Hydrogen Integration in Midstream Infrastructure: Compression Equipment Impacts and Adaptation Strategies

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Fuelling the Future

Session - *Hydrogen Integration in Midstream Infrastructure: Compression Equipment Impacts and Adaptation Strategies*

CGA Energy Nexus and Annual Technical Conference

Speakers: Adesua Eigbe & Kirk Lupkes
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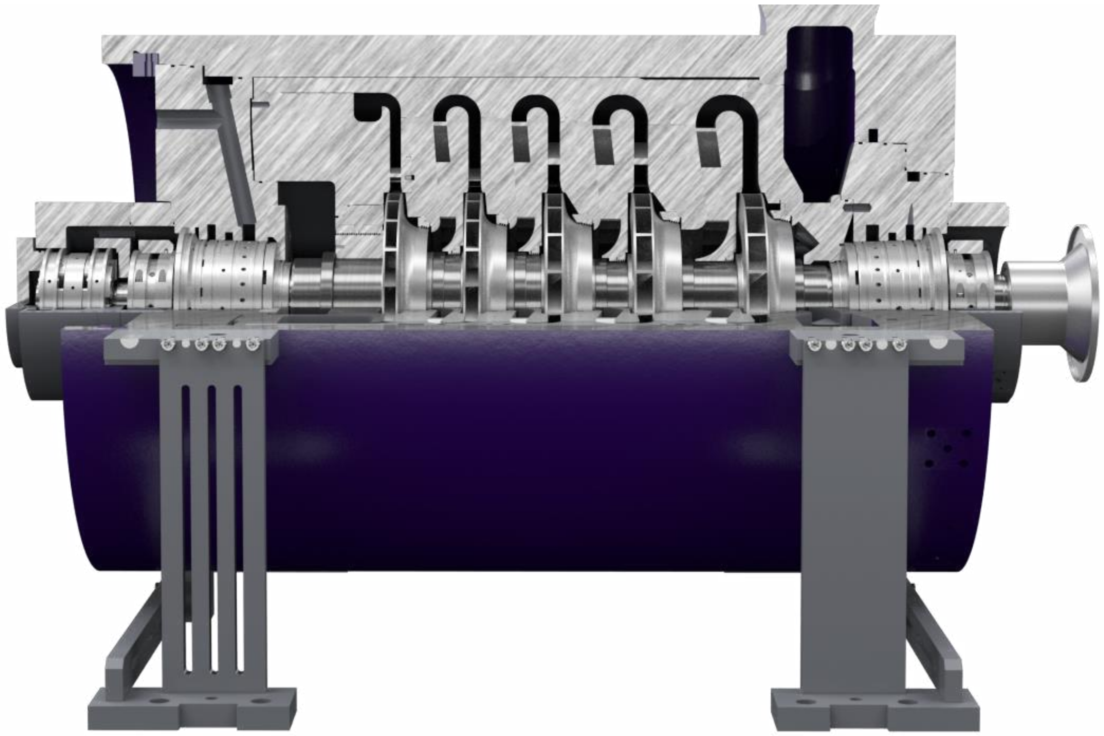
Agenda

1. **Midstream landscape**
   - Evolving role in decarbonization
   - Challenges and opportunities with hydrogen and RNG
2. **Hydrogen properties & compression impacts**
   - Unique properties: low density, high diffusivity, material risks
   - Effects on reciprocating and turbo compressors
3. **Adaptation strategies**
   - Solutions for hydrogen integration
   - Material upgrades and hybrid architectures
   - Innovative designs for efficiency and reliability
   - Mitigating challenges of hydrogen blending

