Hanwha Power Systems

SwRI
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IPER Technology Workshop

Minimizing CO_2 leakage for Closed Loop sCO_2 Cycles and CO_2 Compression

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Why sCO_2?

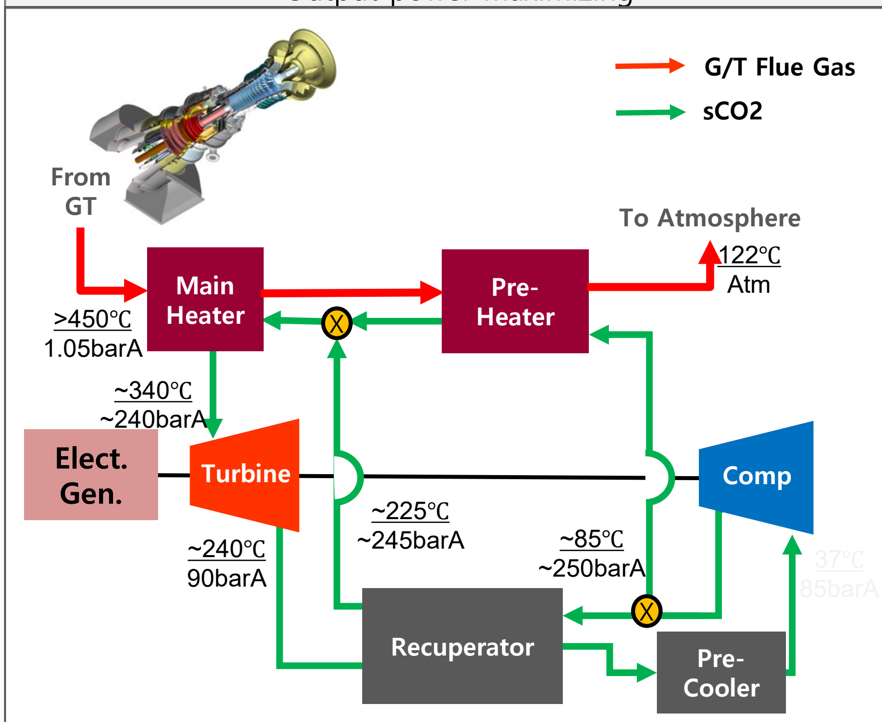
Use the Bad Guy to do Good

Representative sCO2 System Cycles

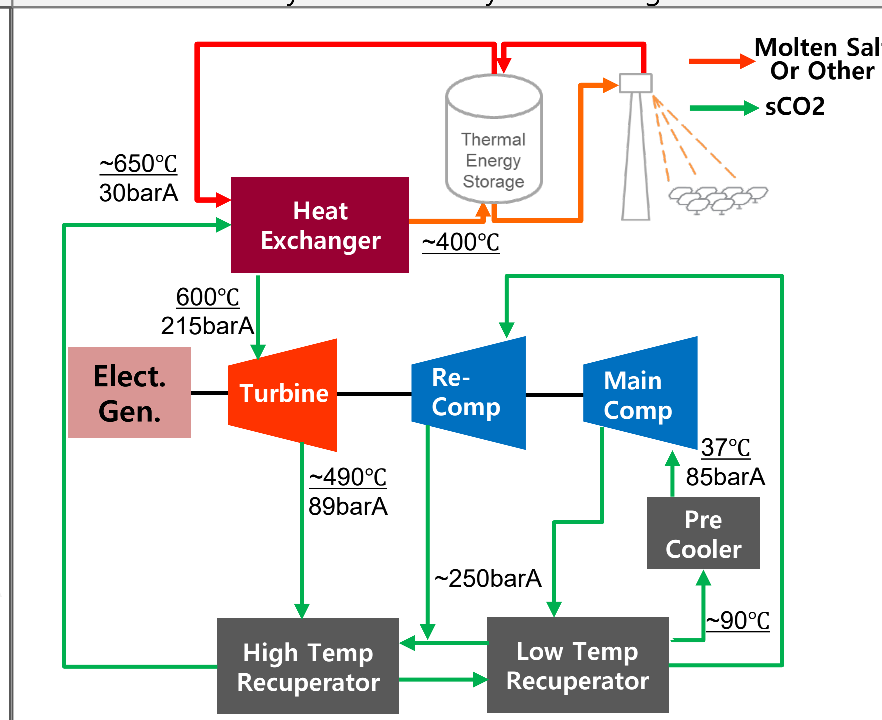
Cycle Features for WHR & CSP/MMR Applications

- WHR[1] : Power output maximized in the cycle by recovering waste heat otherwise lost to atmosphere.
- CSP/MMR[2]: System efficiency maximized in the cycle using high TIT (Turbine Inlet Temperature) by maintaining the high temperature of the heat source. (Heat source is closed-loop.)

WHR Cycle (Pre-Heating)
* Output power maximizing



CSP/MMR Cycle (Re-compression)
* System efficiency maximizing



1) WHR : Waste Heat Recovery
2) CSP/MMR - Concentrated Solar Power / Micro Modular Reactor

Closed Loop sCO_2 Cycle for CSP

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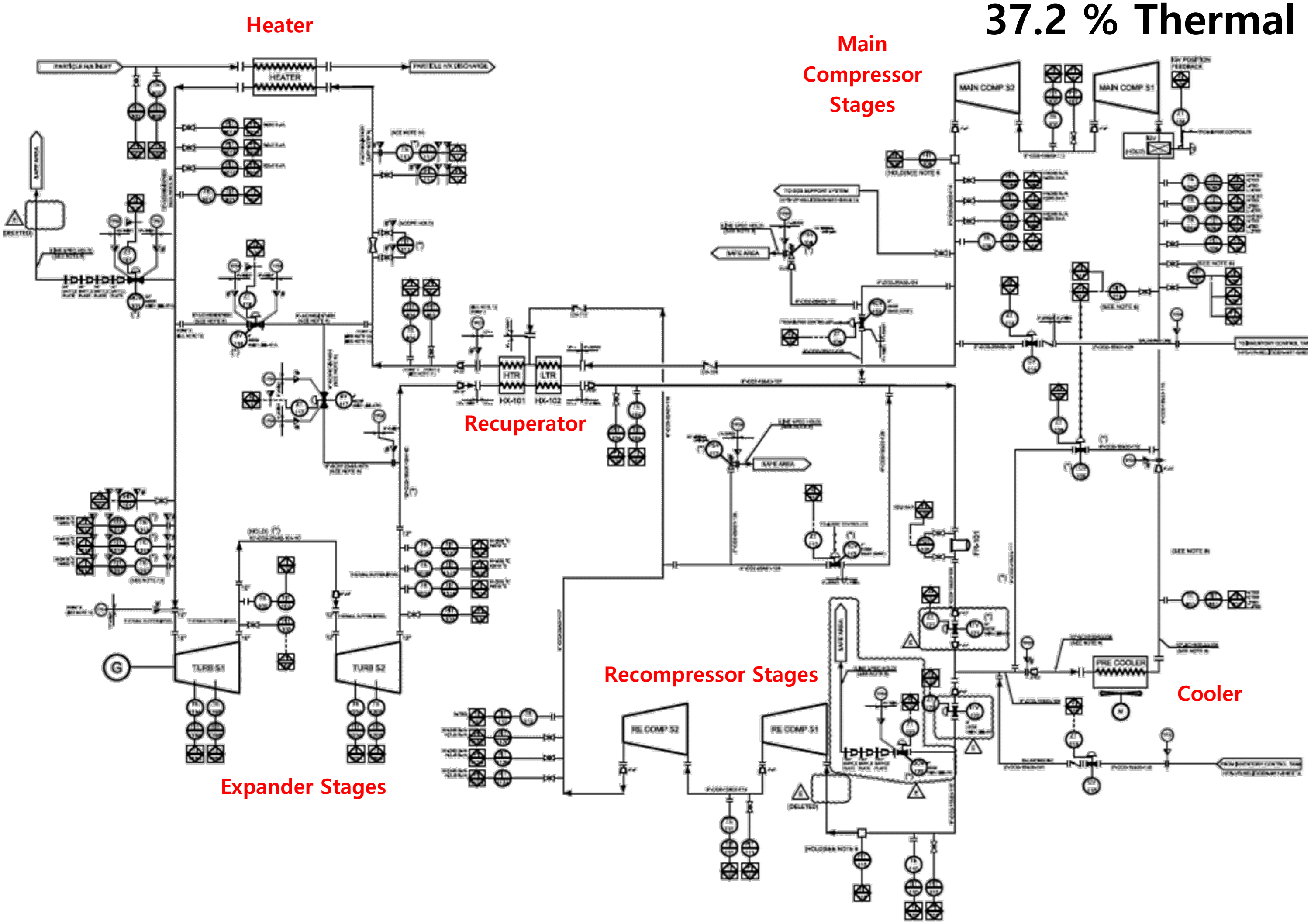
sCO_2 Recuperated Recompression Brayton Cycle

85 bar ➔ 225 bar, 37 C ➔ 600 C

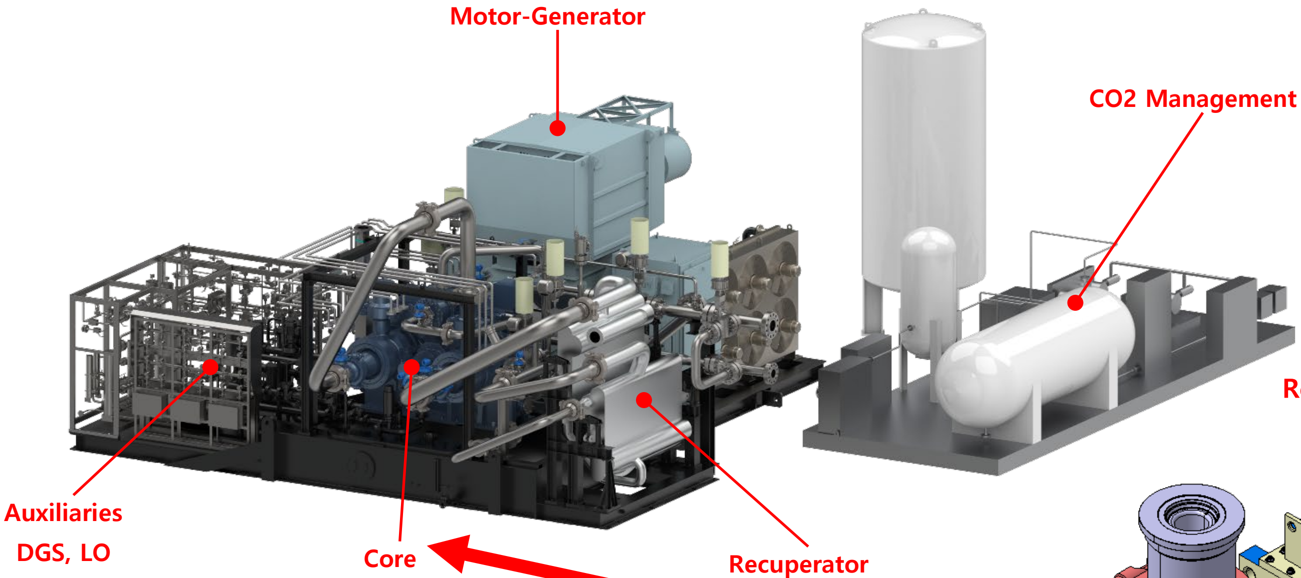
99.9% CO_2 (Food Grade)

