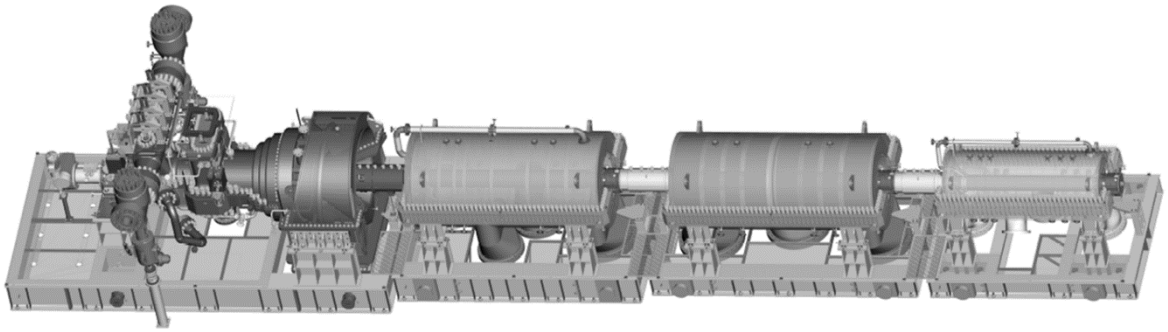
Hydrogen Compression for Energy Storage



Klaus Brun, Ph.D.

Elliott Group

ELLIOTT GROUP
EBARA CORPORATION

ELLIOTT GROUP
EBARA CORPORATION

- Revenue: ~ US$ 1 billion (¥120 billion)
- About 2,600 employees
- 38 locations in 15 countries
- Businesses:
  - Engineered Products (EP)
  - Industrial Products (IP)
  - Global Service (GS)
  - Cryodynamic Products (CP)

- 110 Acre Campus
- 802,000 Sq. Ft Factory Area

Jeannette, PA

- 41 Acre Campus
- 371,000 Sq. Ft Factory Area

Sodegaura, JPN

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Engineered Products

- Centrifugal Compressors
- Axial Gas Expanders
- Axial Compressors
- Steam Turbines (API 612)
- High Speed Balance
- Packaged Solutions

Cryodynamic Products

- Cryogenic Pumps
- Cryogenic Expanders

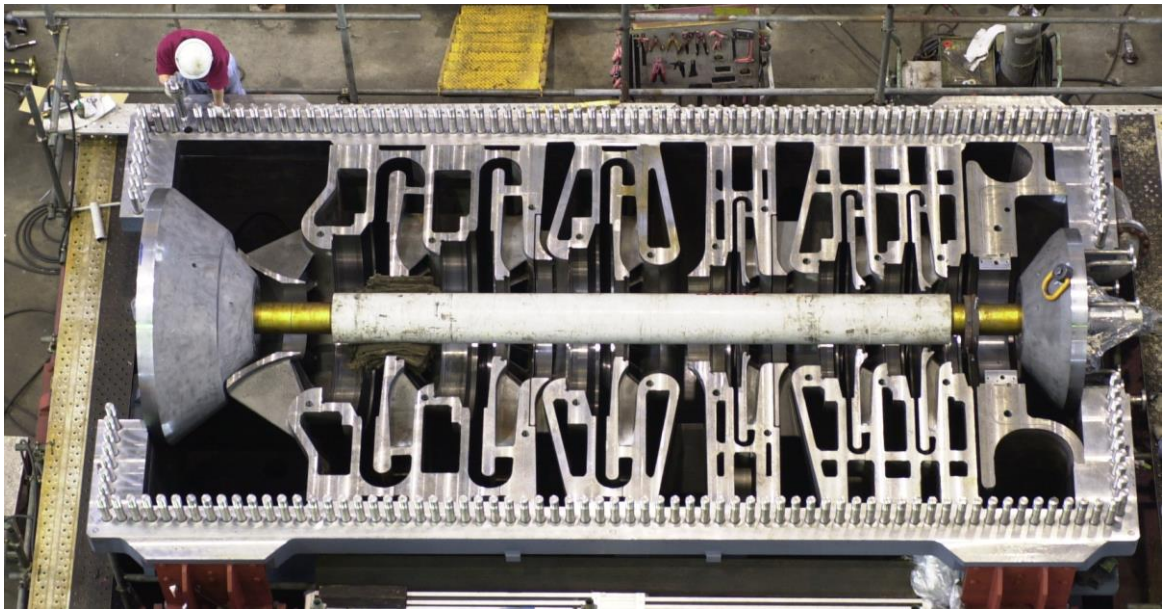
Industrial Products

- Single Stage Steam Turbines (API 611)
- Multi Stage Steam Turbines (API 611)
- Steam Turbine Generators

