



Renewable Hydrogen Projects

How to deliver on the potential of renewable hydrogen projects

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The potential for hydrogen as a green energy source is profound.

Introduction

The potential for hydrogen as a renewable energy source is profound. Transitioning current production methods of hydrogen to green methods would eliminate nearly 830 million tonnes of CO2 emissions. But hydrogen’s potential doesn’t end with production – it can be used as a cleaner energy source for transportation and some of the most polluting industrial sectors. As renewable energy sources like solar and wind become more affordable and abundant, the cost of producing renewable hydrogen is dropping. Given this, hydrogen seems like inevitable solution to a significant part of the energy transition. But to realize this potential, we need to address broad economic challenges and more immediate hurdles to funding and executing these projects.

Immediate project challenges

Far-sited owners recognize hydrogen’s potential and have begun to invest in bringing this vision to reality. Often led by developers in close collaboration with technologists, these projects have different needs than traditional large energy projects. Traditional projects are funded internally and come with an established ecosystem of management and construction processes, contractual strategies, and well-known vendors. New hydrogen projects face challenges in technical and financial risk, have more aggressive ROI demands, and a new set of covenants with banks and equity partners. These owners must navigate a complex project process, risk reluctant contractors, new technology implementation, and changing government incentives, while still meeting their investors’ demands.

Compliance

As the hydrogen market emerges, projects rely on government incentives to overcome financial hurdles. But the gap

between planning for these incentives and realizing their benefits is larger than most realize. Incentives such as the Inflation Reduction Act (IRA) come with difficult to meet requirements such as prevailing wage and a proscriptive apprenticeship program. In addition, these projects have extensive documentation and auditing burden, extending in some cases for up to 20 years of production.

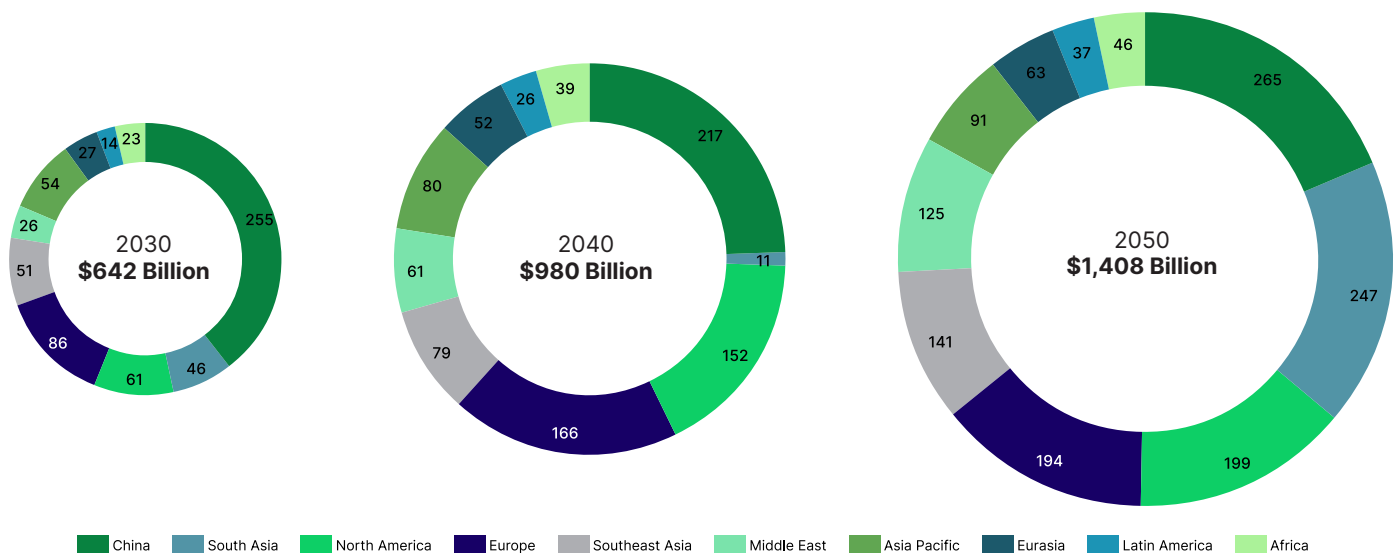
Contractual

The potential for hydrogen projects is its biggest asset and its largest liability. Large scale, financed, zero recourse green hydrogen projects in new locations with new technology and government compliance requirements pose a unique risk. Many of these risks are being transferred to contractors from investors. Contractors are hesitant to take on the entirety of that risk, especially without significant cost and schedule increases. Technologists lack the balance sheet necessary to backstop performance risk to satisfy banking requirements. Owners must create a unique and dynamic contractual system that balances risk appropriately among all project stakeholders.

