Supercritical CO_2 Turbomachinery Configuration and Controls for a Zero Emission Coal Fired Power Plant: System Off Design & Control of System Transients

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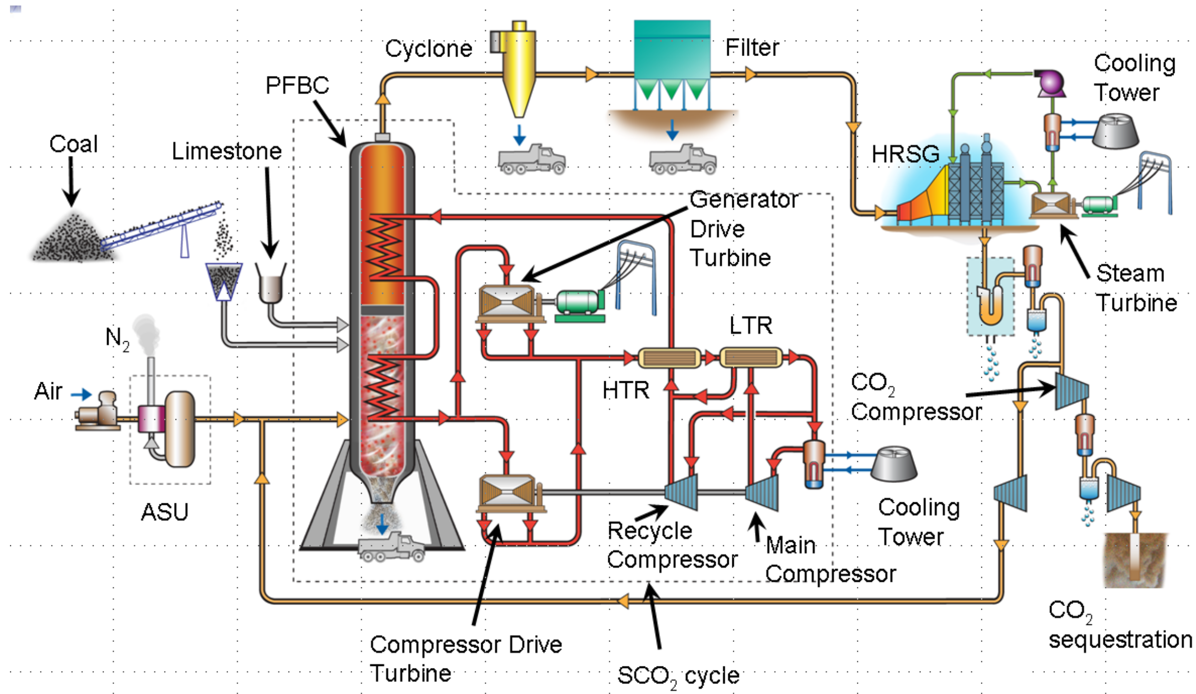
Introduction/Background

- **SCO_2 Recompression Brayton cycle efficiencies have been analytically shown to be very attractive**
  - Relative to an atmospheric oxy-fired supercritical steam pulverized coal plant with carbon capture
- **Previous phase defined a reference plant with a fossil heat source and identified development needs**
  - Study completed for Leonardo Technologies, Incorporated (LTI)
- **Objective of this effort was to analyze transient operation and identify any additional development needs**
  - Start-up
  - Shut-down
  - Partial load operation

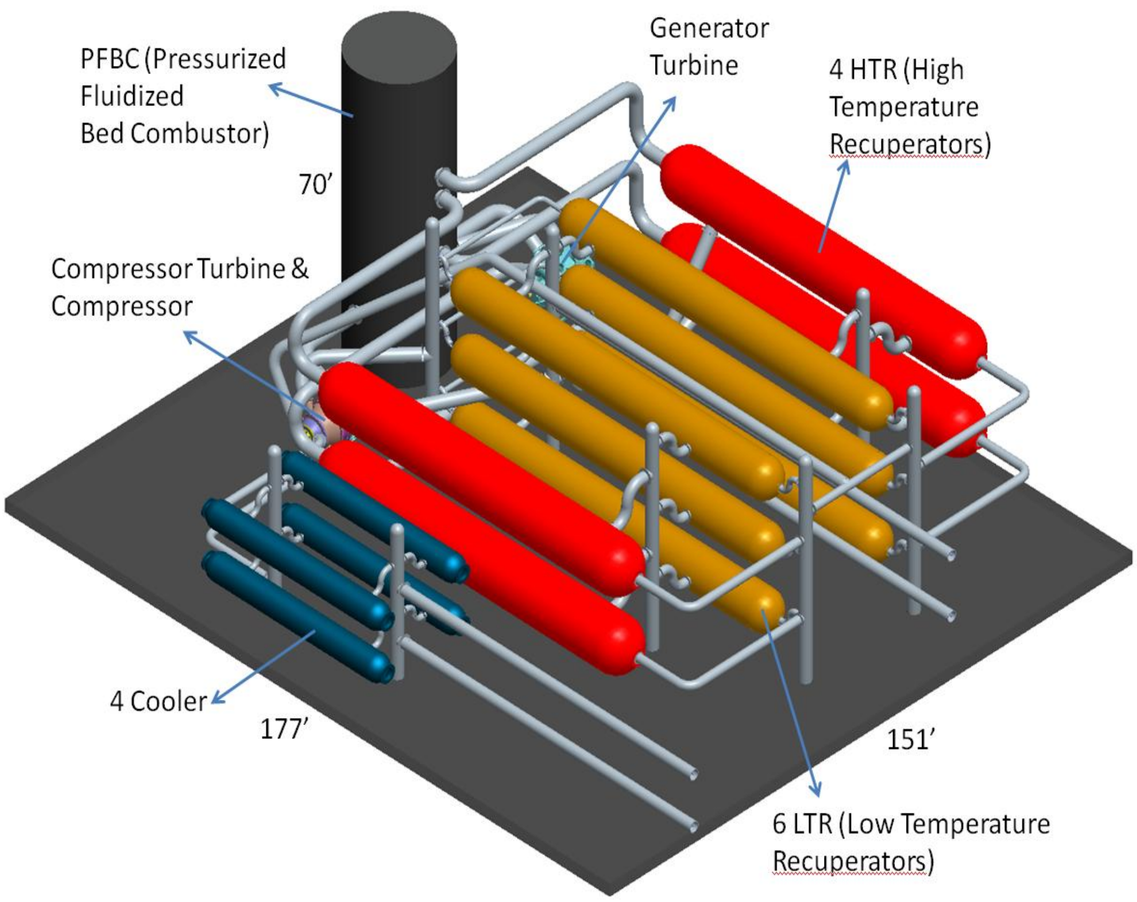
Reference Fossil Fueled Plant

- **550 MWe with Oxy-Fired Pressurized Fluidized Bed Combustor (PFBC)**



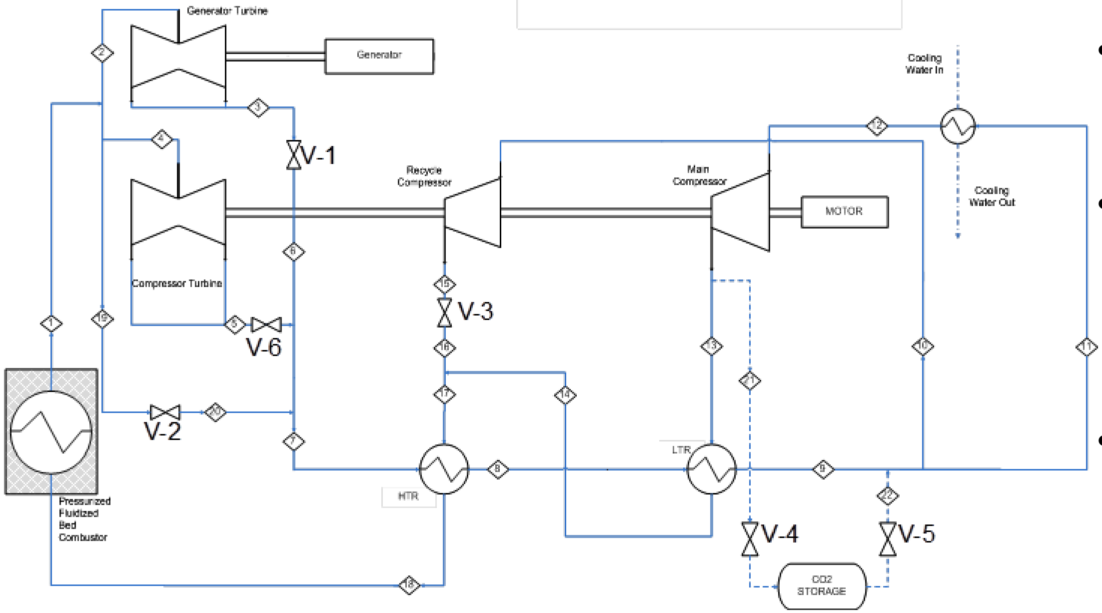
- **Supercritical CO2 (sCO2) power loop key components**
  - Separate Generator and Compressor drive turbines
  - Recompression cycle with two compression and heat transfer elements

