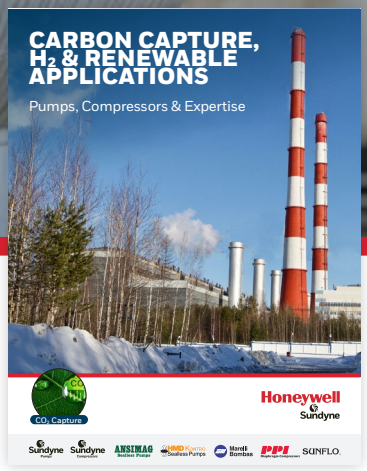
CLEAN HYDROGEN VALUE-CHAIN

Pumps, Compressors & Expertise



Honeywell
Sundyne

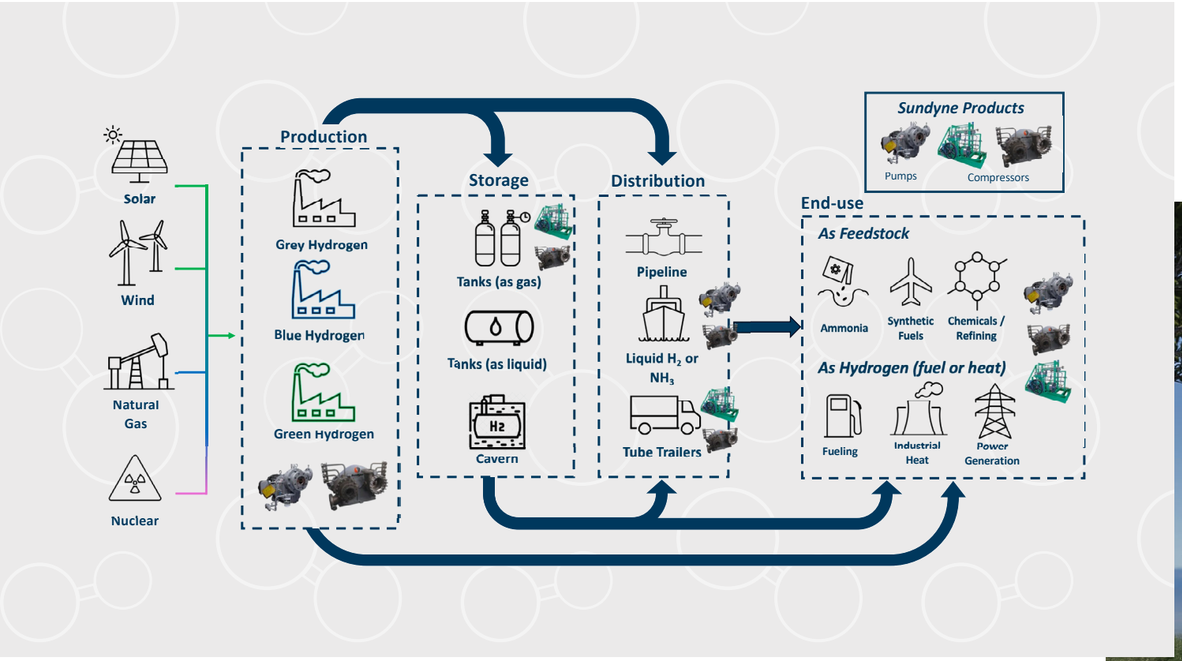
Sundyne Pumps
Sundyne Compressors
ANSIMAG Sealless Pumps
HMD KONTRO Sealless Pumps
Marelli Bombas
PPI Diaphragm Compressors
SUNFLO®

What is the Clean Hydrogen Value-Chain?

Hydrogen is a versatile energy-carrier used in a variety of applications. ***Clean hydrogen*** refers to hydrogen produced in a manner that significantly reduces or eliminates lifecycle greenhouse gas emissions.

As the push for global decarbonization continues across all sectors, there is increasing support for the production and end-use of clean hydrogen for transportation, industrial heat generation, power generation, and as a feedstock for low-carbon products.

This brochure describes the end-to-end value-chain for clean hydrogen – covering production, storage, distribution, and end-use. Sundyne's portfolio of pumps and compressors support applications in each of these elements.



Why is Clean Hydrogen Important?

According to the IEA, global hydrogen use reached 95 Mt in 2022, and has the potential to grow to 150 Mt by 2030[1]. This growth is largely driven by new applications, such as synfuels, power, and transport, which will make up 40% of hydrogen demand in 2030. Traditional uses of hydrogen will remain, and it is expected that ***clean hydrogen*** will displace ***grey hydrogen*** over-time in these markets as well. ***Clean hydrogen*** is expected to grow from 2 Mt in 2022 to 38 Mt in 2030. This represents a 44% annual growth rate and would fulfill 25% of the global hydrogen demand in 2030. Continued growth is expected beyond 2030 as net-zero goals are pursued.