Technical

A project is only economically viable if it chooses a technology compatible with production needs and timing, the project location, power prices and availability, pipeline accessibility, grid compatibility, electrical infrastructure and more. Accurately determining the correct technology is a specialised process which requires technical, financial, commercial and construction experience. Without a solid technical solution, project estimates and configurations are inaccurate – leading to significant projects cost overruns and production delays, destroying the investment model.

Clean hydrogen market size (US billion per year)



Types and Applications of Hydrogen

Hydrogen can be made from a variety of materials, ranging from natural gas, light hydrocarbons such as LPG's, heavier hydrocarbons, bio-mass, coal, or water. Hydrogen is classified by color to indicate feedstock, levels of carbon capture, and energy source. In general, green hydrogen is produced via water electrolysis using renewable energy, such as solar, wind, or hydro-electric. Blue hydrogen processes natural gas and steam using a reforming technology and disposes of waste carbon via a carbon capture system (CCS). Hydrogen produced via reforming without carbon capture is known as gray hydrogen, and naturally occurring hydrogen is colored white. The market for hydrogen is diverse and growing, with a wide range of applications across sectors.

Key Hydrogen Applications

Transportation

Hydrogen fuel cells can be used for various transportation applications, including cars, buses, trucks, and trains. These vehicles emit only water vapor and are seen as a cleaner alternative to traditional gasoline and diesel vehicles.

Energy storage

Hydrogen can be used as a form of energy storage, allowing excess renewable

energy from sources like wind and solar to be stored and used when needed. This can help to balance the grid and increase the reliability of renewable energy.

Industrial applications

Hydrogen is used in a variety of industrial processes, such as in the production of ammonia for fertilizers, in refineries for desulfurization, and in the production of cement, glass and steel.

Power generation

Hydrogen can be used in fuel cells or combusted directly in a boiler or gas turbine to generate electricity, either for grid-connected power plants or off-grid applications. Fuel cells are efficient and produce zero emissions, making them a promising technology for clean power generation.

Heating and cooling

Hydrogen can be used as a clean fuel for heating and cooling buildings, either directly or through fuel cells. This can help reduce carbon emissions from the heating and cooling sectors.

The potential of hydrogen is being realized slowly; hydrogen transportation infrastructure and commercial hydrogen

compatible engines will create a boom in demand. Sectors that will be penetrated first by clean hydrogen must offset its initial costs with significant benefit. These are industries with existing infrastructure and heavy carbon footprints:

High polluting industrial processes such as steel production, cement, jet fuel, and cargo ships

Chemical and fertilizer production – one of the largest consumers of ammonia, typically for use in fertilizers

In the United States, federal incentives support these efforts, and have funded large hubs to divert the production of 'dirty' hydrogen to clean. These hubs include hydrogen fuelling stations in the Appalachian region, heavy duty trucking and port operations in California and the gulf coast, ammonia production in the heartland, steel and glass production in the Midwest, and more.

Hydrogen types and classifications

Color	Fuel	Process	Maturity	Products	GHG Footprint
Black	Coal	Steam reforming/gasification	Mature	H ₂ + CO ₂ (released)	High
Grey	Natural Gas	Steam reforming	Mature	H ₂ + CO ₂ (released)	Medium
Blue	Natural Gas	Steam reforming	Mature	H ₂ + CO ₂ (captured & stored)	Low
Green	Renewable Electricity	Electrolysis	Early Stage	H ₂ + O ₂	Minimal
Pink	Nuclear Power	Electrolysis	Early Stage	H ₂ + O ₂	Minimal
Turquoise	Methane	Pyrolysis	Early Stage	H ₂ + C (Solid)	Solid Carbon

