

New Compressor Solutions for Emerging Hydrogen Applications: The Case for Hybrid Designs

By Michael Schulz and AbulAla Siddiqui, Siemens Energy

Compressors represent an essential part of the emerging hydrogen value chain and are needed to efficiently transport and store hydrogen from the production source to its point of end-use. Siemens Energy is a leading supplier of hydrogen compressors and maintains a large installed base of both reciprocating and turbo-compressors, with 2,500+ units in H2 operation today (more than 2.5 million of installed horsepower).

Historically, reciprocating compressors have been the primary technology for compressing hydrogen in traditional applications, such as refineries. However, as the market for hydrogen grows to support various decarbonization use cases, there is an increasing demand for compression of high volumes of H2, which lends more toward turbo-compressors.

To meet the evolving needs of the market, Siemens Energy developed the Advanced Hydrogen Compressor, the latest evolution based on the STC-SVm Single-Shaft Centrifugal Compressor (Figure 1).

The STC-SVm combines best-in-class features from legacy products like the DATUM and STC lines, and it is applicable to all major industrial markets, including those with case ratings up to 350bar(g) and temperature levels down to -50°C. Beyond typical Oil & Gas applications it features innovative technology to support the decarbonization of industry, for example, Hydrogen Compression.

The Advanced Hydrogen Compressor is designed for pure hydrogen, hydrogen-rich, and other low weight applications. It is ideally suited for applications with high hydrogen flows where the installation of several reciprocating compressor packages is uneconomical or impractical due to footprint constraints. For electrolyzer plants, it can also be combined with reciprocating units in hybrid and/or combination compression packages to improve operating flexibility and reduce total cost of ownership (TCO).

Comparing Different Technologies for Hydrogen Compression

Reciprocating compressors demonstrate high efficiency at part-load operation and exhibit turndown capabilities up to 85% (i.e., difference between minimum flow and design flow). As a result, they are the primary choice in low- to medium-flow hydrogen applications where

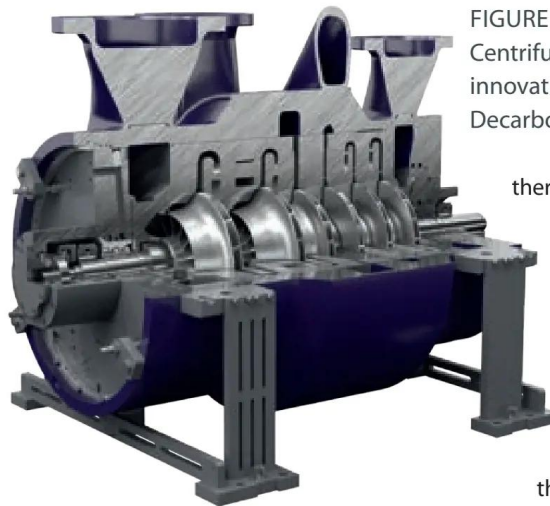


FIGURE 1. STC-SVm Single-Shaft Centrifugal Compressor featuring innovative technology to support the Decarbonization of Industry.

there is significant process variability or if high compression ratios are required.

For medium- and high-flow hydrogen applications, turbo-compressors typically represent a more economical solution and can achieve similar performance to several reciprocating compressors in a smaller footprint. However,

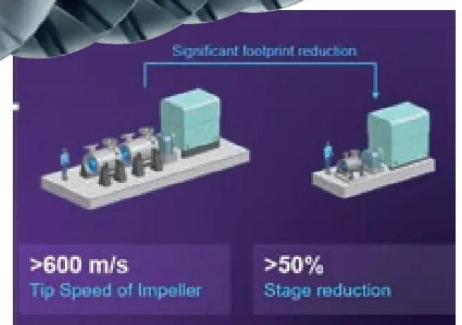
the physical properties of hydrogen, particularly its low molecular weight (2 g/mol vs. about 16 g/mol for natural gas), means that a high amount of specific work is required to achieve meaningful pressure ratios, as there is a comparatively lower pressure rise per stage relative to heavier gases.



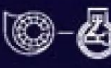

To overcome inherent limitations and achieve high discharge pressures in a reasonable footprint, the Advanced Hydrogen Compressor, and its evolutionary rotor technology for hydrogen duties (Figure 2) facilitates circumferential speed at the impeller discharge up to 600m/s, without compromising

FIGURE 2. The advanced hydrogen rotor facilitates high tip speeds, up to 600m/s.



FIGURE 3. The turbo-compressor footprint can be reduced by up to 50% compared to a conventional solution.



