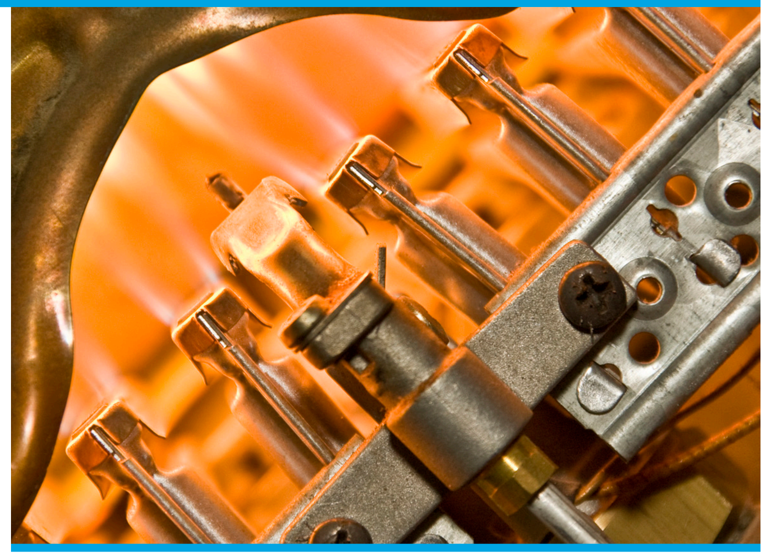
Advanced Reciprocating Engine Systems (ARES)

Raising the Bar on Engine Technology with Increased Efficiency and Reduced Emissions, at Attractive Costs

The U.S. Department of Energy's (DOE) Advanced Reciprocating Engine Systems program (ARES) was designed to promote separate but parallel engine development among the major stationary, gaseous fueled engine manufacturers in the United States. The program promoted cooperation among engine manufacturers, universities, national laboratories, and engine consultants to obtain maximum engine efficiency and low emissions from natural gas reciprocating engines for power generation. Through competitively funded, multiple-participant R&D, researchers investigated advanced combustion systems, unique fuel handling and processing systems, advanced ignition and materials including catalysts, and technology that is compatible with existing transmission and distribution systems.



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Benefits for Our Nation

Advanced natural gas power generation systems offer a comparative advantage in dispersed power generation, combined heat and power applications, and total energy systems to maximize efficiency and minimize environmental impacts. With or without the benefit of waste heat recovery, ARES systems can result in billions of dollars in savings for the U.S. economy, under a variety of operating and market strategies.

Additional benefits of ARES systems include:

- 40% higher fuel efficiency and greater flexibility than conventional systems
- Lessened dependence on foreign sources of fuel
- Ultra-low emissions
- Lower cost power technologies

With a wide power range and operating flexibility, reciprocating engines are suitable for numerous sites, including commercial, industrial, institutional, and even residential applications.

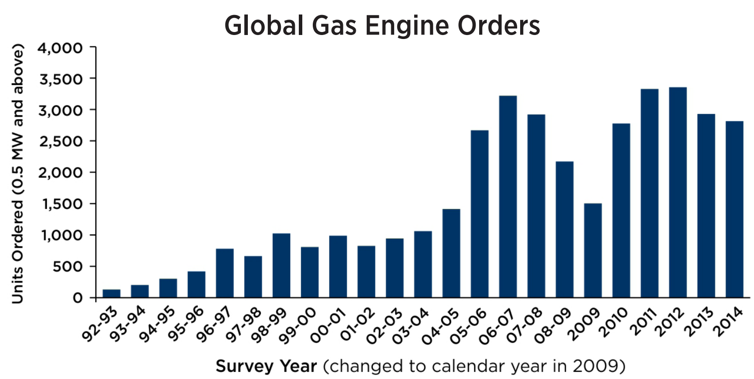
ARES Strategy

The manufacturers and supplier teams, along with considerable involvement from several universities and national laboratories, researched advanced combustion systems, unique fuel and air handling systems, advanced ignition and materials, catalysts, lubricants, and other technologies to promote efficient use of natural gas and simultaneously lower pollutant emissions.

