

Commercial Application of sCO₂ Power Systems



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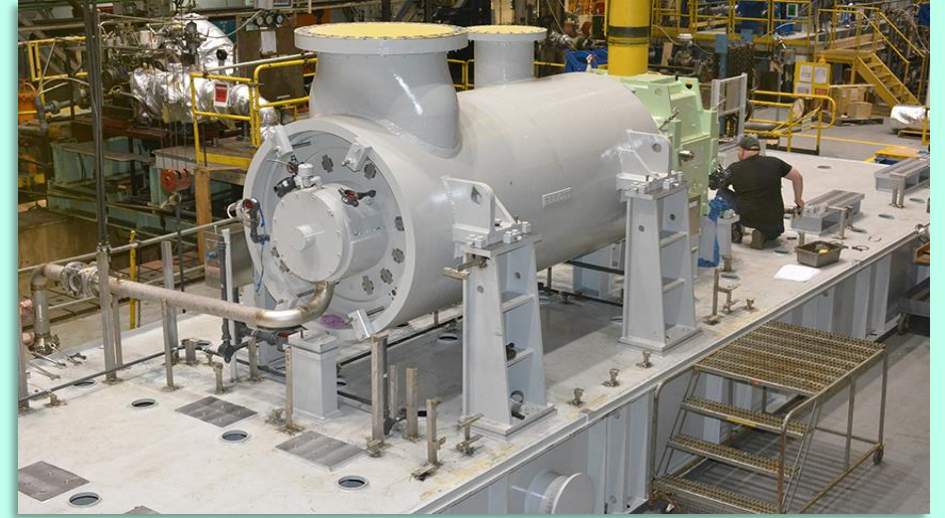


US Headquarters – Jeannette, PA

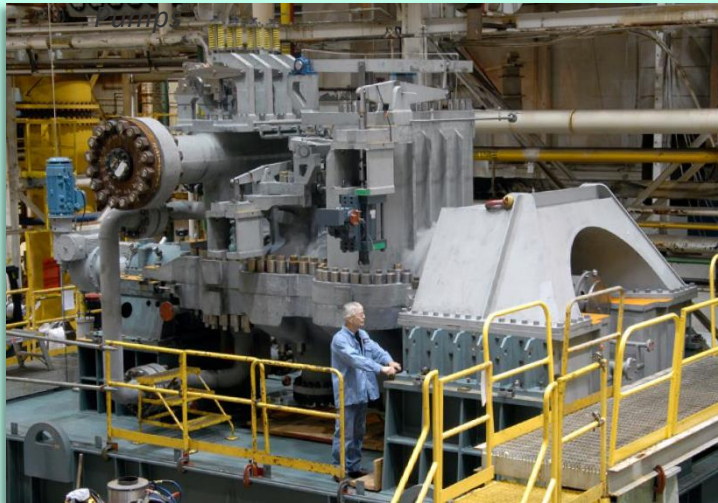
- Established 1910, Pittsburgh, PA
- Process gas compressors
- Horizontal and vertically split casings
- High flow axial compressors
- Steam turbines
- Cryogenic Pumps