There are several key advantages that clean hydrogen offers as a decarbonization solution:

1. Clean hydrogen is **versatile** – it is able to be produced via multiple pathways and utilized in several end-markets
2. Clean hydrogen is an **energy carrier** – it is able to be produced when and where it is most economical, and then can be transported where needed
3. Clean hydrogen is an **energy building block** – it is a feedstock for ammonia and low-carbon fuels

[1] I IEA (2023), Global Hydrogen Review 2023, IEA, Paris https://www.iea.org/reports/global-hydrogen-review-2023, Licence: CC BY 4.0

Production Pathways

There are several production pathways for clean hydrogen, often denoted by “color” which identify the source and production process.

Today, “green” and “blue” hydrogen are the predominant production pathways:

Green Hydrogen:

produced by electrolysis of water powered by renewable electricity

Blue Hydrogen:

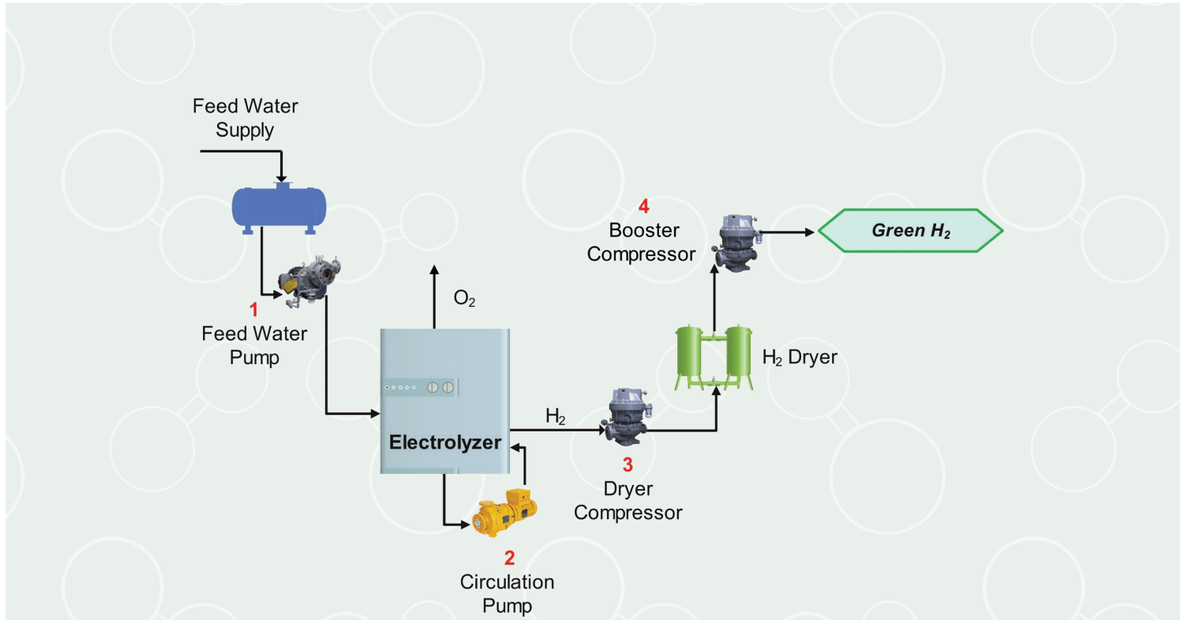
produced by reforming natural gas with carbon capture installed to capture the CO_2 emissions generated in the process

Green Hydrogen Production

Green hydrogen production offers an emissions-free pathway to produce hydrogen.

It is most-economical where low-cost renewable electricity generation is available. Today, green hydrogen production is typically more expensive than blue hydrogen on a unit-cost basis, but technology improvements in renewable electricity generation and electrolyzer technology will drive the cost down over time to be competitive with alternative production pathways.

Green hydrogen is produced by splitting water into hydrogen and oxygen via an electrolyzer.



Loc	Service	Equipment Type	Medium
1	Feedwater Supply	Sundyne LMV, Marelli OH or VS	Water
2	Circulation Pump	HMD or Ansimag	PEM: deionized water Alkaline: KOH electrolyte
3	H_2 Dryer Compressor	Sundyne LF-2000, LMC or BMC	Wet H_2
4	Booster Compressor	Sundyne LF-2000, LMC or BMC	H_2

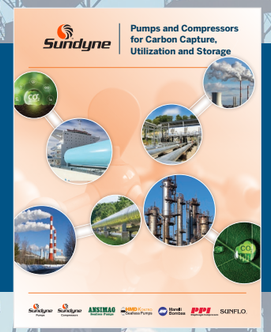
Blue Hydrogen Production

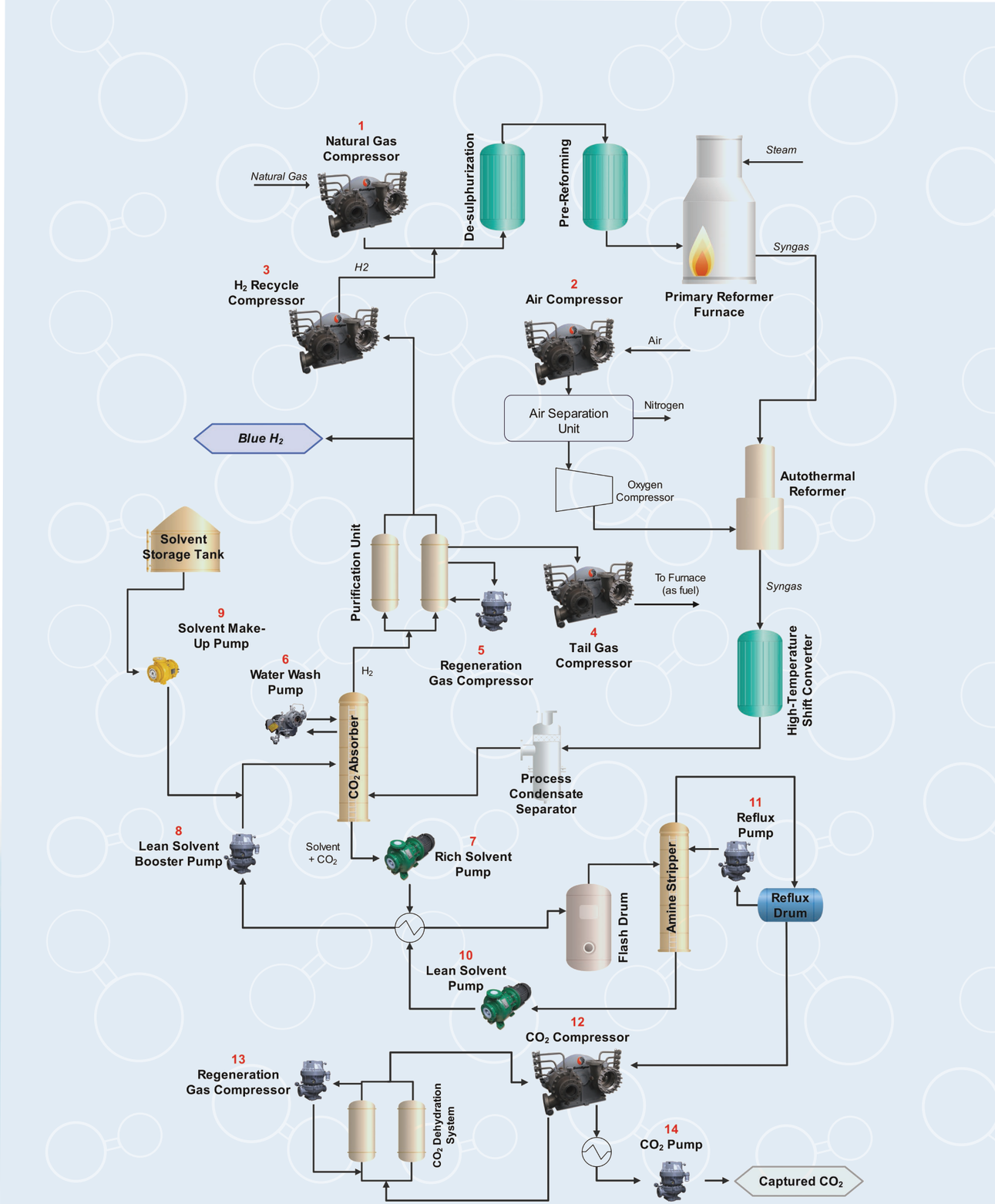
Blue hydrogen eliminates up to 98% of CO_2 emissions in the hydrogen production lifecycle through the use of carbon capture technology. It is most advantageous in regions with low-cost natural gas and available carbon storage geology and infrastructure.

The primary production processes are **steam methane reforming** and **auto-thermal reforming**, which are both mature technologies, with a carbon capture unit.

Loc	Service	Equipment Type	Medium
1	Natural Gas Feed Compressor	Sundyne LF-2000 compressor	Natural Gas
2	Air Compressor	Sundyne LF-2000, LMC or BMC compressor	Air
3	Hydrogen Recycle Compressor	Sundyne LF-2000, LMC or BMC compressor	Hydrogen
4	Tail Gas Compressor	Sundyne LF-2000, LMC or BMC compressor	Hydrocarbons N_2, CO_2, H_2
5	PSA Regeneration Compressor	Sundyne LF-2000, LMC or BMC compressor	Hydrocarbons N_2, CO_2, H_2
6	Wash Water Pump	Marelli or LMV pumps	Amine, Water
7	Rich Amine Circulation Pump	LMV, HMD, Ansimag pumps	Amine + CO_2
8	Lean Amine Booster pump	LMV, HMD pumps	Amine + CO_2
9	Solvent Make-Up Pump	LMV, HMD pumps	Amine solvent
10	Lean Amine Circulation pump	LMV, HMD, Ansimag pumps	Amine + CO_2
11	Reflux Pump	Marelli or LMV pumps	Amine + CO_2
12	CO_2 Compressor	Sundyne LF-2000, LMC or BMC compressor	Carbon dioxide
13	Molecular Sieve Regeneration Gas Compressor	Sundyne LF-2000, LMC or BMC compressor	Hydrocarbons N_2, CO_2, H_2
14	CO_2 Pump	HMP or LMV Pumps	CO_2

For more information on Carbon Capture, Utilization and Storage, please refer to Sundyne's brochure on Pumps and Compressors for CCUS.





Distribution

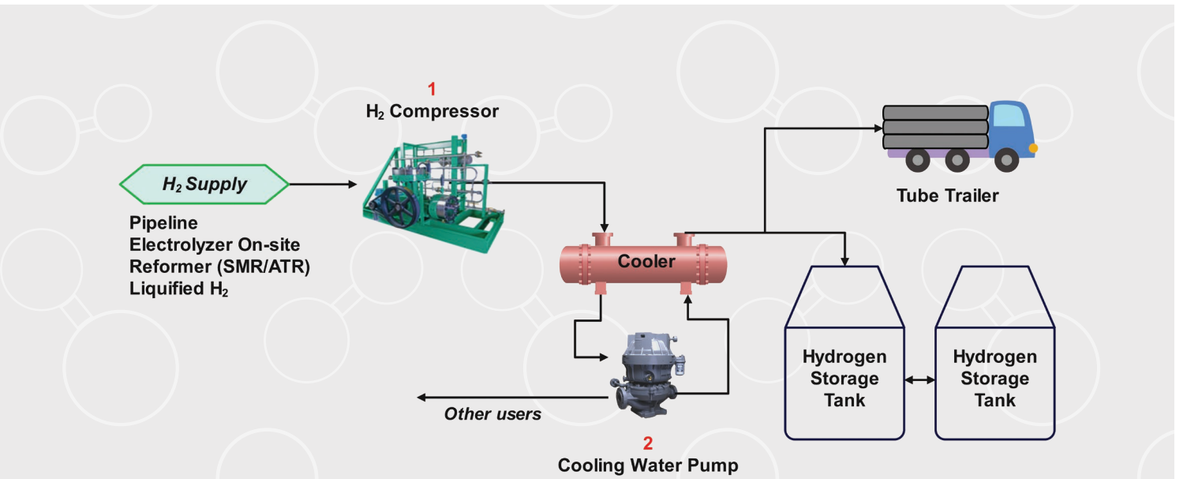
Clean hydrogen distribution can take on many forms depending on the volume, distance, and end-use application. Options include pipelines, tube trailers, liquid hydrogen trucks, and shipping as liquid or ammonia.

For long-distance shipping, hydrogen is often converted to ammonia, which has a higher volumetric energy density and is therefore a more efficient carrier. After shipping, ammonia can be "cracked" to re-claim hydrogen for end-use. In this brochure, we will be covering tube trailer filling stations and ammonia cracking applications.

Tube Trailer Filling Stations

Trucks that haul gaseous hydrogen are often called tube trailers. Gaseous hydrogen is compressed to pressures of 180 bar (~2,600 psi) or higher into long cylinders that are stacked on a trailer that the truck hauls. This gives the appearance of long tubes, hence the name *tube trailer*.

Steel tube trailers are most commonly employed and carry approximately 380 kg onboard at 250 bar. Recently, composite storage vessels have been developed that have capacities of 560–900 kg of hydrogen per trailer at up to 500 bar.



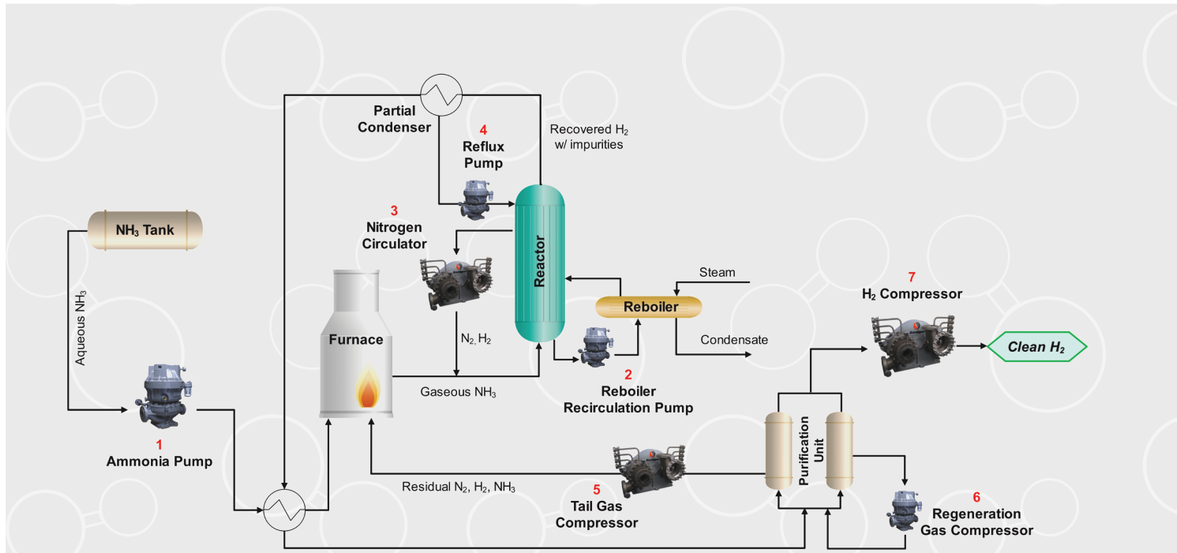
Loc	Service	Equipment Type	Medium
1	Hydrogen Compression	PPI Diaphragm Compressor	H_2
2	Cooling Water Pump	Sundyne LMV, Marelli, Sunflo	Water