Global Services

- Service Parts
- Field Services
- Repair Operations
- Re-rate Engineering
- Product Upgrades
- Technical & Training Services
- Engineered Support Systems

Elliott Centrifugal Compressors



- Small To Large
- All kinds of fluids

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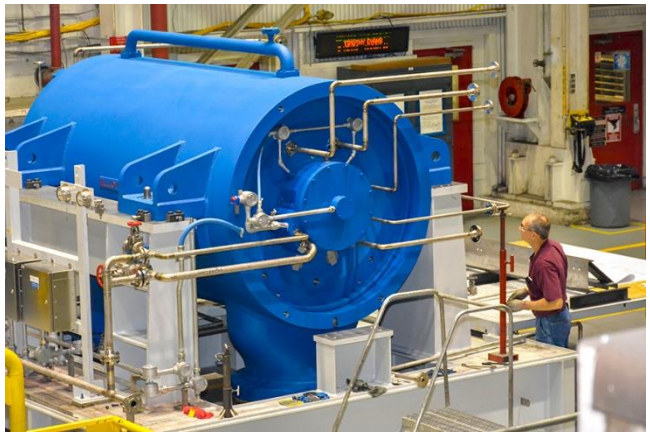
Compressing Hydrogen

Various Hydrogen Rich Compression Applications in Refineries and Petrochemical Industries

- Hydrogen Recycle
- Pure Hydrogen
- Net Gas Hydrogen
- Hydrotreater Feed

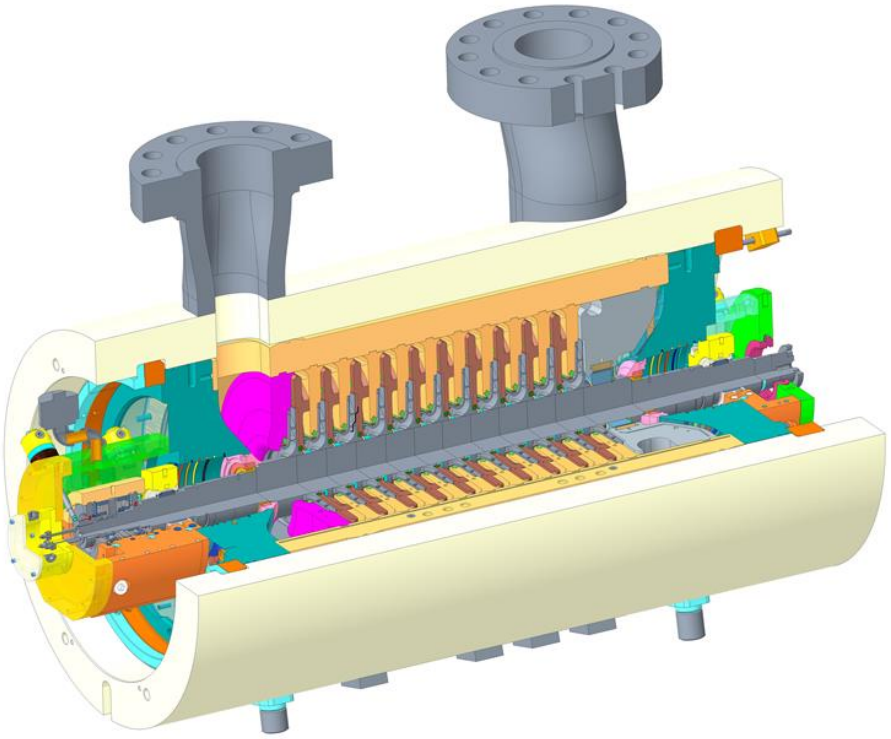


Typical Conditions

- Flow Range: 345 m^3/hr-86079 m^3/hr
- Pressure Range: 3 BarA-162 BarA
- Nozzle Size Range: 4 in.-36 in.
- MW Range: 2.4-18.7 (depending on percent H_2)

Compressing Hydrogen

- Elliott has been building Hydrogen compressors since 1955
- Over 100 hydrogen rich compressor trains produced from 2001-2014
- Elliott has built compressors for a wide range of pure hydrogen and high-hydrogen process applications



