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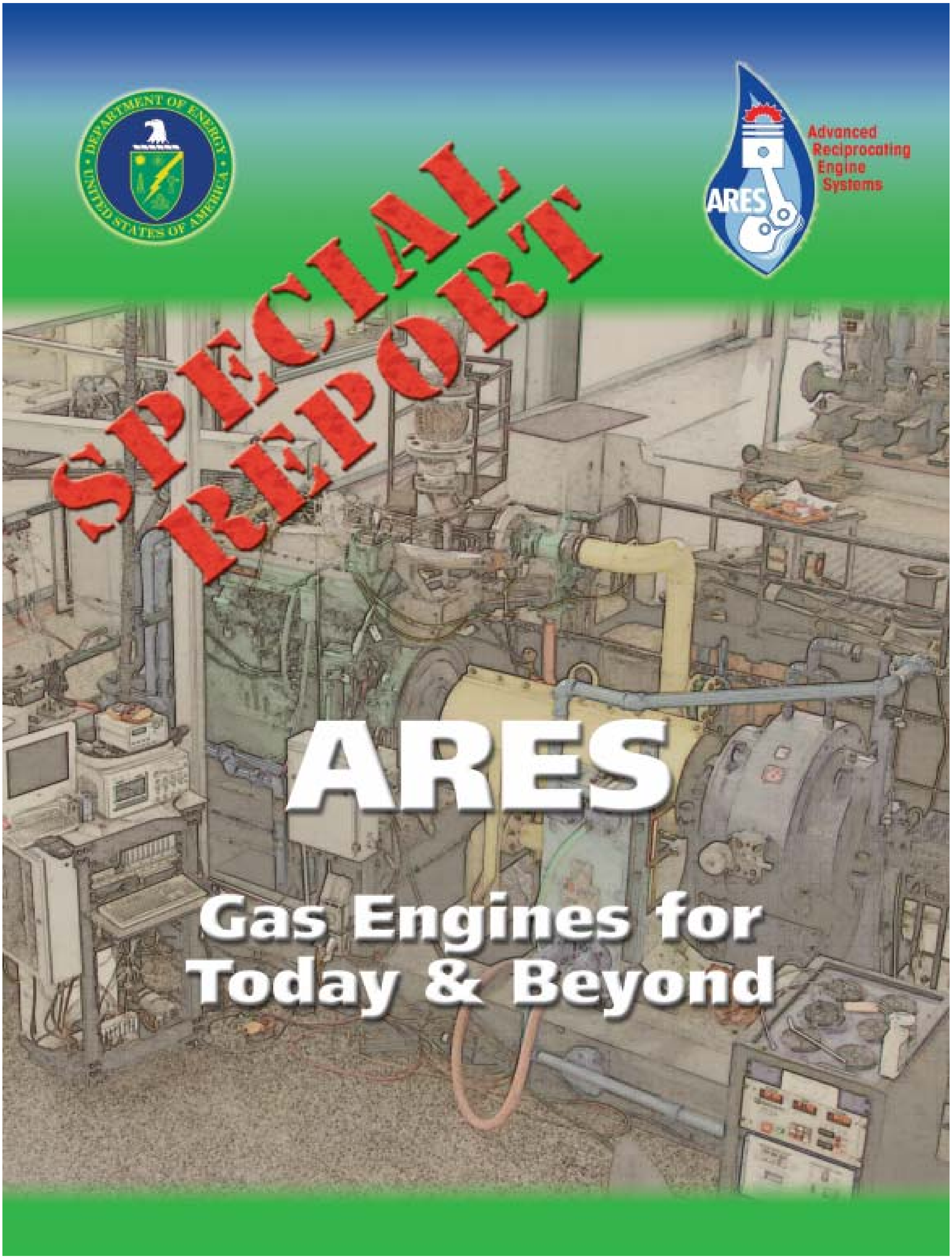

Special Report

ARES – Gas Engines for Today & Beyond

Caterpillar, Cummins and Waukesha drive technology toward goals of low emissions, high efficiency, low cost gas engines

by Mark McNeely

To say that reciprocating engines have evolved technically more in the past decade than at any other time in their 100-plus year history is not a stretch of the imagination. Driven by emissions regulations and efficiency requirements — and aided by advancements in electronic control technologies — the modern piston engine has secured its future as a primary driver for multiple markets.

With this in mind and the energy industry as a major market segment for reciprocating engines, three U.S. engine manufacturers have embarked on a cooperative venture with the U.S. Department of Energy (DOE) to raise the bar on engine technology — specifically large natural gas-fired engines.

The Advanced Reciprocating Engine Systems (ARES) program is a competitively funded, multiple participant arrangement involving DOE, Caterpillar, Cummins and Waukesha Engine. The engine output range targeted by ARES is roughly 500 to 6500 kW for power generation applications. Special attention has been given to technologies that compare to current and future competing distributed generation technologies.