Compliance Challenges

Most clean hydrogen projects are developed by smaller, non-oil and gas companies and rely on government incentives in the Inflation Reduction Act (IRA) and the DOE's independent clean energy financing program for viability. On paper, the project economic equation seems obvious: meet standards, qualify for credits, offset construction cost, and maximize profit. But the standard for compliance to these programs is high and the reporting requirements are new and cumbersome. Signed into law in the fall of 2022, the IRA aims to improve domestic manufacturing investment, encourage domestic supply procurement, and commercialize leading edge technologies. Under the IRA, hydrogen projects can qualify for carbon credits, tax credits and lower interest rates – if they meet prevailing wage and apprenticeship standards, which were only finalized in June 2024.

Prevailing Wage

The IRA sets wage standards based on job classification and requires a ratio of skilled to entry level craft labor which varies depending on the craft type. Even companies with existing labor definitions can struggle with the process of assigning and documenting IRA standard labor classifications: they change on a county-by-county basis with a varying level of specificity. Mismatches between contractor labor definitions and government definitions lead to incorrect bid estimates – and can cause costly change orders. Contractors without labor classifications must develop and document them, down to the individual criteria. Sometimes these classifications aren't defined until after work has been completed, which means companies must retroactively examine contractors and payments according to new conditions – and forfeit benefits and receive hefty penalties that come with interest.

Apprenticeship Program

Apprenticeship program requirements in the IRA are similar to existing requirements from the Davis Bacon Act (originally enacted in 1931), which are required on federally funded construction projects. The standard is relatively easy to meet in regions with robust union contractors; Unions have historically provided formal apprenticeship programs, most of which have gone through the qualification and registration process with the U.S. Department of Labor (DOL). Historically, non-union or open shop contractors have not provided apprenticeship programs to the same formal standard.

However, it is possible for open shop contractors to achieve these programs through DOL registered or state approved programs. Large regional and national non-union contractors are typically well versed in the basics for meeting apprenticeship program standards. However, many of the contractors serving smaller companies do not have these programs and must create and document their apprenticeship program or pay penalties and forgo tax credits.

Clean Energy Financing Program

The Clean Energy Financing program, administered through the U.S. Department of Energy, is another path for financial support. This program arranges federal financing for innovative energy, supply chain, and infrastructure projects, and supports certain state funded energy projects. To qualify for this program, projects must support clean energy deployment and energy infrastructure reinvestment that reduce greenhouse gas emissions and air pollution. Projects that qualify for this program become eligible for direct federal loans or partial guarantees of commercial debt. However, the administrative burden of these programs is high: the DOE requires multiple applications, audits and other formal steps in the loan approval process. After financial close, the DOE monitors the project for the life of the loan (typically 20 years).

Contractual Challenges

Many hydrogen projects rely on project financing from outside the project organization, like banks or equity partners. These financing organizations often prefer to protect themselves from the risk of new technology projects with a Lump Sum EPC contract and a more burdensome requirement called a financial wrap.

In a lump sum EPC contract structure, project owners' typically contract with a single company to manage the engineering, procurement, and construction of a project for a specific fixed price, or "lumpsum," which also includes a performance risk. This risk is a guarantee that the plant will produce a specific capacity at a specific quality. These contractors typically perform most of these services in house. However, due to a recent history of major cost overages in lump sum EPC projects, large contractors are hesitant to assume this risk. Some smaller contractors without full in-house EPC capabilities will take on the extra liability for some of the services outside their own capabilities, though few

will take on liability for construction or technology services. This challenge can be overcome by forming a joint venture or consortium with several members who together are able to perform or administer the performance of the project. In this arrangement, all members are responsible and liable for the others, irrespective of fault. It is still a high-risk proposition for contractors, but risk is more evenly distributed. For this arrangement to be possible, owners must source competent contractors amenable to sharing risk and form a rigorous side agreement between the parties appropriating risk failures.