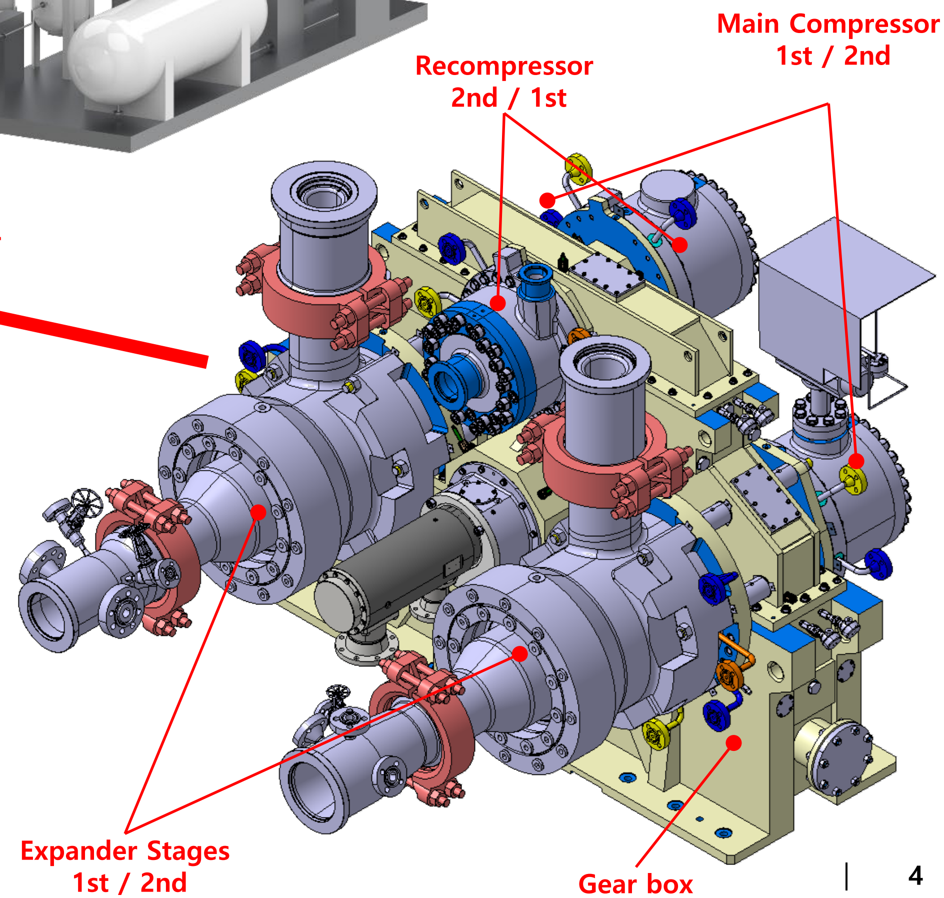
5 MWe Net Power Output

37.2 % Thermal Efficiency



Closed Loop sCO_2 Cycle Machinery





sCO_2 Recuperated <u>Recompression</u> Brayton Cycle

Power Block Components

Closed Loop sCO_2 Cycle for WHR

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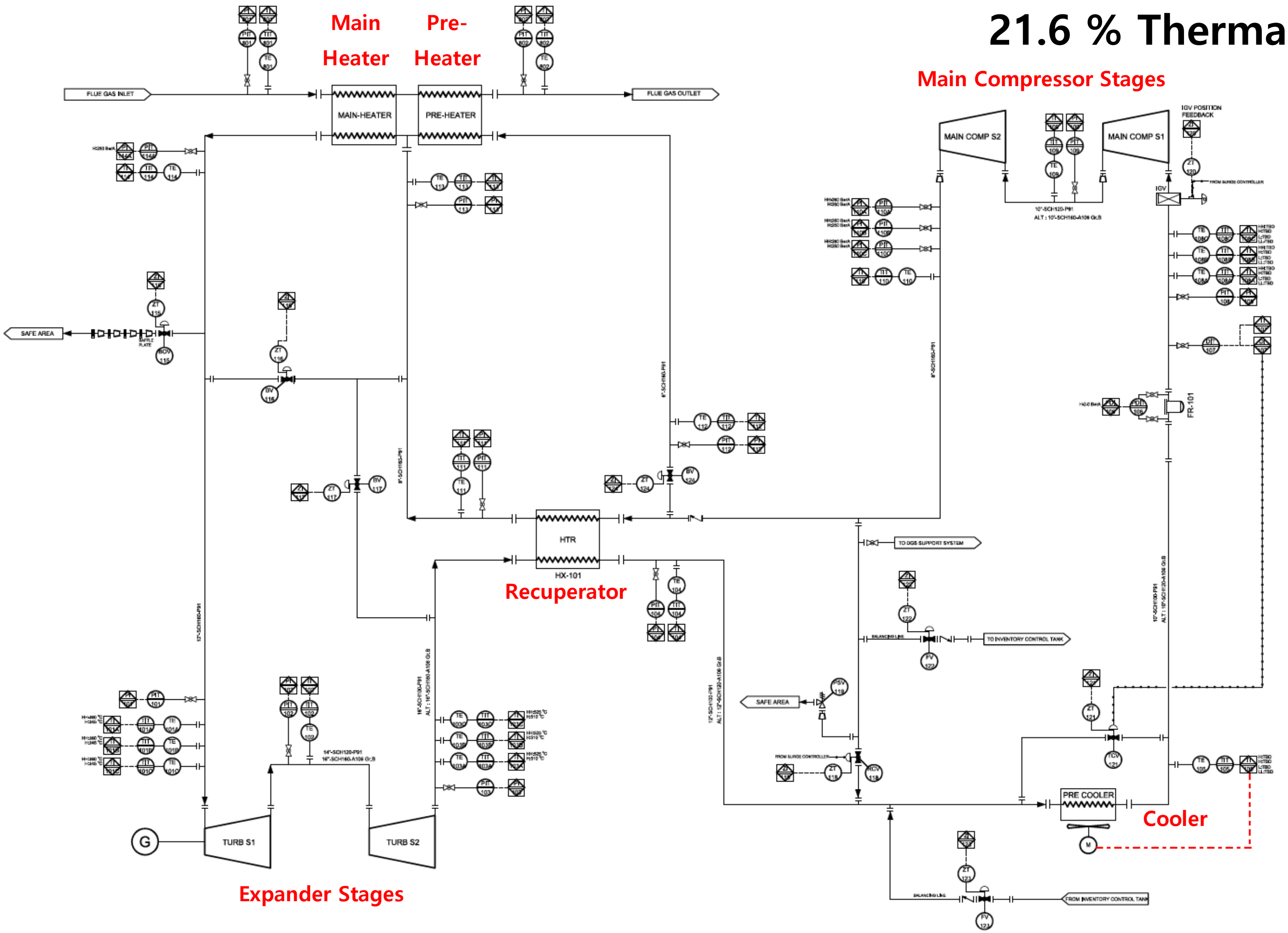
sCO_2 Recuperated <u>Pre-Heating</u> Brayton Cycle

