the ENERGY lab

PROJECT FACTS

Existing Plants, Emissions & Capture

Ramgen Supersonic Shock Wave Compression and Engine Technology

Background

The mission of the U.S. Department of Energy's (DOE) Existing Plants, Emissions & Capture (EPEC) Research & Development (R&D) Program is to develop innovative environmental control technologies to enable full use of the nation's vast coal reserves, while at the same time allowing the current fleet of coal-fired power plants to comply with existing and emerging environmental regulations. The EPEC R&D Program portfolio of post- and oxy-combustion carbon dioxide (CO_2) emissions control technologies and CO_2 compression is focused on advancing technological options for the existing fleet of coal-fired power plants in the event of carbon constraints. This project is one of several R&D carbon capture projects from the EPEC program that were selected by DOE to receive funding from the American Recovery and Reinvestment Act (ARRA). These projects will accelerate carbon capture R&D for industrial sources toward the goal of cost-effective carbon capture, utilization, and storage (CCUS) within 10 years.

Studies conducted by DOE have revealed the high cost and energy requirements that exist for CO_2 compression. The CO_2 captured from a power plant will need to be compressed to 1,500 to 2,200 pounds per square inch absolute (psia) to be effectively transported via pipeline and injected into an underground sequestration site. The energy requirement for compression can be as much as 7.5 percent of the electrical output of a subcritical pressure, coal-fired power plant, which represents a potentially large auxiliary power load on the overall power plant system. Reduction of the compression cost and energy requirements will be beneficial to the overall efficiency of carbon capture, utilization, and sequestration for both utility and industrial applications.

Ramgen Power Systems (Ramgen) has developed an advanced CO_2 compression technology utilizing supersonic shock waves that can lower the cost of CCUS and reduce greenhouse gas emissions. Integrated with the development of the CO_2 compressor, a novel concept engine for power generation will be developed that combines shock wave compression and advanced vortex combustion (AVC) to offer significant cost savings over conventional designs. This innovative engine shows potential as an important tool for load leveling with renewable power generation operations, further reducing emissions of greenhouse gases.

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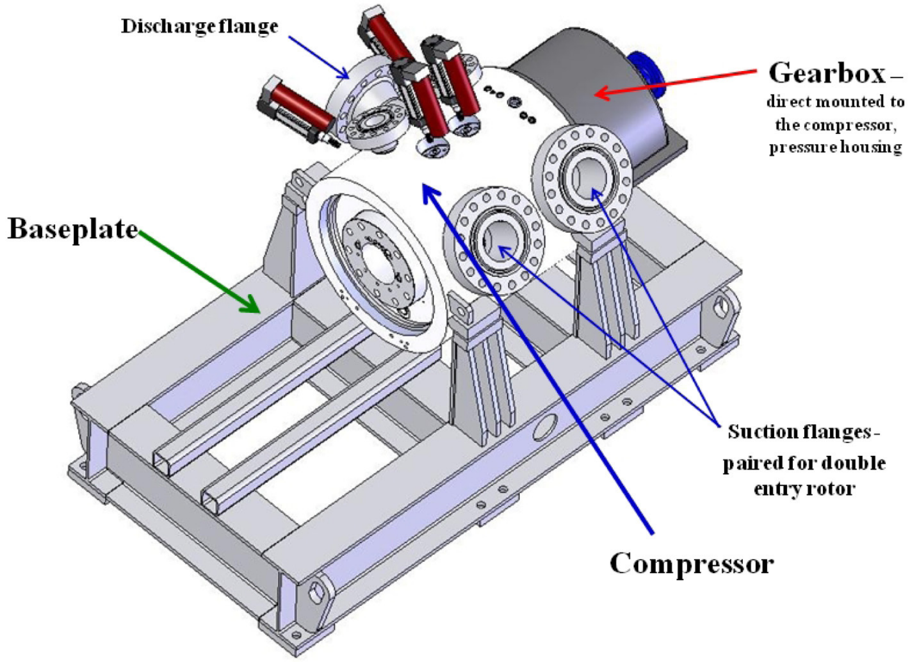
PARTNERS

Dresser-Rand

PERFORMANCE PERIOD

Start Date
08/01/2009

End Date
12/30/2013



13,000 hp supersonic shock wave compression demonstration unit.