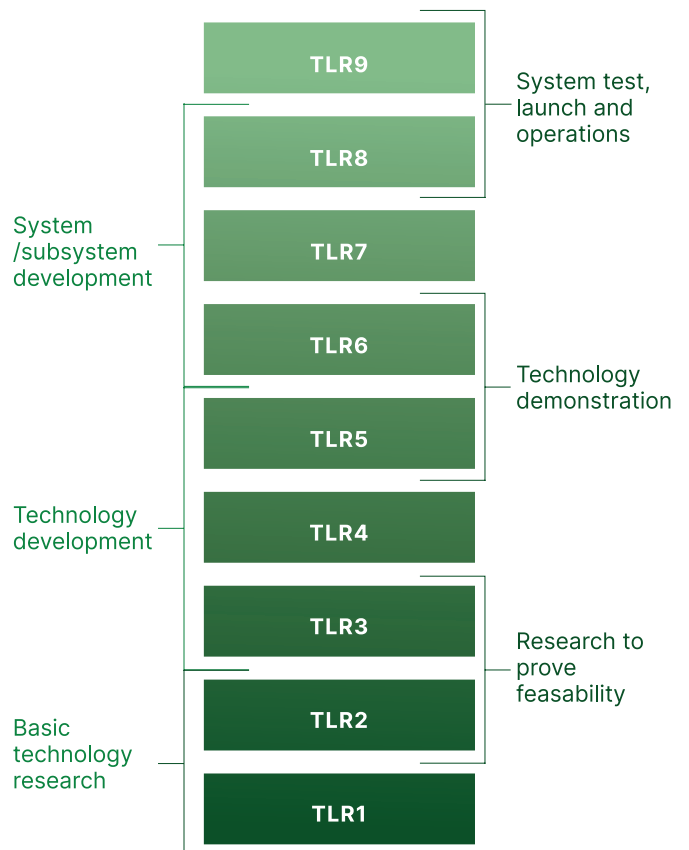
Technical Challenges

Customers choose to invest in blue or green technology based on differences in government incentives, production outcome needs, location and infrastructure availability, and investors' risk stance. Mature organizations generally opt to invest in blue hydrogen projects on a large scale and will invest in green hydrogen on a smaller or demonstration level. Developers often opt for green hydrogen projects because of their larger government incentives and to gain the advantage of being first to market.

Government incentives for hydrogen are generated under the inflation reduction act. Section 45v provides \$0.60 credit per kg of hydrogen, depending on the amount of CO2 equivalent generated. If prevailing wage and apprenticeship requirements are met, then the credit can be increased 5x, meaning a credit up to \$3.00/kg hydrogen. Blue hydrogen projects consider the 45Q credit, which is calculated on the amount of carbon captured and sequestered. Developers are awarded up to \$85 per metric ton of carbon captured and sequestered. However, these credits cannot be applied simultaneously.

Once that decision has been made, owners select a technology selection and evaluate the best vendor for supplying that technology. These decisions must consider production needs, location, power cost and availability, pipeline accessibility, grid compatibility, price, ongoing maintenance and more. Crucially, these factors must amount to an economically feasible project suitable for investment. Many banks and investors also require a technology readiness level rating to quantify the maturity of a project. Recent hydrogen projects have been funded only when the maturity rating has reached seven, which requires that a system prototype has been demonstrated in an operational environment.

Project Maturity Rating Scale



Blue Hydrogen

Blue hydrogen uses traditional hydrogen sources and production technologies (reforming) but offsets pollution by capturing CO₂ generated during production. There are three main methods currently utilized to generate blue hydrogen: steam methane reforming (SMR), partial oxidation (POX), and autothermal reforming (ATR).

Steam Methane Reforming

SMR is a proven technology widely applied for conventional hydrogen production, especially in petroleum refining. In SMR, natural gas is exposed to moderate pressure and high temperatures steam and produces H₂, CO and CO₂. SMR technology is widely available, and market tested, however POX and ATR are more cost effective

Partial Oxidation

The POX reaction occurs when fuel-oxygen mixture is partially combusted in a reformer, producing hydrogen rich syngas. Compared to SMR, POX technology can maximize carbon capture efficiency and simplifies the process lineup. This can greatly offset the cost of O₂ production. In addition, since POX does not require steam, it avoids the cost of gas pretreatment.

Autothermal Reforming

ATR is a combination of SMR and POX processes. ATR fires oxygen and natural gas in a refractory lined reactor with a catalyst bed. ATR is more energy efficient than SMR or POX technology. It also has faster startup and response times than SMR. However, ATR systems use costly feed gas pretreatment facilities and oxygen production plants.

