Advanced Reciprocating Engine Systems (ARES)

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.

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

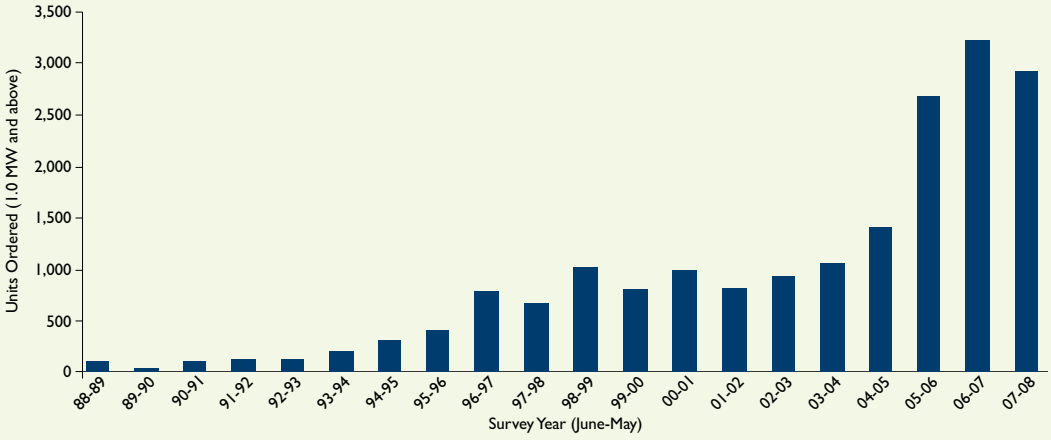
The U.S. Department of Energy's (DOE) Advanced Reciprocating Engine Systems program (ARES) is designed to promote separate, but parallel engine development between the major stationary, gaseous fueled engine manufacturers in the US. The program promotes cooperation between engine manufacturers, universities, 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.

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 gm /bhp-hr NOx emissions
- Maintenance costs below $0.01/EkW-hr
- Maintaining cost competitiveness

Gas Engine Order Trends



Sales of reciprocating engines for power generation (1MW and above) have been growing at a healthy rate, with record breaking orders each year.

Source: Diesel and Gas Turbine Worldwide, October 2008

The ARES Projects

There are currently 3 active ARES projects led by the major engine manufacturers, and 2 additional research projects led by the National Laboratories of the U.S. Department of Energy. These efforts 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.

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

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 has selected a lean burn approach for achieving the targets of Phase I and a stoichiometric system with exhaust gas recirculation (EGR) and three way catalyst (TWC) with thermo chemical recuperation (TCR) for Phase II. For Phase III Cummins selected homogenous charge compressions ignition (HCCI) technology as the best candidate for excellent break thermal efficiency (BTE) and brake specific NOx potential. The three technologies described above complement and build on each other through the application of advanced combustion models, high efficiency air handling, advanced controls, advanced ignition systems and advanced aftertreatment. There is a demonstration planned for the end of each phase.

Milestones

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

Phase II: 47% efficiency, 0.1 g/bhp-hr NOx by 2010

Phase III: 50% efficiency, 0.1 g/bhp-hr NOx by 2012

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 Stoichiometric operation with EGR and TWC combustion technology, including durability test on 19L platform. Developed new TWC formulation and ignition technologies.
- Developed HCCI combustion and control/sensor technologies. Demonstrated research concept on real multi-cylinder engine.

Caterpillar

Project Partners: Caterpillar, Colorado State University.

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

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 NOx emissions.

In its current development stage (Phase II), the project is focusing on value-added after-treatment, and exhaust heat recovery. A Phase-II demonstration of 47% efficiency and less than 0.1g/bhp-hr NOx is currently underway. In phase III Caterpillar will demonstrate 50% thermal efficiency and 0.02g/bhp-hr NOx.

Milestones

Phase I: 44% efficiency, 0.50 g/bhp-hr NOx by 2004 (Completed)

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

Phase III: 50% efficiency, 0.1g/bhp-hr NOx, by 2010

Highlights

- Phase I objectives have been successfully met.
- Caterpillar's G3520E can exhibit 44.0% efficiency or 0.5 g/bhp-hr NOx.
- More than 3.84 GW of ARES G3500 have been installed, worldwide.