Challenges

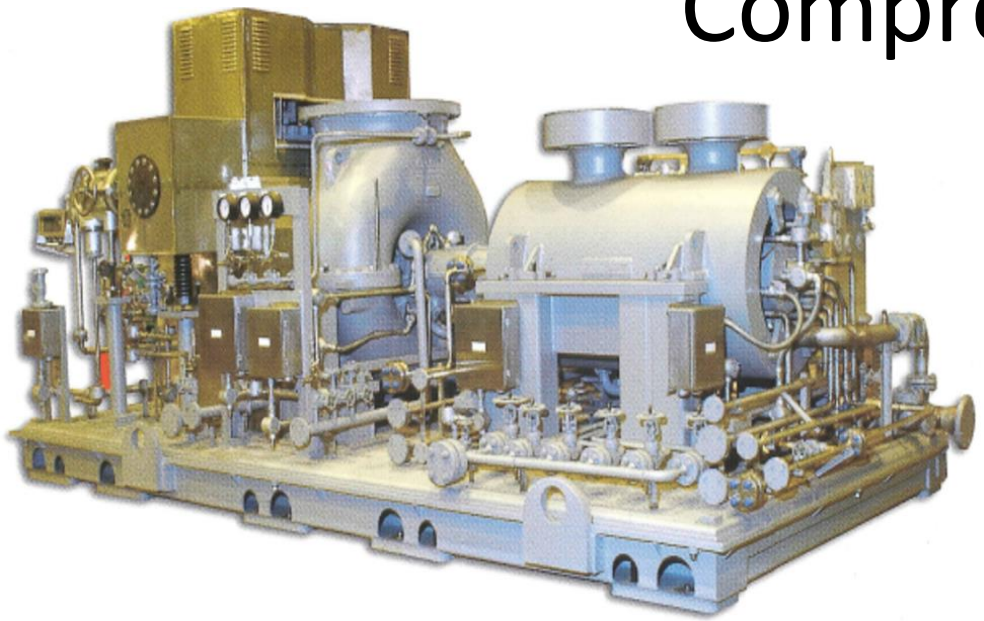
Issues

1. Low Mol Weight->Low Pressure ratio per stage-> High number of stages with high running speeds
2. Hydrogen Embrittlement
3. Static and Dynamic Sealing difficulties

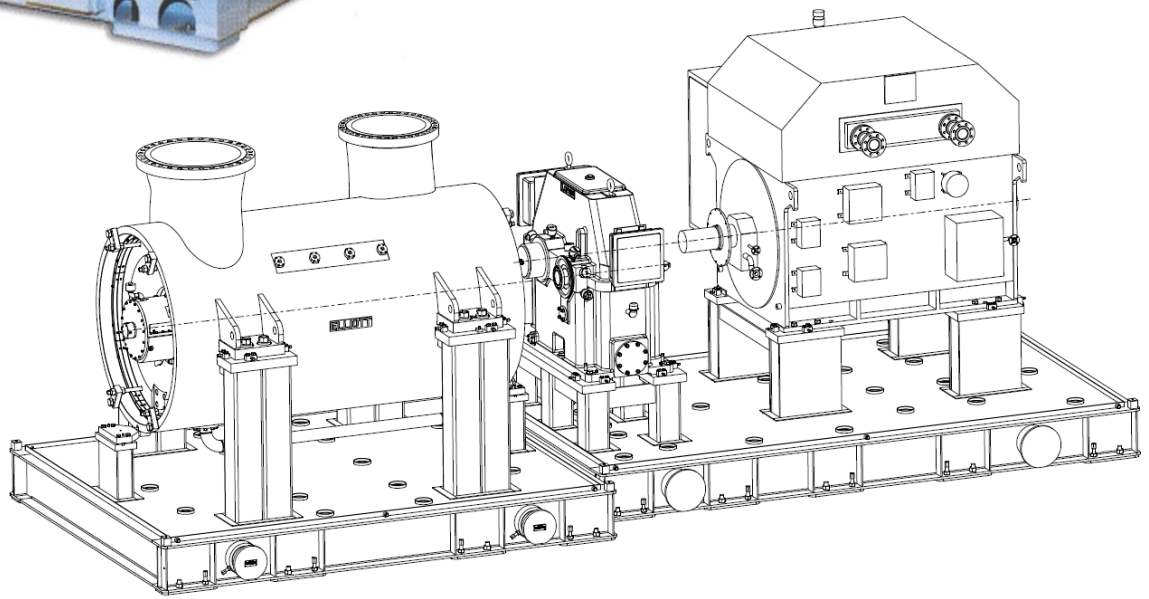
Solutions

1. Rotor dynamic Analysis. Advanced Bearing Designs
2. Material Yield Strength limited to 827MPa (which limits the impeller speed- an additional challenge)
3. Static O-rings. Dynamic Dry Gas Seals