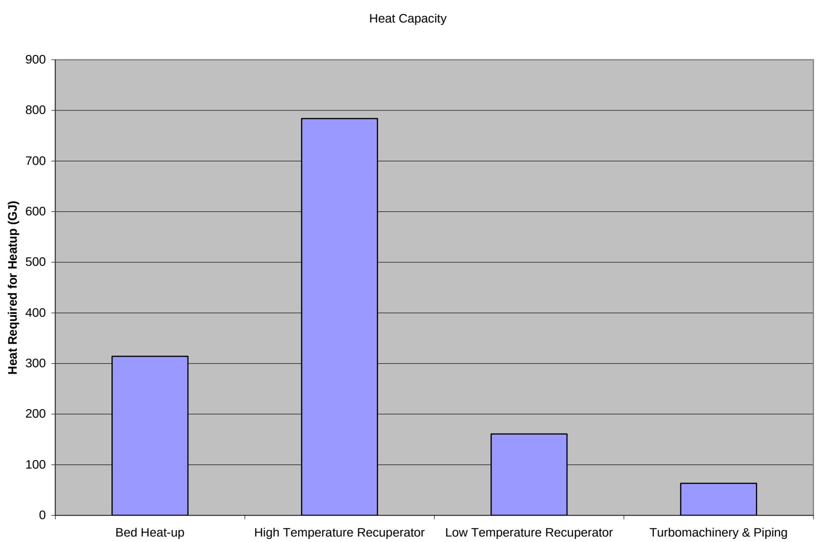
Zero Emmissions Power and Steam (ZEPS™) Power Plant



- **Plant layout developed**
  - Used to estimate piping pressure losses and volumes
  - Assumed enhanced shell & tube HX technology
- **System model updated**
- **Equipment performance maps updated**
- **System Control Methodology assessed for both transient and steady state operation**

