The Potential for Hydrogen in Louisiana

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What is Hydrogen

Hydrogen is the smallest and lightest element and therefore, the first element listed in the Periodic Table. Two atoms of hydrogen combine to form one molecule of hydrogen, denoted by H_2, or "free hydrogen", which is also the lightest molecule. Unless specified otherwise, "hydrogen" will describe H_2. While hydrogen is the most abundant element in the universe (LBL, 2000), it is rarely found in its molecular form (NOAA, 2023) and instead is typically produced by separation from water (H_2O) or a hydrocarbon.[2] In either case, hydrogen production requires energy. Hydrogen is commonly used in industrial applications, such as crude oil refining, and as a feedstock in creating ammonia – the most common source for "fixed" nitrogen in fertilizers. However, there is a growing interest in using hydrogen as a fuel.

Why are we interested in hydrogen?

Fossil fuels, such as natural gas, are used to generate energy needed to run modern society. At present, fossil fuels are used to produce about 80% of total energy used both globally (IEA, 2021) and within the United States (EIA, 2023b). Although fossil fuels such as natural gas (comprising of primarily methane, CH_4) are abundant on earth, their combustion generates carbon dioxide (CO_2, as shown in Reaction 1).

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O + energy \quad \text{(Reaction 1)}$$

Carbon dioxide is a greenhouse gas. Governments and businesses globally have made pledges, and adopted policies to reduce greenhouse gas emissions. Companies investing in Louisiana are increasingly considering the emissions intensity or "carbon intensity" of production processes, leading to interest in fuels such as hydrogen. The combustion of hydrogen generates water as the only product (Reaction 2). Therefore, if obtained in the proper way, hydrogen is considered a low-carbon (or theoretically zero-carbon intensity) as a fuel.[3]

$$2H_2 + O_2 \rightarrow 2H_2O + energy \quad \text{(Reaction 2)}$$

"Clean hydrogen" is the focus of the Internal Revenue Service (IRS) Section 45V production tax credits (USDT, 2023) included in the 2022 Inflation Reduction Act (IRA), which has led to additional interest in producing hydrogen in Louisiana through low carbon emissions processes. Since 2018, Louisiana Economic Development (LED) has identified approximately \$32 billion in potential hydrogen-related projects, including the production of hydrogen and other chemicals such as ammonia and methanol. LED estimates that, if completed, these projects would have the potential to support 2,100 direct jobs and 8,500 indirect jobs by 2030. In addition to domestic policies, the European Union is in the process of implementing a Carbon Border Adjustment Mechanism (CBAM), which will in essence impose a fee on

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2 A molecule made up of carbon and hydrogen. Methane, CH_4, is the smallest hydrocarbon.

3 Practically, there will be lifecycle carbon dioxide emissions if, for example, the hydrogen is obtained from natural gas or obtained through electrolysis with electricity generated from a carbon based fuel (such as natural gas or coal).

imports into the European Union based on the carbon intensity of the products (European Commission, 2023). Among materials such as cement, iron, aluminum, etc., hydrogen is the only commodity chemical included in the CBAM transitional phase, which lasts through 2025.[4] This is likely of interest to companies seeking to export hydrogen into Europe, as hydrogen produced with low carbon emissions can have a competitive advantage selling into this market.

How is hydrogen produced?

Hydrogen can be produced in many ways, and its production process affects its carbon intensity and its eligibility for tax incentives. Since hydrogen is usually found in nature bound to other elements (e.g., to oxygen, in the case of water or carbon, in the case of hydrocarbons), it needs to be separated, which requires energy. A color-coding system is commonly used to describe the process to obtain hydrogen, although the end product (hydrogen) is the same in all cases. An illustration of common color coding is shown in Figure 1. Broadly, there are two ways to produce hydrogen: (1) using electricity to split hydrogen and oxygen from water (called electrolysis), and (2) using hydrocarbons (such as methane, coal, etc.) to produce hydrogen (through processes such as steam reforming).

Figure 1: Hydrogen Color Wheel

[4] The CBAM transitional phase serves as a pilot/learning period before the CBAM definitive period is fully phased in beginning in 2026.

Current production of hydrogen in the United States relies on converting methane present in natural gas into hydrogen and carbon dioxide (Reaction 3), typically using two reactions, steam methane reforming (SMR) and water gas shift (WGS).[5] The process requires energy, and as can be seen from the overall reaction below (Reaction 3), also generates carbon dioxide (CO_2). The US produces about 10 million metric tons[6] (MMT) of hydrogen annually with roughly 95% of this obtained using SMR and WGS or a variation of the process called Autothermal Reforming (ATR) and WGS.

$$CH_4 + 2H_2O \rightarrow CO_2 + 4H_2 \quad \text{(Reaction 3)}$$

Grey Hydrogen: Most hydrogen produced today is considered gray hydrogen. The CO_2 from reforming natural gas or methane in Reaction 3 is simply vented to the atmosphere.

Blue Hydrogen: It is possible to couple the grey hydrogen process with carbon capture and storage (CCS). Carbon capture occurs when the CO_2 emissions from an industrial process (such as Reaction 3) are captured before they can be emitted to the atmosphere. Once captured, CO_2 can be transported, injected, and permanently stored underground. Hydrogen produced in this way is referred to as "blue hydrogen." It should be noted that adding CCS step to the hydrogen production process increases the energy required as well as costs of the process.

Green Hydrogen: Hydrogen can also be produced using electricity to split water to produce H_2 and O_2 (electrolysis). If renewable electricity is used, this is referred to as 'green hydrogen' and it benefits from lower carbon emissions compared to producing hydrogen from fossil fuels. Since renewable electricity production methods such as wind and solar energy are intermittent (wind energy is only produced when the wind is moving whereas solar energy is only produced during the day), hydrogen production could occur when these resources are available, and then the hydrogen may be stored. In this way, *hydrogen can be thought of as a battery in a molecule*.

Pink hydrogen: 'Pink hydrogen' is produced when the electricity for water electrolysis originates from nuclear fission (a non-carbon-based energy source) such as from a nuclear power plant.

Other Colors: 'Black' (or 'Brown') hydrogen is produced from the gasification of coal and could be coupled with CCS to reduce its carbon intensity. 'Turquoise hydrogen' refers to the use of methane pyrolysis using natural gas feeds. In this case, the carbon is converted to solid char rather than gaseous CO_2, potentially simplifying sequestration. 'White hydrogen' refers to naturally occurring H_2 in the earth's crust. Thought to be very rare, this refers to H_2 that has been observed in geological deposits and can be mined for recovery—the potential of this is currently unrealized.

How is hydrogen transported?

Since molecular hydrogen (H_2) is the lightest compound (12.5% the mass of methane), its low density makes it challenging to store and transport. Currently, hydrogen is transported from merchant suppliers to industrial users in the form of a gas using pressurized pipelines, similar to natural gas transmission (EERE, 2024a). One such network of pipelines, spanning 3,200 km (~1,988 miles) along the Gulf Coast,

[5] As previously mentioned, hydrogen can be produced from hydrocarbons – natural gas is the hydrocarbon used to produce hydrogen in the US Gulf Coast.

[6] 1 metric ton, MT (or tonne) is ~1.1US tons (or short tons).

delivers hydrogen, oxygen, and nitrogen to industrial users in Texas and Louisiana (Air Liquide, 2017). While compression and liquefaction (turning hydrogen gas into liquid by cooling it to -253 °C) are viable options for increasing the density of hydrogen, they require more energy. One way of overcoming this disadvantage is to convert hydrogen into heavier compounds such as methane, methanol or ammonia for use as “carriers” of H_2. Since the hydrocarbons methane and methanol contain carbon, their combustion produces CO_2, whereas the combustion of ammonia (NH_3) does not. Further, the ammonia can be reformed into N_2 and H_2 at the point of use. Ammonia contains ~17% hydrogen by mass and is easier to liquefy, which makes it attractive as a hydrogen carrier, allowing the potential for long-distance shipping of this fuel. Research and development efforts into effective ways of storing and transporting hydrogen are currently underway.