85 bar ➔ 250 bar, 37 C ➔ 350 C

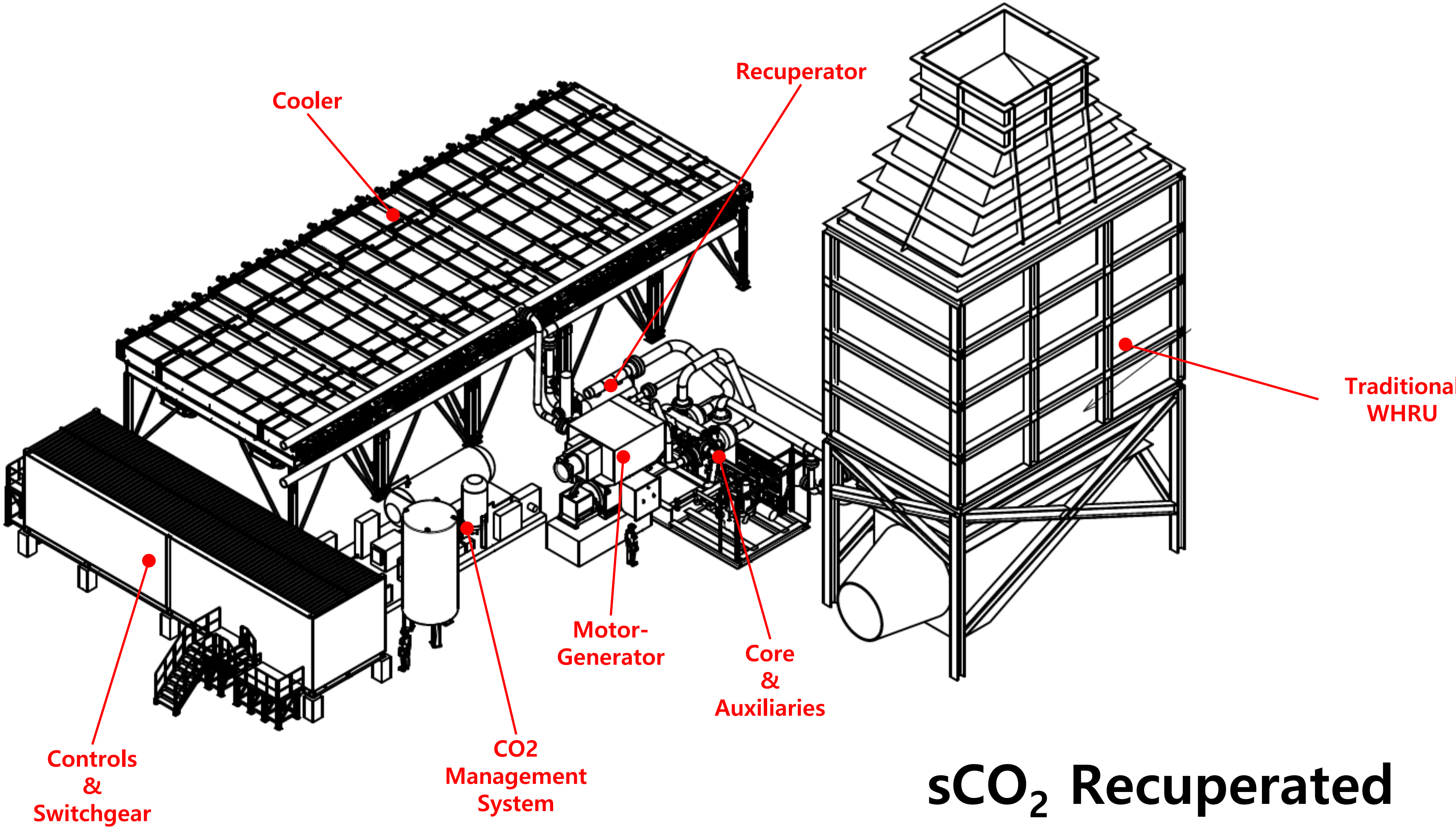
99.9% CO_2 (Food Grade)

5.5 MWe Net Power Output

21.6 % Thermal Efficiency



Closed Loop sCO_2 Cycle Machinery



sCO_2 Recuperated

Pre-Heating Brayton Cycle

Layout 1

Closed Loop sCO_2 Cycle Machinery

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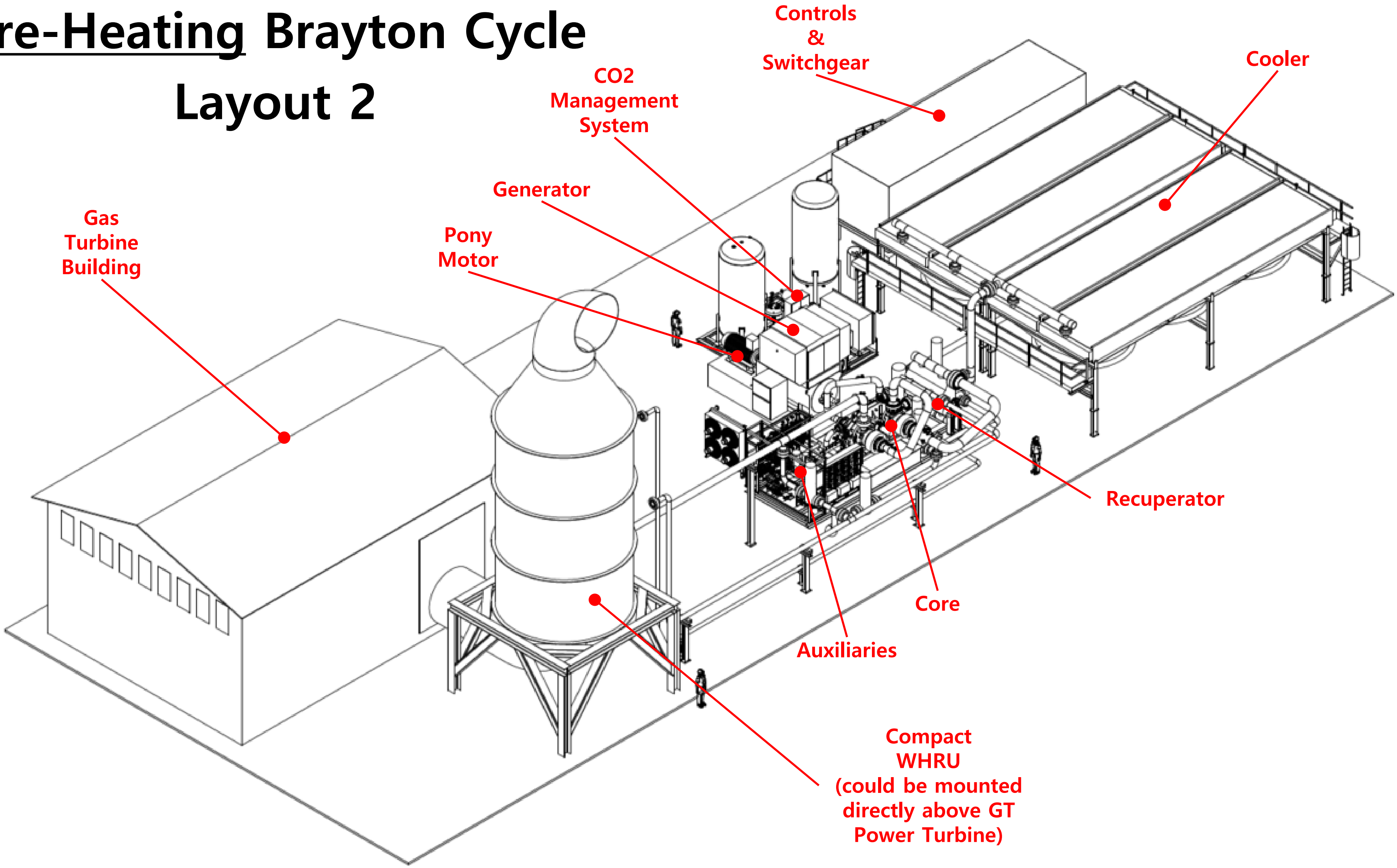
sCO_2 Recuperated
Pre-Heating Brayton Cycle
Layout 2