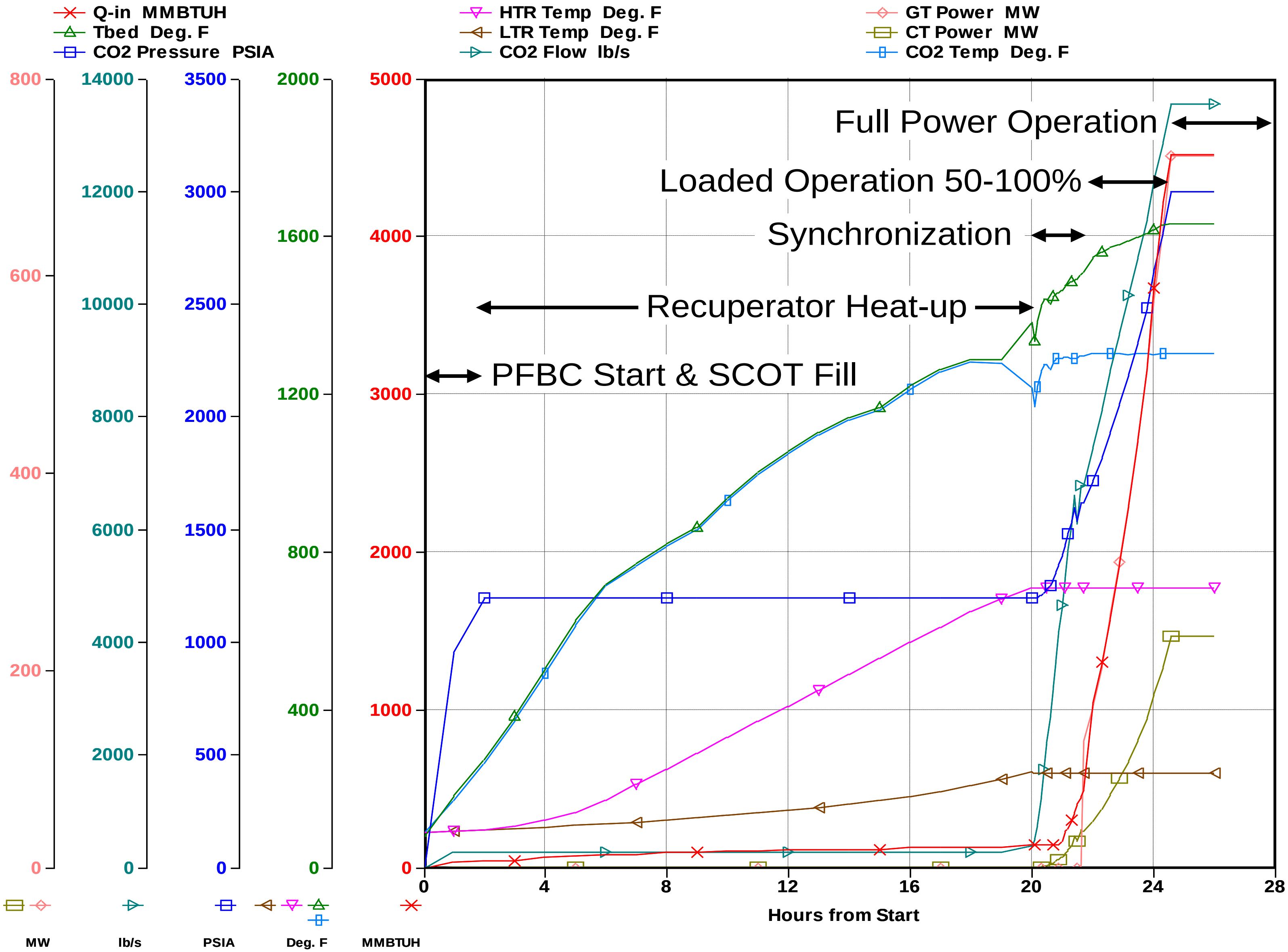
System Start





- **Variety of start-up/shutdown schemes evaluated – initially 14 valves, 4 bypass legs, & storage**
- **Detailed evaluation of two start-up approaches**
  - Spin start - concerns for thermally shocking in-bed heat exchanger
  - Motor assist bootstrap - Selected
- **Start-up requirements to mitigate damage to the system:**
  - Prevent compressor stall
  - Prevent heat exchanger overheat
  - Do not overspeed turbines
  - Avoid low Main Compressor Inlet Temperature/Pressure
- **Modified start until successful**
  - Flow split between the recycle and main compressors modified
  - LTR initially lagged thermally
  - Recirculating flow during heat up reduced
- **Final system: 6 valves, 1 bypass leg, & CO2 storage system**

System Start-Up Transient (Conventional Recuperator Technology)