Quantifying Current Uses and Potential Market for Hydrogen

In this analysis, we consider the total current and potential future use of hydrogen from six industries, and byproduct hydrogen production from two industries in Louisiana. Current usage of hydrogen in Louisiana arises from the refining of crude oil and the manufacturing of ammonia and methanol. Hydrogen is also generated as a byproduct in the steam cracking of natural gas liquids (NGL) and the production of chlorine using the chlor-alkali process. Estimating future hydrogen usage in place of natural gas can be done using data for natural gas utilization in electricity generation, exports of liquefied natural gas (LNG), and non-electricity energy consumption in manufacturing (also referred to as industrial heat) along with matching the energy equivalent of natural gas. This assessment is limited to the eight cases described above and does not consider other potential applications of hydrogen.

Current Uses of Hydrogen in Louisiana

Ammonia for Fertilizers

Ammonia is an important commodity chemical used primarily for the manufacture of fertilizers – as a medium for “fixed nitrogen” inputs to crops. Nitrogen is an essential nutrient input to plants, responsible for plant growth and development, and other important functions. Nitrogen is the fourth-most abundant element in plant tissues (after carbon, hydrogen, and oxygen) and is part of chlorophyll, the green pigment required for carrying out photosynthesis (DeFelice et al., 2022). Although nitrogen is plentiful in the earth’s atmosphere (~78% by volume), plants can only utilize reduced or “fixed” forms of this element (e.g., NH_3), typically supplied to them through nitrogen-based fertilizers or manure.

Ammonia contains more than 82% nitrogen by mass, making it an effective nitrogen delivery system compared to other nitrogen-containing fertilizers, such as nitrates. NH_3 (anhydrous ammonia) is often converted to other forms such as solid (urea) and liquid (urea ammonium nitrate, UAN) nitrogen fertilizers to improve the ease of handling.

Production of ammonia utilizes hydrogen (typically from SMR and WGS using natural gas) in the Haber-Bosch process to combine with nitrogen (from the atmosphere). US ammonia production capacity in 2022 was 18.9 MMT, of which facilities in Louisiana (3 locations and 7 total plants) accounted for about 33% (USGS, 2022). Total ammonia manufacturing capacity in Louisiana was 6.18 MMT in 2022 (USGS, 2022). Estimates are based on a 90% utilization of ammonia production facilities.

An estimated 0.98 MMT of hydrogen is used annually in the manufacture of ammonia in Louisiana. For perspective, this accounts for approximately 10 percent of U.S. hydrogen usage.[7]

Refining of Crude Oil

Refining is the process of separating the components of crude oil into finished petroleum products, such as gasoline, diesel fuels, kerosene, asphalt, etc. Hydrogen in crude oil refining is primarily utilized for desulfurization (removal of sulfur from crude oil—turning 'sour' into 'sweet' crude) and hydrocracking of 'gas oil' (heavier hydrocarbon mixture from atmospheric or vacuum distillation towers) into lighter fractions, such as jet fuel, diesel, kerosene, etc. (EIA, 2013). Refineries typically generate hydrogen on-site or have it supplied by merchant hydrogen producers.

In this estimate, we used the 'Louisiana Refinery Annual Operable Atmospheric Crude Oil Distillation Capacity' data (in barrels per stream day) from the EIA to estimate state-wide refinery capacity (EIA, 2024a). In 2023, Louisiana refineries reported 3.12 million barrels per stream day of atmospheric crude oil distillation capacity. Since H_2 consumption for refining crude oil depends on factors such as sulfur content and the specific gravity of the feedstock, hydrogen demand varies regionally depending on the origin of the crude. The H_2 consumption estimate for the Petroleum Administration for Defense Districts (PADD) 3 region (comprising New Mexico, Texas, Arkansas, Mississippi, Alabama, and Louisiana) is 329 cubic feet of hydrogen per barrel of crude oil (Elgowainy et al., 2020). Estimates of hydrogen use are based on a 93.8% refinery utilization capacity for 2023 (EIA, 2024a).

An estimated 0.89 MMT of hydrogen is used annually for the refining of crude oil in Louisiana. For perspective, this accounts for approximately 9 percent of U.S. hydrogen usage.