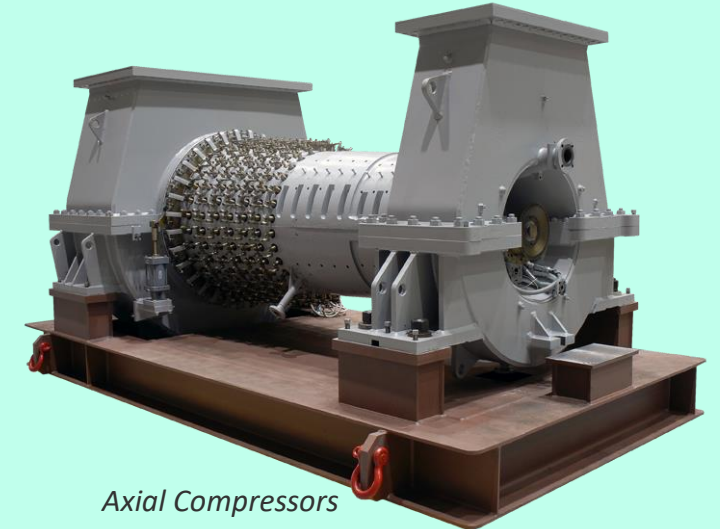
Cryogenic



Centrifugal Gas Compressors

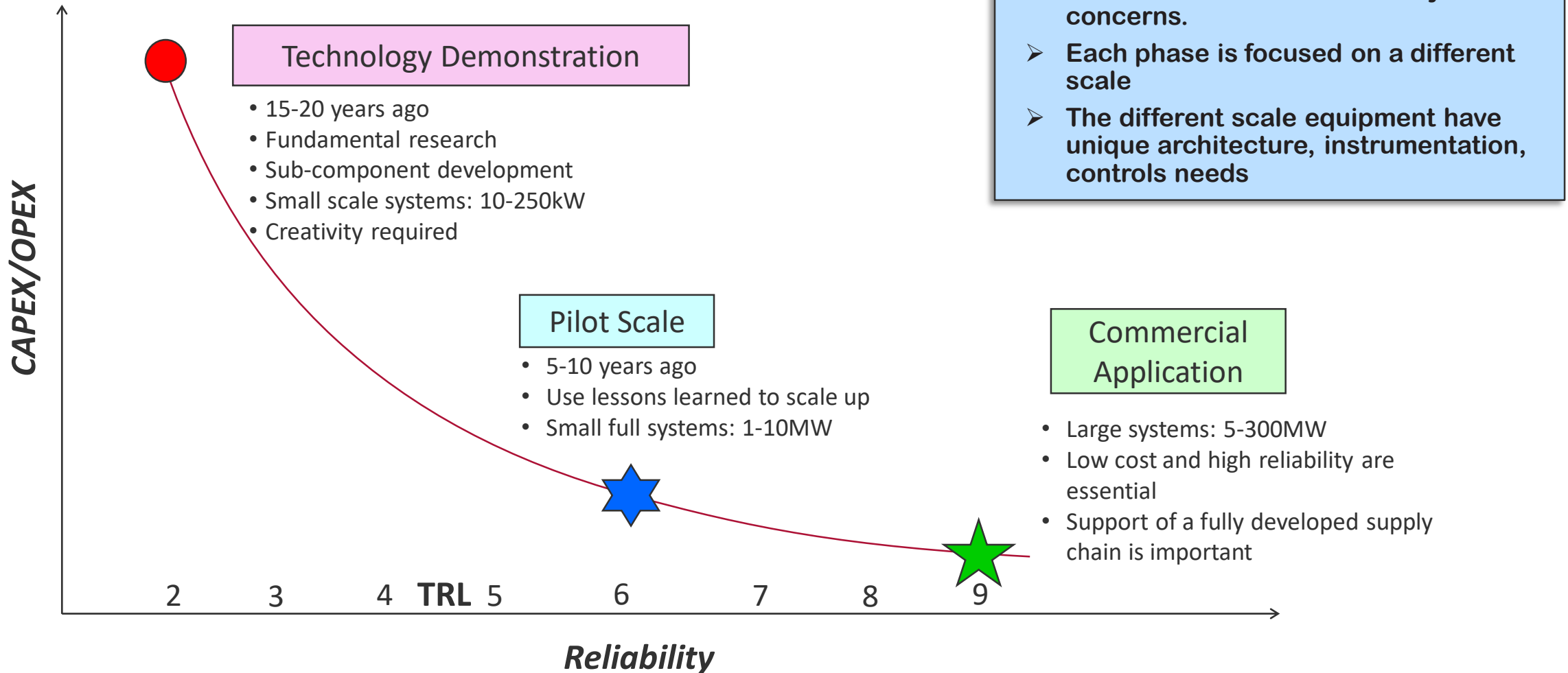


Steam Turbines

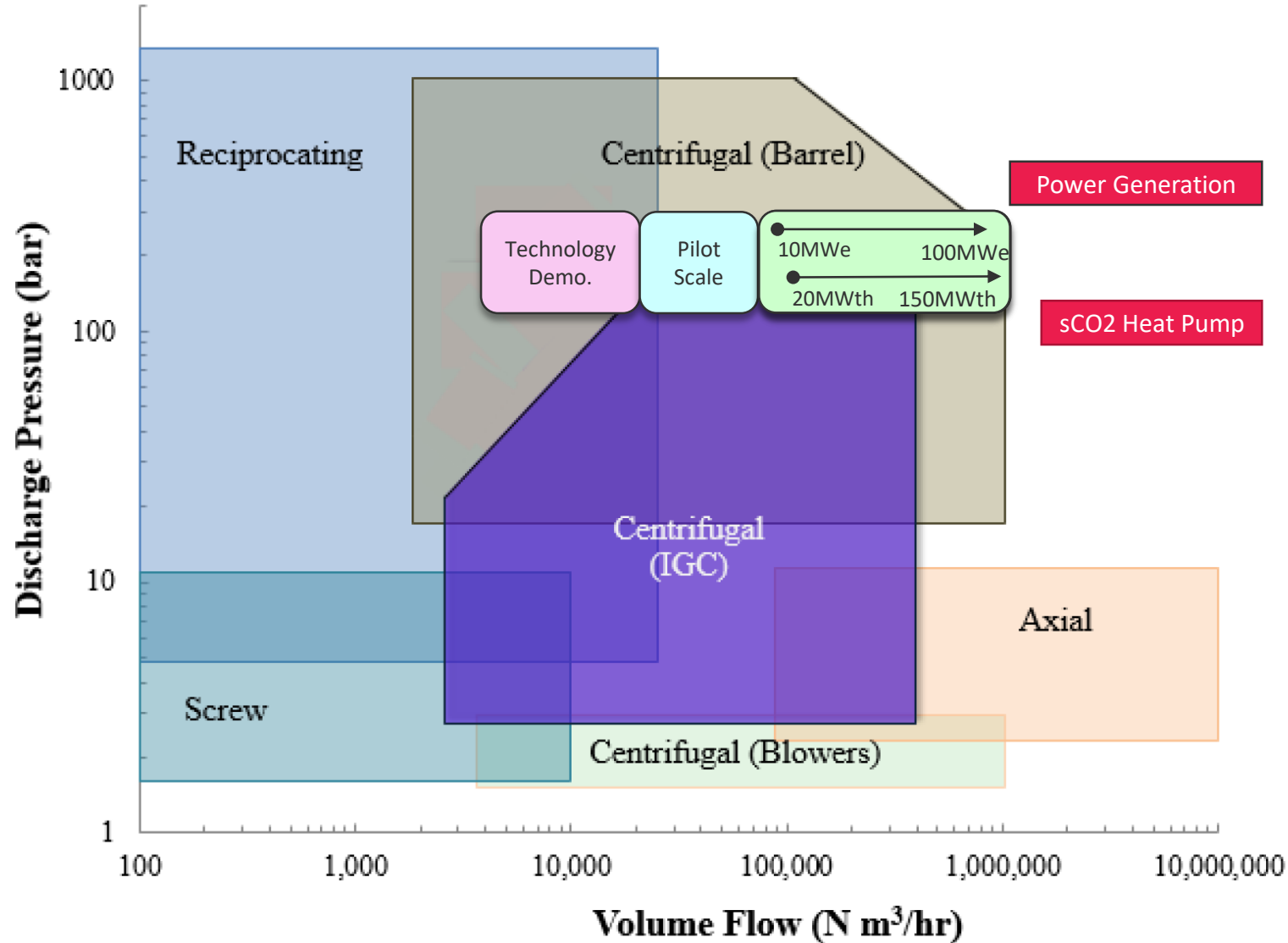


Axial Compressors

Commercialization of sCO2 Power Systems



Application Matching



Power Cycles

High Temp: 650C +

- CSP
- Nuclear
- Direct Fired

Med Temp: up to 500C

- Waste Heat Recovery

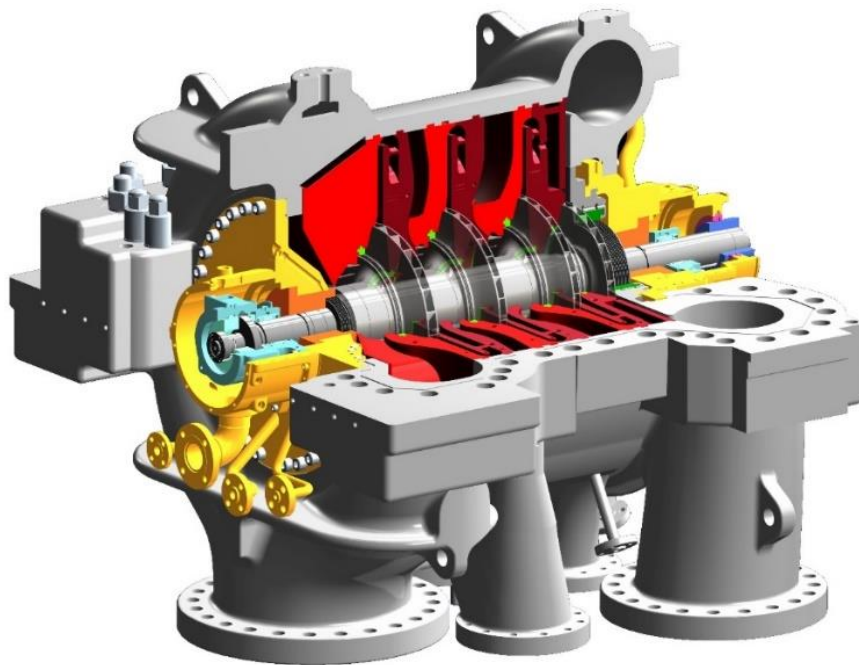
