

Series: Green Solutions for Building a Hydrogen and Ammonia Supply Chain (1)

Centrifugal Compressors Contributing to Carbon Neutrality

#Carbon Neutral #Sustainability #Industrial Equipment

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Highlight

Hydrogen and ammonia have received increasing attention in recent years as effective energy sources for combating global warming due to their ability to efficiently produce energy without emitting CO₂. As a result, there is a growing demand to establish a scheme to reduce CO₂ emissions throughout the supply chain, from the production to the use of hydrogen and ammonia.

This series focuses on Hitachi's green solutions aimed at constructing a hydrogen and ammonia supply chain, and introduces its efforts and future directions for preserving the global environment. This article, the first in the series, provides an overview of the centrifugal compressors that are used in various stages of the energy supply chain.

1. Introduction

Amid calls for CO₂ emissions reduction and greater use of renewable energy, international initiatives toward realizing a carbon neutral society are progressing, with new energy supply chains being established to achieve this. These new supply chains include equipment for use with applications such as green hydrogen, green ammonia, carbon capture and storage (CCS), and sustainable aviation fuel (SAF).

Hitachi Industrial Products, Ltd., as a manufacturer of centrifugal compressors, has been supplying highly efficient and reliable centrifugal compressors for various plants, such as oil refineries, petrochemical, and fertilizer plants. Hitachi Industrial Products is also focusing on supplying centrifugal compressors for emerging carbon neutrality applications.

2. Energy Supply Chains for Making Societies Carbon Neutral

2.1 Recent Developments

In pursuit of the goal of making societies carbon neutral, the Paris Agreement was adopted as the successor to the Kyoto Protocol at the 2015 Conference of the Parties 21 (COP 21) of the United Nations Framework Convention on Climate Change. Subsequently, a global stocktake was conducted at COP 28, which was held in November and December 2023, to assess the extent to which the Paris Agreement targets were being fulfilled. This highlighted the need to triple renewable energy capacity, double energy efficiency, and accelerate the phase-out of fossil fuels by 2030(1).

COP 28 was also the venue for the announcement of ISO/TS 19870:2023, a technical standard for assessing greenhouse gas emissions in hydrogen supply chains(2).

In Japan, a range of research and development was undertaken from 2014 to 2019 under the auspices of “Energy Carriers”, a Cross-ministerial Strategic Innovation Promotion Program (SIP) (3). The “Green Growth Strategy Through Achieving Carbon Neutrality in 2050” was formulated in 2020 to make progress on the adoption of renewable energy and improvements in energy efficiency(4).

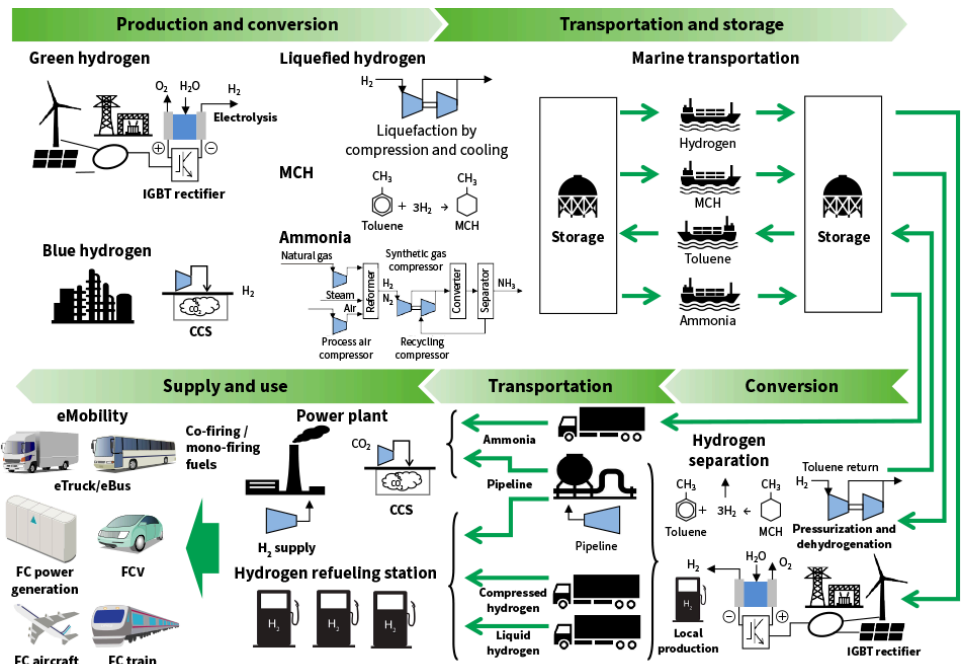
Elsewhere, progress has also been made in strengthening regulations under the European Green Deal of the European Union (EU) and in policy and law making in the USA, including work toward a carbon-free electricity industry(5).