Methanol

Methanol is an important commodity chemical which is used in the production of industrial chemicals and solvents, such as formaldehyde, acetic acid, etc. Methanol production relies on the generation of syngas from SMR or ATR of natural gas. A two-step reaction of CO_2 with H_2 produces methanol and water. While statistics for annual methanol production in Louisiana were not accessible, estimates of production capacity from individual manufacturers were used for this analysis. Total annual methanol production capacity in Louisiana from two facilities in St. James Parish (Koch Methanol St. James) (Koch, 2021) and Ascension Parish (Methanex, LLC) (Methanex) is 4 MMT. Estimates are based on a 90% utilization of methanol production facilities.

An estimated 0.56 MMT of hydrogen is used annually for the production of methanol in Louisiana. For perspective, this accounts for approximately 6 percent of U.S. hydrogen usage.

Hydrogen as a Byproduct

Hydrogen is also currently produced as a byproduct primarily from two major industries: olefin (alkene) production which involves the steam cracking of hydrocarbons (e.g., converting ethane into ethylene and hydrogen), and the production of chlorine from brine using the chlor-alkali process. Hydrogen is not the primary commercial product of these two processes, so is often burned on site for its heating value.

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[7] Estimated U.S. hydrogen production is 10 MMT per year (EERE, 2024b).

NGL Steam Cracking

The source of hydrocarbons for use in steam cracking include hydrocarbons such as ethane, propane, butane, which are typically found as a minor constituent (5%) of natural gas and commonly called NGLs. In their natural state, these hydrocarbons are used in several applications, including space heating and cooling, blending into vehicular fuel, and as inputs for petrochemical plants. The latter application, referred to as the steam cracking of NGL, is used to produce olefins or alkenes, such as ethylene, propylene, etc. Reaction 4 shows the overall simplified conversion of ethane (C_2H_6), the predominant NGL, to ethylene (C_2H_4), a precursor in the production of polyethylene and hundreds of other products.

$$C_2H_6 \rightarrow C_2H_4 + H_2 \quad \text{(Reaction 4)}$$

From the ethane cracking reaction shown above (Reaction 4) the production of 1 equivalent of ethylene (1 mol or 30 g) results in the co-production of 1 equivalent hydrogen (1 mol or 2 g). Hydrogen is a byproduct of this process and is usually separated and burned to produce heat required for the steam cracking reaction (Lee & Elgowainy, 2018). Byproduct hydrogen from the steam cracking of NGL is estimated at 3.5 MMT per year in the US, and steam crackers in Louisiana are estimated to account for ~0.45 MMT of hydrogen each year (Lee & Elgowainy, 2018).

Chlorine

In the chlor-alkali process, chlorine is separated from brine (e.g., NaCl salt in H_2O) using electrolysis to produce chlorine gas (Cl_2) and sodium hydroxide (NaOH) as shown in Reaction 5.

$$2NaCl + 2H_2O \rightarrow Cl_2 + 2NaOH + H_2 \quad \text{(Reaction 5)}$$

From Reaction 5, 1 equivalent of hydrogen (1 mol or 2 g) is co-produced with each equivalent of chlorine (1 mol or 70 g) gas that is generated. Since H_2 is generated as a pure byproduct in this reaction, this gas is commonly sold, used on-site, or burned for its heating value. Byproduct hydrogen from chlorine production in the United States is estimated at 0.4 MMT per year (Lee et al., 2018). For Louisiana, this is estimated at 0.15 MMT per year (Lee et al., 2017). Although the byproduct hydrogen is generated using electrolysis, this is still considered grey hydrogen since the electricity is typically generated by burning natural gas.