Midstream Landscape

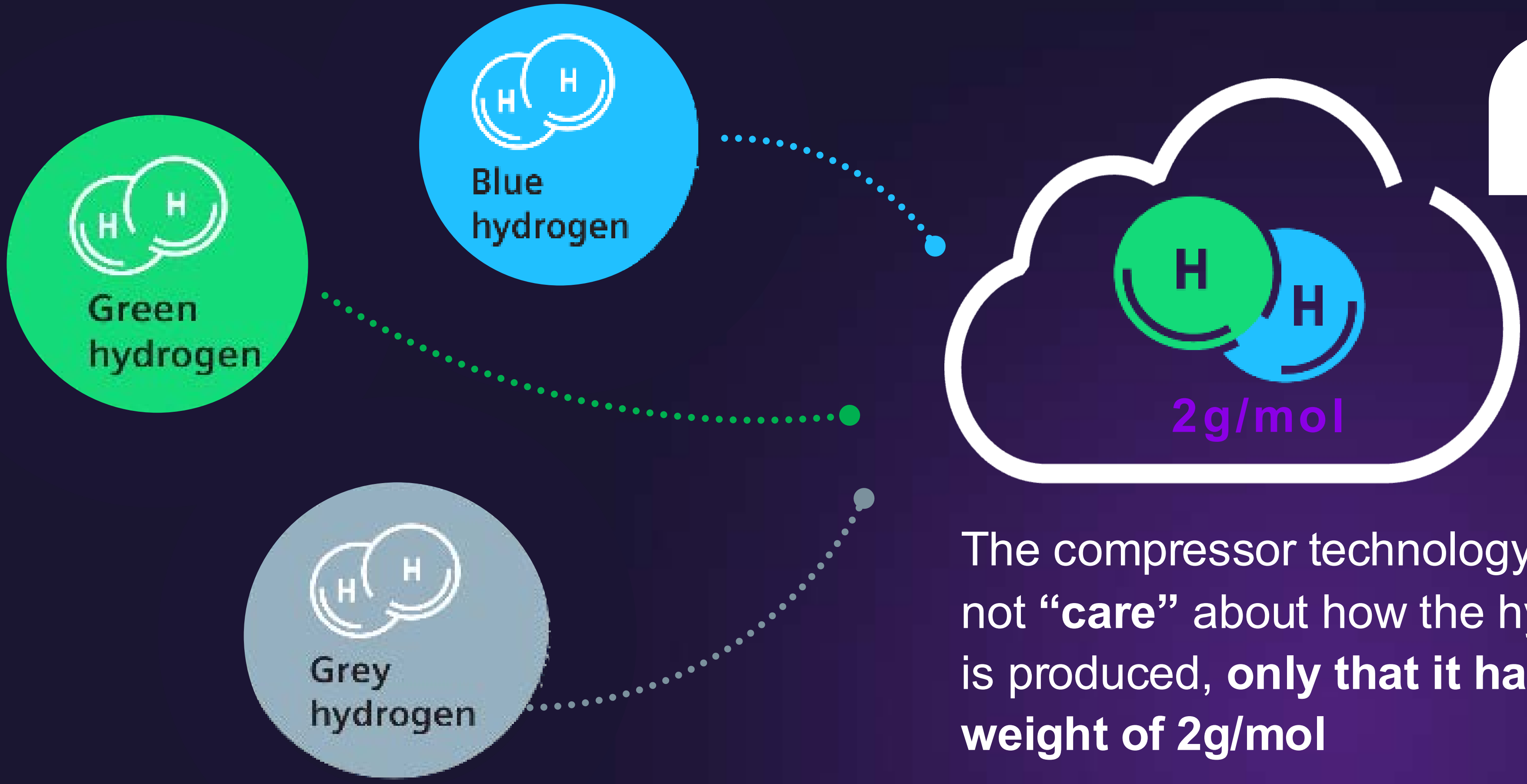
As companies consider the decarbonization of Natural Gas Infrastructure:

- Hydrogen and Renewable Natural Gas (RNG) are key to decarbonization.
- Midstream companies must evaluate the impact of diverse gas blends, especially hydrogen, on compression equipment.

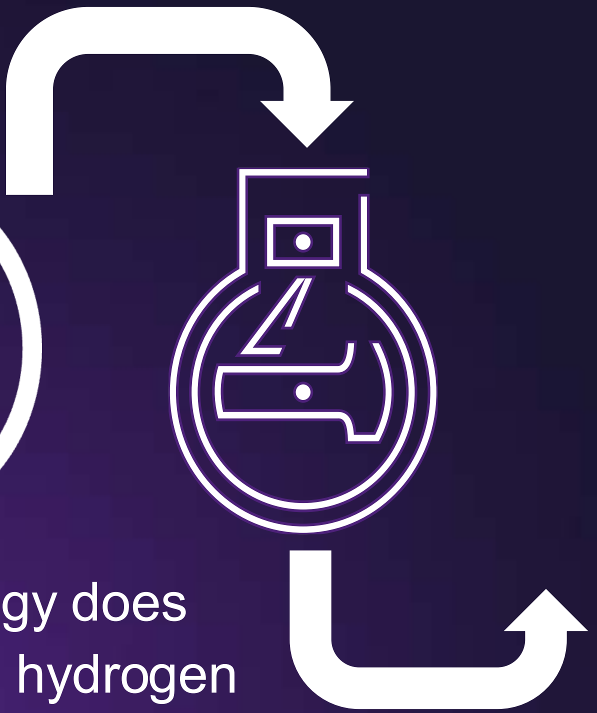


Hydrogen Properties & Compression Impact

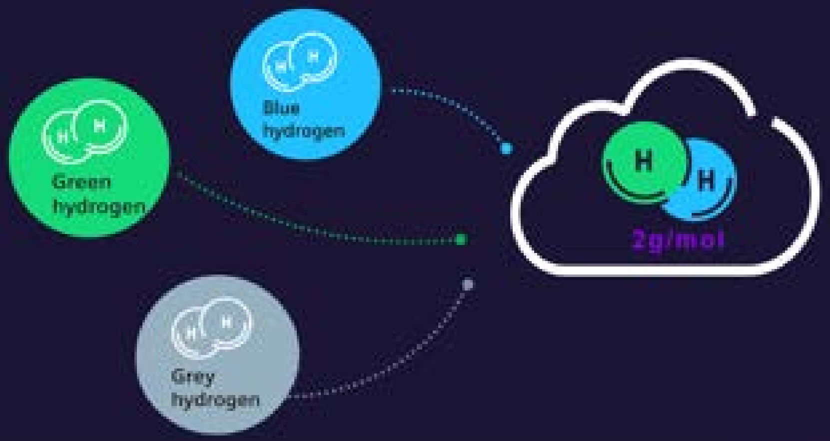
Hydrogen compression doesn't see the color



The compressor technology does not **“care”** about how the hydrogen is produced, **only that it has a mole weight of 2g/mol**



The compressor might not see the color, but It is important to define boundary conditions…



1. What is the gas composition and is there water in the gas?
2. Is the flow provided the dry flow or the wet flow?
3. At what pressure is the gas being provided to the compressor?
4. At what temperature is the gas being provided to the compressor?

5. What cooling mediums are available on site for process gas cooling requirements between compression stages?
6. If there is no water on site, what is the site ambient temperature for finfan air coolers?

7. What discharge pressure is required?
8. What level of lubrication oil carryover is acceptable downstream of compressor?
9. What is the operating philosophy and capacity control requirement?

H_2 Transport
Pipeline applications

Blend in Natural Gas	Flow changes	Technology impacts
~40% – 100%[1]	**3** Times the volume flow of hydrogen is required to keep the energy delivery constant	Compression system expected to be changed
~10% – 40%[1]	**%** Hydrogen mixture will affect volume flow	Compressor internals must be adjusted. Most Gas turbines for pipelines can burn significant amount of H_2 already or can be upgraded
~10%[1]	No major changes	In principle, the existing compression system is assumed to continue operation

Siemens Energy Portfolio

Reciprocating Compressors

Centrifugal Compressors

Gas turbines High % H_2

Revamps & Parts

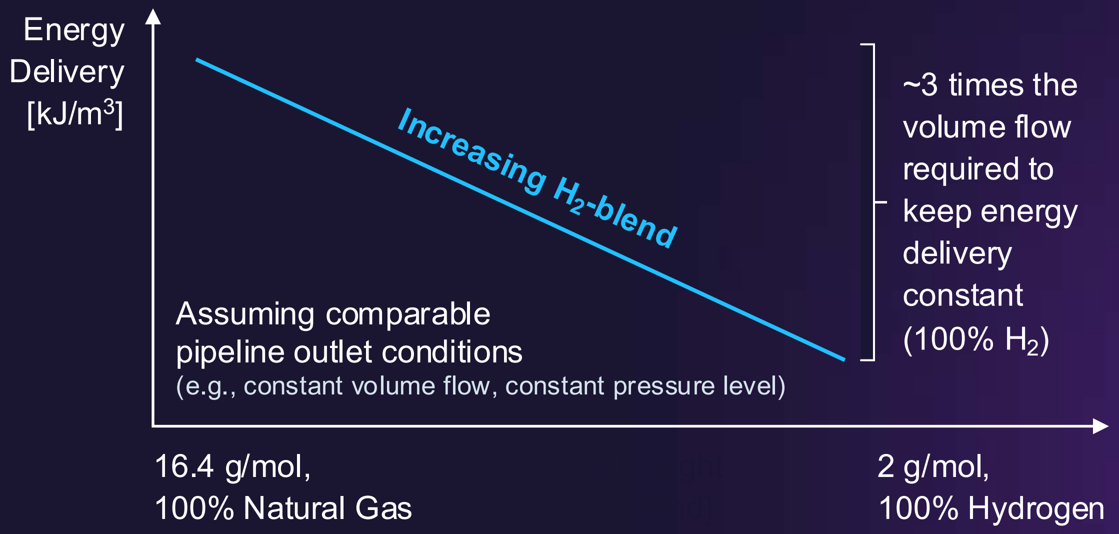
1 To be evaluated and confirmed project-specific