2.2 Energy Supply Chains

To achieve carbon neutrality, new energy supply chains utilizing hydrogen or ammonia produced from renewable energy, as well as biomass, have been proposed as alternatives to conventional energy supply chains centered around fossil fuels such as oil, coal, and natural gas. Efforts are underway to facilitate their commercialization and widespread adoption.

For the widespread adoption of hydrogen and ammonia as energy sources, it is crucial that they can be transported safely and efficiently by sea. While the transportation of ammonia in its liquefied form is already established, hydrogen in its gaseous state has a large volume and is not suitable for maritime transport. For this reason, the use of liquefied hydrogen, organic hydrides, ammonia, and other hydrogen carriers is being considered to reduce the volume of hydrogen gas and transport it safely and in large quantities by sea (6) (see Figure 1).

Figure 1—Schematic Diagram of Hydrogen and Ammonia Supply Chain



IGBT: insulated-gate bipolar transistor, MCH: methylcyclohexane, CCS: carbon capture and storage, FC: fuel cell, FCV: fuel cell vehicle

Liquefied hydrogen, MCH, and ammonia have been suggested as hydrogen carriers to enable transportation by sea.

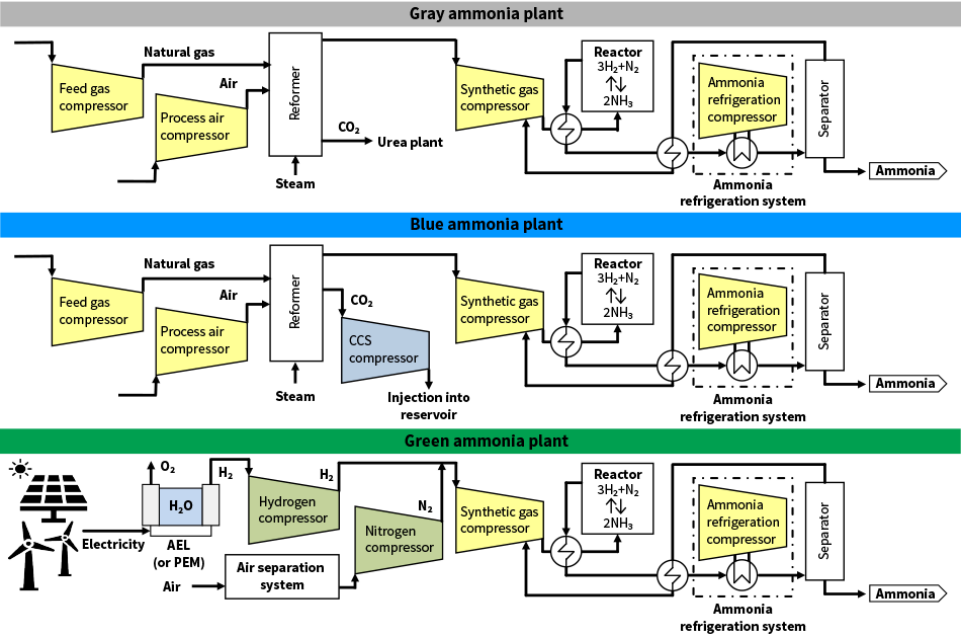
Ammonia can also be used as a fuel in its own right. Centrifugal compressors are used at every step along the associated supply chains.

2.3 Production of Hydrogen and Ammonia

Conventionally, hydrogen has been produced by the steam reforming of fossil fuels such as natural gas and naphtha, and ammonia has been produced using the Haber-Bosch process from a mixed gas of hydrogen and nitrogen. However, this steam reforming process emits carbon dioxide (CO₂). Hydrogen and ammonia made CO₂-free by CCS, where the emitted CO₂ is captured, and stored and isolated underground, are called blue hydrogen and blue ammonia, respectively.