Dresser Waukesha

Project Partners: Dresser Waukesha, Oak Ridge National Laboratory

Fig 3. Waukesha's APG 1000, turbocharged and intercooled, sixteen cylinder, lean combustion gaseous fueled Enginator.

Project Description

Dresser Waukesha has 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 lead to a 10 percent reduction in the cost of electricity produced, with increased reliability and durability. In Phase II, Waukesha is exploring 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 has a laboratory-scale demonstration of its second generation engine currently in use 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 NOx by **2006 (Completed)**

Phase II: 47% efficiency, 0.1 g/bhp-hr NOx by **2010**

Phase III: 50% efficiency, 0.1 g/bhp-hr NOx by 2013

Highlights

- Met ARES Phase I goals and developed one of the world's highest efficiency 1800 RPM engines.
- Commercial product released in 2006.
- Strong customer demand for this product has created manufacturing jobs at Dresser Waukesha.

Argonne National Laboratory

Project Partners: Argonne National Laboratory, several polymeric membrane manufacturers.

Project Description

Fig 4. Argonne's nitrogen enrichment tests on a single cylinder research engine.

Argonne is currently working on the development of advanced laser ignition systems. In these systems, mixtures much leaner than those limiting conventional ignition can be ignited. 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. Additionally, to reduce NOx emissions, ANL is conducting low-temperature combustion studies with nitrogen enriched air provided by polymeric membranes. Significant NOx reductions (50 - 70%) with very small efficiency penalties were observed for lean-burn as well as stoichiometric engine operation. ANL 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 in laser ignition and one patent in nitrogen enrichment.
- Nine technical publications.

Highlights

- Laser ignition extends lean combustion limit to realize simultaneous improvement of engine efficiency and emissions.
- Realized a 50-70% reduction in NOx emissions with nitrogen enrichment.

Oak Ridge National Laboratory

Project Partners: Oak Ridge National Laboratory, Dresser Waukesha

Project Description

Fig 5. Single cylinder research engine at ORNL

Oak Ridge research efforts are focused on improving combustion efficiency, conventional spark plugs, and investigating opportunity fuels. To improve engine efficiency, the team will collaborate with Waukesha and incorporate advanced diagnostics (in-cylinder pressure measurements and surface temperatures) to advance and improve combustion dynamics.

The team anticipates new materials being developed and evaluated under field-conditions that would enable long-life spark plugs for high-power natural gas engines.

Research with opportunity fuels target improvements in the quality of the gas entering the engine, by 1) mitigation of harmful contaminants (e.g., siloxanes), and 2) by increasing the fuel quality or methane content of the fuel. Opportunity fuels are typically low-quality fuels, which can be a significant energy source if effectively used in engines and other industrial equipment. Use of these fuels increases the fuel supplies and reduces methane emissions, which is a potent greenhouse gas.

Milestones

- Installation of large-bore single cylinder test engine
- Completion of combustion studies with Waukesha
- Development of siloxane mitigation strategy suitable for multiple engine manufacturers

Highlights

- Developed and evaluated a functional lean NOx Trap (LNT) emissions control system capable of 90% NOx reduction.
- Identified key material parameters and initial development of first-generation erosion-resistant materials for high-power spark plugs.
- Characterized and mitigated silica deposition from siloxane in a landfill gas engine.

ARES Partners

Engine Manufacturers:

Cummins
Principal Investigator: Edward J. Lyford-Pike
(edward.j.lyford-pike@cummins.com)

Caterpillar
Principal Investigator: David T. Montgomery
(montgomery_dave@cat.com)

Waukesha
Principal Investigator: James R. Zurlo
(jim.zurlo@dresser.com)

National Laboratories:

Argone National Laboratory
Principal Investigator: Sreenath Gupta
(sgupta@anl.gov)

Oak Ridge National Laboratory
Principal Investigator: Timothy J. Theiss
(theisstj@ornl.gov)

A Strong Energy Portfolio for a Strong America

Energy efficiency and clean, renewable energy will mean a stronger economy, a cleaner environment, and greater energy independence for America.

Working with a wide array of state, community, industry, and university partners, the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy invests in a diverse portfolio of energy technologies.

For more information contact:

EERE Information Center
1-877-EERE-INF (1-877-337-3463)
www.eere.energy.gov

Visit the ITP Website at
www.eere.energy.gov/industry

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy