Rocket Engine Innovations Advance Clean Energy

NASA Technology

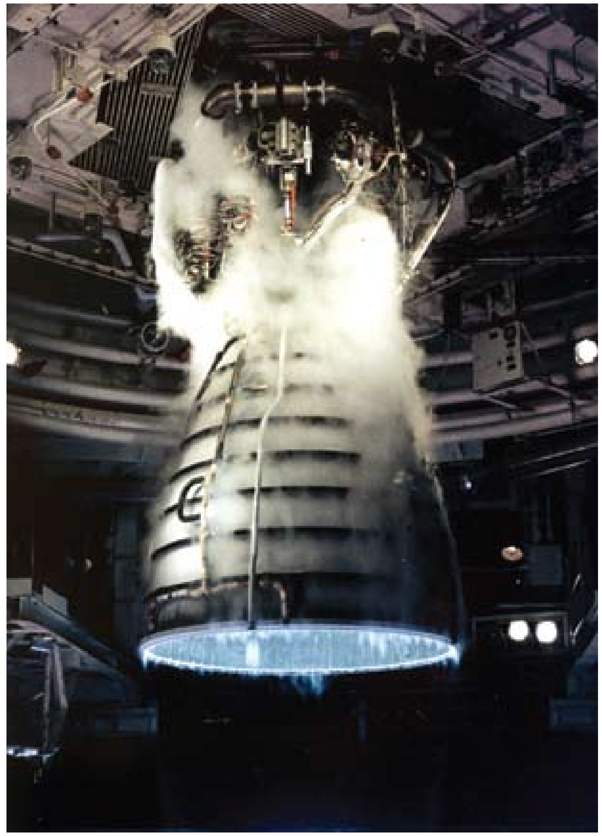
During launch countdown, at approximately T-7 seconds, the Space Shuttle Main Engines (SSMEs) roar to life. When the controllers indicate normal operation, the solid rocket boosters ignite and the shuttle blasts off. Initially, the SSMEs throttle down to reduce stress during the period of maximum dynamic pressure, but soon after, they throttle up to propel the orbiter to 17,500 miles per hour. In just under 9 minutes, the three SSMEs burn over 1.6 million pounds of propellant, and temperatures inside the main combustion chamber reach 6,000 °F. To cool the engines, liquid hydrogen circulates through miles of tubing at -423 °F.

From 1981to 2011, the Space Shuttle fleet carried crew and cargo into orbit to perform a myriad of unprecedented tasks. After 30 years and 135 missions, the feat of engineering known as the SSME boasted a 100-percent flight success rate.

Partnership

In the 1970s, the SSME was designed under contract to NASA by Rocketdyne, now part of Pratt & Whitney Rocketdyne (PWR), a United Technologies Company based in East Hartford, Connecticut. Working with Marshall Space Flight Center, PWR developed the most efficient rocket engines in existence, with ultra-high-pressure operation of the pumps and combustion chamber, which allowed expansion of all hot gasses through a high-area-ratio exhaust nozzle.

Soon after developing the highly efficient shuttle engines, PWR started creating highly efficient gasification systems. Gasification is a chemical process that converts carbon-containing materials such as coal, petcoke (a waste product from oil refineries), or biomass (organic material from plants or animals) into synthesis gas, or syngas. After the material is pulverized, it mixes with oxygen and steam at very high temperatures. The resulting syngas—comprised of carbon monoxide, hydrogen, carbon dioxide, and methane—can be burned as a fuel to create electricity, or further processed to make products such as substitute natural gas, chemicals, fertilizers, or liquid transportation fuels.



A Space Shuttle Main Engine, built by Rocketdyne under contract to NASA, undergoes test firing in 1981. Marshall Space Flight Center was responsible for the shuttle's propulsion elements, including the main engines.

"We started looking at alternate forms of energy and alternate ways of using coal during the 1970s energy crisis," says Don Stevenson, program area manager for Clean Fossil Fueled Energy Technologies at PWR. "By applying our rocket engine expertise, we are able to increase the temperatures and pressures in a gasifier, which resulted in a much higher efficiency system."