ARES Goals

The goal of the ARES program was to deliver a technologically advanced engine/generator system that combines high specific power output and low exhaust emissions with world-class overall efficiency, while maintaining excellent durability, all provided at a low installed cost. The technical end goals of ARES were to ultimately produce an engine/generator that can achieve the following:

- 50% brake thermal efficiency (BTE); 80+% with combined heat and power (CHP)
- A maximum of 0.1 g/bhp-hr NO_x emissions
- Maintenance costs below $0.01/EkW-hr
- Maintaining cost competitiveness



Sales of natural gas fueled reciprocating engines have bounced back after a slowdown in 2008 and 2009. *Source: Diesel & Gas Turbine Worldwide Power Generation Order Survey, 1992-2015.*

Photo courtesy of Cummins, Inc.

The ARES Projects

Two ongoing and three completed ARES projects, led by the major engine manufacturers and the National Laboratories of the U.S. Department of Energy, are bringing forth a new generation of highly advanced, natural gas-fired engines to meet the energy efficiency and emissions reduction needs of end users.

Cummins

Project Partners:

Cummins Inc., Gas Technology Institute, Wisconsin Engine Research Consultants, Argonne National Laboratory

Project Description

This project focused on the development of advanced natural gas fueled engines for power generation that combine high efficiency, low emissions, fuel flexibility, and reduced cost of ownership. Cummins selected a lean burn approach for achieving the targets of Phase I and lean burn with high Brake Mean Effective Pressure (BMEP), improved closed cycle efficiency, optimized engine subsystems, and waste heat recovery system for Phase II. For Phase III, Cummins built upon the Phase II technologies, including application of advanced combustion models, high efficiency air handling, advanced controls, advanced ignition systems, NO_x aftertreatment, and an advanced waste heat recovery system.

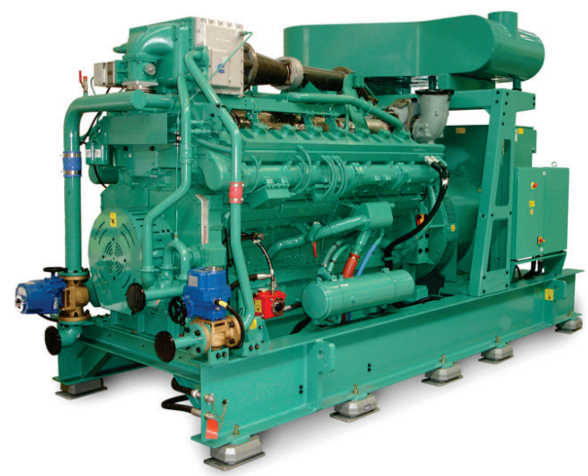


Fig 1. Phase I of the Cummins reciprocating engine was completed with the successful demonstration of this QSK60G engine.
Photo courtesy of Cummins Inc.

Milestones

Phase I: 44% efficiency, 0.5 g/bhp-hr NO_x by 2006 (Completed)

Phase II: 47% efficiency, 0.1 g/bhp-hr NO_x by 2012 (Completed)

Phase III: 50% efficiency, 0.1 g/bhp-hr NO_x by 2014 (Completed)

Highlights

- Developed new lean burn technology applied to the 60L platform. This included a high compression ratio piston, Miller cycle camshaft, long life spark plugs, low loss exhaust valves, high efficiency turbo, and advanced controls.
- Demonstrated < 0.1 g/bhp-hr NO_x with lean burn combustion recipe and waste heat recovery system and demonstrated Phase III target of 50% efficiency.
- Developed advanced technologies, modeling tools, and capability to operate with non-standard gases (renewable fuels). Advanced waste heat recovery system is integrated with the engine components.
- Several of these technologies developed under ARES program will be used in future Cummins natural gas engines and are expected to enter production over the next few years.