Examples: Hydrogen Recycle Compressors

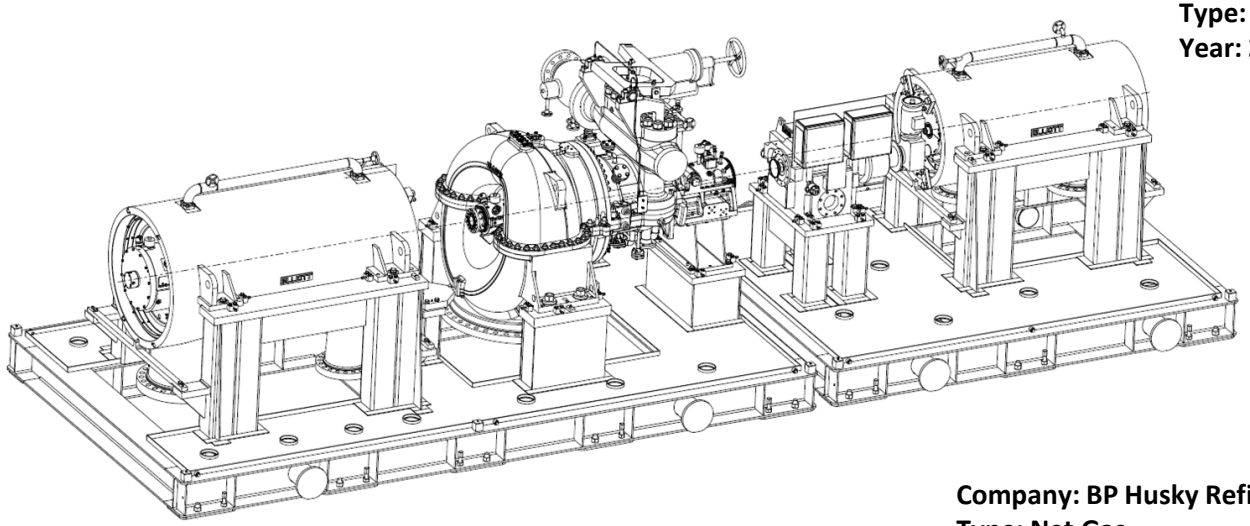


- Hydrocracker
- 4.0 MW (91.5% H2)
- 161 Bara Inlet pressure
- 234 BarG MAWP
- 10” CL2500 nozzles
- 5 stages
- 12027 RPM MCOS



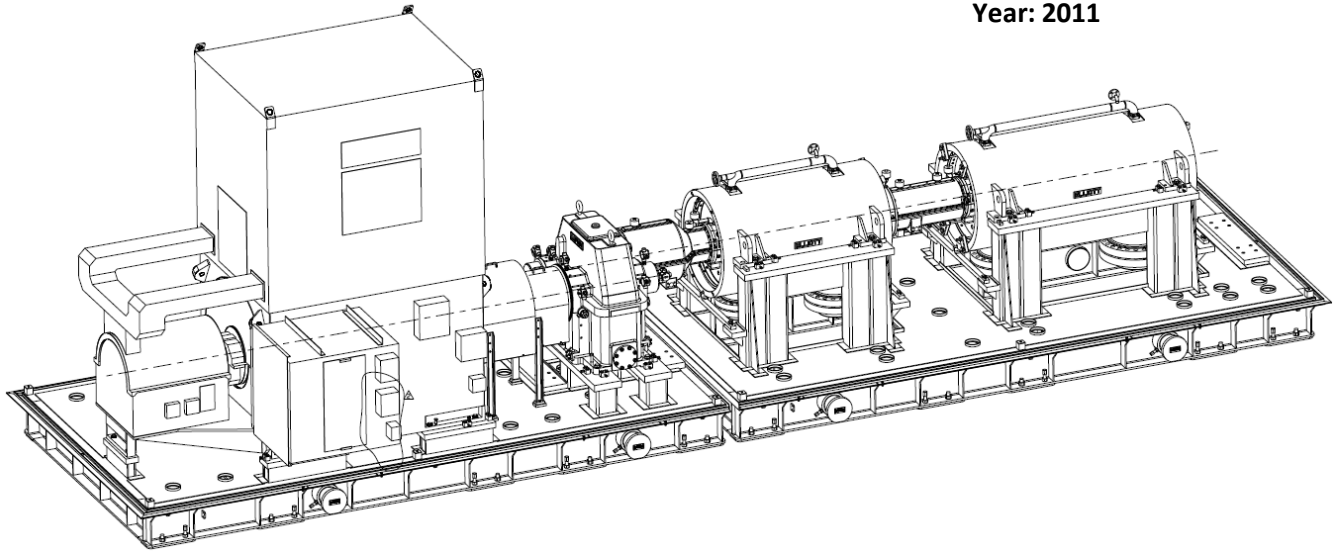
- Recycle
- 9.5 MW
- 82.9% H_2
- 3.4 BarA Inlet pressure
- 7.3 BarG MAWP
- 36” CL300 nozzles-inlet
- 73183 m^3/hr Inlet Flow
- 5 stages
- 5517 RPM MCOS

