

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) is designed to promote separate but parallel engine development among the major stationary, gaseous fueled engine manufacturers in the United States. The program promotes 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 are investigating 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.

Benefits for Our Nation

Advanced natural gas power generation systems will 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.

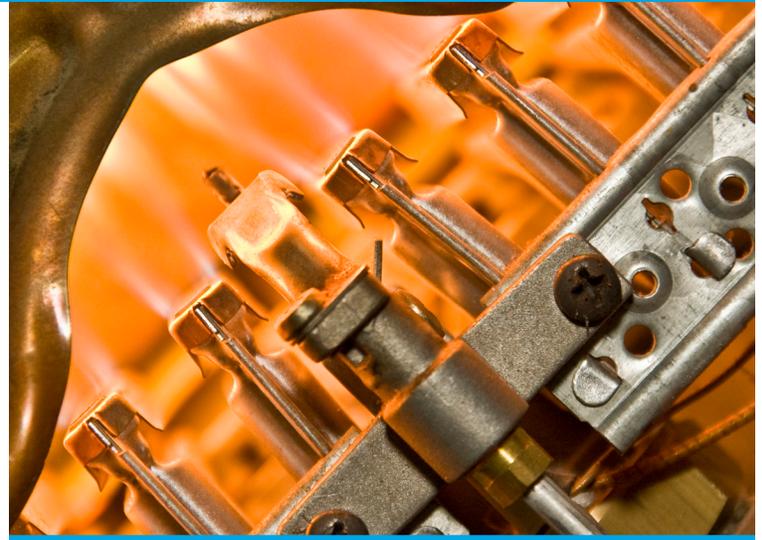
Additional benefits of ARES systems include:

- 40% higher fuel efficiency and 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, are researching 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.

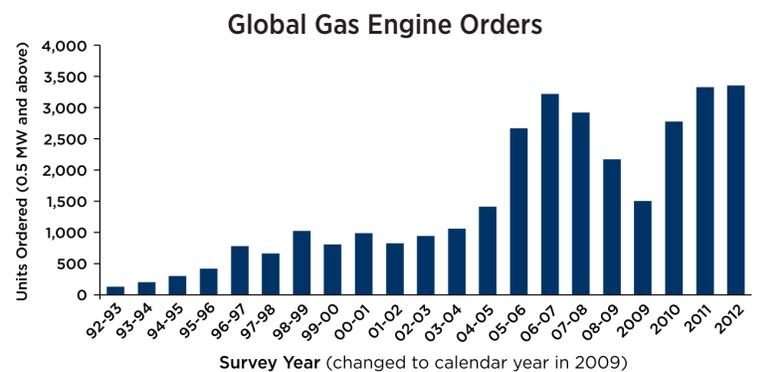


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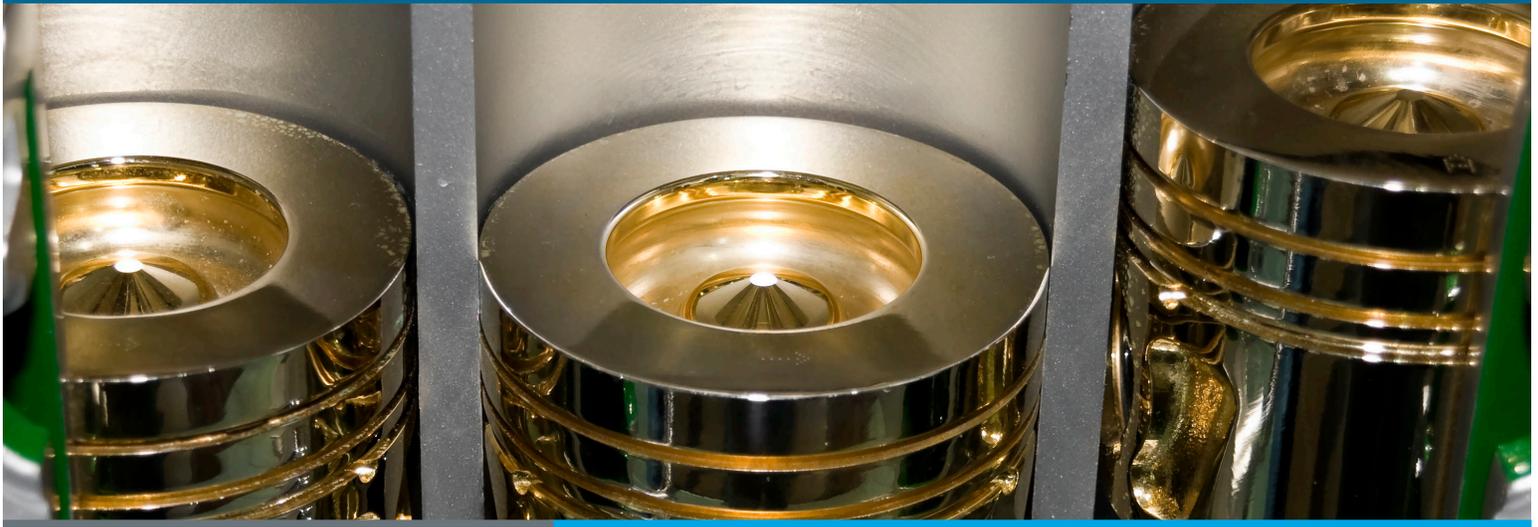
ARES Goals

The goal of the ARES program is 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 are 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, 1992-2012.



