Small-Scale Test Platform (SSTP) for SOFC Stacks

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Introduction:

PNNL is designing and constructing a small-scale test platform (SSTP) that will enable:

a) Evaluation of reliability and performance of solid oxide fuel cell (SOFC) stacks under realistic, long-term continuous system operation at power levels from 1 to 10 kW.

b) Identification of key R&D gaps and needs limiting long-term reliability, especially chrome poisoning, through SOFC system performance testing

c) Assessment of performance and benefits of advanced stack concepts originating from FOA awards or other programs.

The SSTP incorporates a number of advanced design features, including:

- Anode recirculation loop
- External steam reforming, with additional options for testing stacks with onboard reforming
- High efficiency heat exchangers for heat recuperation and equalizing anode and cathode stream temperatures before entering the stack
- Option for electric start-up heating
- Control system capable of managing stack inlet and outlet temperatures, and controlled delivery of air and fuel temperature and pressure differentials in the stack.

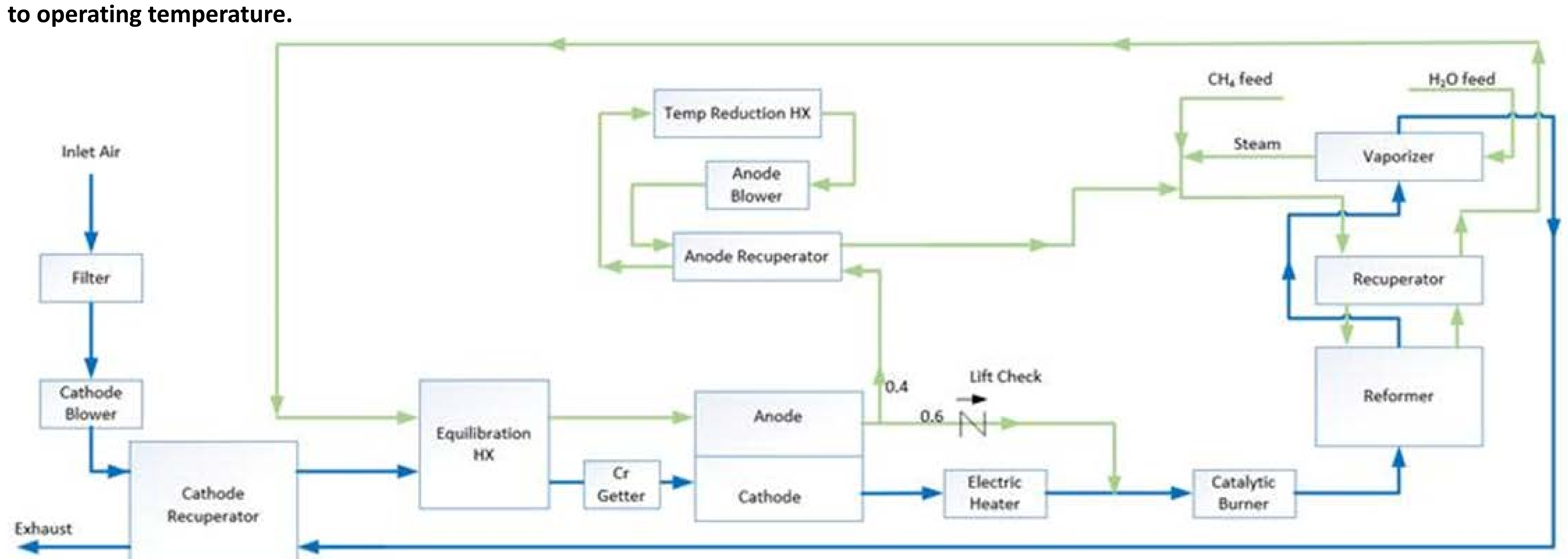
Stack Technology:

The first stack technology to be tested is a Penta 4 Stack Module from Ceres Power utilizing their SteelCell® technology. • Rated at 3.7 kW

- 9 Amps per stack, 36 Amps total
- ~105 V, with four stacks in parallel
- ~600C operating temperature