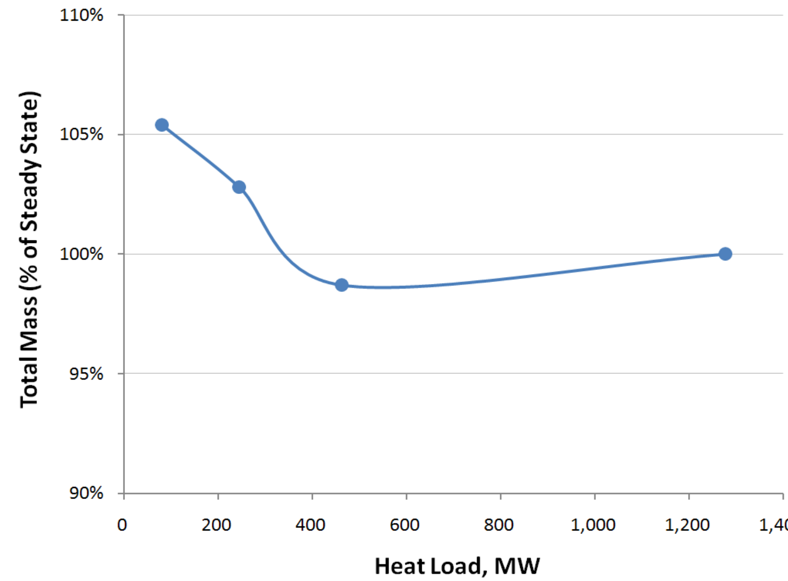


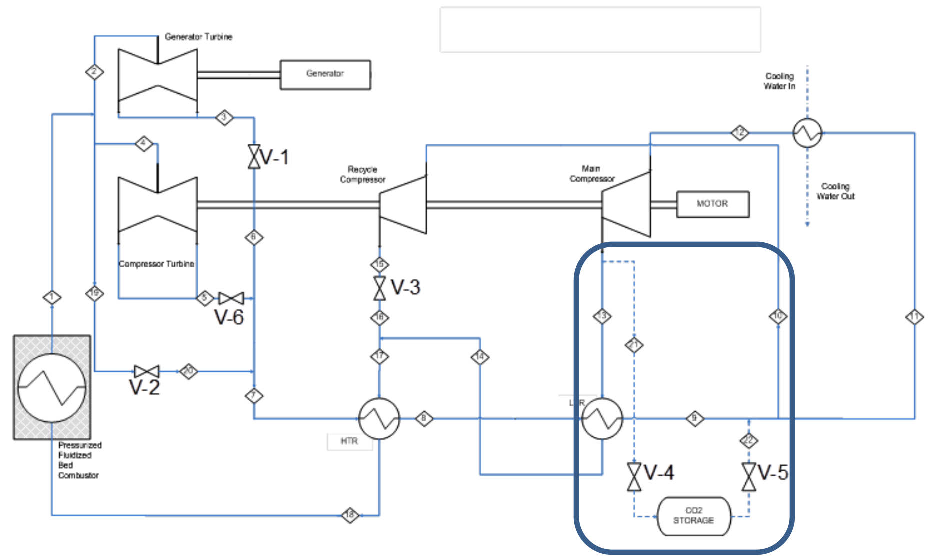
System Shut Down

- **There are three shutdown scenarios envisioned:**
  - Planned Shutdown
  - Emergency Shutdown
  - Disconnect from Grid Shutdown
- **Planned shutdown**
  - Drop to 50% loaded power
  - Fuel will be cut to the unload setting - bed temperature will drop
  - Generator turbine isolation valve (V-1) will close
  - Bypass valve (V-2) will open to maintain power to the compressor turbine
  - Fuel to the PFBC will be cut and the oxygen will be switched to air
  - SCOT CO_2 flow will be circulated until appropriate bed temperatures are met before CO_2 circulation is stopped
- **Emergency shutdown and disconnect from grid are envisioned to be the same**
  - System does not have the luxury of gradually reducing heat load
  - Fuel and oxygen supply will be stopped
  - Continue bed circulation with the recycle CO_2
  - Generator turbine flow will be stopped by closing valve V-1
  - Bypass valve V-2 will be opened to a point where flow supplied to the compressor turbine is maintained
  - CO_2 temperature will decay and SCOT CO_2 flow will drop until the bed reaches a safe temperature
- **There is risk of bed overheating during Emergency shutdown, mitigations:**
  - Coal and oxygen feeds are stopped immediately
  - Water is added to the flue gas and recycle systems to offer immediate protection of the PFBC and the solids handling equipment

Operation at Partial Load

- **CO_2 mass at rated power is 229 tons**
- **Turbine inlet temp maintained at partial load**
- **Storage system required to accommodate variation in mass**
  - +6% to -2%
- **Make-up location at the inlet to the cooler**
  - Avoid impact to the main compressor
- **Drain location at the compressor outlet**
  - Pressure high and temperature low - compatible for storage





Transient Operation Analysis Conclusions

- **Two SCOT system start-up approaches were analyzed in detail and a motor assist bootstrap was selected**
  - Motor on the compressor shaft will be used to force circulation and initiate preheat of the SCOT system
- **No turbine performance issues during transient operation**
  - Normal rotordynamic and structural limits apply
- **Start-up and shutdown operation of the main and recycle compressors are within the surge, choke, and speed limits**
- **No new technology risks identified for the turbomachinery**
- **Significant transient operation benefits with compact heat exchanger designs**
- **Instrumentation and control challenges to maintain main compressor inlet near the critical point**

Acknowledgements

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Questions ?