On the other hand, CO₂-free hydrogen can be produced by electrolyzing water using electricity derived from renewable energy sources. This CO₂-free hydrogen is called green hydrogen, and ammonia synthesized from green hydrogen is called green ammonia (see Figure 2).

Figure 2—Block Diagram of Ammonia Plant and Uses of Centrifugal Compressors



AEL: alkaline electrolysis, PEM: proton exchange membrane

Grey ammonia is ammonia made from fossil fuels (without CCS). Blue ammonia is CO₂-free ammonia made from fossil fuels (with the addition of CCS to eliminate the CO₂). Green ammonia is CO₂-free ammonia made from water and the atmospheric Air utilizing renewable energy.

3. Role of Centrifugal Compressors in Energy Supply Chains

Centrifugal compressors are large rotating machines that are used throughout energy supply chains. They serve as vital equipment in various plants that use fossil fuels as raw materials or energy sources, such as oil refineries, petrochemical plants, and fertilizer plants (see Figure 3).

The importance of centrifugal compressors remains unchanged in the new energy supply chains aimed at achieving a carbon neutral society, as reliable and energy efficient operation of centrifugal compressors is always crucial. The following sections describe the specifications and features of the centrifugal compressors used in carbon neutrality applications and how they differ from centrifugal compressors for conventional processes.

Figure 3—CO₂ Compressor



This CO₂ compressor is used in a urea plant. The compressor train consists of the low-pressure compressor in the foreground and the speed-increasing gear and high-pressure compressor farther back on a common base plate. While compressors used for CCS have a similar configuration, an additional compressor stage is added downstream of the high-pressure compressor when a higher injection pressure is required.

3.1 CCS

At the upstream end of the energy supply chain, CCS involves separating and capturing the CO₂ emitted during the production of hydrogen and ammonia, and then injecting and storing it in underground aquifers or oil reservoirs, thereby achieving CO₂-free energy distribution. Downstream, CCS also helps reduce CO₂ emissions from industrial activities by capturing the CO₂ from production facilities in various industries including power plants, and storing it underground.

Centrifugal compressors are used in CCS facilities to increase the pressure of the CO₂ gas to the level required for injection, and the required pressure depends on the depth of the injection well. Hitachi Industrial Products has experience in manufacturing CO₂ compressors for CCS with a discharge pressure of approximately 23 MPaG.

Conventionally, CO₂ compressors have been widely used in urea plants. CCS applications, on the other hand, require some different measures than those for CO₂ compressors used in urea plants because they handle exhaust gases from various plants that may contain flammable or corrosive gas components. However, these can be dealt with by drawing on the proven technologies used in various compressors in the oil and gas industry.

3.2 Production of Green Hydrogen and Green Ammonia

The Haber-Bosch process is used for ammonia synthesis in green ammonia plants using essentially the same process as in conventional ammonia plants. However, the electric power supply provided by natural energy sources such as the wind or sun is not constant and depends on weather conditions and the time of day. As this in turn influences the amount of hydrogen feedstock produced and the electricity supply for driving compressors, this fluctuation needs to be absorbed by the use of hydrogen holders and batteries. In addition, to maintain the temperature of the synthesis plant equipment, the synthesis plant is operated in turn-down mode where the plant load is reduced to approximately 10% at night or when the power generation decreases due to unfavorable weather conditions.

The following sections describe the features of the different types of compressors used in green ammonia plants.

(1) Hydrogen compressor

There are several different methods of electrolysis to produce hydrogen, including alkaline electrolysis (AEL) and proton exchange membranes (PEM), and the hydrogen pressure generated by the commonly used AEL is almost atmospheric. Although reciprocating compressors are generally suitable for boosting the pressure of hydrogen, which has a small molecular weight, up to the suction pressure of the downstream synthesis gas compressor (typically 2 to 3 MPaG), when considering support for larger capacity and ease of maintenance, it is preferable to be able to boost the pressure using a centrifugal compressor.

For centrifugal compressors, achieving a high head requires increasing impeller peripheral speeds and using multiple impeller stages, requiring advanced technologies in areas such as thermodynamic performance, mechanical design, and rotor dynamics.