Low Temp: Up to 200C

- Heat Pumps

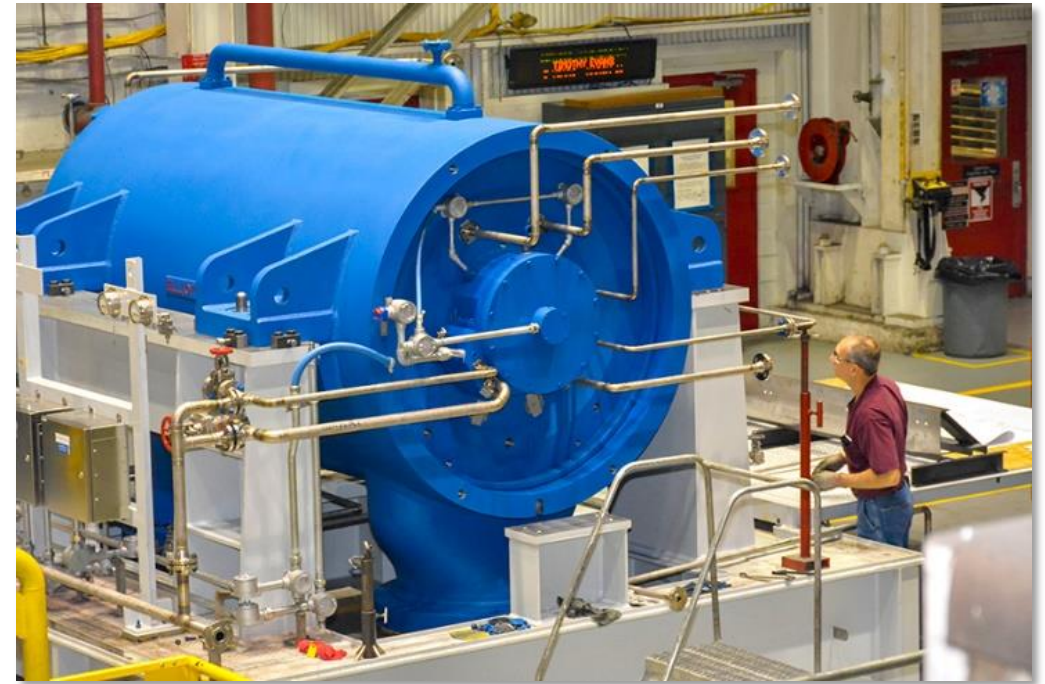
High power density of sCO₂ makes technology demonstration and pilot scale units harder than this plot would suggest...

