EBARA ELLIOTT ENERGY

Geothermal Energy Machinery and Systems Workshop

November 19, 2024

Karl Wygant – Manager of Compressor Development

Ebara Elliott Energy

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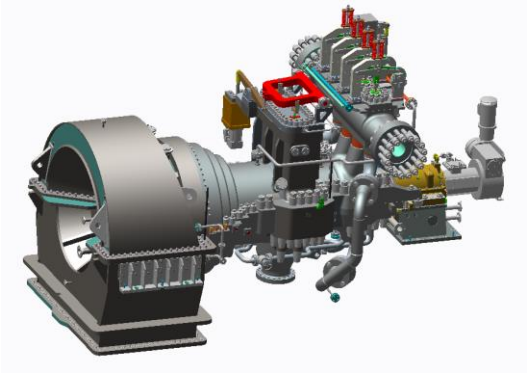
Ebara Elliott Energy Machinery Products

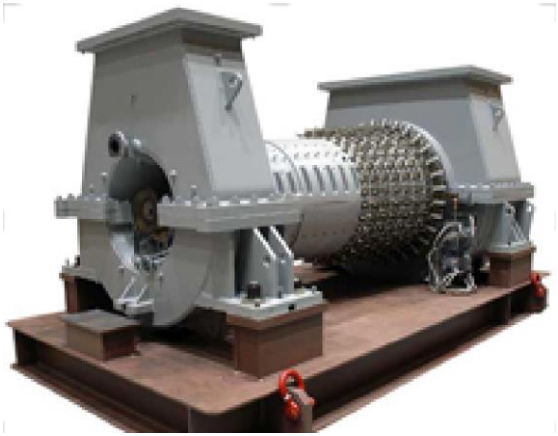
Cryogenic Pumps

Inline Centrifugal Compressors

Cryogenic Expanders



Steam Turbines



Axial Compressors

Single Stage Centrifugal Compressors

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Centrifugal Compressor Products Under Development

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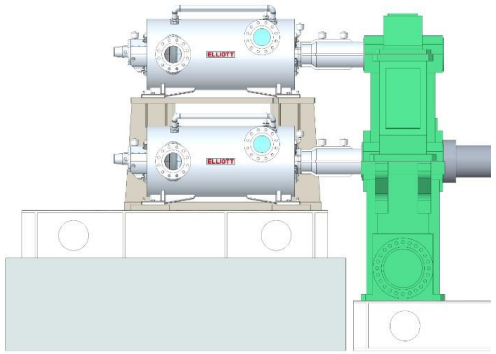
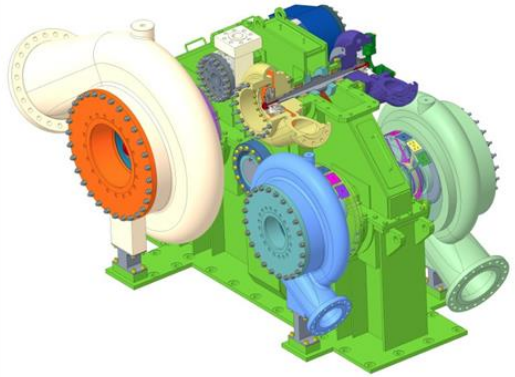


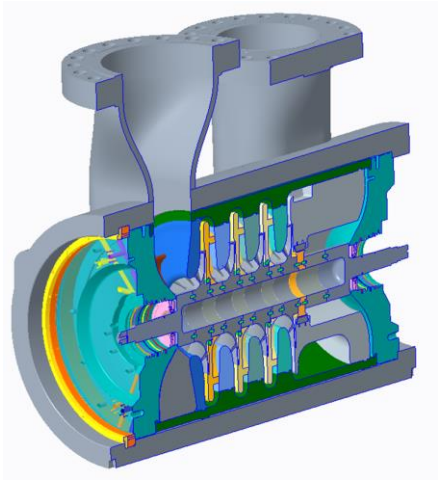
Flex-Op™

Frames	10 MB and 25 MB
Inlet Pressure	0.795 – 1.05 bar (a) (11.5 – 15.2 psia)
Outlet Pressure	149 bar (a) (2,200 psia)
Flow	5,000 – 20,000 lbm/sec (5,000 – 20,000 m^3 / hr)
Inlet Temperature	-29 °C to 50 °C (-20 °F to 122 °F)
Power	260 – 22,360 kW (350 – 30,000 hp)
Gases	Hydrogen



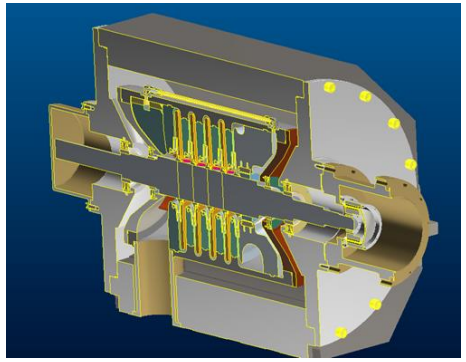
EG (Integrally Geared)

Frames	4 EG-6000 , EG-9000 EG-16000, EG-30000
Inlet Pressure	0.795 – 1.05 bar (a) (11.5 – 15.2 psia)
Outlet Pressure	149 bar (a) (2,200 psia)
Flow	2.2 – 10.5 lbm/sec (H2) (1 – 4.76 kg/sec) 20 – 125 lbm/sec (CO2) (0.454 – 56.7 kg/sec)
Inlet Temperature	-29 °C to 50 °C (-20 °F to 122 °F)
Power	260 – 22,360 kW (350 – 30,000 hp)
Gases	Hydrogen, Carbon Dioxide



H2 Pipeline

Frames	38 MB and 46 MB
Inlet Pressure	37 bar (a) (536 psia)
Outlet Pressure	149 bar (a) (2,200 psia)
Flow	47 – 110 lbm/sec (21.36 – 50 kg/sec)
Inlet Temperature	0 °C to 50 °C (32 °F to 122 °F)
Power	17,829 – 41,888 kW (24,000 – 56,200 hp)
Gases	Hydrogen



Cryogenic Return Gas Blower

Frames	10 MB
Inlet Pressure	1.1 bar (a) (14.65 psia)
Outlet Pressure	2.1 bar (a) (29.2 psia)
Flow	0.10 – 0.12 lbm/sec (0.22 – 0.27 kg/sec)
Inlet Temperature	-230 °C to -250 °C (-382 °F to -428 °F)
Power	38 – 49 kW (51 – 66 hp)
Gases	Hydrogen

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Renewable Energy – Geothermal

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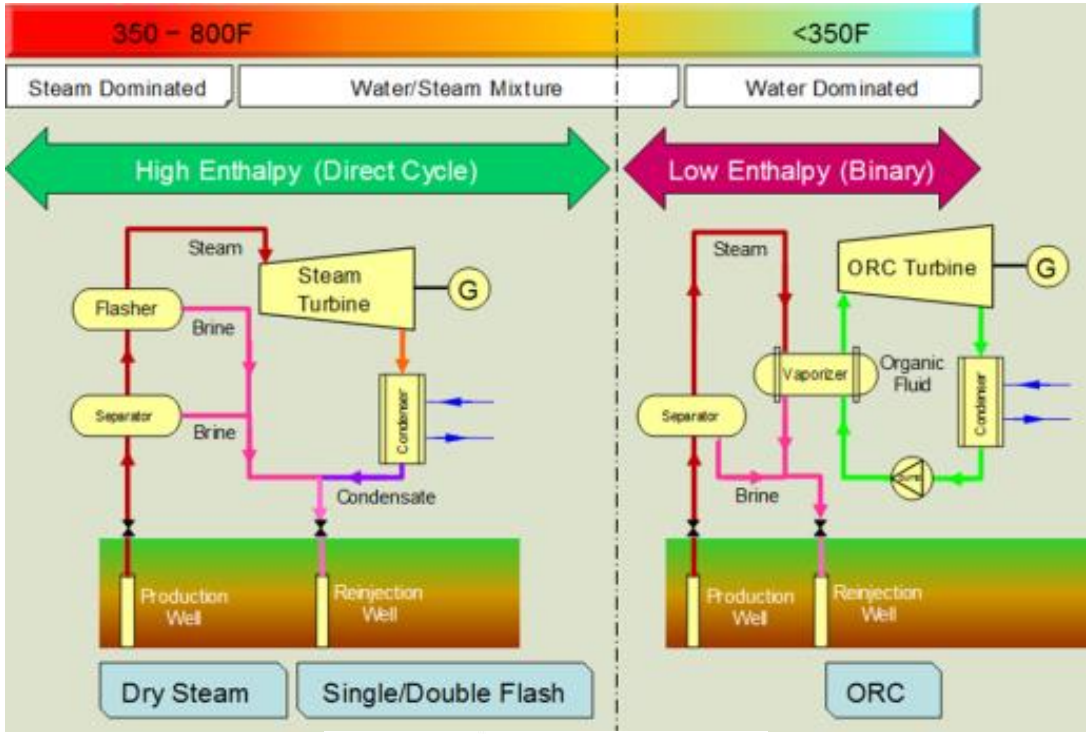
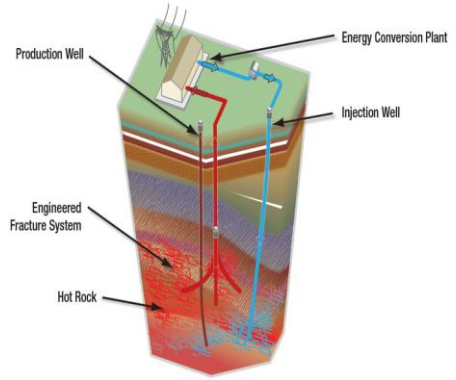
- Conventional:
  - Inlet Temperature 480ºF (250ºC)
  - Power range 2 MW – 30 MW
  - Shallow (<5km)

- Supercritical (sEGS):
  - Inlet Temperature 940ºF (500ºC)
  - Power range 30 MW – 150 MW
  - Ultra-deep (>10km)





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Steam, ORC, and sCO2 Cover a Wide Range of Applications

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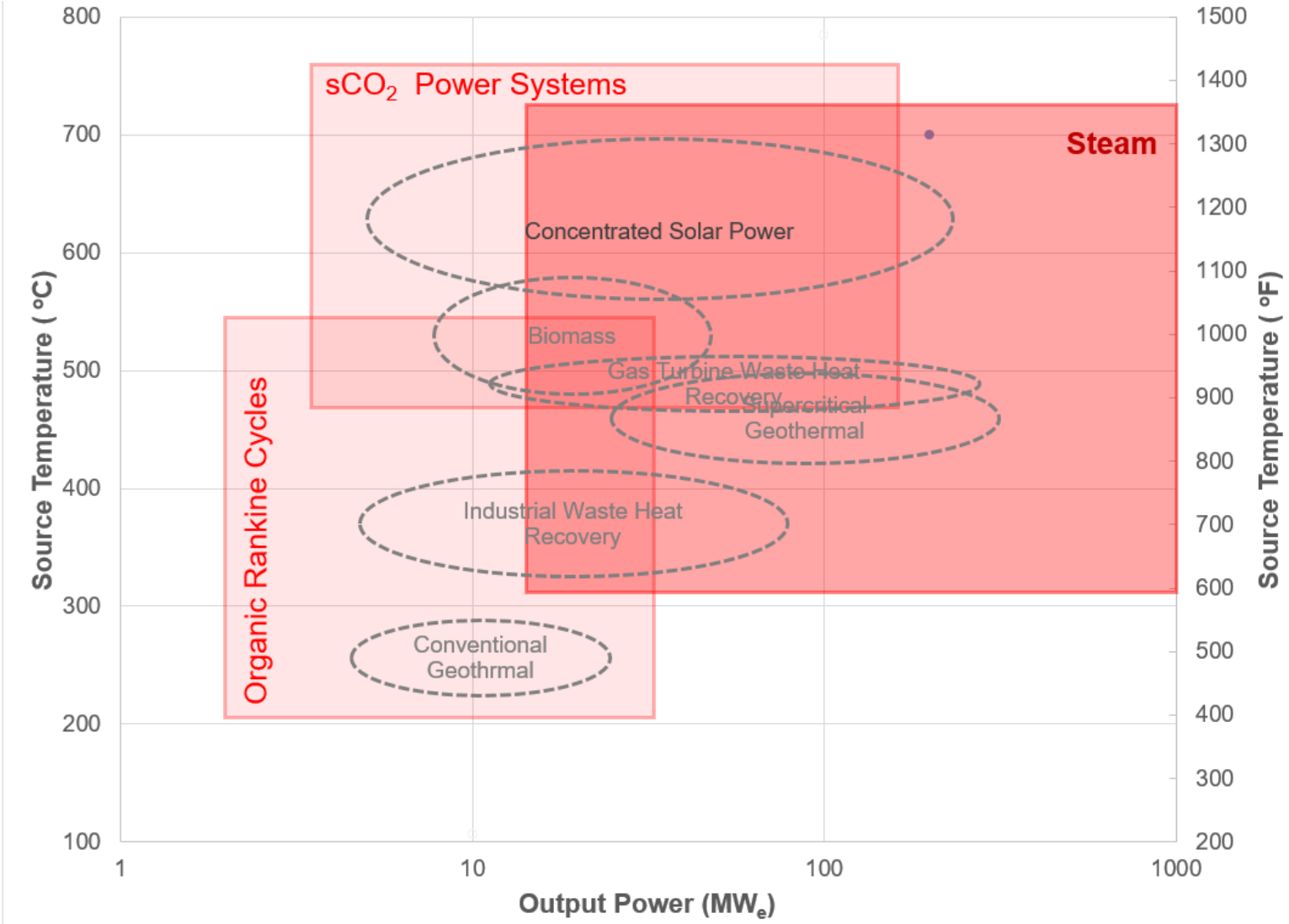

- No one technology covers all applications.
- Steam Turbines still cover a wide range of applications.
- Focus on improving our product ranges and performance to better meet the needs of renewable applications.

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CO_2 Power System

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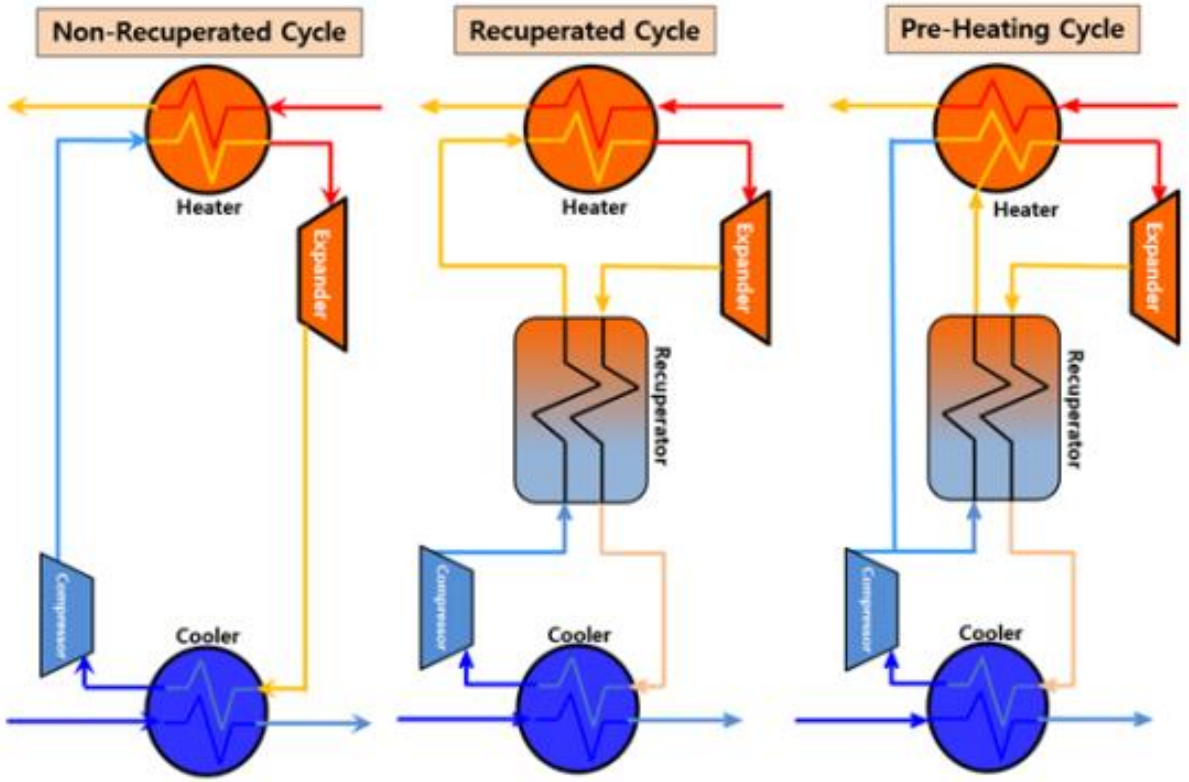
- Range of Cycles from: Simple, Recuperated, Preheating, recompression, re-heat, etc.
- Applications are also varied from: Nuclear, CSP, to WHR.
- Power Levels vary by application. This makes a single case study potentially biasing.
- Key point is that you are not pressuring from atmosphere to Super-critical zone.



Three Cycles for sCO2 of WHR of Gas Turbine

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CO_2 Power System

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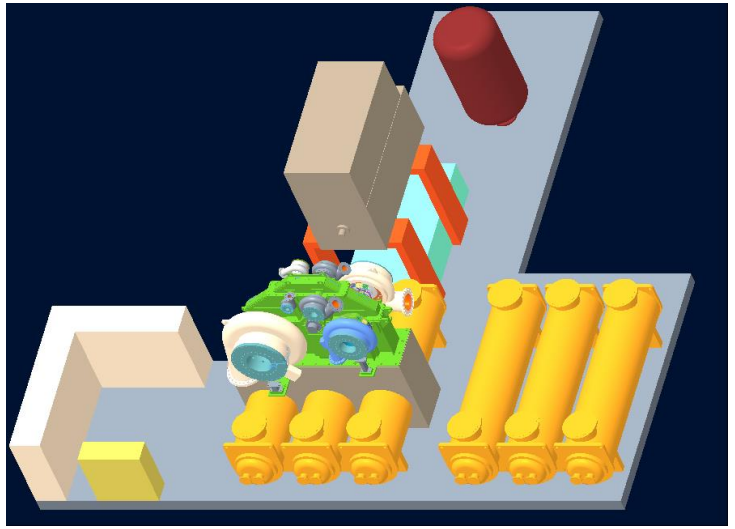
Barrel Compressor (Recompression Cycle)

Design Space	>10MW
Compressor	2 stages
Recompressor	2 stages
Gearboxes	2
Seals	4 seals
Controls	Separate compressor/Recompressor/

Integrally Geared (Recompression Cycle)



Design Space	2-to-25MW
Compressor	2 stages
Recompressor	2 stages
Gearboxes	1
Seals	4 seals
Controls	Integrated mechanical system can complicate controls

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Renewable Energy – Geothermal

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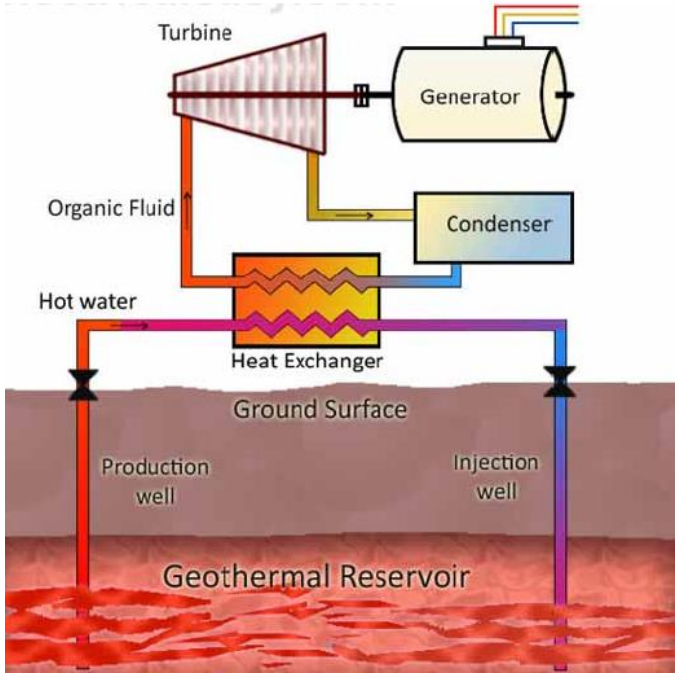
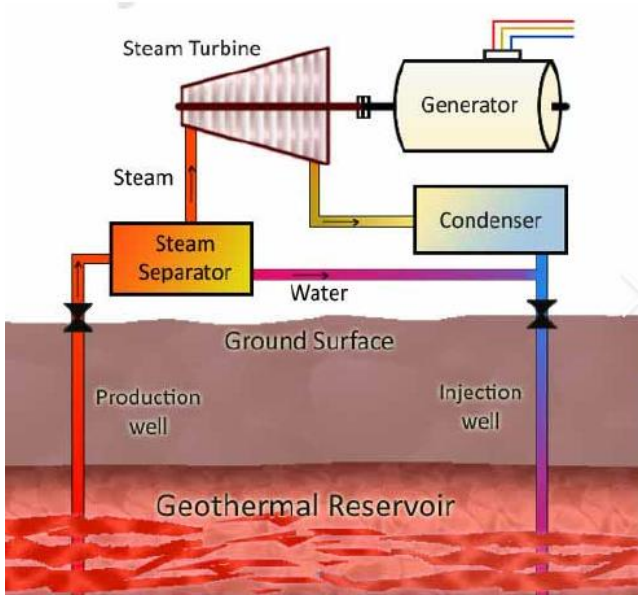
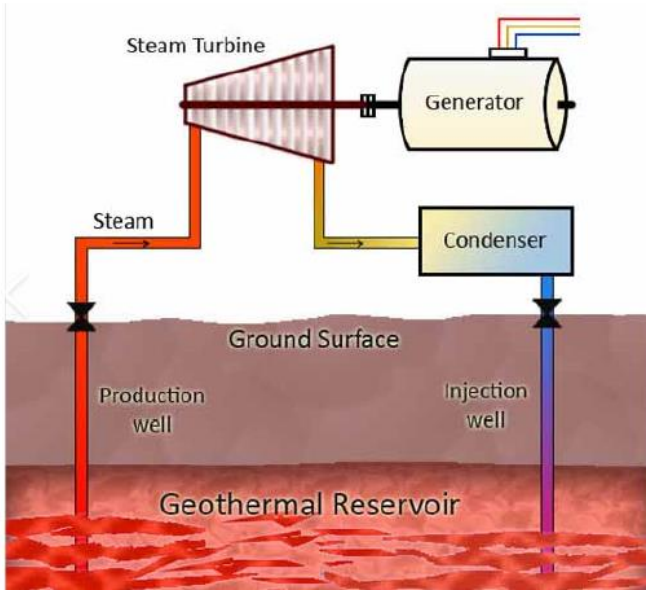


Binary Cycle Plant
1 MW - 50 MW



Flash Steam Plant
Single 0.2 MW - 80 MW
Double 2 MW - 110 MW



Dry Steam Plant
10 MW - 150 MW

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Steam Turbines in Renewable Applications

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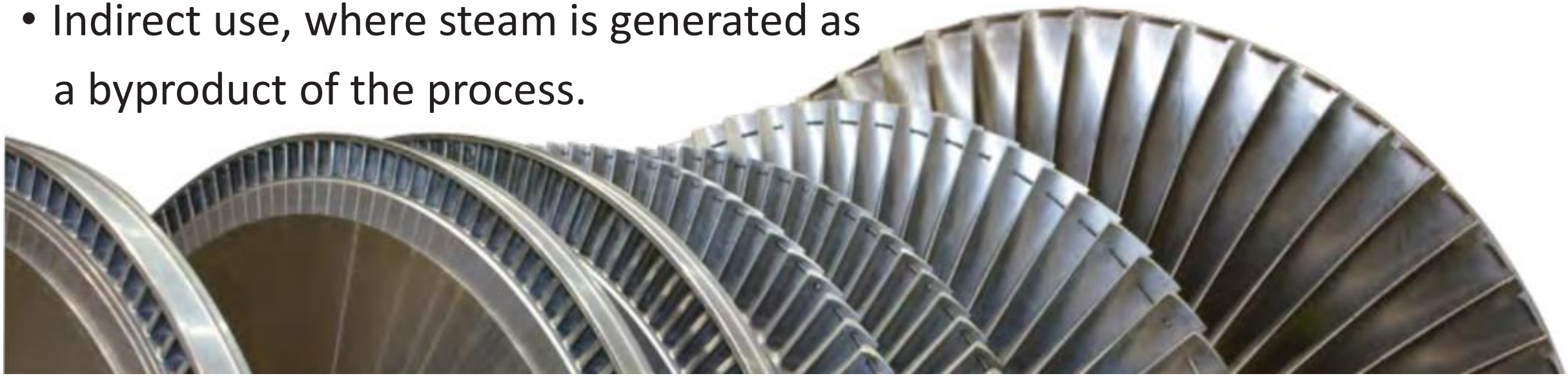
- Steam turbines are easily applied in sustainable applications that generates heat as part of the process.
- Direct use, where steam generation is solely intended to be used as a medium for steam turbine use.
- Indirect use, where steam is generated as a byproduct of the process.



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Steam Turbine Basics

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Thermodynamic Advantages

- Can turn a large percentage of heat energy available into mechanical work
- Capable of producing high work outputs at relatively good efficiencies
- Maintains good efficiencies at reduced loads
- Allows for flexible process heat balances via extractions and/or inductions

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Some Advancements to Improve Performance/Cost/Reliability

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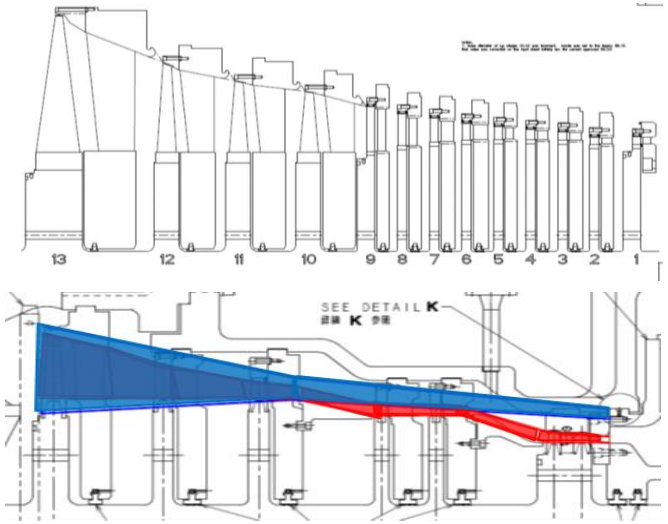
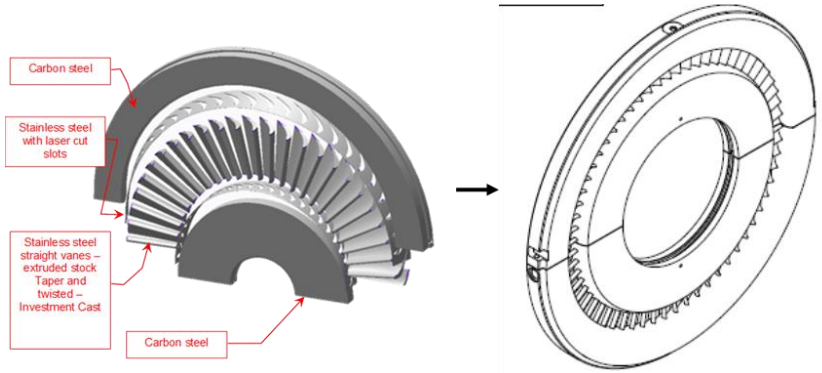
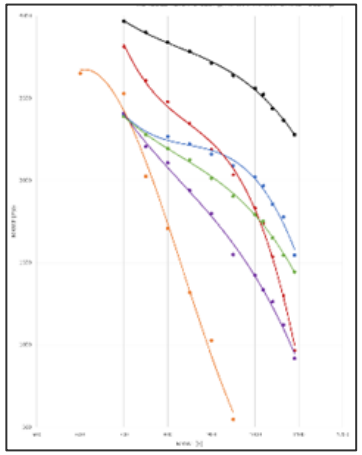
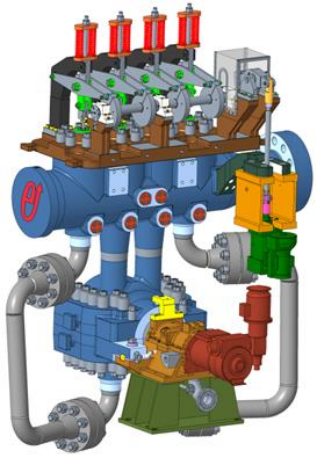
- Automated customized flow path for optimum aerodynamic offering based upon specified operating conditions.



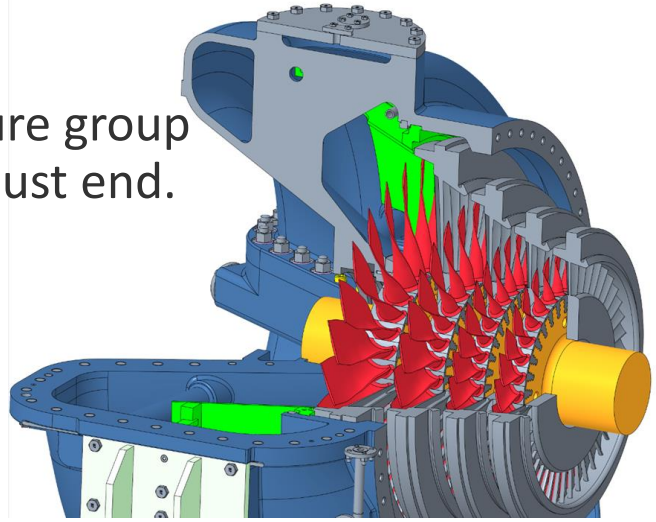
- One piece diaphragm construction







- High efficiency low pressure group stages with diffusing exhaust end.



- Super high pressure (2200psi / 1019°F) casing designs with pressure vs. temperature mapping.

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Summary

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- sCO2 Power Systems have applications in Geothermall systems.
- Global turbine generator market was predominantly large-scale (>100 MW) fossil-fuel technologies and “standard” (fixed speed) units.
- The turbine generator market is changing with the shift to renewables, gas turbine power plants, waste heat recovery, and decentralization of power supply.
- “Small” 10-150 MW steam turbines are a growing market and offer a new opportunities.
- There are additional opportunities for turbines/expanders in modifications to existing sites for energy improvements.

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