Project Description

Ramgen, with the support of DOE's National Energy Technology Laboratory (NETL), is working to develop air and CO_2 compressor products based on shock wave compression technology. This approach builds on well-established ramjet principles of aerospace propulsion, and represents a radical conceptual departure from conventional multi-staged, bladed turbo-compressors. Supersonic inlet technology produces air velocities above the speed of sound, creating shock waves that efficiently compress air or CO_2. Shock wave compression has several advantages over conventional compression technologies: higher compression efficiency, higher single-stage compression ratios, opportunity for waste heat recovery, and lower capital cost.

This project was expanded in 2010 to include further development of the supersonic compression technology with a novel concept engine, the Integrated Supersonic Component (ISC) Engine. In separate research, Ramgen previously developed a high velocity combustor design uniquely suited for direct integration with the supersonic compression process. Working from lessons learned in developing the shock wave-based air and CO_2 compressors and the successful demonstration of its AVC system, Ramgen will combine supersonic shock compression and AVC to produce a working ISC engine design. As the engine is designed and tested, the CO_2 compressor will be advanced along its development path by incorporating the lessons learned in the aerodynamic design of the supersonic shock compression section of the ISC engine power wheel.

Important technical progress on shock wave-based compression has been achieved at a rapid pace because of access to supercomputers made possible by DOE. This enables the development of this revolutionary engine combined with further advancement of the CO_2 compressor. Based on a computational fluid dynamics (CFD) modeling capability that is one of the most advanced in the world, the supersonic compression process can be incorporated into the power wheel and directly integrated with the combustion and expansion of the working fluid required for a highly efficient power generation cycle.

Ramgen will employ classic engineering strategies to execute a successful CO_2 compressor demonstration program using a 13,000 horsepower (hp) unit. Ramgen's technical team will design and analyze the CO_2 compressor demonstration rig in deterministic steps—including Conceptual Design Review (CDR), Preliminary Design Review (PDR), and Final Design Review (FDR)—with an increasing level of detail at each step. The design process incorporates a number of decision gates along with risk assessment and risk reduction tasks. The program is also intended to produce early-stage preliminary aero flow path validation data. The project will feature several risk reduction efforts, including a critical factor investigation for designing a supersonic CO_2 compressor, performance model update, and a risk closure plan. Upon completion of the engineering design, the CO_2 compressor demonstration test rig will be fabricated and assembled. The final compressor testing step will be to operate a 13,000 hp CO_2 compressor rig at a suitable site.

The ISC engine development will include system design and construction of three increasing-scale models: (1) a 1.5 MW proof-of-concept model for initial testing; (2) a 2.5 MW workhorse model that incorporates a low pressure turbine stage to achieve the full efficiency capability of the system; and (3) a 5 MW commercial-scale prototype for field testing that incorporates the lessons learned from the proof-of-concept and workhorse units. The workhorse engine and the 5 MW scale prototype iterations are serialized sufficiently in time so as to allow lessons learned in the design and assembly of each engine to be applied to the next iteration. Performance testing of the 5 MW prototype will further provide critical experimental evidence confirming the effects of system physical scaling on performance.

Goals

The project goal is the integrated development of high-efficiency, low-cost CO_2 compression using supersonic shock wave technology to significantly reduce capital and operating costs associated with carbon capture, utilization, and storage, and of the ISC engine to lower capital and operating costs and increase system efficiencies on the order of 50 percent.