Ammonia Cracking

Ammonia cracking, or ammonia dissociation, is the chemical process of breaking down ammonia into hydrogen and nitrogen by heating ammonia in the presence of a catalyst:

$$2NH_3 \rightarrow 3H_2 + N_2$$

The process involves pumping liquid ammonia to a furnace, where it is vaporized into a gaseous state. From there, the gaseous ammonia is heated further in an ammonia cracking reactor, generally between 700°C to 1000°C to promote decomposition. The ammonia is decomposed to hydrogen and nitrogen in the presence of a catalyst. A compressor can be used to recirculate un-reacted components and the recovered hydrogen is then purified in a pressure swing adsorption (PSA) or membrane separation purification unit. From there, the recovered clean hydrogen can be compressed and sent to storage, pipeline, or directly used.



#	Service	Equipment Type	Medium
1	Ammonia Pump	LMV pump	Liquid ammonia
2	Reboiler Recirc Pump	LMV pump	Water (0.1% mol NH_3)
3	Nitrogen Circulator	Sundyne LF-2000, LMC or BMC	N_2, H_2
4	Reflux Pump	Marelli or LMV pumps	NH_3 + CO2
5	Tail Gas Compressor	Sundyne LF-2000, LMC or BMC	N_2, H_2, NH_3
6	Regen Gas Compressor	Sundyne LF-2000, LMC or BMC	N_2, H_2
7	H_2 Compressor	Sundyne LF-2000, LMC or BMC	Clean H_2 (with N_2 for start-up circulation)

End-Use Applications

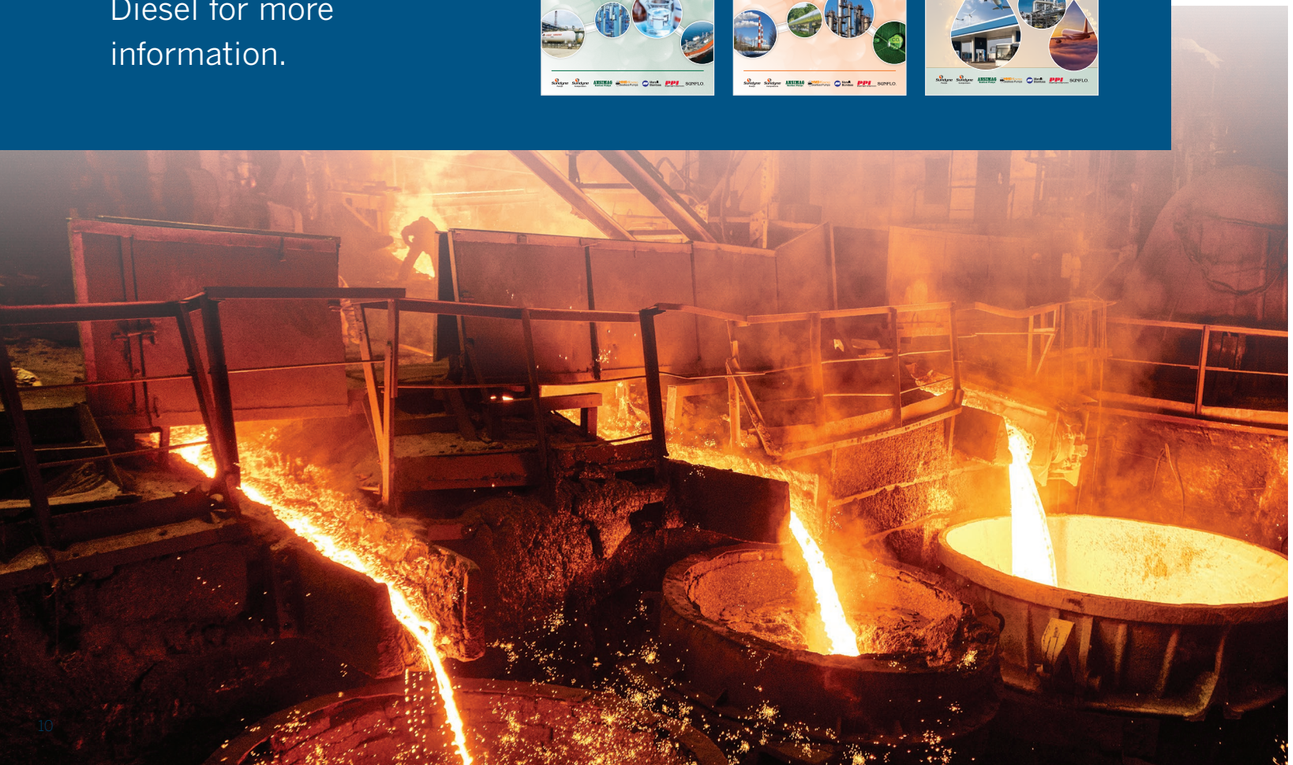
Clean hydrogen can broadly be used in two application spaces:

1. **Energy applications:** combusting hydrogen for heat or power applications, or generating electricity through fuel cells via chemical reaction (e.g. fuel cell vehicles, hydrogen blending for power generation, hydrogen blending for a furnace or boiler)

2. **Low-carbon feedstock:** incorporated as an input to create a low-carbon product (e.g. ammonia, refining, DRI steel, e-methanol, or e-SAF)

In this playbook, we'll describe two applications unique to clean hydrogen: DRI green steel production and clean hydrogen for power generation.

Sundyne's Clean Energy Markets brochures have covered several of these processes and our product fit. Refer to our brochures for Ammonia Synthesis, Carbon Capture, Utilization & Storage (incl. e-methanol production), and Sustainable Aviation Fuel (SAF) and Renewable Diesel for more information.

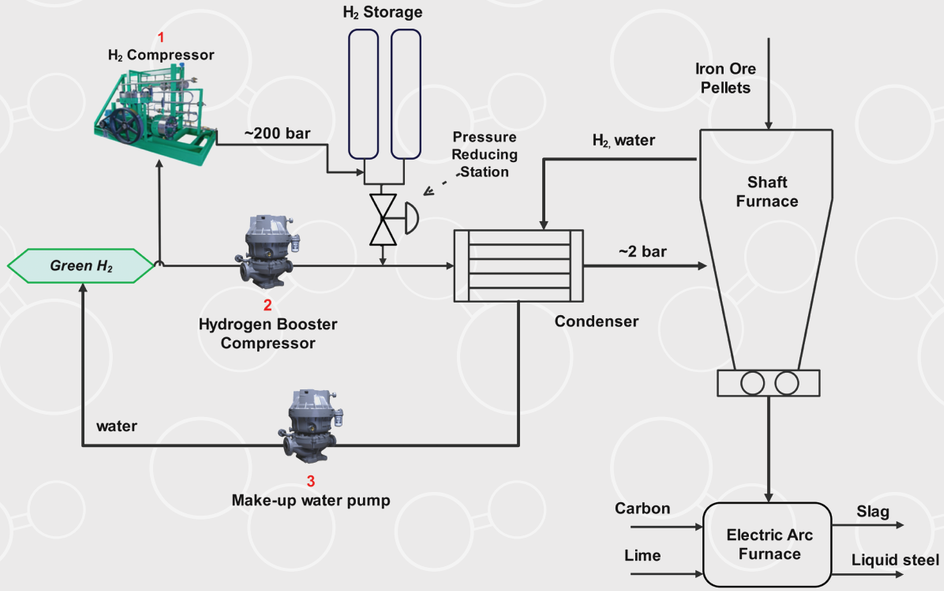


Green Steel Production

The production of steel accounts for approximately 7% of global CO_2 emissions. Steel can be produced via blast furnace or by direct reduced iron (DRI). The DRI process uses hydrogen gas as a reducing agent (instead of natural gas or coal). The hydrogen reacts with oxygen in the iron ore, reducing it to iron and only creating water vapor as a byproduct.

$$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$$

The resulting product is called sponge iron, which is melted in an electric arc furnace (EAF) to produce steel. If clean hydrogen is used instead of natural gas, coal, or grey hydrogen, the DRI-EAF process can reduce CO_2 emissions by up to 97% in the steel making process.



Loc	Service	Equipment Type	Medium
1	H_2 Compressor	PPI Diaphragm Compressor	H_2
2	Booster Compressor	Sundyne LF-2000, LMC or BMC	H_2
3	Make-up Water	Sunflo	Water

