Energy & Environmental Research Center University of North Dakota
15 North 23rd Street, Stop 9018
Grand Forks, ND 58202-9018

Project Title: Integrated Gas Turbine–Gasifier Pilot-Scale Power Plant

Contract Number: RD3-71 Milestone Number: 10 Report Date: Aug 30, 2011

Principal Investigator: Phillip Hutton Contract Contact: Corey Irion

Phone: (701) 777-5204 Phone: (701) 777-5379

Congressional District (Corporate office): Not Applicable

Congressional District (Project location): Not Applicable

MILESTONE REPORT

Executive Summary: During this milestone period, the Energy & Environmental Research Center (EERC) completed Milestone 10; Commence Testing and Demonstration. Because of the inability to overcome the stock software shutdown faults in the C30, the modified microturbine was operated in cooldown mode, with externally controlled input of natural gas and syngas. In cooldown mode, the microturbine ramps up to 45,000 rpm. This increases airflow through the turbine until the combustor is cooled below 190°C (374°F). Externally controlled input of natural gas and syngas maintained turbine operation up to the steady-state operating temperature of 900°C (1652°F) in the combustor. This allowed the analysis of the heat transfer and thermal profile of the heat exchanger. However, under cooldown mode the turbine output contacts are opened and the turbine does not pressurize up to normal operating pressure. This prevents production of significant shaft work, which is a function of the operating pressure. Nonetheless, operating under this mode allowed:

1. Obtaining steady-state operating temperatures.
2. Obtaining self-sustained operation on 100% syngas without an ignition source.
3. Verifying that the designed temperature profile was achieved.
4. Producing some shaft work, albeit much lower than during normal operation.

Project funding provided by customers of Xcel Energy through a grant from the Renewable Development Fund.

Technical Progress: Figure 1 shows a simplified system design for a conventional gas turbine-based power system. A common shaft is attached to an expander and compressor. Hot, pressurized gas from the combustor turns the expander and compressor at the same revolutions per minute (rpm). Compressed air flowing through the compressor is preheated by a recuperator and then injected into a combustor. The hot, pressurized gas exiting the combustor turns the expansion turbine which, in turn, operates the compressor and electric generator.

In a conventional system, syngas from a gasifier must be cleaned of particulates and acid gases and compressed to high pressure to inject into the combustor. The compressor cannot handle hot input gases, requiring cooling of the syngas before compression. This, in turn, requires extensive syngas-scrubbing systems between the gasifier and compressor. The capital and operating costs of the syngas-scrubbing system in this type of design may exceed those of the gasifier and gas turbine, making this system uneconomical for distributed power production.

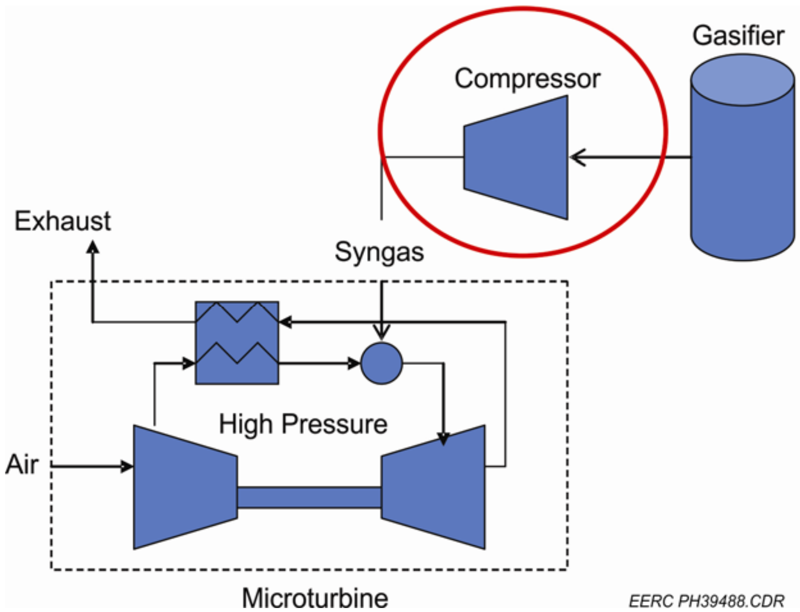

Figure 1. Directly heated gas turbine system for biomass power production.