Optimized solutions typically fall into one of the following categories:	Additional Information	Actual Inlet Flow	Pressure Ratio	Flow Capacity Control Flexibility	Example Application
Full Reciprocating Compressor solution 	<ul style="list-style-type: none"> Achievable flow limited by cylinder bore size and compression ratio -15 – 100% capacity control available 	Low – Med	High	High	Pressurized Electrolyzer, Low flow pipeline, Low flow storage
Full Turbo Compressor solution 	<ul style="list-style-type: none"> High flow capabilities Several impellers required to create compression ratio -70 – 100% capacity control available 	Med – High	Low – Med	Low – Med	Pipeline, Syngas
Hybrid solution: Turbo Compressor feeding into a Recip. compressor 	<ul style="list-style-type: none"> Turbo compresses large flow of first stages to minimize Recip cylinder quantity Recip creates remaining large Compression Ratio whilst also minimizing flow recycling 	High	High	Med	Low pressure Electrolyzer
Combined solution: Turbo Compressor for baseload supported by Recip. Compressor for low loads 	<ul style="list-style-type: none"> Both Recip and Turbo independently achieve full compression ratio Both technologies used individually or in combination to achieve flow range flexibility 	High to Low	Med	High	Large Electrolyzer with fluctuating renewable power input or phased development

Above solution comparison considers single 100% flow units. Greater capacity control can be achieved if application flow requires multiple units

FIGURE 4. Potential reciprocating and turbo-compressor combinations for green hydrogen plants

material limits specified in API 617. This enables compressor stage count and footprint to be reduced by up to 50% compared to a conventional turbo-compressor solution (Figure 3).

The Advantage of Hybrid Compression Packages

Reciprocating and turbo-compressor technology cover the complete map of low-mole weight applications. For electrolyzer plants, selecting the type of machine for hydrogen compression has traditionally been viewed by operators as a binary decision (i.e., one or the other). But a strong business case can be made for combining both reciprocating and turbo-compressors to capitalize on each technology's relative strengths.

In a "hybrid" package, a turbo-compressor is applied to leverage its specific advantage in managing high effective flow in a small footprint. One or more reciprocating compressors are then installed downstream to increase the pressure ratio and potentially reduce the need for recycling. This configuration is suitable for applications with high inlet flows and a requirement for high discharge pressure. A representative example would be a low-pressure electrolyzer feeding green hydrogen into a pipeline or a storage vessel.

Another option is a "combined" package in which a turbo-compressor and one or more reciprocating compressors work independently. In such cases, the turbo-compressor would handle the baseload of the plant, with the reciprocating unit(s) coming online during times of low-load. This configuration is advantageous for large electrolyzer plants with high flow variability due to fluctuating renewable power input. Plants being developed in a phased approach would also be applicable. The reciprocating units could be installed first, with the turbo-compressor being brought online after the plant has reached full capacity.

In certain cases, it may be advantageous to utilize both hybrid and combined configurations to meet compression duties.

Total Cost of Ownership (TCO) Comparison

Several site-specific factors will dictate whether a hybrid compression package is suitable or not. Three of the most important variables are inlet flow, the pressure ratio to be achieved, and the plant's power profile (i.e., continuous, or intermittent).

Siemens Energy has performed a total cost of ownership (TCO)

analysis for green hydrogen plants of various sizes and power profiles, taking into account all lifecycle expenses, including initial CAPEX, installation, energy costs, maintenance, etc.

For small green hydrogen plants (up to 100,000 m³/h effective flow) at medium to high pressure ratios, (i.e., compressing from 1 Bar(a) to 30 Bar(a)), where the supply of hydrogen is highly intermittent, reciprocating compressors usually show the most economical option because of their part-load capability and lower energy costs over their lifetime. However, for the same service with continuous hydrogen flow, a hybrid compression solution might be more economical.

As plant size approaches 200,000 m³/h effective flow and larger, the economics of the hybrid solution become favorable irrespective of the load profile (i.e., intermittent, or continuous), because trains can be arranged in parallel to significantly improve the part-load capability of a turbo-compressor.

Additional studies by Siemens Energy showed that for plants with medium inlet and outlet pressures, an all turbo-compressor solution is the most economical. As an example, for a plant with inlet pressure of 1.2 Bar(a) and outlet pressure of 13 Bar(a), the Advanced Hydrogen Compressor is best suited for both the continuous and intermittent load profile. This is mainly due to smaller footprint and CAPEX, as well as reduced maintenance costs compared to a solution with reciprocating compressors.

Conclusion

Both reciprocating and turbo-compressors possess individual strengths that can be leveraged to efficiently meet the requirements of emerging hydrogen applications. Green hydrogen plants are unique in that they can have large volumes and high production variability. A hybrid compression package may represent a more economical solution than reciprocating compressors in certain instances. As discussed, however, the inlet flow, compression ratio, and load profile are key variables that need to be considered.

Determining the right technology and configuration will ultimately vary on a case-by-case basis. In all instances, plant developers should engage early with the compressor OEM to ensure that all technical and economic variables (e.g., CAPEX, OPEX, footprint, maintenance, etc.) are considered to arrive at an optimized design.