Caterpillar

Project Partners:

Caterpillar, Colorado State University

Project Description

In Phase I, the team successfully integrated a suite of improvements for increased efficiency, which included advanced combustion, improved air systems, and dedicated control systems. Advanced combustion is achieved through an open chamber design, which accepts very low pressure gas, provides nearly equivalent fuel efficiency, and results in lower maintenance costs compared to a pre-chamber design. The improved air system benefits from its larger size, to effectively cool the larger flow of combustion air mixture and higher power density. The control system consists of a simple and flexible design which tightly maintains the level of NO_x emissions.

After the successful Phase II demonstration, the program focused on field deployment of experimental systems targeting the use of producer gas and exhaust waste heat recovery. The aim of this work was to further the understanding of the economics of these technologies and to identify any remaining technical barriers to the commercial development and deployment of these technologies.

Milestones

Phase I: 44% efficiency, 0.5 g/bhp-hr NO_x by 2004 (Completed)

Phase II: 47% efficiency, 0.1 g/bhp-hr NO_x by 2008 (Completed)

Highlights

- Met ARES Phase I and II goals.
- Caterpillar's G3520E demonstrated 47% efficiency and 0.1 g/bhp-hr NO_x.
- Caterpillar's G3520C demonstrated 47% efficiency with exhaust waste heat recovery.

Caterpillar withdrew early from the ARES program. This decision was based on business considerations with regard to distributed energy technologies.

Fig 2. Caterpillar's G3520C, 20-cylinder engine, suitable for the 1-2 MW gas electric power marketplace. *Photo courtesy of Caterpillar.*

GE Dresser Waukesha

Project Partners:

GE Dresser Waukesha, Oak Ridge National Laboratory

Project Description

GE Dresser Waukesha refined its approach to developing natural gas engines with increased use of computer simulations and statistical analysis to reduce the time between technology development and market benefits. In Phase I, Waukesha developed its Advanced Power Generation (APG) engine, focusing on combustion and controls technologies, and application of Miller cycle to achieve its objectives. The APG1000 is a turbocharged, lean-burn unit with 42 percent engine efficiency at 1800 RPM, 0.5 g/bhp-hr NOx (with after-treatment). The application of Phase I technologies has led to a 10 percent reduction in the cost of electricity produced, with increased reliability and durability. In Phase II, Waukesha explored further advances in combustion, low friction technologies, and new controls technology to obtain further efficiency gains and emissions reductions with minimal additional initial and operating costs. Waukesha built a laboratory-scale demonstration of its second generation engine for baseline testing and further technical development. In addition, Waukesha leveraged Phase I technologies to an existing 220 mm bore engine in its product line to enhance efficiency and lower emissions.

Milestones

Phase I: 42% efficiency, 0.5 g/bhp-hr NO_x by 2006 (Completed)

Phase II: 47% efficiency, 0.1 g/bhp-hr NO_x by 2010 (Completed)

Highlights

- Met ARES Phase I and II goals and developed one of the world's highest efficiency 1800 RPM engines.
- Phase II technology was deployed in APG1000 engine.
- Strong customer demand for new products created manufacturing jobs at GE Dresser Waukesha.

Following the purchase of Dresser Waukesha by General Electric, a decision was made to withdraw from the ARES program. This decision was based on business considerations with regard to distributed power generation.

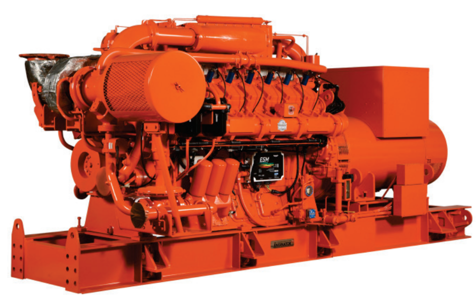


Fig 3. Waukesha's APG1000 Enginator is a turbocharged and intercooled, sixteen cylinder, lean combustion gaseous fueled engine system. *Photo courtesy of GE Dresser Waukesha.*

Argonne National Laboratory

Project Partners:

Argonne National Laboratory, Cummins Engine Company, Altronic, Inc., DENSO Corp., Capstone Turbine Corp., Princeton Optronics, Inc., Oak Ridge National Laboratory

Project Description

Argonne works in the development of various technologies that improve the performance of large-bore natural gas engines. Primary focus has been ignition systems that improve ignition stability, extend lean-burn combustion, and provide flame acceleration. In concert with industrial partners, Argonne has developed and demonstrated different micro-laser ignition systems to realize significant performance benefits. Lower NO_x emissions were achieved through nitrogen enriched air provided by polymeric membranes, and Argonne has conducted in-cylinder spectroscopic studies and flame visualization. The team also investigates engine performance optimization for varying natural gas and opportunity fuel compositions.