Process Characteristics Compared for Blue Hydrogen

	SMR	POX	ATR
Carbon Feedstock	Natural Gas	Gaseous or liquid hydrocarbons	Natural Gas
Oxygen Feedstock	Air for fuel combustion	Oxygen from ASU	Oxygen from ASU
Steam Requirements	Yes	No	Yes
Catalyst Required	Yes, Ni	No	Yes, Ni or Co
Energy Required/Released	Endothermic	Exothermic	Balance of endothermic/exothermic
Syngas Temperature	850°C	1400°C	1000°C
Syngas Pressure	15-40 bar	40-80 bar	30-40 bar
Hydrogen content in Syngas *	~70%	~60%	~65%
Maturity	Mature	Mature	Mature
Cost Effectiveness	Medium	High	High

Green Hydrogen

A commercially successful hydrogen project must choose the best technology for the project circumstances, solve renewable power variability issues, and meet requirements to receive federal funding and carbon credits.

Power Variability

Variable power means that owners must invest in energy controls like micro grids and storage infrastructure like batteries or hydrogen storage. Peaks and valleys in energy create an unsteady mode of operation that must be managed in the context of the entire hydrogen production system; while electrolyzers have quick ramp up and down times, other mechanical equipment and downstream units may not. Owners must decide to manage overcapacity on the power or process side.

Power Availability

It is not enough for hydrogen projects to be powered by renewable sources; they must be powered contemporaneously by sources built within the three years prior to the date they start to produce product. The intent of this legislation is to eliminate competition for existing renewable power and ensure hydrogen projects are run by additive renewable power. Because of this requirement, green hydrogen projects become, largely, power projects. They require significant electrical infrastructure,

including solar/wind farms, transmission lines, substations, transformers, rectifiers, and battery storage.

Hydrogen Electrolysis

Alkaline Water Electrolysis

In an AWE electrolyzer, a lye solution is fed into a cathode at high temperatures (80°C), generating hydrogen and hydroxide ions. With slight variability depending on vendor technology, the hydrogen produced is ~99.5% pure. AWE technology currently achieves the highest levels of efficiency of electrolysis and is characterized by high long-term stability and comparatively low investment costs. AWE electrolysis is the most mature out of the three electrolysis technologies. The higher maturity comes with more “bankable” OEMs. AWE technology also brings with it the challenges of dealing with KOH lye solution it adds to the operating expense for initial fill and replacement of the lye solution.

Polymer Electrolyte Membrane

In PEM electrolysis, demineralized water feed enters the anode side where it is oxidized into hydrogen protons and oxygen. Then the hydrogen protons cross a polymer membrane to generate hydrogen. PEM technology operates at lower temperatures than AWE but uses higher temperature to generate consistently pure forms of hydrogen (~99.999%

purity). This process uses expensive material for construction, which is seen in the higher capital installation cost. PEM technology while technically comparable with AWE, as the less mature technology of the two comes with higher capital expense plus fewer OEMs that are considered traditionally “bankable”.

Solid Oxide Electrolysis Cell

SOEC is the newest electrolyzer technology in the market. At very high temperatures steam is fed into the cathode. When an electrical voltage is applied, the vapor at the cathode-electrolyte interface is reduced to form oxygen ions and nearly atmospheric hydrogen. With high temperatures, the reactions can happen faster which leads to high efficiency. Steam also heats the stacks, lowering the electrical requirement by approximately 20-25%. SOEC is the newest player to the market and is still in development. The lack of maturity in the technology makes the SOEC electrolyzers seem not bankable when compared to AWE or PEM even though the operational flexibility and energy efficiency is better for SOEC.