(2) Nitrogen compressor

In conventional ammonia plants, the synthesis gas (hydrogen and nitrogen) used for ammonia synthesis is obtained using a process air compressor to pressurize atmospheric air and feed it to a steam reformer. In green ammonia plants, however, nitrogen is obtained from atmospheric air using an air separation unit, and then the nitrogen is pressurized by a nitrogen compressor to the suction pressure level of the synthesis gas compressor.

(3) Synthesis gas compressor

The synthesis gas compressor consists of a make-up compressor that pressurizes a three-to-one mixture of hydrogen and nitrogen and feeds it to the ammonia synthesis loop, which includes a reactor and a recycle gas compressor that recirculates the gas in the ammonia synthesis loop.

The ammonia synthesis pressure is generally high, at 150 barA or more, and the make-up compressor has a high pressure ratio. The recycle gas

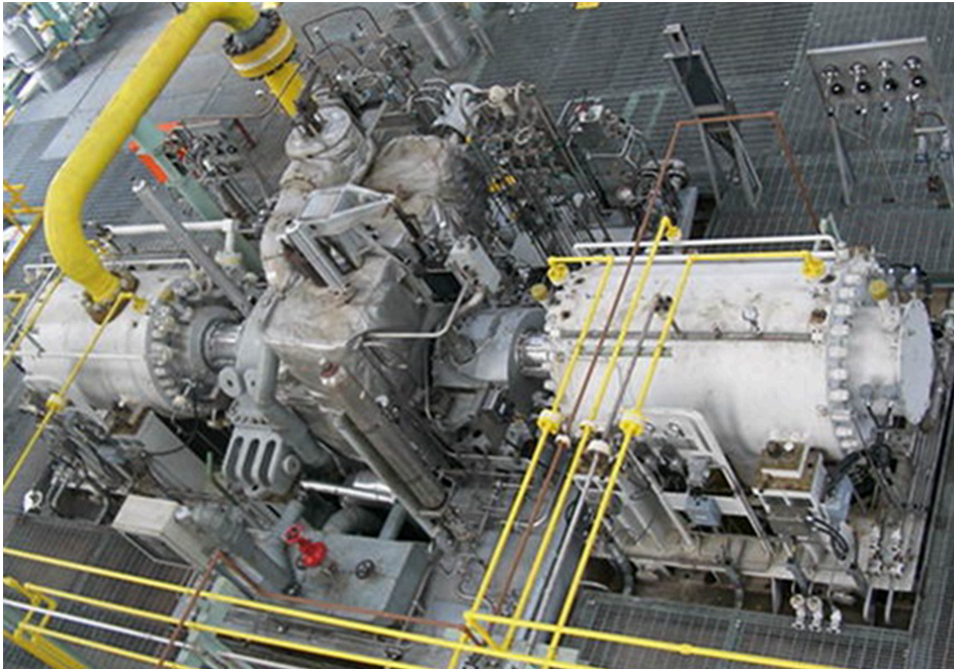
compressor, on the other hand, only needs to increase gas pressure to compensate for the pressure losses in the synthesis loop. Although the pressure ratio of the recycle gas compressor is low, its flow rate is four to five times larger than that of the make-up compressor.

The synthesis gas compressor is vital equipment in a conventional ammonia plant, and its design requires high technical capabilities and know-how. In green ammonia plants, however, there are also new requirements to be met, such as low power consumption during night-time turndown operation (see Figure 4).

(4) Ammonia refrigeration compressor

The gaseous nitrogen, hydrogen, and ammonia present in the ammonia synthesis loop in an equilibrium state are cooled to extract the ammonia component by liquefaction. A refrigeration cycle using ammonia as the refrigerant is used for this purpose, with the ammonia refrigeration compressor being used to pressurize and circulate the refrigerant.

Figure 4—Ammonia Synthesis Gas Compressor



The compressor shown here is used to pressurize the synthesis gas (a mixture of hydrogen and nitrogen) produced by steam reforming. The low-pressure (front) and high-pressure (rear) compressors are driven by a steam turbine (center). (In a green ammonia plant, electric motor drive would be applied instead.) The high-pressure compressor includes the recycling compressor as well as the make-up compressor.