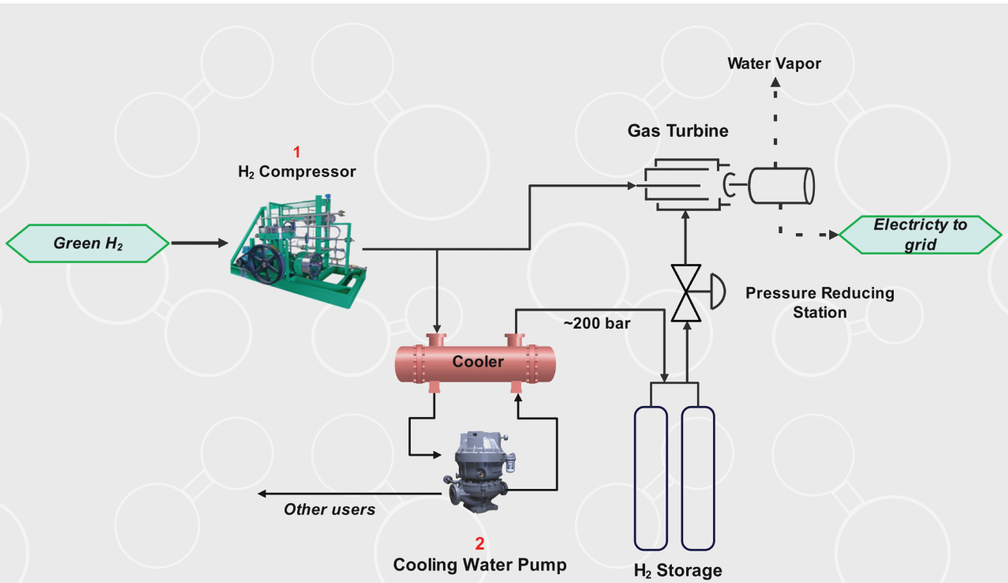
Clean Hydrogen in Power Generation (Hydrogen Blending)

Hydrogen blending is a process that involves injecting hydrogen into natural gas systems to create cleaner energy for power plants and other end users. This process can help the power industry to reduce its carbon emissions and meet sustainability goals, while meeting the increasing global electricity demand.

Hydrogen produces no carbon emissions when combusted, so blending it with natural gas can help reduce emissions. For example, a 20% hydrogen blend could reduce emissions by 7% due to the lower energy density of hydrogen compared to 100% natural gas. For this reason, a higher volume of hydrogen-blended natural gas is required to deliver the same amount of energy to a power plant or heater.

End-use applications, such as existing gas-fired power plants or industrial processes, may not be designed to handle hydrogen blending beyond a given limit. New turbine and burner designs are under development to accommodate 100% hydrogen fuel.

The required gas pressure for conventional gas turbines is around 250 to 300 psig, or 17.5 to 21 barG on average. However, the latest generation of industrial gas turbine requires higher-pressure gas at 500 to 600 psig (35 to 42 barG). Aeroderivative gas turbines can require inlet gas pressures that exceed 900 psig (~60 barg) to operate efficiently. Sundyne's compressors can be used to boost the hydrogen pressure from a supply stream into a turbine.



Loc	Service	Equipment Type	Medium
1	H_2 Compressor	PPI Diaphragm Compressor	H_2
2	Cooling Water Pump	Sundyne LMV, Marelli, Sunflo	Water

Other Services

In addition to the hydrogen and CO_2 streams, Sundyne equipment supports utilities and balance-of-plant services.

Here are some common services that Sundyne equipment can provide:

Service	Equipment Type	Medium
Boiler Feed Water Circulation Pumps	Marelli, LMV, Sunflo	Water
Boiler Feed Water Feed Pumps	Marelli, LMV, Sunflo	Water
Condensate Pump	Marelli, LMV, Sunflo	Water
Sea Water Pump	Marelli	Water
Closed Cooling Water Pumps	Marelli	Water
Corrosion Inhibitor Pumps	HMD or Ansimag	Alkaline compounds Amine Hydrazine
Demi Water Feed Pumps	Marelli, LMV, Sunflo	Water
Demi Water Circulation Pumps	Marelli, LMV, Sunflo	Water
Refrigerant Gas Compressors	Sundyne LF-2000, LMC or BMC	HCFC or CFC Hydrocarbons CO_2 Ammonia
Flare KO Drum Pumps	LMV or HMD	Hydrocarbons, Water, various
Fuel Gas Compressors	Sundyne LF-2000	Natural Gas
Quench / Condenser Pump	Ansimag or HMD	Process Water
Gas Treatment Compressor	Sundyne LF-2000, LMC or BMC compressor	Hydrocarbons N_2, CO_2, H_2
Flare Gas Recovery	Sundyne LF-2000, LMC or BMC	Mixture Corrosive gases
Residual Gas Compressor	Sundyne LF-2000, LMC or BMC	Mixture Corrosive gases

Pumps and Compressors for the Clean Hydrogen Value-Chain

Sundyne's Value Proposition for Clean Hydrogen

Sundyne's unique combination of technology, expertise and support provides a 360-degree, full lifecycle service that spans everything from project pre-FEED to comprehensive 24x7 support, utilizing a global network of Authorized Service Centers and aftermarket specialists.

Sundyne LMC/ BMC/LF-2000 Compressors

Sundyne compressors leverage more than 60 years of experience and innovation from thousands of deployments in some of the world's most demanding environments. Sundyne compressors feature single- and multi-stage integrally-geared centrifugal designs (IGC) that are custom built to provide pulsation- and vibration-free operation, and to deliver oil-free process gas with zero emissions.