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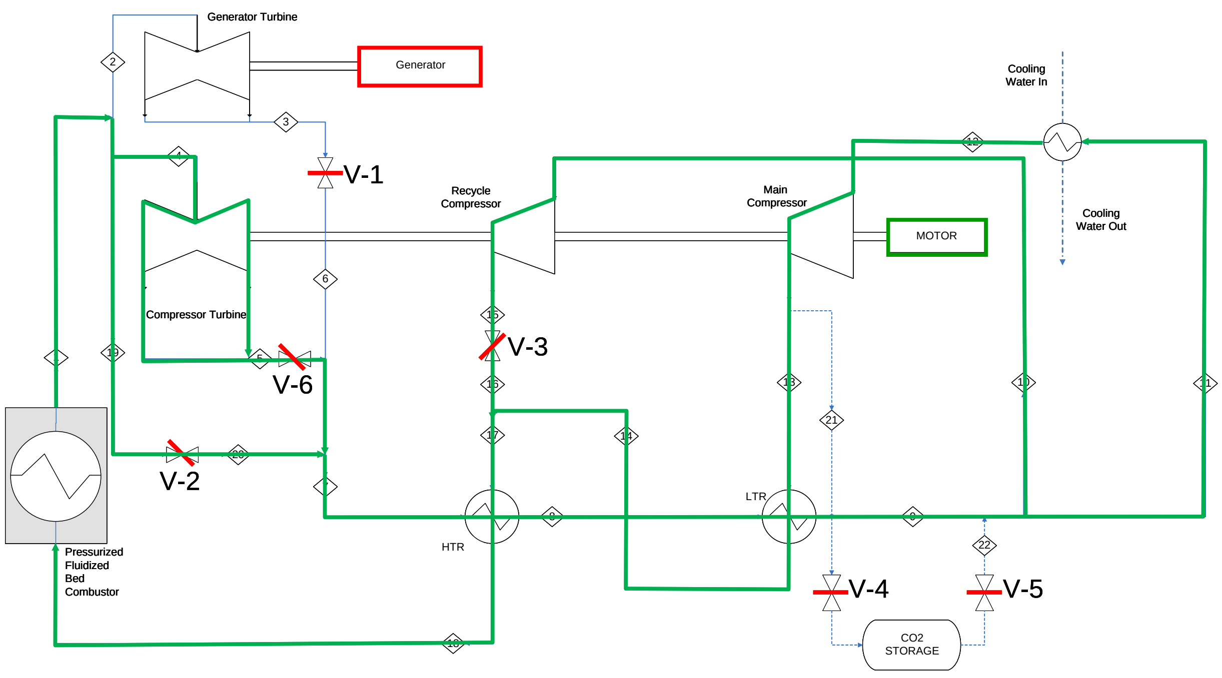
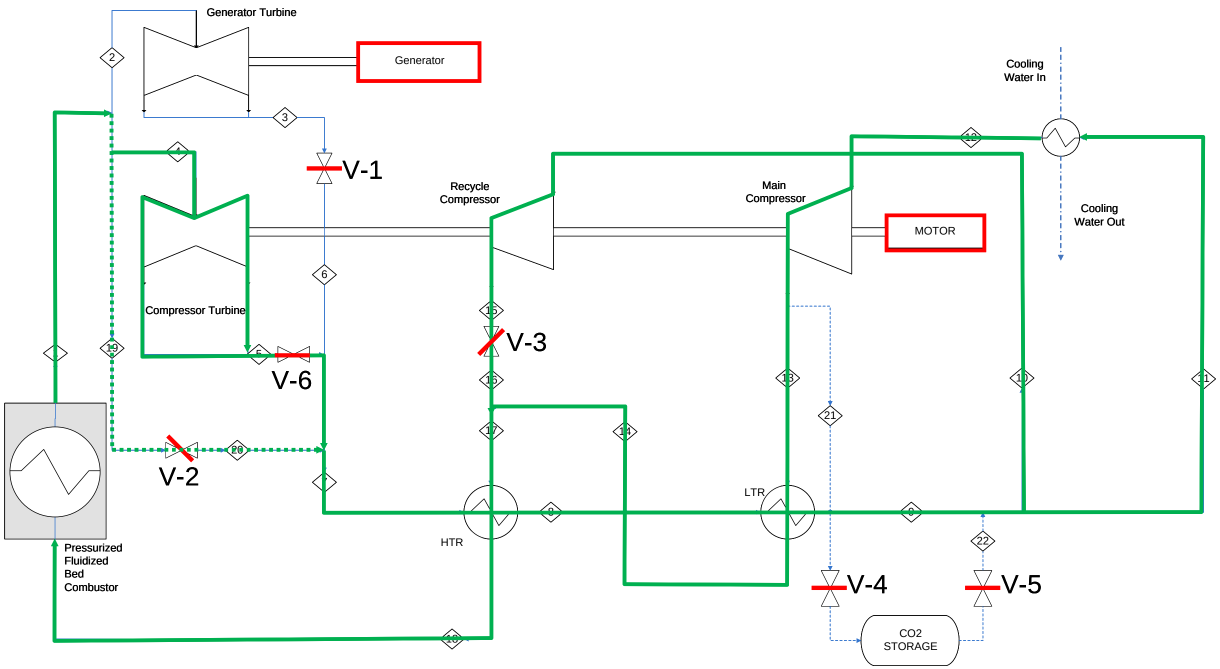
Back-Up