Blending of Natural Gas with H_2
Pipeline example

Today

Pipeline Transport of Natural Gas

⇨ Primarily with Turbo Compressors



Future

Pipeline Transport of up to 100% Hydrogen

⇨ Will remain an application for Turbo Compressors

- Compression solution to be aligned with pipeline architecture
- Current R&D targets on Hydrogen Compression to be supported by Turbo Compressor on equivalent casing and stage count as for natural gas
- But change of compression architecture to be considered according to changed boundary conditions of compression duty

H_2 Compression with Turbo Compressors …

Properties of Hydrogen

Density (ρ)	**0.089 kg/m³ (at 0°C)[1]**
Specific volume (v)	11.24 m³/kg (at 0°C)[1]
Mol weight	2 g/mol
Speed of sound	1284 m/s (at 0°C)[1]

Hydrogen compression with Turbo Compressors …

- Requires a comparable high amount of compression stages for a given pressure ratio, because of a very low gas density
- Needs special consideration about materials, because of hydrogen embrittlement and related stress limitations
- Will most likely not be a transonic compression, because of the high speed of sound of H_2

Specific work Δh_s required to compress from a suction pressure p_s to a discharge pressure p_d.

$$\Delta h_s = \int_{p_s}^{p_d} v \, dp$$

⇨ The amount of specific work required depends on the specific volume/density of the gas

- $Y_{wheel} = U_2 * C_{2u} - U_1 * C_{1u}$ (specific work per wheel; *simplified*)
- Circumferential velocity (U_2) can be increased with train speed n and/or with a change in outer wheel diameter D_2
- Circumferential portion of absolute velocity (C_{2u}) can be increased by revised impeller geometry

⇨ ⇧ Impeller Tip-speed/Head per stage
⇩ Stage Count/Casing Count

Reciprocating Compressor Product Portfolio

Hydrogen Rich Applications

2,500+

Units in operation

Recognized as a Global market leader

2,500,000+

Horsepower installed

100+ Years of compression experience

Why Reciprocating Compressors for hydrogen compression

Reciprocating Compressors

2g/mol

The low mass of H_2 means a reciprocating compressor is a more efficient method of compression

Centrifugal Compressors

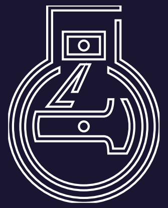
More Power

In general, **Dynamic** machines require more power to achieve the same process conditions

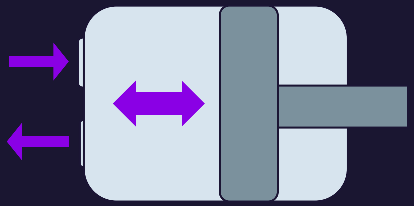
Optimal compression between reciprocating compressors and centrifugal compression depends on compression ratio, flowrate and operating range

Why Reciprocating Compressors for MOST hydrogen compression

Reciprocating Compressors



Positive Displacement



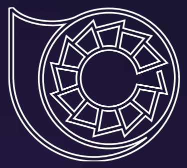
Compresses through the reciprocating motion of the piston

Centrifugal compression is **highly dependent on molecular weight.** The low mass of H2 means a reciprocating compressor is a more efficient method of compression.

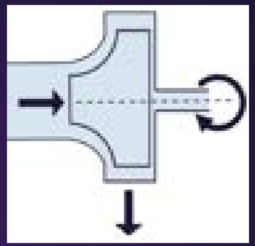
Head is developed by increasing gas velocity to create Kinetic Energy (KE) and then converting the KE to pressure.

The amount of kinetic energy is a function of gas velocity and mass (molecular weight).