Milestones

- Distributed Energy Research Center with three engine test cells (Completed)
- A gas blending system for testing various low-BTU gaseous fuels (Completed)
- Development and demonstration of micro-laser ignition system for a 6-cylinder natural gas engine (Completed)

Highlights

- Laser ignition extends lean combustion limit to realize simultaneous improvement of engine efficiency and emissions.
- Nitrogen enriched air, a clean alternative to exhaust gas recirculation, could reduce NO_x emissions by 50%–70%.

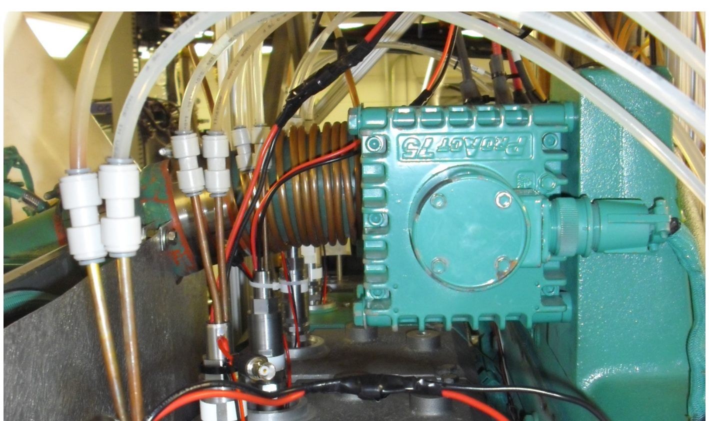


Fig 4. Laser igniters installed on a 6-cylinder engine. *Photo courtesy of Argonne National Laboratory.*

Oak Ridge National Laboratory

Project Partners:

Oak Ridge National Laboratory, Solar Turbines Inc., Capstone Turbine Corporation, Thermal Centric Corporation

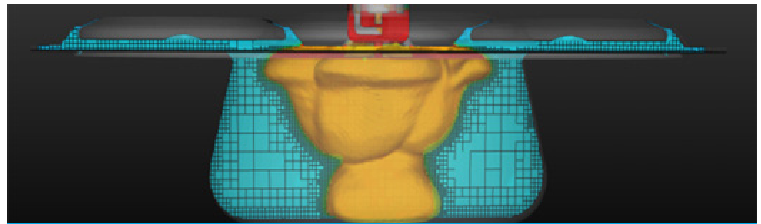


Fig 5. Simulation results for conventional, lean-burn spark ignition operation provide a baseline comparison for estimating potential efficiency and emissions benefits of reactivity controlled compression ignition. *Photo courtesy of Oak Ridge National Laboratory (ORNL).*

Project Description

Oak Ridge research efforts are focused on improving the efficiency and viability of CHP systems and high efficiency electrical generation systems while supporting the U.S. manufacturing base as it re-vamps to supply these technically advanced systems. Oak Ridge is employing additive manufacturing (AM) for CHP systems, improving electrical efficiency of power generation, and lowering manufacturing costs through advanced materials. Current projects include: development and deployment of new materials that can operate at higher temperatures with reduced degradation, development of novel heat exchangers with AM, rapid prototyping of high efficiency engines and components, and advanced geospatial modeling of CHP system installations.

Milestones

- Fabrication and operation of a small reciprocating engine with additive manufacturing (Completed)
- Development of novel heat exchanger designs with additive manufacturing

Highlights

- Less expensive, high temperature alumina-forming austenitic (AFA) foils exhibited lower corrosion under combustion conditions than current stainless steel alloys
- IGATE-CHP geospatial modeling tool identifies spark spread and thermal-to-electric ratio for manufacturing facilities at the zip code level

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