Objectives

The project objectives are detailed in five Phases. Phase 1 objectives are to show the feasibility of high-pressure shock wave compression by testing a high-pressure ratio air compressor rotor and evaluating a number of candidate conceptual configurations. Phase 2 objectives are to identify and reduce technical risk areas through the execution of a critical success factors/risk reduction validation and test program, and to complete the 13,000 hp proof-of-concept, supersonic shock wave CO_2 compressor preliminary and final designs. The Phase 3 objective is to operate the proof-of-concept, supersonic shock wave CO_2 compressor producing supercritical CO_2 at approximately 1500 psia. Phase 4 objectives are to expand the CO_2 key aerodynamic scaling algorithms and shock compression flow-path refinements for the proof-of-concept ISC engine power wheel and apply them to the optimization and efficiency improvement of the CO_2 compressor rotor. Phase 5 objectives are to scale the ISC engine power wheel up to a 5 MW size, which will provide further design rules and refine performance scaling algorithms that can be directly applied to support the design refinement and optimization of the shock compression section of the CO_2 compressor rotor.

Planned Activities

- Complete a feasibility study on the 13,000 hp CO_2 compressor.
- Perform a technical review, including static testing and test design requirements of the compressor.
- Perform CFD validation testing of the compressor.
- Complete a final design review summary on the CO_2 compressor demonstration unit design.
- Construct and operate the 13,000 hp supersonic shock wave CO_2 compressor test unit at the Dresser-Rand facility in Olean, New York, to successfully produce supercritical CO_2 at 1500 psia.
- Complete a results summary on the analysis, testing, and performance results for the CO_2 compressor.
- Perform system definition and preliminary design of the ISC engine, including 3-D CFD modeling.
- Complete the final design and develop a test plan for the ISC engine.
- Perform sub-component testing.
- Construct and test the 1.5 MW prototype unit.
- Complete analysis of prototype unit test data and conduct program review.
- Redesign and test the 3 MW-scale ISC engine.
- Design, construct, and test the field-scale 5 MW ISC engine at a coal mine.
- Incorporate the prototype test results into rotor performance scaling algorithms.
- Complete the final ISC engine program report.

Accomplishments

- The number of candidate configurations analyzed were expanded to increase the technology performance beyond the current project targets and to reduce the time required for the next phase (conducting future CCUS field demonstration projects).
- A review of the requirements and feasibility of the CO_2 compressor demonstration unit was initiated.
- The CFD tools and computing resources for use throughout the program were improved and expanded.

COST

Total Project Value
$79,737,997

DOE/Non-DOE Share
$50,000,000/$29,737,997

Government funding for this project is provided in whole or in part through the American Recovery and Reinvestment Act.

AWARD NUMBER

DE-FE0000493

- Preliminary engineering was completed for the test facility, and work was started on the detailed facility design.
- Facility preparation started in August 2010.
- An extension to the project was awarded in September 2010 to work on the ISC engine design that utilizes key technologies from the CO_2 compressor technology.

Benefits

Supersonic shock wave compressors are projected to reduce the volume of space needed in a power plant compared to that needed for the compressor section of a conventional turbine, while producing energy more efficiently and cost-effectively. Improved operating efficiency results from the integration of recovered heat from the compressor into the plant cycle, which can result in an approximate operational cost savings of 18 percent. The capital cost requirement is reduced by approximately 50 percent with a supersonic shock wave compressor. This technology is also projected to increase the pressure of captured CO_2 prior to geological sequestration, lowering sequestration costs.

An additional important benefit of expanding the work in this project is that the ISC engine will have the capability to generate electricity efficiently using dilute methane gas released during coal mining operations and from landfills. This unique capability is based on the combustion of the air/methane mix occurring virtually instantaneously following its supersonic compression. This eliminates the possibility of premature ignition or detonation of the fuel-air mixture. Using this methane as a fuel could mitigate its effect as the second largest anthropogenic greenhouse gas contributor, after CO_2, to global warming.