Potential Markets for Hydrogen

Exports of Liquefied Natural Gas (LNG)

Due to its low volumetric density (0.8 kg/m^3 at STP[8]), natural gas needs to be liquefied for long-distance shipping, particularly for export to other countries. The liquefaction process requires energy inputs to cool the natural gas to -162.2 °C (-260 °F) which increases the density of natural gas by ~600 times. This LNG is loaded onto specialized tanker vessels for long distance transportation between terminals (FECM, 2021). The vessels are equipped with double hulls to limit the re-gasification (evaporation) of the LNG, although some of the LNG is lost as ‘boil-off’. Louisiana is currently home to four LNG export terminals: Sabine Pass, Cameron Pass, Cameron (Calcasieu Pass), and a recently inaugurated facility in Plaquemines Parish; LNG is exported from these terminals to markets in Europe and Asia. LNG exports from Louisiana

[8] STP: Standard temperature and pressure (0 °C and 1 atm)

totaled 2,634.8 billion cubic feet (Bcf) in 2023 (EIA, 2024b).[9] Hydrogen could also be exported from the Gulf Coast, likely in the form of ammonia, to ensure sufficient energy density for long-distance transport. We calculated the amounts of hydrogen and ammonia (and the amount of hydrogen needed to produce this ammonia) that represents the equivalent amount of energy currently exported in the form of LNG.

An estimated 22.69 MMT of hydrogen would be needed to export the same amount of energy currently associated with LNG exports. If this hydrogen were to be exported in the form of ammonia, this would require 25.92 MMT of hydrogen annually.[10]

Manufacturing Energy Consumption

The industrial manufacturing of goods and commodities requires energy inputs for multiple applications, such as electricity, fuel use for industrial processes (e.g., the production of steam), facility lighting, transportation, etc. Within the industrial sector, process heat accounts for about one-half of all onsite energy usage and nearly one-third of total greenhouse gas emissions (EERE, 2024c). Industrial energy consumption, besides electricity, includes indirect uses (boiler fuel), direct uses (process heating, cooling, refrigeration, machine drive, etc.), and non-process direct uses (facility lighting, onsite transportation, etc.). These are referred to as manufacturing energy consumption or *industrial heating*.

We obtained national and census region metrics from the US EIA's Manufacturing Energy Consumption Survey (MECS) results (survey circulated in 2018) (EIA, 2021). Energy consumption associated with industrial heat in manufacturing was 1.73 Quads for the South Census Region. This was adjusted to assess the energy consumption for industrial heat in Louisiana supplied by natural gas using the US EIA State Energy Data System (SEDS) (EIA, 2022).

An estimated 3.5 MMT of hydrogen would be needed to meet industrial manufacturing energy currently supplied by natural gas in Louisiana.

Electricity Generation

Natural gas is the primary source of electricity generation in Louisiana, accounting for ~2/3 of the total produced in the state. Natural gas consumption for the electric power grid in Louisiana in 2023 was 527.9 trillion cubic feet (Tcf) (EIA, 2023a).

For this estimate, we calculated the amount of hydrogen needed to meet the energy contained in the amount of natural gas used for electricity generation in the state. This conversion includes the assumptions that: 1) only existing natural gas power plants are converted to H_2; and 2) the efficiency of the conversion of H_2 to electricity is identical to the efficiency of the conversion of natural gas to electricity.

An estimated 4.55 MMT of hydrogen annually would be needed to produce the same amount of grid-based electricity currently generated from natural gas in Louisiana.

Results Summarized

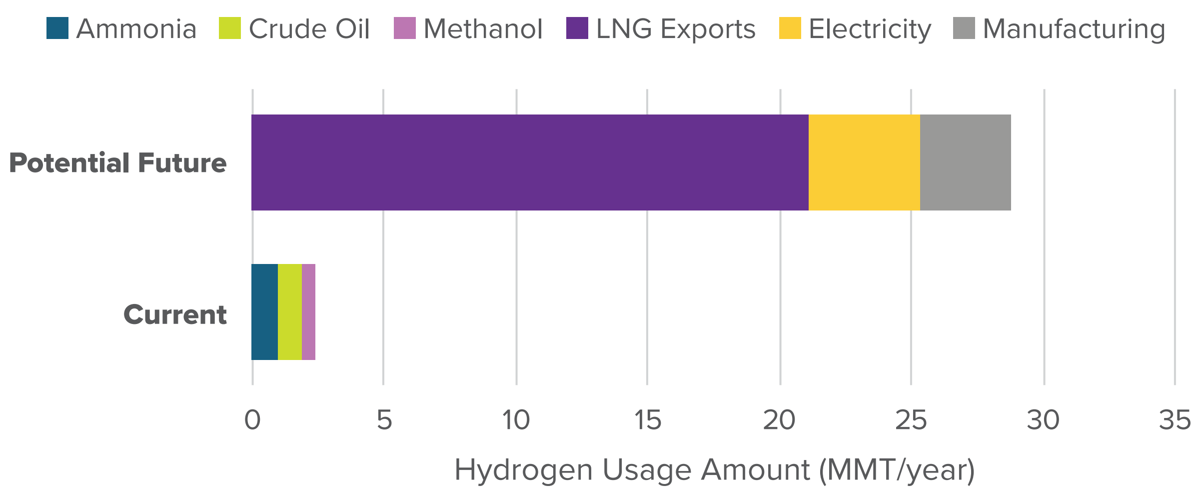
Figure 2 summarizes estimates of hydrogen potential from the prior sections. In summary, we estimate ~2.4 MMT of hydrogen is currently used in Louisiana per year. Results suggest a potential of 30.8 MMT