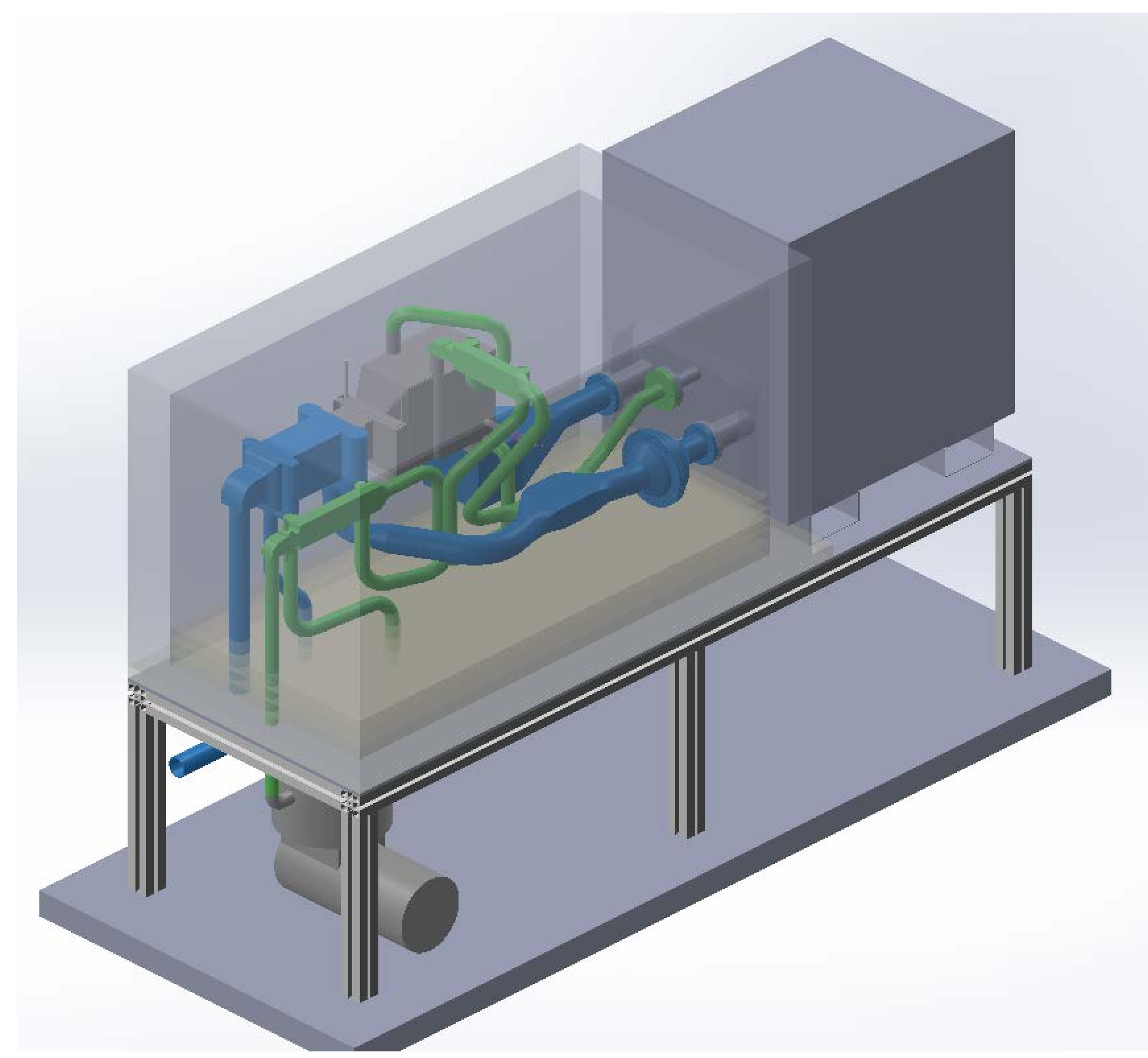
Flow Diagram:

The flow diagram shows the key components of the SSTP. Several heat exchangers and a burner are required to maintain stack temperature. An electrical heater will be used during start-up only to help bring the system to operating temperature.



Overall Component Layout:

The layout presented below may be modified to increase compactness. The Penta 4 Stack Module is mated to the SSTP balance of plant. Conventional insulation panels are used at the base, with a vacuum insulation box over the top. The cathode blower and anode pump sit below the level of the main table.



Control Scheme:

The SSTP will be fully instrumented with mass flow controllers, temperature and pressure sensors, and equipped for gas sampling for GC analysis. A dedicated control system will run the following control loops:

1) Fuel cell stack temperature is controlled by the cathode blower speed.
2) System power is controlled by the voltage set point on the load bank.
3) Fuel and water feed rates are proportional to the stack current. Water feed is controlled from methane feed for desired steam-to-carbon ratio.
4) Recirculation rate is controlled by the anode blower speed.
5) Control for on-stack reforming is achieved by having two controlled entry points for methane, one upstream of the reformer, and one downstream.