Application and Advantages of Beam Style Centrifugal Compressors

- Beam style compressors are a well established solution for applications at high pressure and power
- Many stages can be accommodated in a single casing
- Only 2 seals needed per casing
- Vertically split compressor casings preferred for managing pressures of sCO₂ cycles

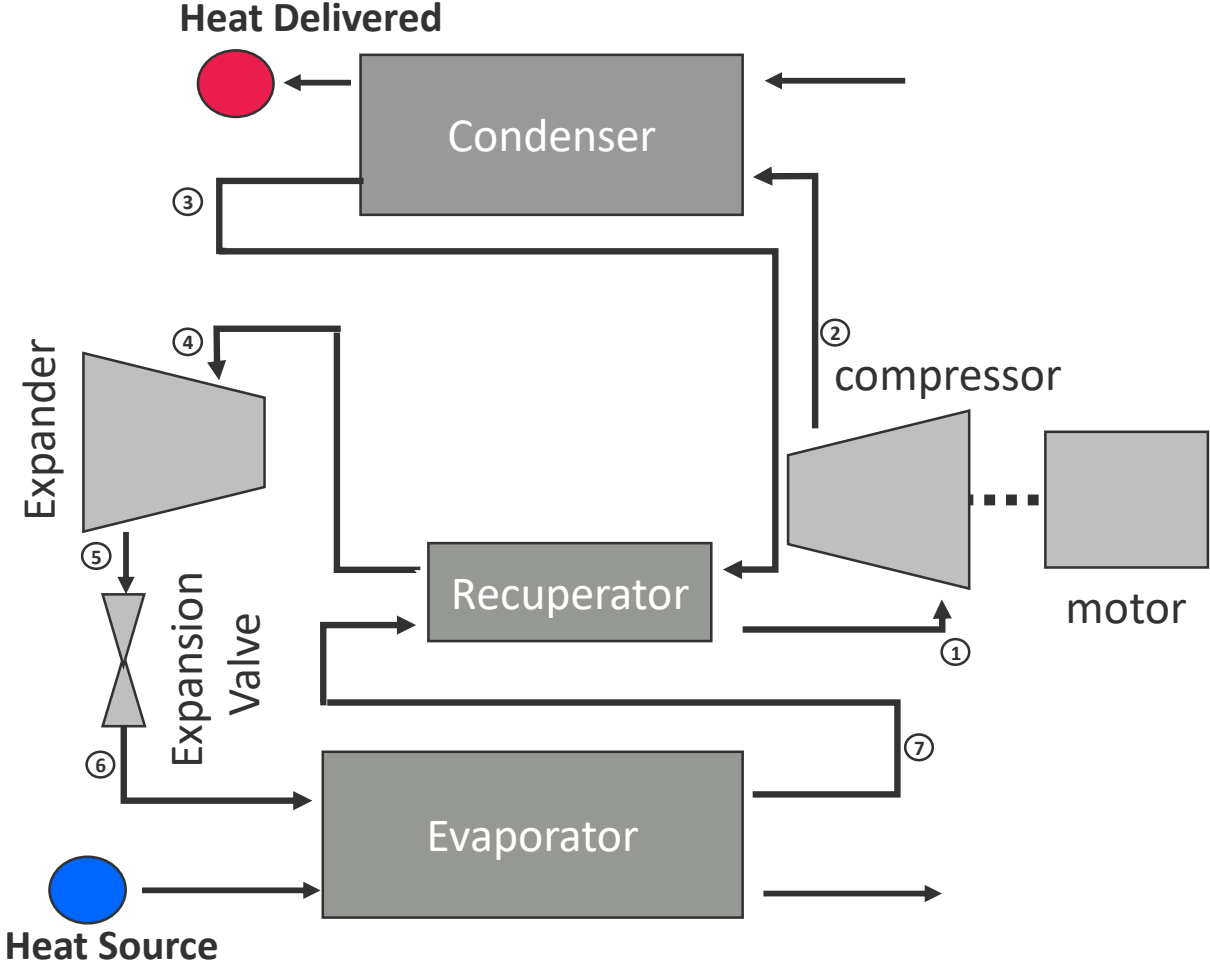
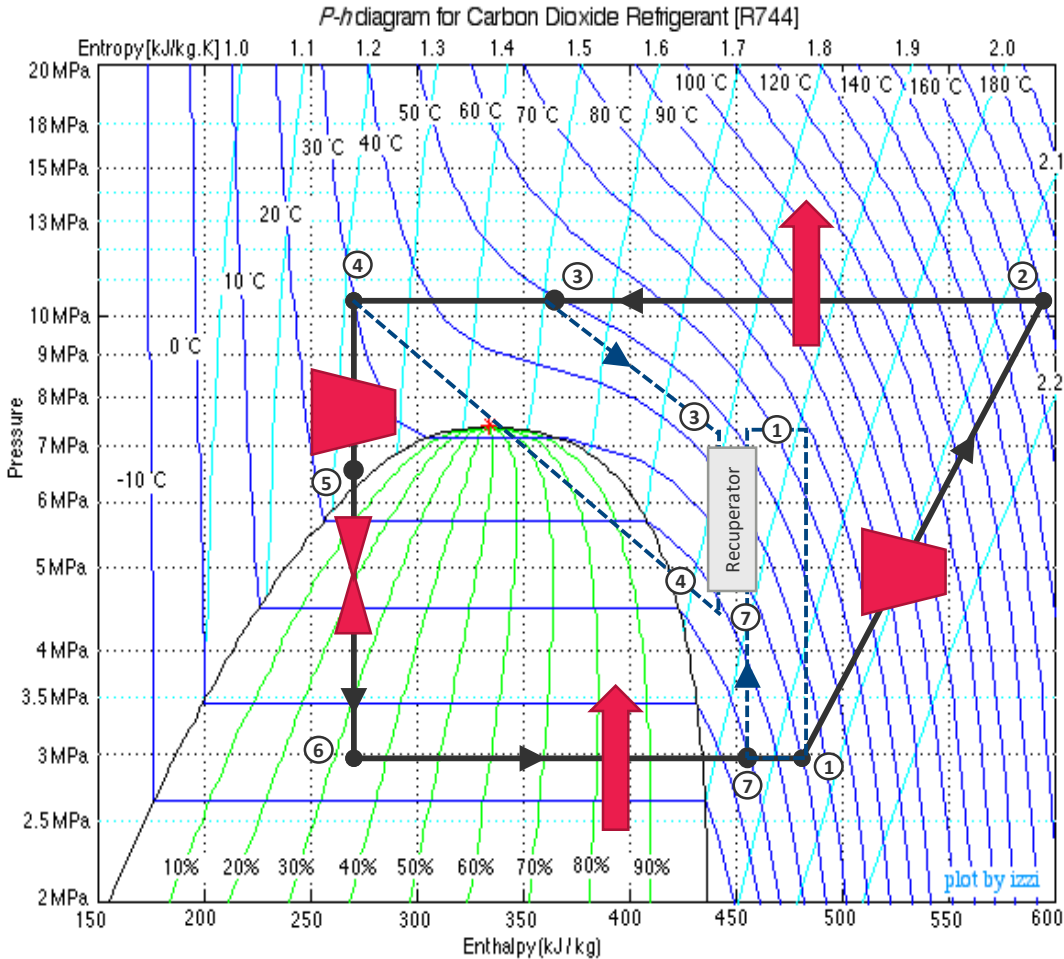