[9] Note this is from just three facilities, as the Plaquemines Parish facility came online in 2024.

[10] Note that this is because the energy density per unit mass of ammonia is ~6.3 times lower than that of hydrogen.

per year of hydrogen would be needed to fulfil these uses. For perspective, this is approximately 13 times greater than current usage. Note that this does not represent a forecast of the growth of hydrogen, but it illustrates the scale of hydrogen use that could be possible in Louisiana. Data illustrated in Figure 2 is listed explicitly in Table 1.

Figure 2: Current and potential future estimates of hydrogen usage from multiple applications in Louisiana



Source: US Energy Information Administration. Manufacturing Energy Consumption Survey (MECS), Annual Electric Generator Report, Louisiana Refinery Operable Atmospheric Crude Oil Distillation Capacity, US Natural Gas Imports & Exports by State; US Geological Survey. Nitrogen Statistics and Information; Koch Methanol and Methanex; and authors' calculations.

Table 1: Total potential consumption of hydrogen in Louisiana from several applications

The Potential for Hydrogen in Louisiana	
Panel A: Estimated Current Usage (MMT/year)	
Production of Ammonia (MMT/year)	0.98
Refining of Crude Oil	0.89
Methanol	0.56
Total Current	*2.43*
Panel B: Estimated Potential Usage (MMT/year)	
Exports of LNG	22.7
Electricity Generation	4.6
Manufacturing Energy	3.5
Total Potential	*30.8*
Current + Potential	*33.2*

Source: US Energy Information Administration. Manufacturing Energy Consumption Survey (MECS), Annual Electric Generator Report, Louisiana Refinery Operable Atmospheric Crude Oil Distillation Capacity, US Natural Gas Imports & Exports by State; US Geological Survey. Nitrogen Statistics and Information; Koch Methanol and Methanex; and authors' calculations.

Conclusions

In this analysis, we provide perspective on the potential for hydrogen utilization in Louisiana and show that future uses can be roughly an order of magnitude greater than current levels. Several multibillion-dollar investments in hydrogen production over multiple decades would likely be needed to achieve the levels described in this analysis. The largest potential market for hydrogen is the energy export market. Louisiana currently exports ~2,638 Bcf of natural gas per year (2023 estimate) and this is equivalent to about 23 MMT of hydrogen on an energy basis.

Other applications such as using hydrogen for electricity generation and industrial uses are also large relative to current usage of hydrogen. Depending on how hydrogen is produced, it can offer varying degrees of decarbonization potential for these sectors—further reducing the greenhouse gas emissions intensity of other products sold nationally or internationally. In terms of chemical manufacturing, blue or green hydrogen could be used as a feedstock or an energy source and holds the potential to reduce the carbon intensity of the many products that Louisiana has produced for a century. Ultimately, the growth in the market for hydrogen is likely to be driven by global customers' willingness to pay for lower-carbon intensity fuels and products. This analysis puts into perspective the potential size of this market, but ultimately, market participants and policymakers will decide the extent to which a hydrogen buildout is economical and can accomplish decarbonization targets.

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