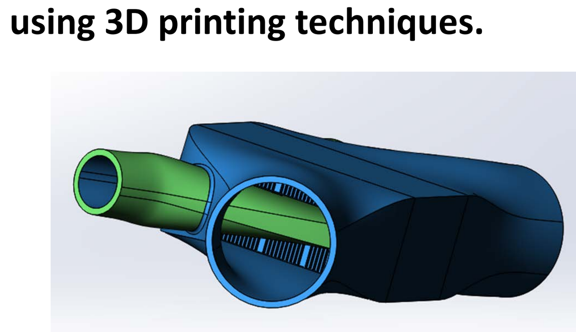
Chrome Poisioning Prevention and Monitoring:

Chrome poisoning of the SOFC cathodes is a key issue to be studied during SSTP operation. Haynes 214 alloy steel is used on all hot components in contact with the air stream. Haynes 214 is an alumina former, which limits chromium volatility. A chrome getter is placed just upstream of the SOFC cathode inlet. The getter consists of an alumina honeycomb (4" diameter, 1" thick) dip coated with LSC and sintered. Flat coupons of similar composition will be placed before and after the getter, as well as at the SOFC cathode exit. These coupons will be removed periodically during testing so the LSC coating can be dissolved and analyzed via ICP for chromium content.

Heat Exchangers:

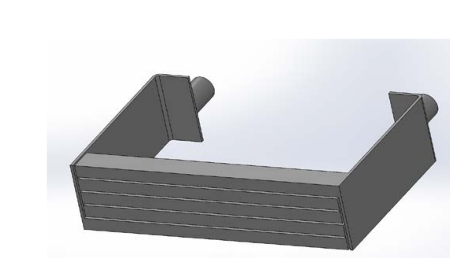
PNNL has produced many microchannel heat exchangers, allowing for very compact and efficient designs. Traditionally, these have been produced by a shim lamination process. For the SSTP, heat exchangers were 3D printed using direct metal laser sintering (DMLS) at i3D MFG in The Dalles, OR. New capabilities allowed the use of Haynes 214 alloy on the components contacting the air stream. Anode side heat exchangers were produced from Inconel 625.

The equilibration heat exchanger incorporates a unique design with intersecting headers for smooth flow paths for both the air and fuel streams. Such a design is only possible using 3D printing techniques.



Electrical Startup Heater:

A proven electrical heater design is incorporated upstream of the burner to provide heat during startup. Fecralloy foam is cut into a serpentine electrical path with solid Fecralloy conductors. An SCR controller provides variable control over heat input.

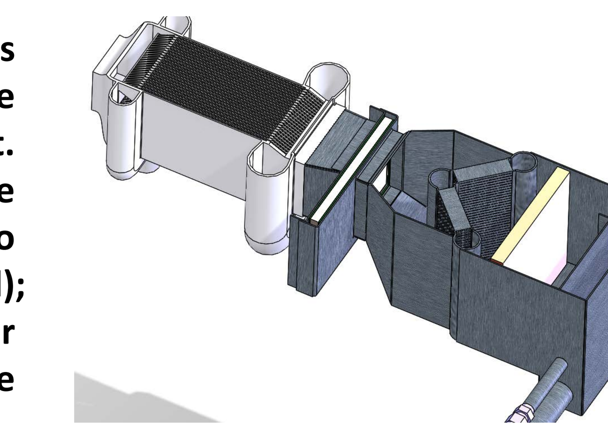


Anode Pump and Cathode Blower:

Anode gas recycle requires a pump that can handle a hot, combustible gas stream. PNNL selected a double headed KNF diaphragm pump for this purpose. The high-speed cathode blower from R&D Dynamics was chosen for it's high efficiency and maintenance free operation using air bearings.

Reformer Unit:

The reformer unit incorporates several components in one enclosure for efficient use of heat. From right to left shown here: the burner; the catalytic burner to react unburned fuel (white panel); the reformer reactor; the water vaporizer; the cathode recuperator.



Test Plan:

1) Initial system shakedown
2) Heat up to 600C
3) Continuous Operability Test
   a) 500 hours at 9A per stack and 40% recycle rate
   b) 20 or more thermal cycles, one per day
   c) 10 or more emergency stop cycles, one per day
   d) Recycle rate experiments at 30%, 35%, 45%, and 50% recycle rate

Project Status:

Component acquisition is nearly complete. System assembly is starting in June, 2018 with target system shakedown and testing commencement in July, 2018.

Future stack technologies can be tested with the SSTP. The first candidate technology to be evaluated will be a stack module from Ceres Power. Future modifications to the flow sheet and certain components may be necessary for different stack architectures due to different operational requirements. The use of 3D printed heat exchangers will make modifications much faster and more cost effective.

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