sCO_2 step change in Texas

Following site clearance and groundbreaking in October 2018 (see *MPS*, November 2018, p14), the STEP Demo (10 MWe sCO_2 pilot plant) facility being built at Southwest Research Institute's San Antonio campus in Texas, is now well into the construction phase and the project is making good progress. For further information see www.stepdemo.us

February 2019 saw completion of the 'design phase' ($19.5 million from DOE, $4.9 million cost share) of the STEP (Supercritical Transformational Electric Power) pilot plant test facility project, with designs completed for turbine stop valve, gas-fired heater, low temperature recuperator and main process cooler. The turbine preliminary design review has also been completed.

Major equipment is now in manufacturing: low temperature recuperator; process coolers; compressor; cooling tower; and turbine stop valve. The Nimonic 105 turbine rotor forging has been received and 740H tubing finned with 304SS has been manufactured for the fired heater.

At the site, the gas pipeline has been installed, facility design is complete, the building permit is approved and the general contractor is mobilised. Building occupancy is scheduled for May 2020 and mechanical completion by October 2020.

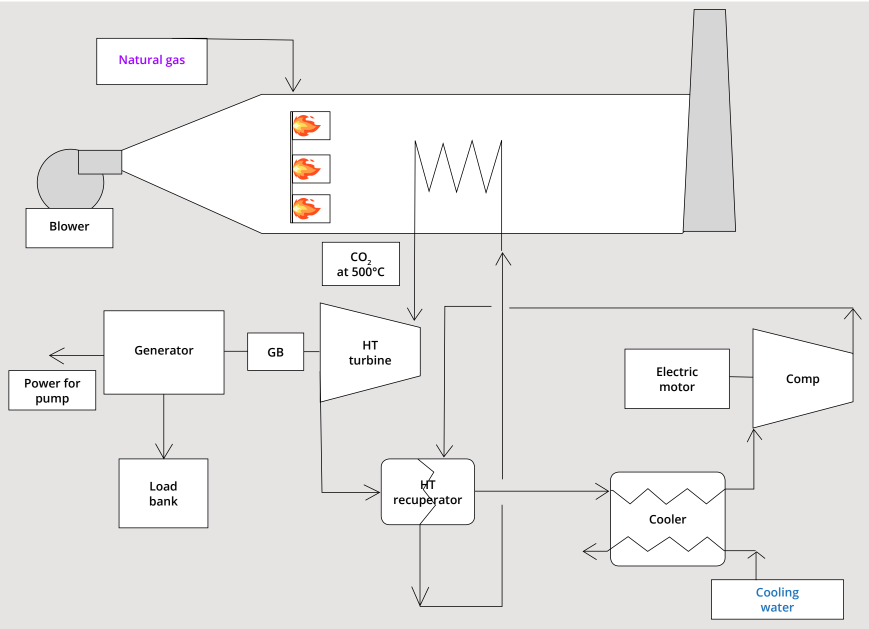

Figure 1a. Simple cycle configuration (turbine inlet temp, 500°C, 250 bar)