Initial Start-Up



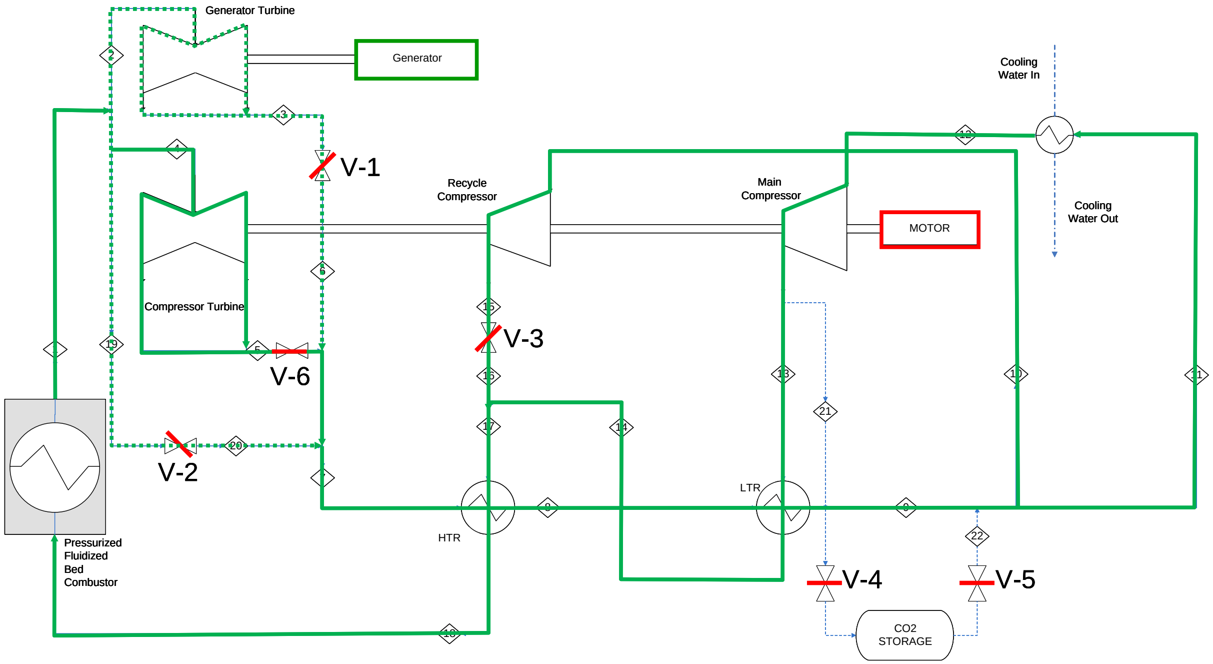
- **The SCOT system will be pressurized once the PFBC bed temperature reaches 150°F**
  - Opening valve V-5 on the CO_2 storage tank or
  - Filling from CO_2 tanker trucks using a vaporizer
- **Once the system is filled, valve V-5 is closed**
- **Generator turbine valve (V-1) is closed**
- **Recycle CO2 flow is controlled by adjusting valve V-3**
- **Motor on the compressor shaft will be used to force circulation and initiate preheat**