Turbo Compressors



Dynamic Compression



Compresses through centrifugal force using impeller rotation

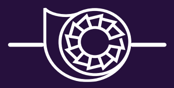
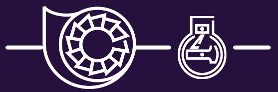
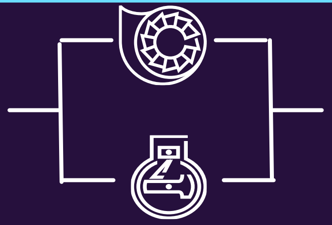
Vs. Other Positive Displacement (Screw) Compressors

- Siemens Energy has a legacy screw compressor product line that we still service today, but we see the future market needs being better met by reciprocating and single shaft compressors. Still it should be noted that **oil flooded screws are a viable commercial solutions**.
- However, for **non-lube applications**, despite dry screw technology being available, they **are mechanically more complex and expensive** and are typically only used when absolutely necessary.
- This additional scope and engineering results in **reciprocating machines being a more cost effective solution**.

Siemens Energy H2 compression portfolio

- **Reciprocating compressors** are more efficient at compressing H2 gas and provide high flexibility in flow capacity control. As they are positive displacement machines, they are limited on the volume flow. The higher number of wearing parts require more maintenance.

- **Turbo compressors** are able to compress large flows - rely more heavily on recycling if large flow range (e.g; H2 electrolysis output powered with renewables) is required. Due to the low mole weight of H2 gas, turbo compressors are less efficient and require several compression stages for a high compression ratio.

	Additional Information	Volume Flow	Pressure Ratio	Flow Capacity Control Flexibility	Example Application
Full Reciprocating Compressor solution 	• Achievable flow limited by cylinder bore size and compression ratio • ~15-100% capacity control available	Low-Med	High	High	Pressurized Electrolyser ; Low flow pipeline; Low flow storage
Full Turbo Compressor solution 	• 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 	• Turbo compresses large flow of first stages to minimize Recip. cylinder quantity • Recip. creates remaining large Compression Ratio required whilst also minimizing flow recycling	High	High	Med	Low pressure Electrolyser ; Cavern Storage
Combined solution: Turbo Compressor for baseload supported by Recip. Compressor for low loads 	• 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 Electrolysis 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

Comprehensive product portfolio for Hydrogen Compression

Our most referenced product for H_2-compression, best flexibility and efficiency

Application areas:

- Conventional markets, e.g., refineries
- Small to medium sized H_2 applications and medium to high pressure ratios

and / or

Application areas:

- Large flow electrolysis system with potential flow fluctuation (renewables) and higher pressure ratios

Products can be used in series/parallel for an optimum solution to project-specific requirements

Application areas:

- H_2-pipelines; H_2-transport in general
- SynGas applications
- Large flow electrolysis with lower pressure ratios

Optimized footprint and spare parts / low maintenance concept

Pressure Ratio [-]

10,000 – 30,000 | 100,000 | 200,000 | Actual Inlet Flow [m^3/h]

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Adaptation Strategies

STC-SVm single Shaft Compressors
Turbo technology is key to scale the Hydrogen economy

SIEMENS energy

Turbo Compressors are crucial to **scale Hydrogen economy** and generate required flows

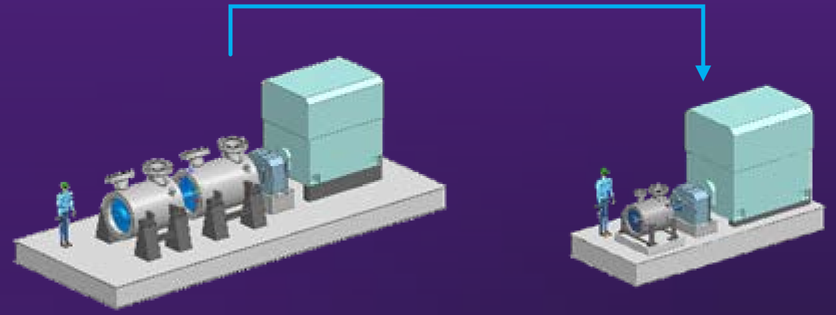
Provide **delta p** for **typical H2 compression duties** (e.g. Pipeline or H2 boosting after electrolysis) in a **single compressor casing**

We **developed and tested a technology** to **reduce footprint by increasing tip speed**