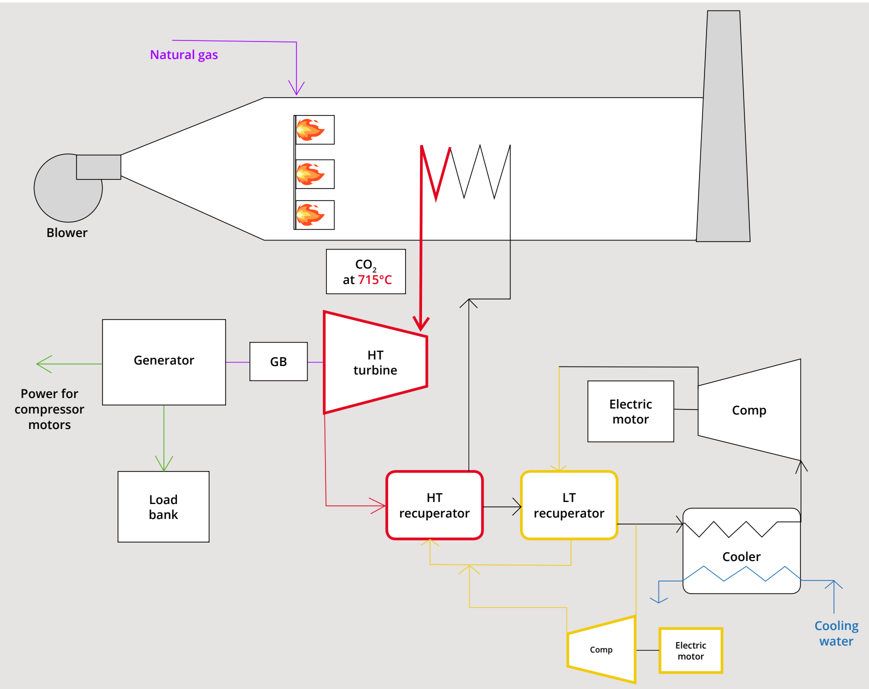

Figure 1b. Recompression closed Brayton cycle (turbine inlet temp, 715°C, 250 bar)

The simple cycle test programme is due for completion by 2021, while reconfiguration to RCBC (recompression closed Brayton cycle) is scheduled for September 2021, with RCBC testing completed by September 2022.

The STEP Demo project is being implemented by a team led by GTI, Southwest Research Institute (SwRI) and GE. The objective is to design, construct, commission, and operate a versatile and reconfigurable fully-functional power plant employing sCO_2 as the working fluid.

The key project goal is to advance high temperature sCO_2 power cycle performance from proof of concept, TRL (technology readiness level) 3, to TRL 7 (system prototype validated in an operational system).

The US DOE has awarded $84 million for the $122 million project, while cost share is provided by the team, component suppliers and other stakeholders.

Several technical risks and challenges associated with sCO_2 technology are being addressed in the STEP Demo project:

- turbomachinery (aerodynamics, seals, durability);
- recuperators (design, size, fabrication, durability);
- materials (corrosion, creep, fatigue); and
- system integration and operability (startup, transients, load following).

Among the project objectives are the following:

- Demonstrate the operability of the indirect sCO_2 power cycle;
- Verify the performance of components (turbomachinery, recuperators, and compressors, etc);
- Show the potential for achieving a lower cost of electricity and the potential for a thermodynamic cycle efficiency greater than 50% at commercial scales;
- Demonstrate at least a 700°C turbine inlet temperature and a recompression closed Brayton cycle configuration that demonstrates system and component design and performance, including generating at least 10 MWe; and
- Construct a reconfigurable facility to accommodate future testing of, for example, system/cycle upgrades, new cycle configurations (such as cascade cycles, directly fired cycles, etc), and new or upgraded components (turbomachinery, recuperators and heat exchangers).

GTI is responsible for overall management of the project. SwRI is performing systems integration, facility design and construction, and will operate the test facility. GE is providing the technical definition for the turbomachinery (turbines and compressors) as well as a first-of-a-kind sCO_2 turbine stop/control valve based on their line of valves for high-pressure steam turbines.

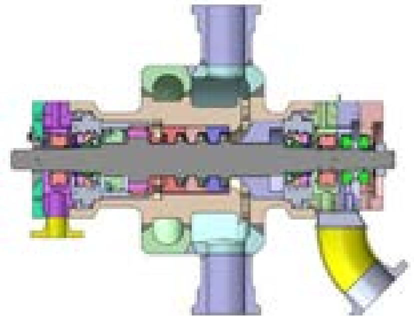

Figure 2. Conceptual design of STEP sCO_2 turbine

The combined team has been involved in over two dozen previous sCO_2 technology related projects, forming the building blocks of the STEP Demo. GTI has experience in large pilot/facility projects. SwRI offers technology development and test operations experience at the San Antonio site. GE leverages experience with existing 1 MWe sCO_2 turbomachinery component hardware developed for the DOE SunShot programme.

The project has a steering committee consisting of DOE, GTI, GE, and SwRI, plus KEPCO (Korea Electric Power Corp), Natural Resources Canada and industry partners, including Southern Company and American Electric Power. It is described as an 'open project' and parties such as OEMs, engineering companies, and power plant owner/operators are invited to join.

The two phase test programme

As already mentioned, once the facility is built, the STEP Demo testing will be done in two distinct phases, see Figures 1a and 1b.