To overcome these issues, the system was designed to employ an indirectly heated gas turbine, as presented in Figure 2. Hot syngas is fed to an atmospheric combustor which then heats high-temperature air through a high-temperature heat exchanger. The high-temperature heat exchanger is designed to reduce gas temperatures to an acceptable level for the stock recuperator. For the C30 microturbine, the stock recuperator requires an input temperature below 650°C (1202°F). Since the syngas never contacts the high-speed turbine, particulate cleanup requirements are greatly reduced. The external compressor is eliminated, and the need to cool the syngas below the condensation temperature of tars is also eliminated. This eliminates tar fouling in the pipes and greatly reduces the particulate cleanup requirements.

The EERC has modified an off-the-shelf Capstone C30 microturbine to move the combustor out of the high-pressure zone and into the low-pressure zone. A new combustor and heat exchanger were installed in the microturbine to work with the stock recuperator. Figure 3 shows an image of the modified microturbine. Both the high-temperature heat exchanger and combustor are integrated into a single unit and installed directly to the recuperator to minimize pressure losses.

The stock control software employed in the C30 is optimized for the original design and monitors temperatures, valve positions, timing, power output, rpm, and a host of other parameters. Sensor measurements outside of the normally expected operating conditions of the C30 initiate immediate shutdown or cooldown faults. The modifications incorporated in the C30 to convert it to an indirectly heated microturbine changed much of the timing associated with the process parameters. Testing throughout the past 6 months was hampered by shutdown faults before the steady-state operating temperature could be reached. We were unable to overcome the shutdown faults, but found that initiating cooldown mode allowed us to reach the steady-state operating temperature of 800°–900°C (1472°–1652°F). However, in cooldown mode the turbine remains unpressurized. Shaft work and electrical output are a function of the ratio of operating

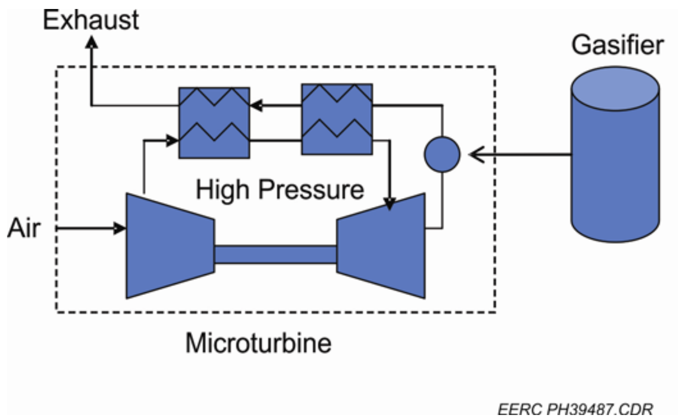

Figure 2. Indirectly heated gas turbine system for biomass power production.

Figure 3. Image of indirectly heated microturbine.

pressure and atmospheric pressure. For the C30 under normal operation, this ratio is 3–4. Under cooldown mode, this ratio was maintained at approximately 1.

To move forward with the demonstration, the microturbine was connected to the gasifier, as shown in Figure 4. The gasifier was started on charcoal and brought up to operating temperature on wood pellets. The syngas was initially flared to atmosphere. Once the gasifier reached steady-state operating conditions, the microturbine was started on natural gas and brought up to a