System Start-Up



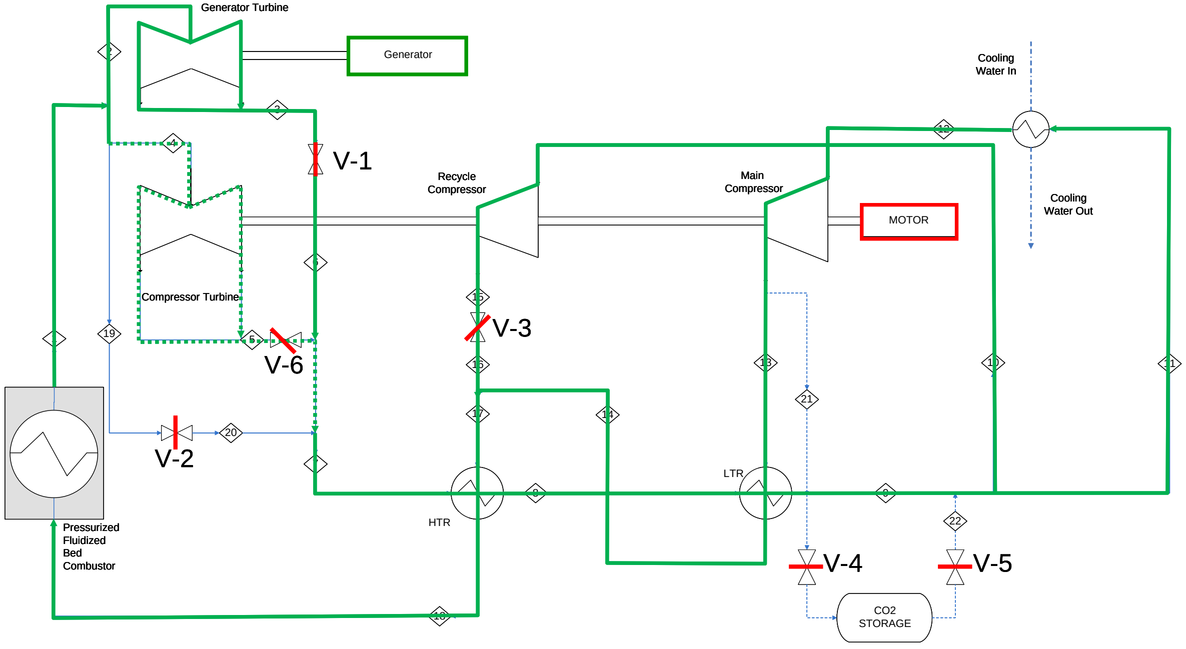
- **Compressor turbine will quickly begin offsetting motor power**
- **System control to a low flow during the initial heat-up**
  - Bypass more flow through valve V-2 than the compressor turbine
- **Once the recuperators have reached their average temperatures and the bed has reached 1100°F, the PFBC is switched to coal firing**
- **The bypass valve admits more flow to the compressor turbine**
- **Bed heat duty continually rises and increases the flow to 50% of maximum flow.**

System Start-Up (Continued)



- **During ramp, the generator turbine will be preheated by slightly opening valve V-1**
- **Once 50% flow is reached, the generator turbine flow will be increased by further opening valve V-1**
  - Synchronize with the grid

Completion of System Start-Up



- **Once connected to the grid, the system will increase heat duty to the desired load**
- **System control will be transitioned to the turbine compressor by closing valve V-2 and throttling valve V-6**
  - Completing the startup