Process Characteristics Compared for Green Hydrogen

	AWE	PEM	SOEC
Feedstock	Demineralized water with lye solution	Demineralized Water	Steam
Electrode Materials	Cathode: Ni, Co, or Fe, Anode: Ni	Cathode: Pt/Pd, Anode: IrO ₂ /RuO ₂	Cathode: Ni, Anode: La/Sr/MnO or La/Sr/Co/FeO
Technology Maturity	Mature	Commercial	R&D, soon commercially available
Energy Source	Electricity	Electricity	Electricity and heat from steam
Current Density*	200-500 mA/cm ²	800-2500 mA/cm ²	300-1000 mA/cm ²
Cell Voltage*	1.8-2.4 V	1.8-2.2 V	0.95-1.3 V
Gas Outlet Pressure	0-40 bar but typically 15 bar	0-40 bar but typically atmospheric	Close to atmospheric
Cell Temperature	~ 60-80°C	~ 40-60°C	~ 750-850°C
Hydrogen Purity*	99.3-99.9 vol%	99.999	85%

Recommendations

- 1 Thorough Project Basis**

Often performed in tandem with technology selection, the project basis and economics must be tested to ensure they meet project goals. The basis must consider capacity, energy cost and availability, labor, ease of sale, location, feedstock supply, and offtake agreements.
- 2 Select Technology**

Make a thoughtful technology choice that manages risk, considers variable power supply, renewable power availability and in the case of blue hydrogen, CO2 sequestration well availability.
- 3 Determine Financing**

Financing and equity need to be set up front and synced with project spend schedule. Mis-sequenced release of financing means that contractors and vendors cannot be paid when needed, will not perform work at planned times, and will create costly delays that ripple exponentially through remainder of project.
- 4 Calculate Risk Landscape**

Understand and mitigate project risks (hydrogen projects may use mature technology but are now using it in new applications and with new power).
- 5 Build Experienced Owners' Team**

An owner's operations team should be involved from the beginning of a project. Ideally project teams will have expertise in the technology subject matter, operations, and each stage of a project.
- 6 Retain an experienced primary contractor or contractors**

The ideal contractor is not necessarily the lowest cost contractor. Experienced contractors will lower the overall cost of a project, but inexperienced contractors can cause time delays and ballooning costs. Follow the gated work process and perform a pass gate review at the end of each phase to determine if the project is ready to move to the next phase, e.g. from conceptual engineering (FEL-2) to basic engineering (FEL-3). Many developers attempt to move from FEL2 straight to a FEED/EPC fixed price contract. This approach is fraught with challenges as the definitions aren't set and change is inevitable.
- 7 Calculate Regulatory Cost and Benefits**

Establish an intimate understanding of the regulatory and carbon credits landscape. This is where much of the project's revenue is derived. Assess the economic equation to determine what you're looking for – which specific agency or company is paying money for carbon credits and what are the criteria to earn those credits.

8

Establish Wrap Terms

Wrap agreements are quite challenging to obtain in today's market. Most major EPC firms have had lopsided financial results because of agreeing to Lump Sum EPC contracts with performance guarantees. There are segments of the market where these contracts have proven successful – Gas Fired Power Plants, LNG facilities, etc. In these markets the technologies are well understood, and the companies have broad experience with the construction landscape in the area they intend to work. The technologies employed for the Energy Transition aren't as broadly adopted, yet the financing structure needed to fund the project requires a complete risk backstop. There are EPC firms that have their own technology but may not possess the regional construction capability to be capable of offering a wrap. There are EPC firms that have regional construction capability but don't possess the technology and therefore are reticent to trust it's performance enough to offer a wrap. At TritenLAG we have worked to solve this equation. We have developed an approach that provides the owner an investment grade contract, while simultaneously creating a risk distribution model that allows two parties (EPC with Technology and EPC with Construction) to partner yet not share the risk for those things outside their control.

9

Contractor Selection – Labor Management and Apprenticeship Experience

Chose contractors with experience managing labor and wage standards according to IRA standards. If major contractors do not have this program in house, hire consultants that can help build a system of classification, adherence incentives, and reporting. The contractor must also have experience with apprenticeship programs or be willing to build a program that complies with state or federal systems.

10 Be willing to stop when project economics, schedule, and costs are out of line.

About TritenIAG

We know that every capital project comes with the opportunity to drive our client's business forward. We also know that circumstances shift and so can the players — but not our team. As project development and management consultants, TritenIAG is the constant in a sea of variables. TritenIAG has spent over 75 years entrenched in business-critical projects, establishing the project experience and nurturing the industry connections that we share with our clients. From project development through commissioning and startup, TritenIAG has the specialized expertise and proven methodologies to design and execute the most strategic solutions throughout a project's lifecycle. We provide the intelligent foundation on which successful projects are built.