Solution based on **STC-SVm single shaft design with advanced rotor & bearing technology**

First bids out in customer projects and technology qualification underway with customers including full scale H2 prototype testing

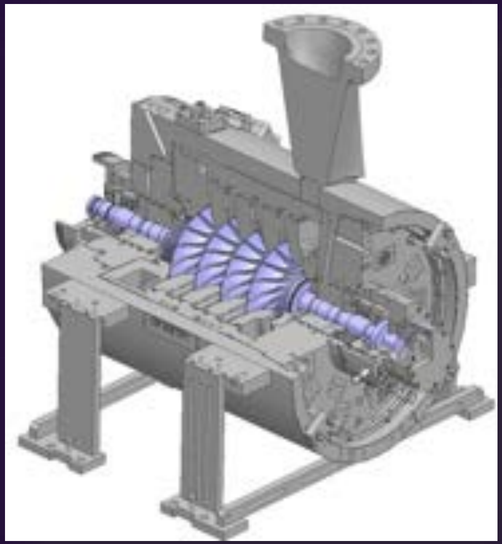
Significant footprint reduction



> 600 m/s
Tip Speed of Impeller

> 50%
Stage reduction

High Speed Advanced Rotor Development
Key Accomplishments



Design

- Single piece construction
- Nearly 2x increase in tip speed while simultaneously reducing critical stresses for hydrogen applications
- Compressor validated at full scale, full speed in 100% hydrogen test loop

Example: Target pressure ratio of 3.0 for pure dry H2

	Conventional Rotor	Advanced Rotor
Pressure Ratio / stg	1.05	1.15
Tip Speed	1150 ft/s	2000 ft/s
Stages Required	**23**	**8**

Optimized Reciprocating Compressors to enable energy transition growth

Market Requirements

- Speed to market (fast bidding, competitive lead times)
- Fully Integrated modularized package for quick handling and installation
- Plant standardization with multiple units being duplicated
- Highly price competitive
- Non traditional customer specifications
- Low Energy Consumption
- Large bore, Non-Lube applications
- Higher operational flexibility

H_2 Cylinder lineup

- Optimized Design for low mol weight gases
- Optimized for casting and machining

H_2 Console in a box

- Containerized Jacked Water and Frame Oil Consoles
- Simple logistics
- Reduced Effort in I&C onsite

H_2 Drive Train

- Standardized Drive lineup
- Reduced project efforts

Phase 1 → **Phase 2**

H_2 Plug&Play Package

- Standardized/ Modularized Design
- Reduced project efforts in Design
- Simple logistics
- Effort reduction for installation and commissioning onsite

H_2 Capacity Control (HVVCP, ISC)

- Addressing operational flexibility
- MAGNUM™ Plus

H_2 Modularized Frame & Crank

- Expanse of Supplier base
- Simplified logistics
- Enables modularized packaging for 8+ throws

Cylinder Lineup
Key Accomplishments – Ø 48.5" Cylinder Assembly

Design

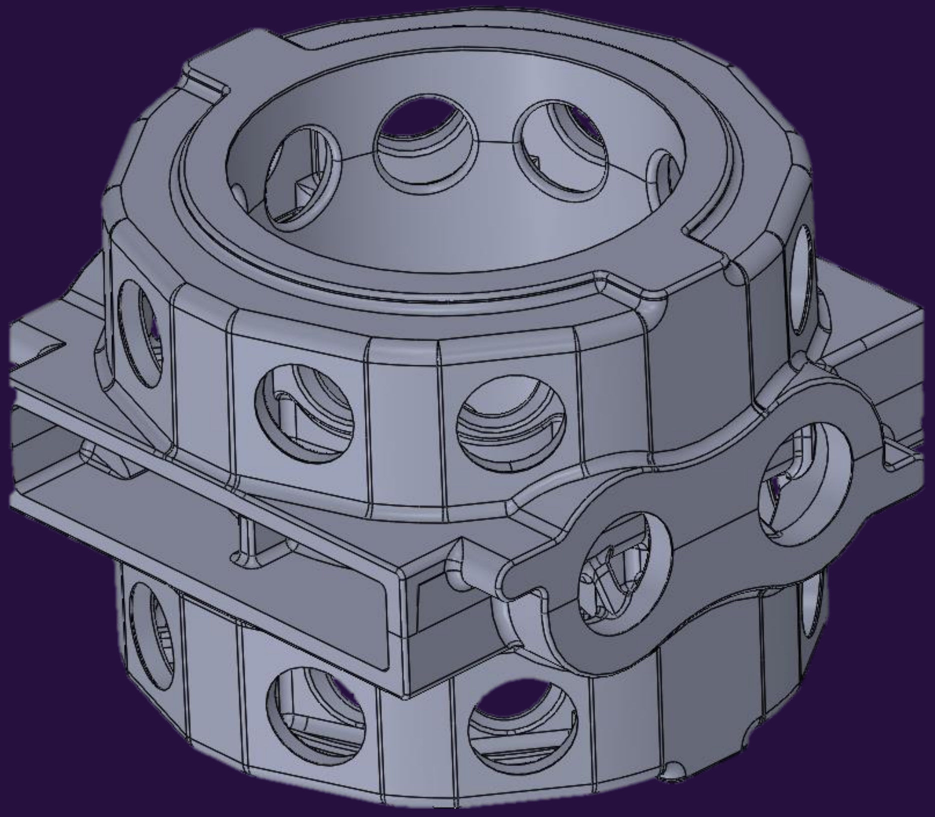
Supporting requirements of PEM atmospheric electrolysis by max. diameter increase