Do the sCO_2 Cycles Emit CO_2?

sCO_2 Compander Sealing System

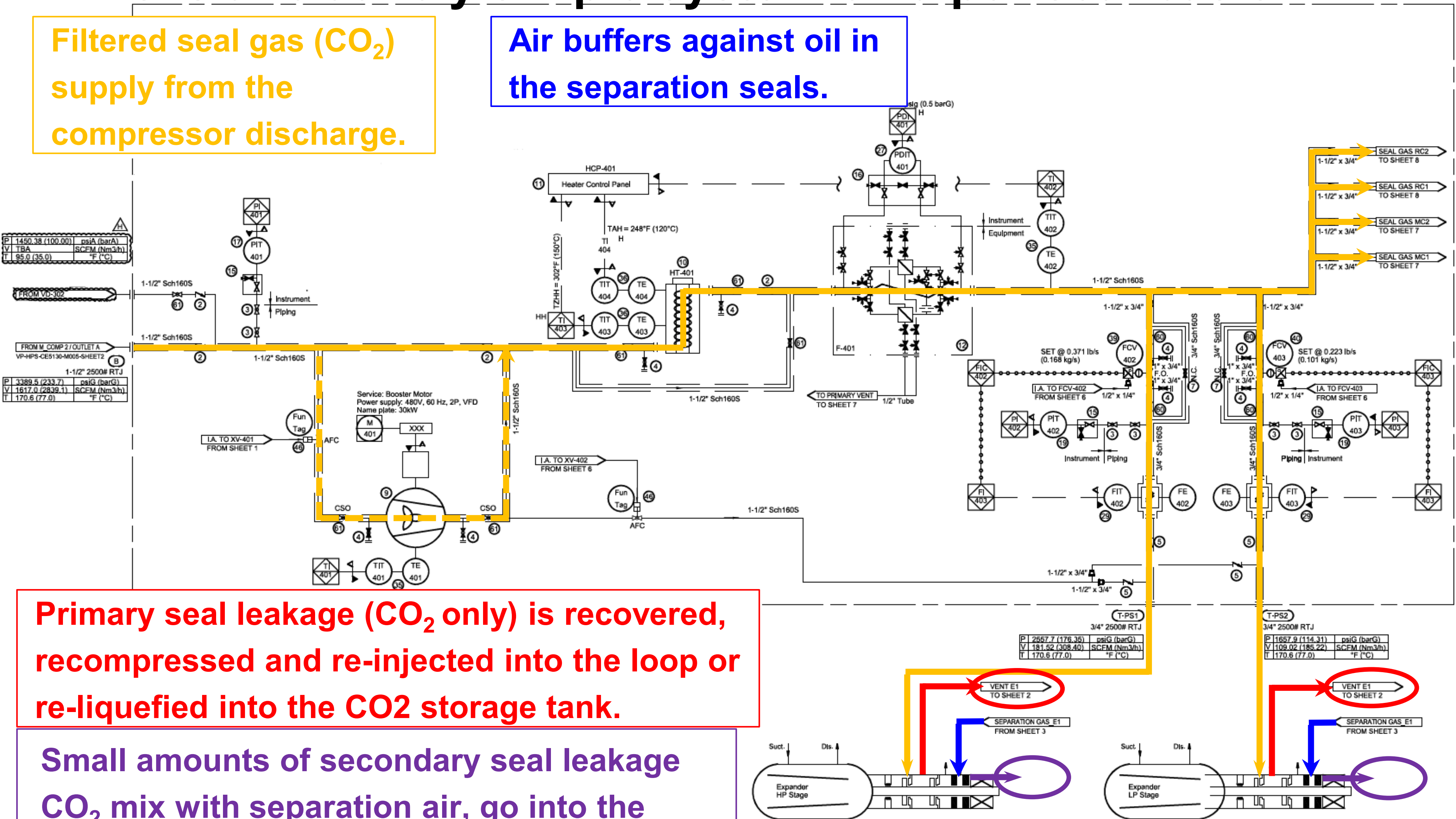
- Face Sealing Systems (Dry Gas Seals) are used to minimize the leakage from the shaft seals.
- Tandem seals are used as they provide a means to recover >95% of the primary seal leakage instead of venting to atmosphere.
- This is particularly necessary in closed loop sCO_2 cycles where the leakage depletes the inventory of CO_2 within the loop.
- Operating cost is reduced as much less CO_2 needs to be replenished.
- The leakage also imposes a loss in net power of the system as the flow consumes compression power but by-passes the expansion stages without doing meaningful work.
- Conversely, the supply of clean filtered gas to the expanders does provide some power recovery and is also used for cooling.
- Process Side Buffering or recovering from Intermediate Buffering with another gas (e.g. N_2) does not work because it dilutes the CO_2 in the loop and negatively affects performance of the system.