Horizontally Split Casing



Vertically Split Casing

Compressor Selection - CO2 Heat Pump



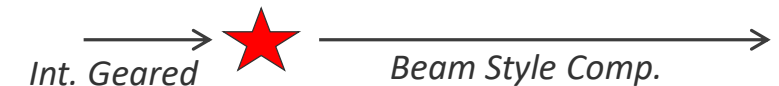
CO2 Heat Pump Compressor Selection



Standard Elliot Casings

- 690 bar: 10-18" Impellers up to 20,000rpm
- 345bar: 20-24" Impellers up to 10,000rpm
- 219bar: 27-32" Impellers up to 7,500rpm

		sCO2 Heat Pump			
		Tech. Demo.	Pilot Scale	Commercial Application	
Heat Out	MWth	1.0	10.0	30.0	50.0
Compressor Power	MW	0.345	3.5	10.3	17.2
Number of stages	-	3	3	3	3
Flow Coeff	-	0.05	0.05	0.08	0.09
Impeller Diameter	in	3.1	9.8	13.4	16.3
Shaft Speed	rpm	55691	17582	12858	10565



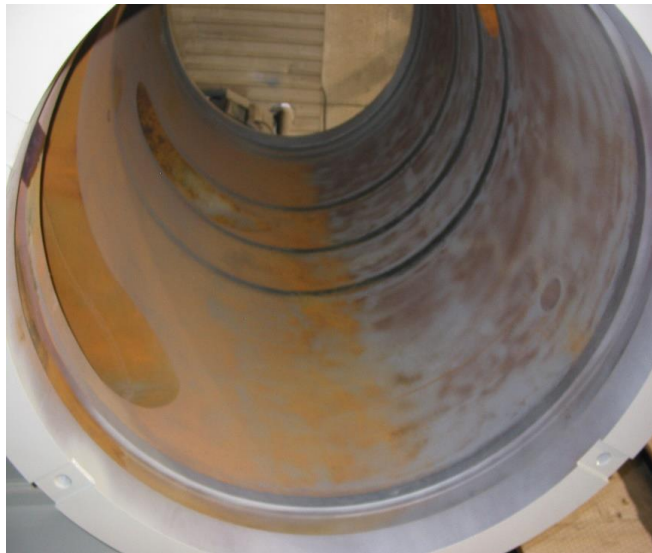
- **Technology Demonstration:** Speeds are too high for traditional beam style machines, better suited to an integrally geared (IG) configuration. An IG configuration will have more seals and more challenging rotordynamics.
- **Pilot Scale:** 10MWth, with a 3.5MWe drive. The smallest scale application that can be applied to a standard beam style compressor casing
- **Commercial Application:** 30-50MWth fit easily within the traditional range of beam style compressors.

Max Cycle Temperature Impact on Cost and Reliability

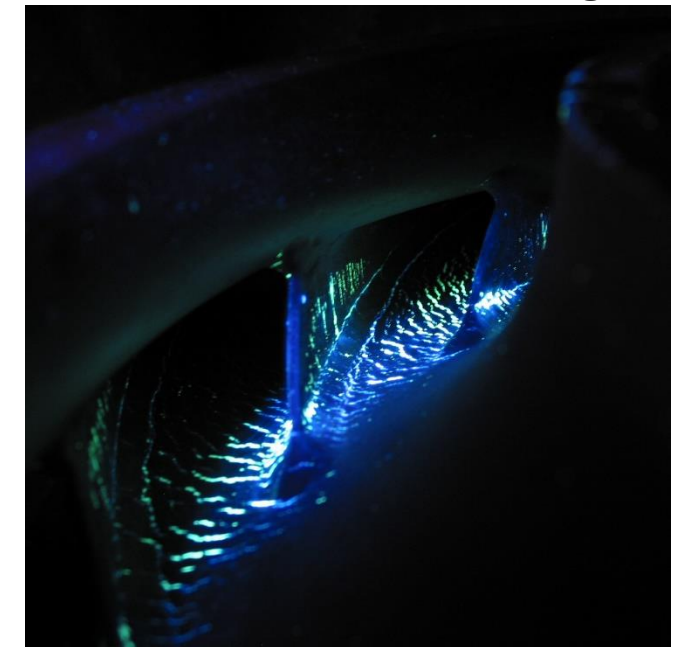
- Moving to higher temp applications requires the integration of **new materials**.
- Higher raw **material costs**
- Full **material performance data** must be established for design; Life assessment, stress-corrosion, creep, etc.
- **Design guidelines** must be established
- **Manufacturing procedures** need to be developed and key personnel trained
- **Supply chain** may not be well established for procuring and producing parts in some materials
- Understand the **reliability** of seals, valves, and instrumentation