Size

- ~15% cylinder & throw length reduction
- ~10% reduction in CoCo footprint

Advanced functionalities

- ISO piping connections to pressure vessels
- 5 inlet port holes for low flow load points



Capacity Control
Key Accomplishments

Design

MAGNUM™ Plus innovative valve technology
- Increased reliability
- increased energy efficiency
- Improved serviceability

CAPCON product portfolio solution supporting flow flexibility
- Hydraulic variable volume pocket System (HVVCP)
- Infinite step control System (ISC)
- Standard Unloading in configurations

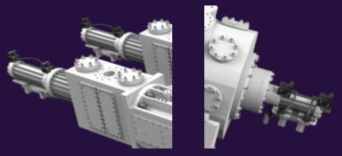
Advanced functionalities

- MAGNUM™ Plus efficiency adds 15,000 kg of Hydrogen per year
- ISC provides 2% higher output of a Hydrogen Plant
- ISC system references in United States & Asia Pacific

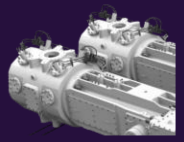
Capacity Control
Key Accomplishments

Valve Design
Designs in respect to flow ratios, gas specifics & customer specs
- Magnum™ Design
- MAGNUM™ Hammerhead Design
- Ported Plate and Plate Designs

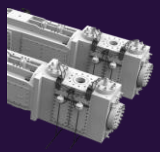
Unloader – Classic Step Control
- Valve Operation System
- Opens the valve for no compression
- Utilization on each cylinder end possible