3.3 SAF

SAF is the general term for aviation fuel made by mixing conventional aviation fuel (CAF) with neat SAF produced from 100% synthetic fuel. The American Society for Testing and Materials (ASTM) standard ASTM D7566 currently certifies eight different processes for producing SAF⁽⁷⁾, ⁽⁸⁾ (see Table 1).

As the centrifugal compressors in the SAF production process are used for purposes such as pressurizing a gaseous mixture of high-temperature steam and alcohol that do not feature in conventional oil refineries and petrochemical plants, compressor manufacturers need to adapt their products to suit the specific gas mixtures and operating conditions that apply in SAF processes.

Table 1—Neat SAF Synthesis Process Certified Under ASTM D7566 Standard

Annex	Conversion process	Abbreviation	Possible feedstocks	Maximum blend ratio
Annex 1	Fischer-Tropsch hydroprocessed synthesized paraffinic kerosene	FT	Biomass, etc.	50%
Annex 2	Synthesized paraffinic kerosene from hydroprocessed esters and fatty acids	HEFA	Vegetable oils, animal fats, used cooking oils	50%
Annex 3	Synthesized iso-paraffins from hydroprocessed fermented sugars	SIP	Biomass used for sugar production	10%
Annex 4	Synthesized kerosene with aromatics derived by alkylation of light aromatics from non-petroleum sources	FT-SKA	Biomass, etc.	50%
Annex 5	Alcohol to jet synthetic paraffinic kerosene	ATJ-SPK	Ethanol, isobutanol and isobutene from biomass	50%
Annex 6	Catalytic hydrothermolysis jet fuel	CHJ	Vegetable oils, animal fats, used cooking oils	50%
Annex 7	Synthetic paraffinic kerosene produced from hydrocarbon-hydroprocessed esters and fatty acids	HC-HEFA-SPK	Algae	10%
Annex 8	Synthetic paraffinic kerosene with aromatics	ATJ-SKA	C2-C5 alcohol from biomass	50%

FT: Fischer-Tropsch, HEFA: hydroprocessed esters and fatty acids, SIP: synthesized iso-paraffins, FT-SKA: FT-synthesized kerosene with aromatics, ATJ: alcohol to jet, ATJ-SPK: ATJ- synthetic paraffinic kerosene, CHJ: catalytic hydrothermolysis jet, HC-HEFA-SPK: SPK from hydroprocessed hydrocarbons, esters and fatty acids

As of July 2024, methods for producing neat SAF are stipulated in Annex 1 to 8 of the ASTM D7566 standard. Neat SAF must be blended with CAF up to the limit specified in the above table to produce semi-synthetic jet fuel. Neat SAF is also called synthesis blending component (SBC) or un-blended SAF.

3.4 Use of Ammonia and MCH as Hydrogen Carriers

The benefits of ammonia as a hydrogen carrier are that it has a high hydrogen density and that its handling practices are already established. Comparisons by the International Energy Agency (IEA) show that it has the best economics for maritime transportation(9). Methylcyclohexane (MCH), an organic hydride, on the other hand, has the advantages of being chemically stable and liquid at room temperature and pressure(10).

MCH is formed by reacting hydrogen with toluene at the hydrogen production site. The hydrogen is then extracted at the point of use and the toluene recovered. It is anticipated that centrifugal compressors will be used for high-volume hydrogen gas pressurization in applications such as the supply of fuel to gas-fired power plants. However, the large size of the equipment involved means that there will be demand for increasing centrifugal compressor speeds and reducing their size.

4. Conclusions

Based on the Paris Agreement, countries and regions around the world have set specific medium- and long-term targets for reducing greenhouse gas emissions. Efforts to transform energy supply chains are already underway in the form of technology development and demonstration projects. While widespread commercialization has yet to begin, it is anticipated that the future will bring genuine progress in the shift to new energy supply chains.

This article has presented an overview of how energy supply chains are being transformed toward a carbon neutral society and the role of centrifugal compressors in this process. As renewable energy usage increases in the future, it is anticipated that CO2-free energy supply chains centered on hydrogen and ammonia and CO2-free industrial activities through CCS will rapidly spread as social infrastructure. By supplying highly reliable centrifugal compressors, Hitachi Industrial Products will contribute to making societies carbon neutral through the reduction of greenhouse gas emissions.

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