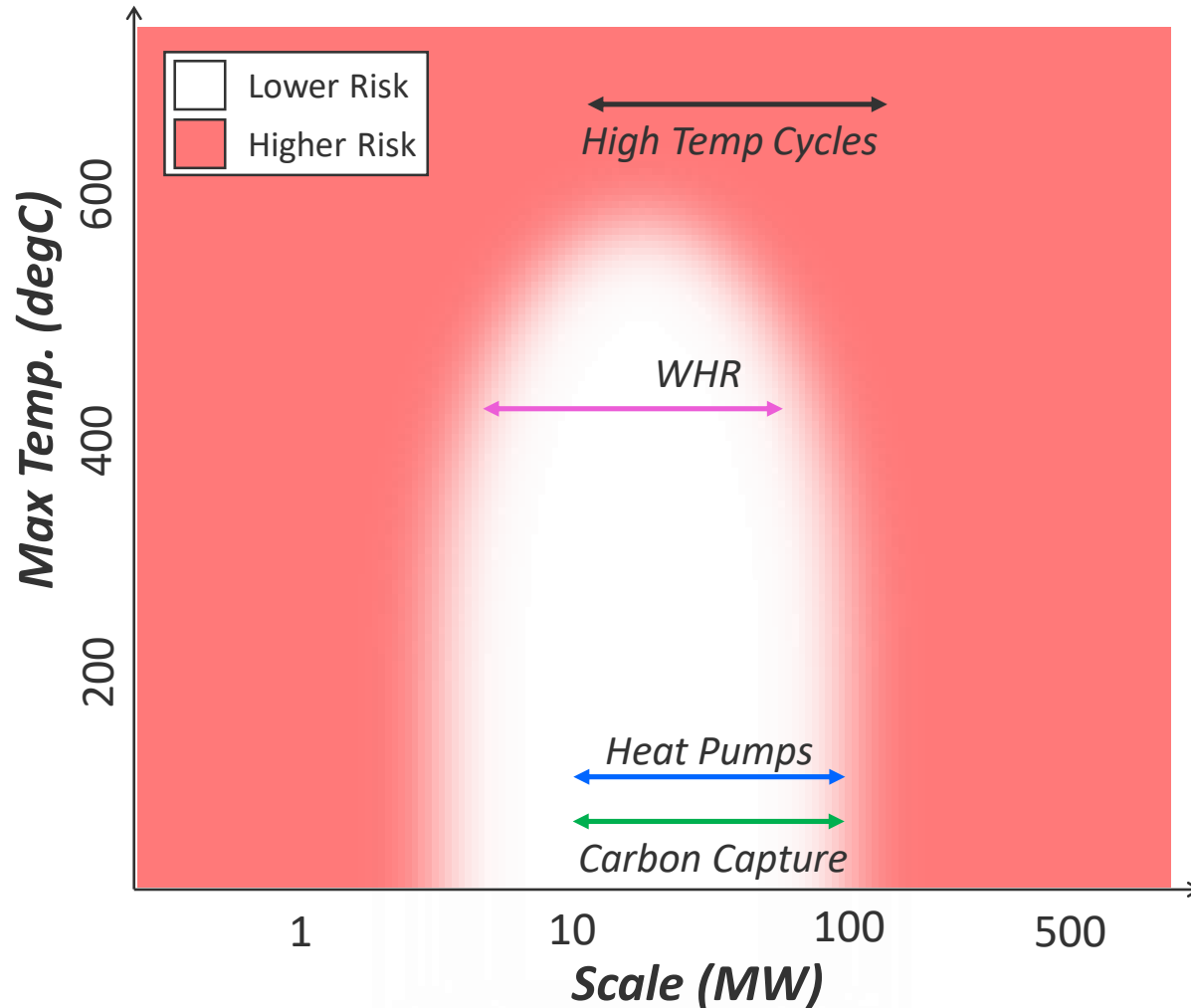
Stress Corrosion Cracking



CO2 Compressor Casing



Balancing Commercialization Risk and Opportunity



☐ Lowest risk applications will be the easiest to commercialize.

- Applications where temperature can be handled with established materials
- Equipment scale fits within current commercial experience

Commercialization Opportunities

1. sCO₂ Heat Pumps (10-100MWth)
2. CO₂ Capture
3. Waste Heat Recovery
4. High Temp Power Generation Cycles