the equipment.
7. **Technology Leadership**: By investing in and deploying innovative technologies like methane pyrolysis, we can establish ourselves as leaders in the energy transition. This leadership can attract partnerships, collaborations, and recognition in the industry.

8. **Partnerships and Collaborations**: PSE can partner with technology providers, research institutions, and other stakeholders to develop and optimize methane pyrolysis technologies. Collaboration can help share knowledge, reduce costs, and accelerate technology development.
9. **Regulatory Incentives and Compliance**: In Washington with carbon pricing established by CCA, end-users may enjoy financial incentives, tax breaks, and regulatory compliance advantages through CCA penalty avoidance.
10. **Value-Added Services**: PSE can offer value-added services such as hydrogen distribution, storage, and integration into various sectors. This can create new revenue streams beyond traditional energy supply.
11. **Consumer and Industrial Applications**: Clean hydrogen produced from methane pyrolysis can be used for various applications, such as fuel cells for electric vehicles, industrial processes, and power generation. PSE can tap into these diverse markets.
12. **Carbon Credit Markets**: In some regions, utilities can generate carbon credits by reducing carbon emissions through the adoption of low-carbon technologies like methane pyrolysis. These credits can be sold or traded.

Recommendations and Next Steps

Promoting the adoption of methane pyrolysis as a utility involves a multifaceted approach that encompasses raising awareness, engaging stakeholders, demonstrating value, and addressing concerns. Here are several strategies that a utility can consider to encourage the adoption of methane pyrolysis:

1. **Education and Awareness Campaigns**: Educate stakeholders about the benefits of methane pyrolysis. Create informative materials, websites, and presentations that explain the technology, its environmental advantages, and its potential applications.
2. **Engage with Regulators and Policymakers**: Work with regulatory agencies and policymakers to advocate for favorable policies, incentives, and regulations that support the adoption of clean hydrogen technologies like methane pyrolysis.
3. **Collaborate with Industry Partners**: Collaborate with technology providers, research institutions, and other utilities to share knowledge, pool resources, and accelerate the development and deployment of methane pyrolysis technology.
4. **Demonstration Projects**: Develop pilot or demonstration projects to showcase the viability of methane pyrolysis. These projects can serve as tangible examples of how the technology works and its benefits.
5. **Financial Incentives**: Offer financial incentives to encourage customers and industries to adopt methane pyrolysis technology. These incentives can include new tariffs, rebates, grants, or favorable pricing structures.

6. **Participation in Clean Energy Programs and Grant Opportunities**: Join and actively participate in clean energy programs and grant applications that focus on promoting hydrogen technologies and carbon management pathways.
7. **Community Engagement**: Engage with local communities to address concerns, provide information, and gather feedback. Building community support can be crucial for project approvals and public perception.
8. **Case Studies and Success Stories**: Share case studies and success stories that highlight the positive impacts of adopting methane pyrolysis, including carbon reductions and economic benefits.
9. **Participation in Research and Development**: Contribute to research efforts focused on improving methane pyrolysis technology, efficiency, and cost-effectiveness.
10. **Advocacy and Outreach**: Use your platform to advocate for the benefits of methane pyrolysis through articles, press releases, and participation in conferences and industry events.

Promoting the adopting methane pyrolysis will require a collaborative and persistent effort. We should seek to tailor our approach to the needs and priorities of your customers, regulators, and stakeholders, and be prepared to address concerns, overcome challenges, and adapt as the technology landscape evolves.