Face Sealing Systems (Tandem)

This is a relatively simple system on a per-seal basis.

Filtered seal gas (CO_2) supply from the compressor discharge.

Air buffers against oil in the separation seals.



Primary seal leakage (CO_2 only) is recovered, recompressed and re-injected into the loop or re-liquefied into the CO2 storage tank.

Small amounts of secondary seal leakage CO_2 mix with separation air, go into the gearcase and then to atmosphere via the Lube Oil Reservoir vent.

Face Sealing Systems Leakage

So how much leakage are we talking about?

Primary Seal							
Leakage Rate - kg/year	Total	MC1	MC2	RC1	RC2	E1	E2
Expected	681,592	102,862	154,813	75,848	112,213	145,462	90,394
Guaranteed	1,024,467	154,813	232,739	114,291	168,320	218,193	136,111

Secondary Seal							
Leakage Rate - kg/year	Total	MC1	MC2	RC1	RC2	E1	E2
Expected	6,234	1,039	1,039	1,039	1,039	1,039	1,039
Guaranteed	9,351	1,559	1,559	1,559	1,559	1,559	1,559

Based on full-time operation.

However, staying stopped but pressurized will also result in leakage, though lower.

Primary Seal Leakage Recovery

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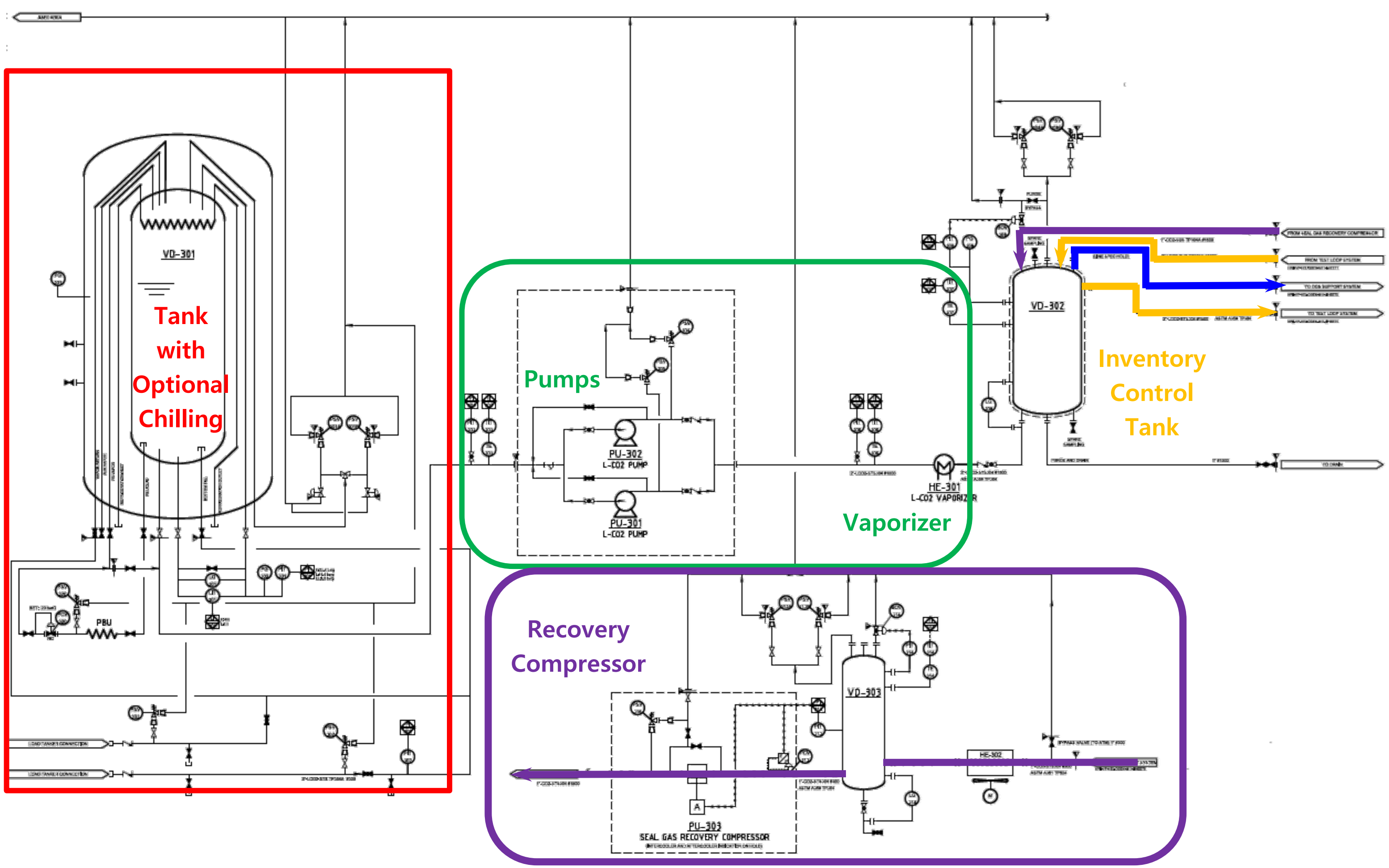
Requirements: Minimize Emissions, Reduce OPEX

- L-CO_2 Storage Tank
- L-CO_2 Pump and Vaporizer
- Inventory Control for Off-Design Optimization
- Primary Vent Leakage Recovery Compressor
- >99% Leakage Recovery Saves ~$80k/ year cost of replenishment

CO_2 Management System works with typical DGS support for tandem seals without intermediate laby, but adds a few enhancements…



- Plus Emergency Cooling Flow for Expander Seals

Where Can We Apply sCO_2?

Potential Applications of sCO_2 Power Systems:

- **Gas Turbine Waste Heat Recovery –**
  - Pipeline simple cycle GTs.
  - GT-driven Shipping.
  - Offshore/FPSOs?
- **Other –**
  - Concentrated Solar Power with Heat Storage
  - Furnace/Kiln/Incineration Exhausts
  - MMR and other Nuclear Applications.
  - Anywhere a Steam Bottoming Cycle could be used.

And Seal Leakage Recovery?