Benefits

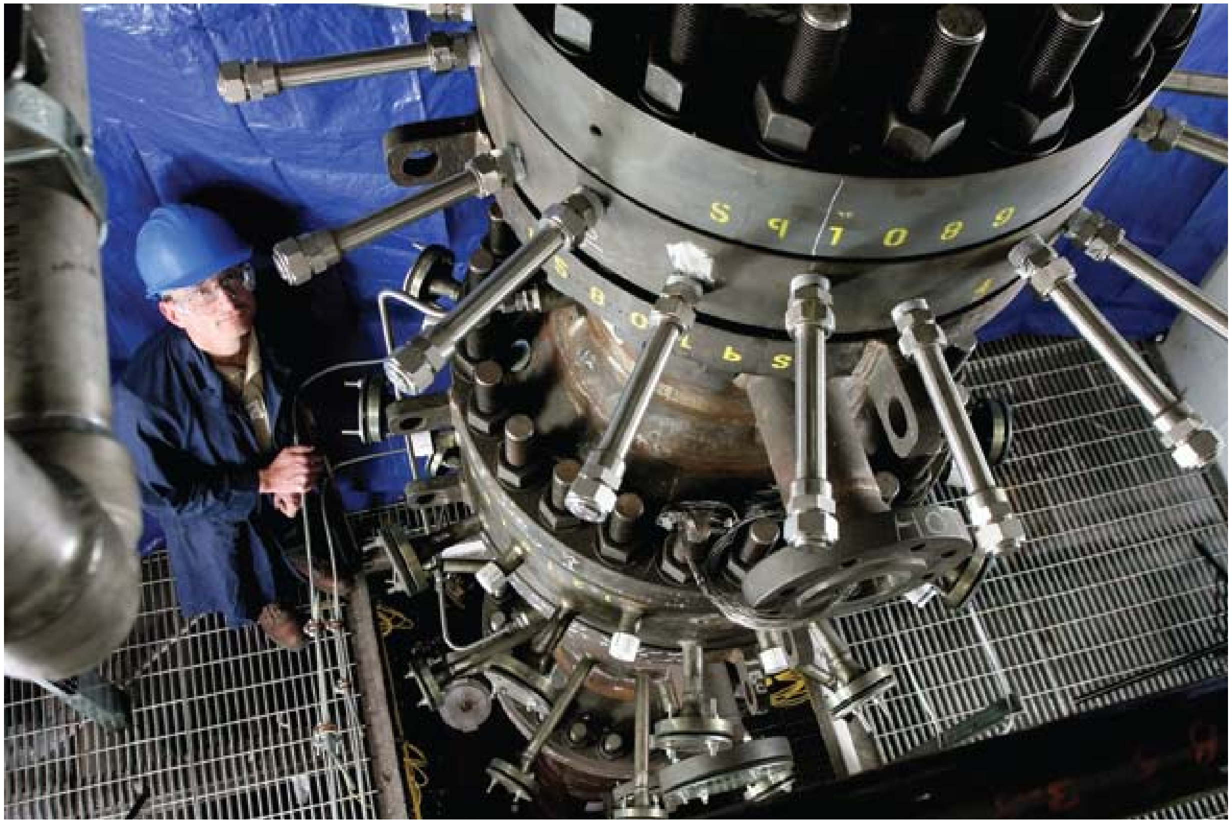
In the 1980s, PWR built its proof-of-concept gasifier, but due to a lack of funding, the company temporarily shelved the technology. Years later, interest in the technology resurfaced, so PWR pursued new partnerships with the U.S. Department of Energy, ExxonMobil Research and Engineering, and Canada's Alberta Innovates, to design, develop, and test the technology. By 2009, PWR had begun operating a pilot plant at the Gas Technology Institute in Des Plaines, Illinois, and in June 2011, test results established the gasifier's successful performance and operation over a range of conditions.

PWR's experience developing rocket technology was instrumental in improving gasification technology. Stevenson says, "The result is a much more compact, efficient, and lower-cost system."

Several aspects of the compact gasification system have been influenced by the company's experience with rocket engine design and development. The main component, however, is the rapid mix injector. "If it weren't for the injector, which we think is the key secret ingredient, this wouldn't be possible," says Stevenson.

PWR's rapid mix injector allows the gasifier to mix the carbon-based material, oxygen, and steam more efficiently at higher temperatures so the reaction can happen more quickly. PWR's experience with rocket engines, which typically run at 5,000 °F or more, provided the expertise needed to build a gasifier system capable of withstanding extreme temperatures.

"The modeling and analysis required to understand high heat loads for rocket engines is something that we have directly applied to the gasifier. Others in the field don't have that expertise, so they have been reluctant to go to the higher efficiencies because they can't handle the temperatures," says Stevenson.



Rocketdyne, now part of Pratt & Whitney Rocketdyne (PWR), used its rocket engine expertise to advance gasification technology. Compared to standard gasification systems, PWR's technology is more compact, efficient, and lower cost.

In addition to the smaller size, another advantage of PWR's system is lower costs, compared to the prevailing gasifier technology. According to the company, the capital cost to build a commercial-scale compact gasification plant using PWR's technology is estimated to be 10–20 percent less than conventional gasification plants. Another main advantage is that the system is expected to reduce carbon dioxide emissions by up to 10 percent, compared to standard gasification technologies—which are already the cleanest coal-based power systems available. For each commercial system deployed, it is equivalent to removing 50,000 cars from road.

These advancements hold real promise for the energy and chemical processing industries. According to the Gasification Technologies Council, worldwide gasification capacity is projected to grow 70 percent by 2015, with 80 percent of the growth occurring in Asia. In fact, PWR has already granted a license to Zero Emission Energy Plants, Inc. (ZEEP) of Katy, Texas, for commercial implementation of the compact gasifier system. "ZEEP has a unique energy plant concept, and they want to make our technology a centerpiece. They were willing to come in with an early license, and that provided some additional financial resources to support the development," says Stevenson.

In the future, PWR expects to license the technology to various national and international entities such as oil refineries, electric power, liquid fuels, and chemical plants. The next step in the commercialization efforts is to demonstrate the gasifier at a commercial scale over a long period of time. To this end, PWR is beginning to work with partners to build a commercial-scale plant in either Asia or North America.

Perhaps the greatest benefits of using more efficient, cost-effective gasifiers to produce electricity, however, will be for the environment. As Stevenson says, "One of the industry's challenges has been how to continue to use coal in an environmentally friendly way. Once gasification can be brought in as a cost-effective mechanism for a means to producing electricity, we can replace coal-fired power plants and make a huge improvement on the global emissions problem."

While the demand for energy continues to rise, coal continues to be a major source of energy, so Stevenson finds gasification of coal offers the opportunity to dramatically reduce carbon dioxide emissions into the atmosphere. By using a gasifier, the carbon dioxide can be captured much more efficiently. "Extensive research is being conducted in North America, Asia, and Europe to pump captured carbon dioxide underground and store it or use it to enhance oil recovery. There are some major pilot projects taking place to prove the technology for carbon sequestration, which will ultimately be the key enabler for near-zero emissions from these types of facilities," he says.

Stevenson suggests this type of innovation, similar to the innovation required to build the SSMEs, is what will help to meet the world's energy and environmental goals. ❖