Sundyne IGC compressors offer a unique combination of high-performance impeller materials and advanced geometry, optimized for high-speed operation, delivering exceptional compression ratios for hydrogen applications. With hundreds of compressors already in use for H_2 purification and boosting processes, our technology is proven and reliable.

Additionally, Sundyne compressors, utilized as fuel gas boosters for turbines generating electricity, are fully capable of handling hydrogen-natural gas blends. Existing installations can be easily retrofitted to meet new performance requirements, supporting CO_2 reduction initiatives.

Sundyne LMV Pumps

Sundyne integrally geared centrifugal pumps are optimized for low flow-high head applications. They offer the highest efficiency in the low flow range with a proven track record of high reliability. A single impeller in a Sundyne LMV pump spins at high speed to produce the same head as a multistage pump running at synchronous speed. Sundyne LMV pumps are ideally suited for services such as boiler feed water pumps, condensate transfer pumps, solvent circulation pumps and reflux pumps. To achieve higher heads yet, two or more integrally geared stages run in series in a Sundyne HMP pump. The compact design reduces installation cost, and the simplicity limits the number of spare parts while making maintenance easier.

Sealless Magnetic Drive Pumps – HMD and ANSIMAG

Sundyne sealless pumps provide optimum safety and environmental protection for a wide range of applications found within Hydrogen Electrolysis, Ammonia Synthesis and E-methanol production. These magnetic driven pumps are designed for harsh and hazardous liquids, and applications that are difficult to seal. HMD Kontro metallic and Ansimag ETFE-lined sealless pumps ensure total product containment, increased reliability and uptime and simplified maintenance with no seals or seal support systems, whilst meeting industry standards such as ASME, ISO and API.

Sundyne sealless pumps are particularly well suited to alkaline and PEM circulation applications in H_2 electrolysis due to their compact footprint and simple, easy-to-maintain design, and the seal-free design eliminates the risk of emissions of harmful product such as KOH or contamination of the pumped medium which is critical for high purity applications found in PEM Electrolyzers. The HMD ZeroLoss shell provides a high energy efficiency solution for a wide range of services including Methanol, Ammonia and Solvents, and options for Secondary Control and Containment are available to provide additional protection for more hazardous pumping applications.

Marelli Pumps

Marelli pumps leverage a track record of more than 60 years in centrifugal pump design, development, manufacturing and service. Marelli caters to global markets from conventional oil & gas and petrochemicals to fast evolving Clean Energy segments, including green/blue hydrogen, ammonia, carbon capture, and renewable fuels processing. Marelli covers wide range of API610 in OH, BB and VS types and meets customer's stringent specifications.

Sunflo Pumps

Industrial grade Sunflo pumps are specifically designed for low flow-high head applications such as boiler feed water, condensate, demineralized water circulation. Sunflo pumps leverage the engineering knowledge and legacy of the Sundyne heavy duty API integrally geared pumps. A single impeller runs at high speed to produce high heads in a very compact and reliable design. The close coupled configuration eliminates alignment, simplifies installation while further reducing footprint. The Sunflo cartridge shaft assembly comes complete with all the rotating parts and enables quick and easy servicing of the pump in-place.

PPI Compressors

Sundyne enables organizations to deliver Net-Zero through sustainable, safe and environmentally conscious compression solutions with the broad portfolio of advanced Hydrogen compressors and packages renowned for highly reliable, leak-free performance that deliver the critical non-contaminating compression of Hydrogen. This makes PPI the ideal compressor for Hydrogen production, storage and distribution. Aftermarket support for PPI Diaphragm compressors is provided via Sundyne's global network of channel partners.

When it comes to Clean Hydrogen Value-Chain applications, Sundyne is the **Safer**, **Better**, **Best** choice.

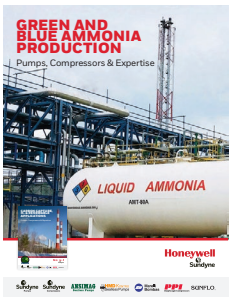
Safer for Operations

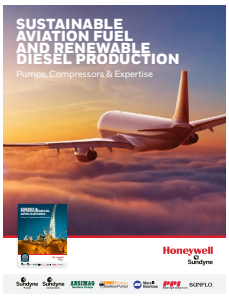
Better for the Environment

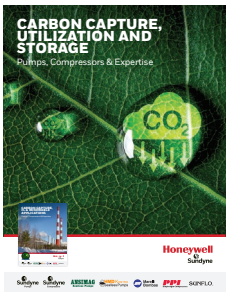
Best Total Lifecycle Value

For more information on Sundyne's product fit in Clean Energy Markets, refer to our other clean energy brochures:

- Green and Blue Ammonia Production
- Sustainable Aviation Fuel and Renewable Diesel
- Carbon Capture Utilization and Storage







For more information please visit www.sundyne.com and fill out the Contact Me form. A Sundyne representative will contact you.

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