Potential Applications of Seal Leakage Recovery:

- **Any of the sCO_2 Power Systems described –**
  - WHR
  - CSP
  - Furnace/Kiln/Incineration
  - MMR/Nuclear
- **Other –**
  - CO_2 Compression for EOR/CCUS
  - Why limit its use to sCO2 Systems?

Thank-you!

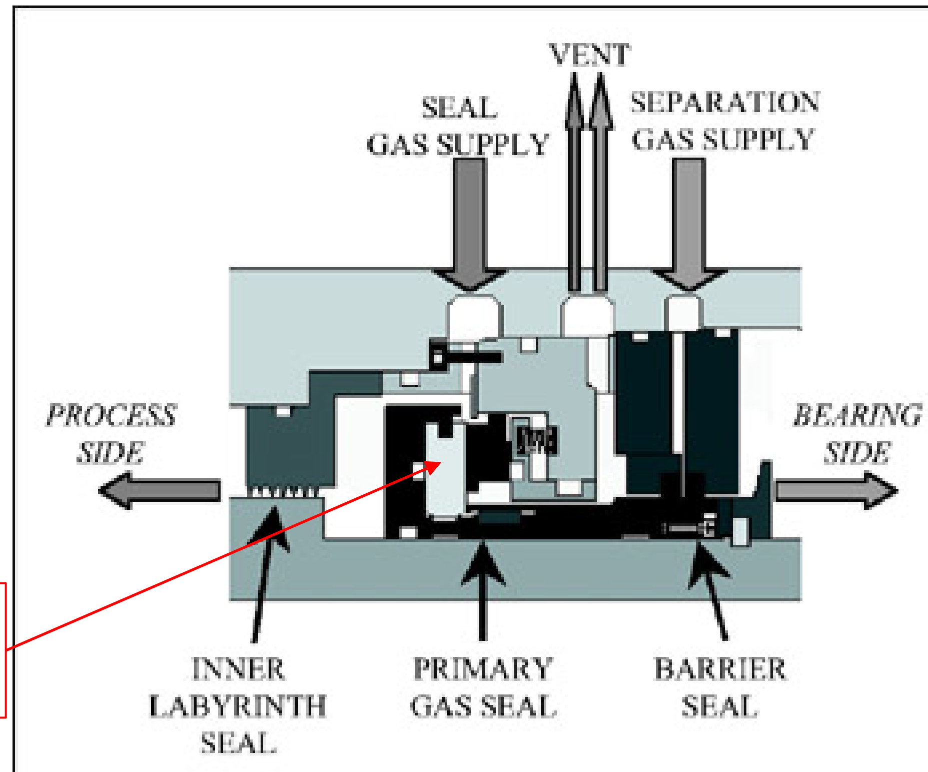
Back-Up

Face Sealing Systems Recap

Dry Gas Seals

- Used extensively in In-Line and Integrally Geared Compressors
- Tight axial running clearance between seal faces ➔ Very Low Leakage
- Axial travel limits but usually sufficiently generous. Self-adjusting.
- Not very tolerant of contamination – requires clean buffer both sides (oil and process).
- Very high pressure capability.
- No known rotordynamic effects.

Rotating Ring



Face Sealing Systems

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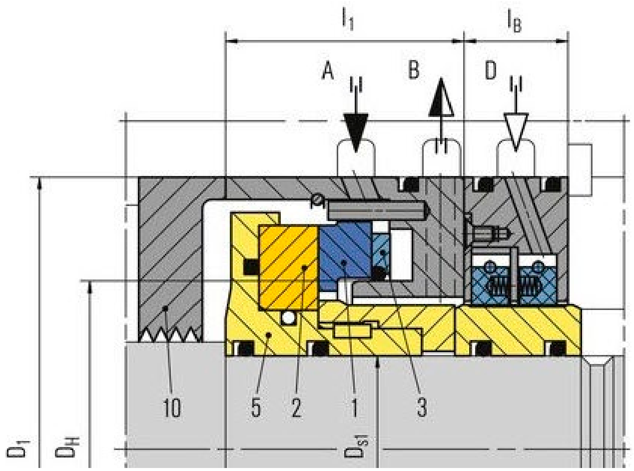
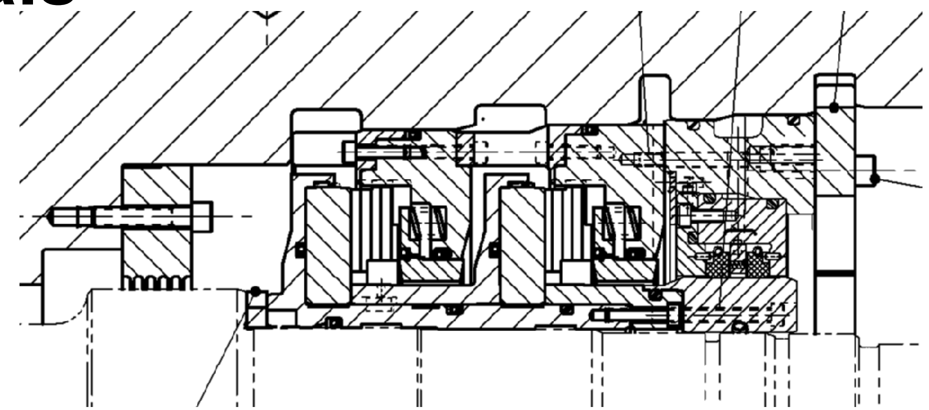
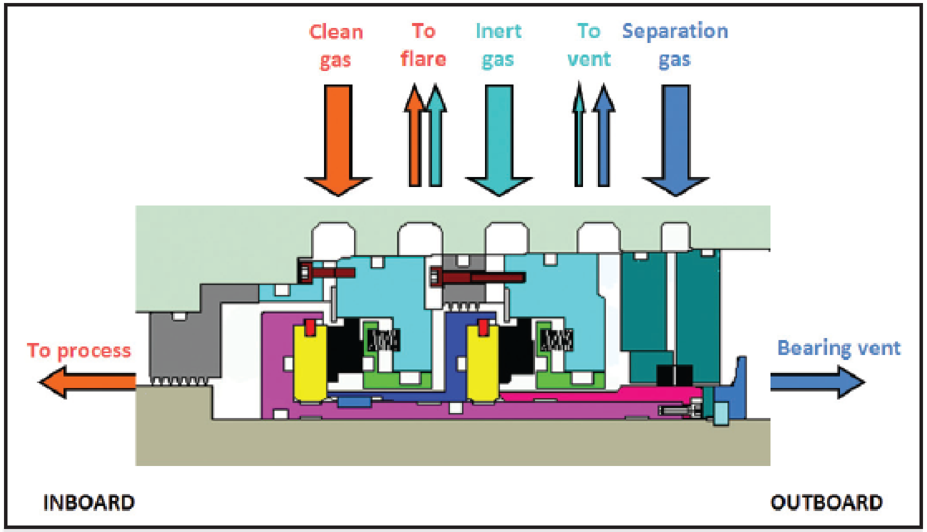
Variations of Dry Gas Seals