The initial system configuration will be the sCO_2 simple cycle, which comprises a single compressor, turbine, recuperator, and cooler. Heat will be supplied by a natural gas fired heater that closely resembles a duct-fired HRSG (heat recovery steam generator). In simple cycle testing, sCO_2 will be delivered to the turbine at approximately 500°C and 250 bar. This test configuration offers the shortest time to steady-state and transient data, while demonstrating controls and operability of the system, and performance validation of key components. In the second phase of testing, the system will be reconfigured to the RCBC, recompression closed Brayton cycle. This is a high-efficiency cycle capable of achieving the >50% thermodynamic efficiency goals

Figure 3. STEP stop/control valve

of the programme. In this second phase, a second (lower-temperature) recuperator and a bypass compressor will be installed. The turbine inlet temperature will be increased to the target level of 715°C. This phased testing approach will address specific technical risks while minimising added complexity at each phase. In this manner, programmatic risk can be minimised by reducing unnecessary complexity and applying lessons learned from prior phases to address technical challenges.

Technology development tasks

The project includes several technology development tasks involving the turbine, turbine stop valve, and materials testing.

The STEP Demo turbine (Figure 2), with three stage gas path, leverages the existing DOE-funded SunShot programme, in which SwRI and GE have fabricated and have successfully tested a similar turbine. This turbine was also designed for a turbine inlet temperature of around 700°C. It has achieved 715°C (highest for sCO_2 to date) and 27 000 rpm. It was operated at reduced flow conditions, limiting power output to 1 MWe.

The 10 MWe (16 MW gross power) STEP turbine will offer improvements over the SunShot turbine, including: increased casing and rotor life (100 000 h vs 20 000 h); shear ring retention rather than bolts; and improved aero performance with increased volute flow area. Also, upgrades to hot gas seals and thermal management local to seals

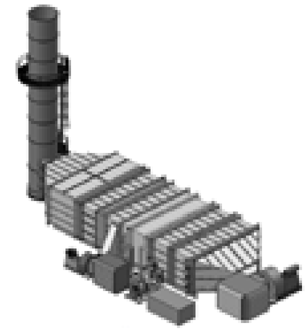

Figure 4. STEP gas-fired process heater

will be implemented based upon lessons learned from the SunShot effort and related supporting projects (eg, improved thermal management under FOCUS).

Supercritical CO_2 turbines, and associated components, are very compact, which has many advantages, but a downside is that the compactness makes thermal management more challenging.

GE is also leading the design work on the turbine control/stop valve (Figure 3), which will be placed upstream of the turbine. The design is based on the existing GE commercial product line of steam valves, but with modifications to accommodate sCO_2 fluid and high operating temperatures, including novel stem seal materials.

The valve leverages Haynes 282 material development under the DOE AUSC programme, and Baker Hughes GE seal and actuator experience.

GTI is leading the procurement of the heater, compressor, recuperators, and cooling tower. The heater is natural gas fired with a tube bundle fabricated out of Inconel 740H to accommodate the >700°C, 250 bar supercritical CO_2 conditions. It is based upon a duct-fired HRSG) see Figure 4, and is being supplied by Optimus Industries. The application of 740H alloy is also supported by the results of the DOE AUSC programme.

The sCO_2 compressor will be sourced from Baker Hughes GE, and leverages an existing commercial sCO_2 compressor product line as well as work undertaken as part of the DOE-funded Apollo programme.

The heat exchangers include the high and low temperature recuperators, a main process cooler and a bypass process cooler. All units are compact, with high surface area/volume ratios, and will employ printed circuit heat exchange technology to be supplied by Heatric and VPE.

Why supercritical CO_2?

The unique properties of supercritical carbon dioxide offer intrinsic benefits over steam as a working fluid in closed cycles to absorb thermal energy, to be compressed, and to impart momentum to a turbine.

The temperature and pressure threshold conditions required for the supercritical state of CO_2 are nominally 31°C and 7.4 MPa. These conditions are easily achieved, and above these conditions CO_2 is a supercritical fluid with high density, like a liquid, while maintaining compressibility, like a gas. High fluid density is maintained throughout the power cycle by keeping both the inlet and exhaust pressures in the sCO_2 cycle above the critical pressure, resulting in dramatically smaller turbomachinery (factor 10:1) for a given power production level.

Thus, sCO_2 power cycles can offer several benefits:

- higher cycle efficiencies due to unique thermodynamic properties of sCO_2;
- reduced emissions resulting from lower fuel usage;
- compact turbomachinery, resulting in lower capex, reduced plant size/footprint, and more rapid response to load transients;
- reduced water usage, including water-free capability in dry-cooling applications; and
- heat source flexibility.

These benefits can be achieved in a wide range of power applications including gas and coal fired generation, bottoming cycles, waste heat recovery, CSP, biomass, geothermal, and nuclear power plants.