Examples: Net Gas Compressor



Company: PEMEX
Type: Net Gas String
Year: 2010

- Net Gas String
- 10.4/8.9 MW
- 82.4/83.4 % H_2
- 6.4/16.2 BarA Inlet Pressure
- 21.1/51.8 BarG MAWP
- 20”/12” CL600 nozzles-inlet
- 8/8 stages
- 9001/12494 RPM MCOS

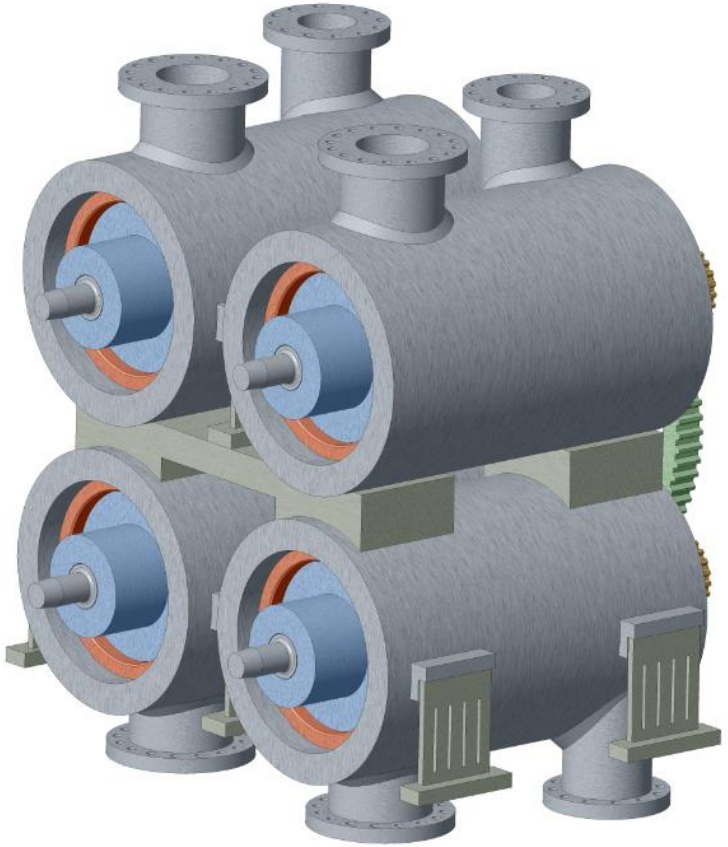


Company: BP Husky Refining
Type: Net Gas
Year: 2011

- Net Gas String
- 7.26/6.87 MW
- 88.9/89.4 % H_2
- 7.3/12.5 BarA Inlet pressure
- 16.7/24.3 BarG MAWP
- 20”/16” CL600 nozzles-inlet
- 8/6 stages
- 9844/9844 RPM MCOS

Flex Operation Hydrogen Compressor Concept

- 3-4 Integral Barrel Arrangements with independent variable speed control
- High flow, high ratio, high efficiency
- Parallel and series arrangements
- Intercooled
- Potential for multiple sidestreams
- Compact and ease of access for maintenance and repair



Elliott has built hydrogen compressors for over 65 years.

Thank you!

Questions?