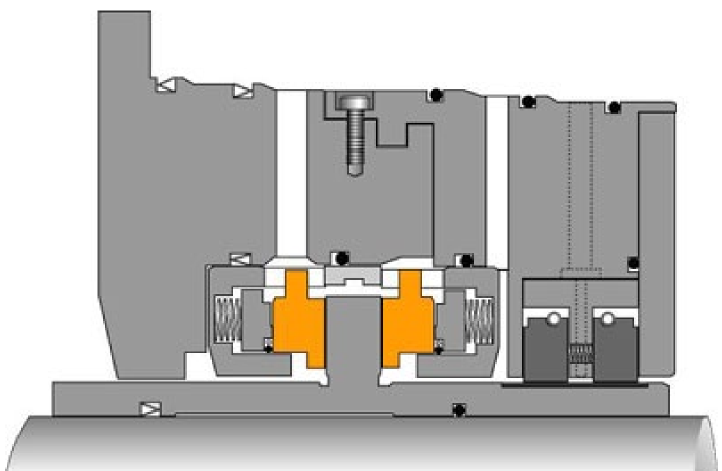
Single



Tandem w/o Intermediate Laby



Tandem with Intermediate Laby

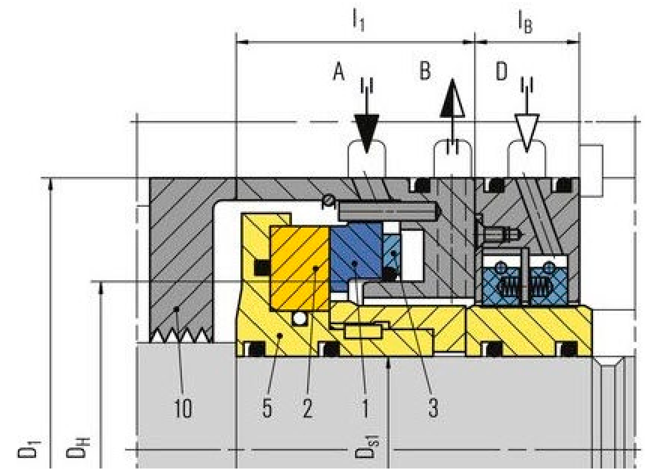


Double

Face Sealing Systems

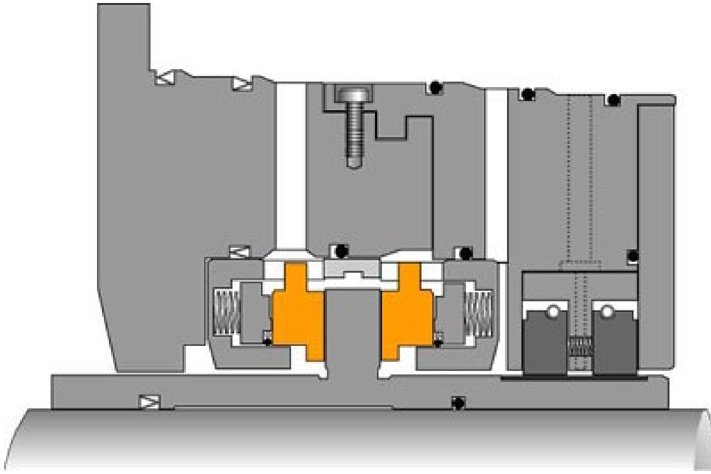
Single Dry Gas Seals

- Used in non-flammable/toxic applications – no back-up sealing element.
- Require a high pressure clean gas supply to the inboard laby.
- Have the shortest axial length – good for rotordynamics.



Double Dry Gas Seals

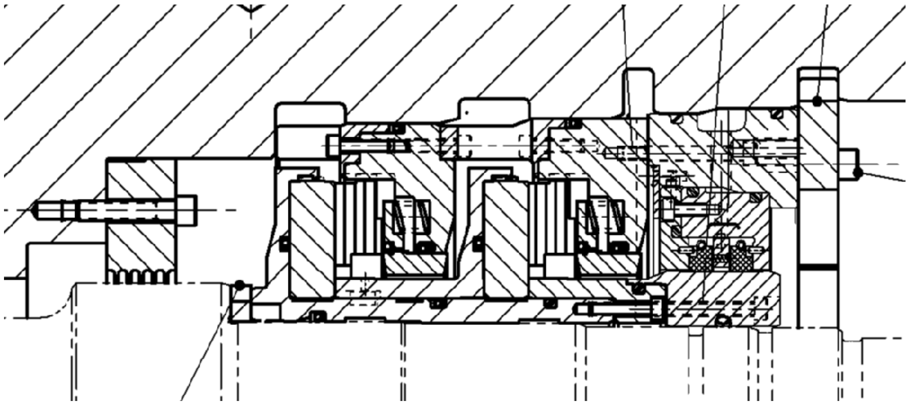
- Used in toxic applications (sour gas).
- Have a shorter axial length than tandem.
- Can be zero process gas leakage to atmosphere - requires a high pressure clean and inert gas supply to the seal.
- Require a high pressure clean gas supply to the inboard laby.



Face Sealing Systems

Tandem Dry Gas Seals without Intermediate Laby

- Used in flammable/toxic applications – back-up sealing element.
- Require a high-pressure clean gas supply to the inboard laby.
- Longer axial length affecting rotordynamics.
- Process gas can leak to atmosphere.



Tandem Dry Gas Seals with Intermediate Laby

- Same attributes as above, except.
- Requires low pressure clean and inert gas supply to intermediate laby.
- No process gas leakage to atmosphere (if primary leakage gas is recovered or flared).