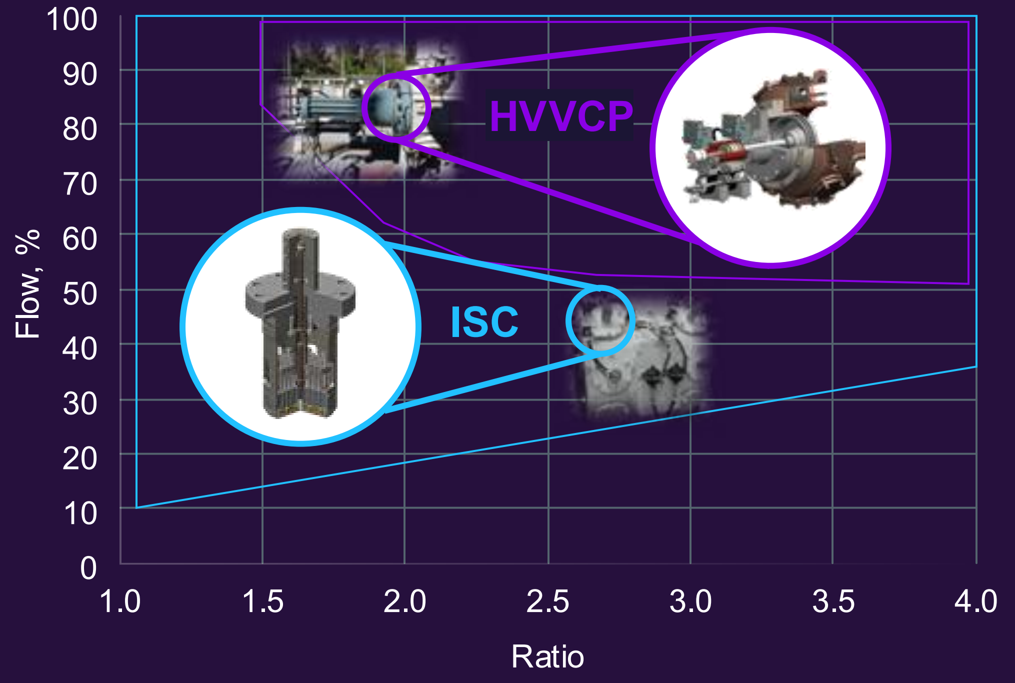


HVVCP – Hydraulic Variable Volume Clearance Pocket
- Modular system changing clearance vol. & flow with highest efficiency
- Additional hydrogen capacity to meet growing liquid hydrogen needs coming from various industries
- Utilization on frame cylinder end volume possible



ISC – Infinite Step Control System
- Valve Operation System
- Utilization on each cylinder end possible
- Proven technology with previous references from established installed fleet





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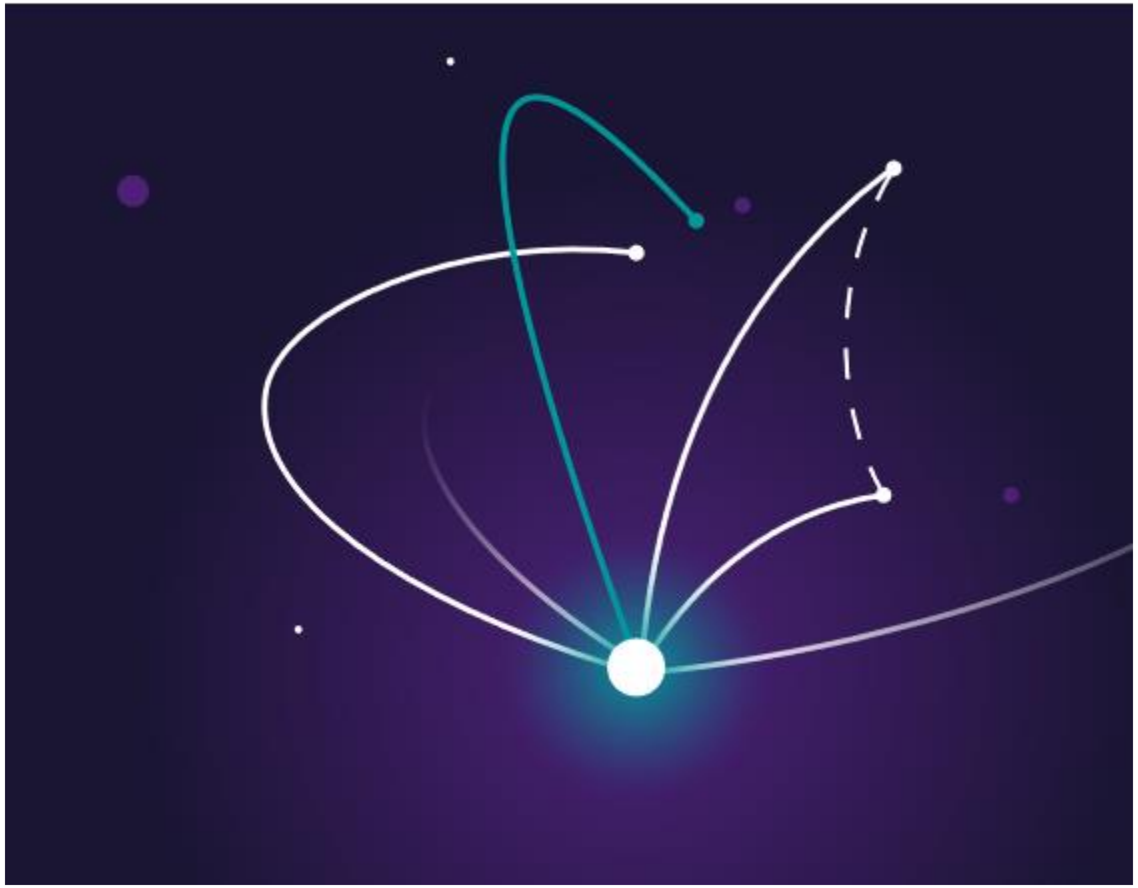

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