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The ARES Projects

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

Cummins

Project Partners:

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

Project Description

This project focuses 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 is building upon the Phase II technologies, including application of advanced combustion models, high efficiency air handling, advanced controls, advanced ignition systems, and an advanced waste heat recovery system.

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 2013

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. Currently in production.
- Demonstrated < 0.1 g/bhp-hr NO_x with lean burn combustion recipe and waste heat recovery system. Currently working on demonstrating 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.

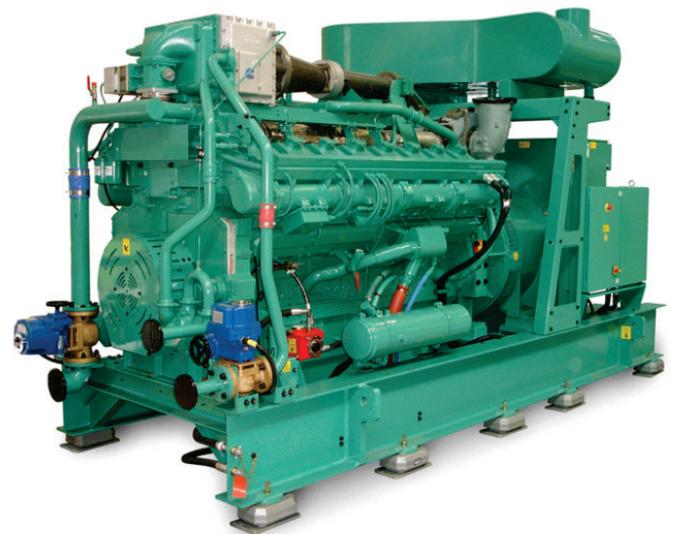


Fig 1. Phase I of the Cummins reciprocating engine was completed with the successful demonstration of this QSK60G engine.
Photo courtesy of Cummins Inc.

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 has withdrawn 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 NO_x (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 is leveraging 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 being deployed in APG1000 engine.
- Strong customer demand for new products has 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.

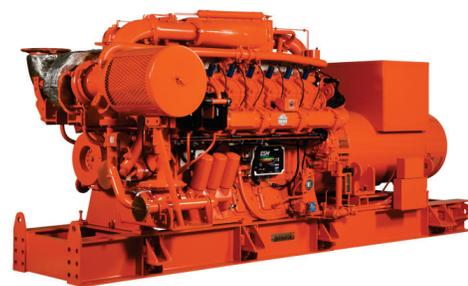


Fig 3. Waukesha's APG1000 Enginator is a turbocharged and intercooled, sixteen cylinder, lean combustion gaseous fueled engine system. *Photo courtesy of GE Dresser Waukesha.*

Argonne National Laboratory

Project Partners:

Argonne National Laboratory,
Cummins Engine Company,
Altronic, Inc.

Project Description

Argonne is working on the development of advanced laser ignition systems, which are suitable for lean fuel mixtures. Performance and emissions benefits have already been demonstrated at the lab scale, on a single cylinder engine.

A laser ignition system for a multi-cylinder engine is being developed. To reduce NO_x emissions, Argonne is conducting low-temperature combustion studies with nitrogen enriched air provided by polymeric membranes. Argonne is also conducting spectroscopic studies of natural gas combustion to perform advanced diagnostics and real-time combustion measurements. The team plans to conduct transparent engine studies to identify potential fuel additives that enhance ignitability and increase flame speed for natural gas as well as opportunity fuels.

Milestones

- Distributed Energy Research Center (DERC) commissioned
- Two patents on laser ignition and one on nitrogen air enrichment
- Nine technical publications

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. Argonne's nitrogen enrichment tests on a single cylinder research 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

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 power generation, and lowering manufacturing costs through advanced materials. Projects include: development of novel heat exchangers with AM, rapid prototyping of high efficiency engines and components, advanced thermodynamics modeling of CHP systems, modeling of reactivity controlled compression ignition (RCCI) for high efficiency stationary power systems, waste heat recovery from harsh environments in manufacturing, and new materials and processes for low-cost manufacturing of CHP systems.

Milestones

- Completion of advanced thermodynamic analyses of engines
- Development of novel heat exchangers
- Advancement of reciprocating engine efficiency

Highlights

- Expanded the advanced thermodynamic analyses of engines to include an advanced combustion regime.
- Added new projects to include examination of heat exchangers in harsh industrial environments and use of AM to advance reciprocating engine efficiency.

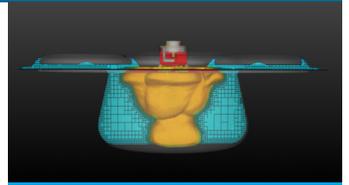


Fig 5. Simulation results for conventional, lean-burn spark ignition operation provide a baseline comparison for estimating potential efficiency and emissions benefits of reactivity controlled compression ignition.
Photo courtesy of Oak Ridge National Laboratory (ORNL).

ARES Partners

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