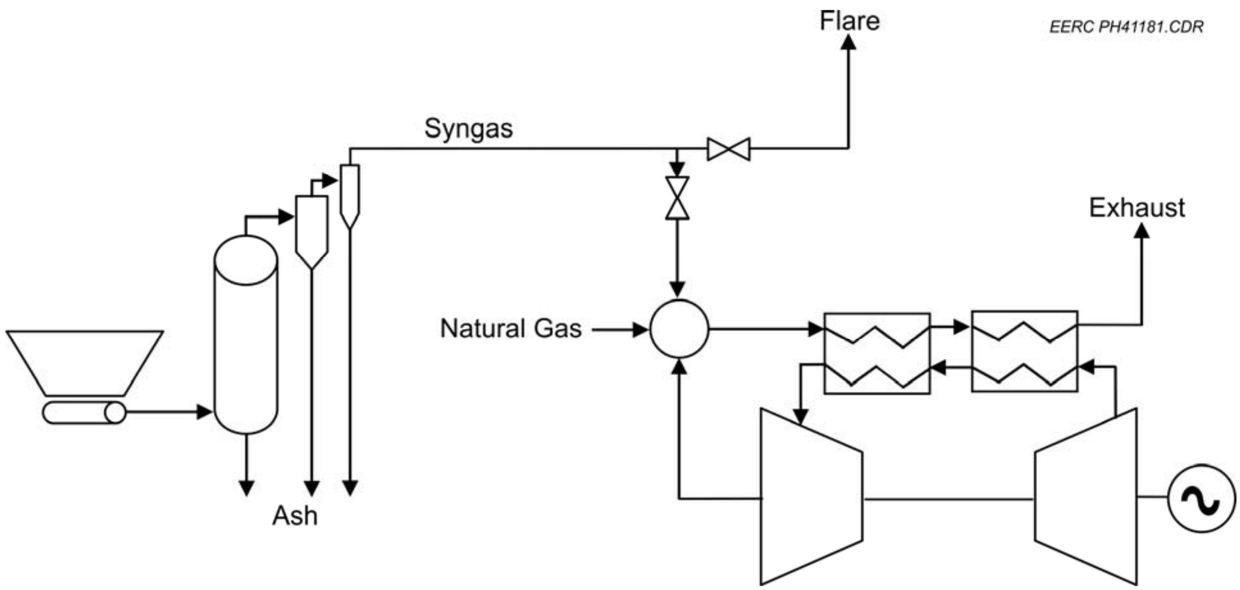

Figure 4. Line diagram of microturbine–gasifier test system.

steady-state operating temperature of 900°C (1652°F) in cooldown mode. The syngas valve was then opened, and the valve leading to the flare was incrementally choked. The natural gas input was closed and the spark ignitor turned off.

Figure 5 provides an image of the microturbine combustor operating on 100% syngas. Self-sustained operation on syngas was achieved, and the temperature profile matched the design specifications of the modified turbine. The combustor temperature was measured at 900°C (1652°F), and the input to the stock recuperator was 650°C (1202°F), which is the designed input temperature of the stock recuperator. Heat transfer through the heat exchanger can be calculated from the flow rate and temperature difference between the combustor and input to the stock recuperator. The difference in temperature on the low pressure side of the heat exchanger is due to the transfer of heat to the high pressure side of the heat exchanger. Videos are available to Xcel energy upon request.

Additional Milestones/Project Status: Testing is complete and work has commenced on compiling the data and presentation materials for the final report in accordance with Milestone 11.

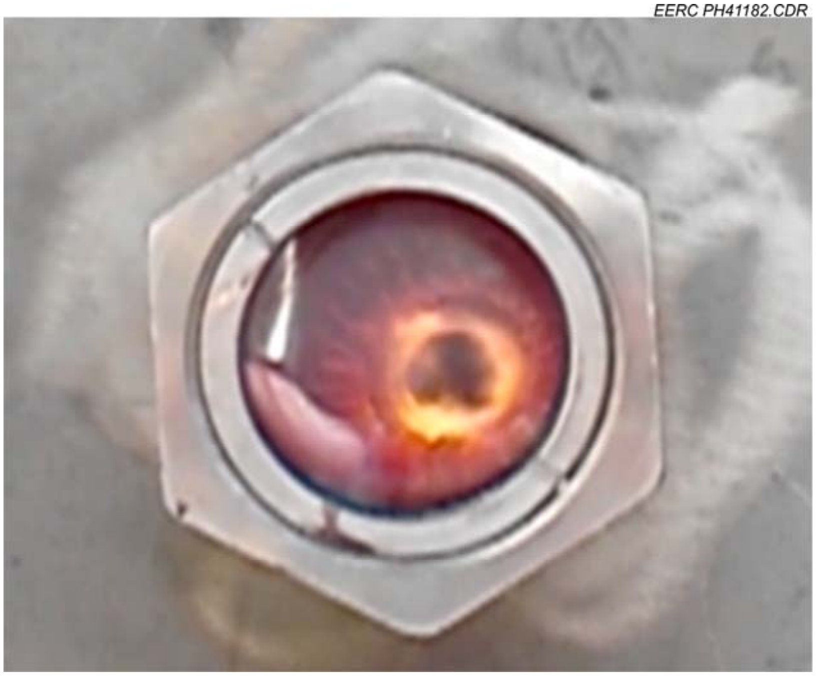

Figure 5. Image of the stable flame in the microturbine operating on 100% syngas.