The manufacturers and supplier teams, along with considerable involvement from several universities and national laboratories, are researching advanced materials, unique fuel and air handling systems, advanced ignition and combustion systems, catalysts, lubricants, and technologies that are compatible with existing transmission and distribution systems.

The U.S. Department of Energy has teamed up North America's three large gas engine manufacturers to implement the Advanced Reciprocating Engine Systems (ARES) program, which focuses on gas engine technologies to increase efficiencies, decrease emissions and lower life cycle costs. Caterpillar, with the introduction of its G3520C, has been the first to commercialize some of its ARES developments. Shown is a Cat G3520C gen-set installed in 2002 at Heber Light & Power in Heber City, Utah, U.S.A.

Launched in September 2001, ARES consists of three phases, each with specific targets to reach the program's overall goals. Phase 1 is headed for completion in the 2004-5 timeframe, while the final phase is expected to be completed in 2009-10.

ARES' goals for advanced gas engines are substantial, including 50% thermal efficiency (80+% with CHP), NO_x emissions of 0.1 g/bhp-hr, installed capital costs of US$400 to $450 per kWe and maintenance costs of US$0.01 per kWe-hr. The goals must also be met while maintaining current engine reliability.

Despite aggressive goals and a relatively short timeline in which to achieve them, initially there were varying degrees of support for the ARES program. "During early meetings to review the ARES concept, there was a lot of discussion about whether or not there should even be funding for reciprocating engine technology because some people who are not familiar with the technology thought it was old school," explained Tom Kruziki, vice

Each engine manufacturer is using a specific engine platform for applying their ARES development work and technologies. Waukesha Engine is using its venerable VGF Series. Pictured is a VGF P48GLD, rated 800 kW.

president of marketing for Waukesha Engine.

"A very valid argument is, however, that reciprocating engines represent current technology that's proven. These engines have done a good job of providing distributed generation not just in the U.S. market, but worldwide," Kruziki added. "And if you want a high probability of success with a research project, why not go with proven technology at this point. Then, parallel to that, continue to fund leading edge technology that some day might provide additional gains 15, 25 years down the road. The ARES program concept eventually turned on some lights for some of the people in Washington that if we want some kind of a win in the next five to 10 years, we do have to look at current technology to provide these gains."

A market assessment report prepared for the ARES program by Joel Bluestein, president of Energy and Environmental Analysis, Inc., estimates the sales potential for ARES-type engines to be roughly 5100 1.0 MW units by 2010, as well as sizeable growth through 2020. "There are a huge number of establishments, both commercial and industrial, in the 500 kW to 5.0 MW range that do have a need for power quality or CHP. And distributed generation has real cash value to them," Bluestein said.

"If you can manufacture an engine that meets the ARES envelope of very high efficiency, very low emissions and low costs, then you can sell that engine anywhere," Bluestein added.

So what are some of the ARES successes to date? There is the design, manufacture, startup and initial testing of the first ARES single cylinder test engine at Caterpillar. The modeling, simulation design and engine test of the Cummins diesel pilot injection (DPI) injectors for the program. And there is the engine layout and control system design completed with multiple lab engines running test systems at Waukesha Engine. Finally, there is the high level of cooperation achieved among the engine builders themselves and with DOE.

DOE's Program Manager Ron Fiskum said, "We have a very good relationship with the engine manufacturers. We are making progress, but we also have several issues to overcome. Some goals have been met and are implemented onto production engines. However, the three major areas to be worked on are — in order — emissions, ignition systems and lubricants. If we are to go to higher efficiencies, this may require going to higher temperatures, which will require better materials and lubricants. It will not be easy and will require increased funding.

"We have 11 universities working on this program in the most important topics, i.e. sensors, laser ignition, lubricants, and those materials that will improve the engine technology. The universities will work with the manufacturers as they see fit with these technologies as they apply. There are also three national labs working with us, including Oak Ridge, Sandia, and Argonne," Fiskum said.

Reaching 50% brake thermal efficiency is one of the most important goals and Figure 1 outlines some areas where the ARES program aims to achieve these efficiency gains. Air handling, heat rejection and friction losses are some of the primary targets.

Each of the three engine manufacturers is using a slightly different engine platform on which to develop and apply the first phase of the ARES technologies.

Cummins is using a combination of its QSK and QSV gas engines for its ARES participation, including the QSV91.

Waukesha Engine is using its VGF Series, Caterpillar is using its 3500 Series and Cummins is utilizing a mix of its QSK and QSV gas engines. Each engine series operates at 1500 and 1800 r/min for 50 and 60 Hz markets, respectively. While the companies are focusing on certain proprietary technologies, by necessity all three are traveling down similar paths with regard to controlling combustion characteristics and optimizing internal and external engine components.

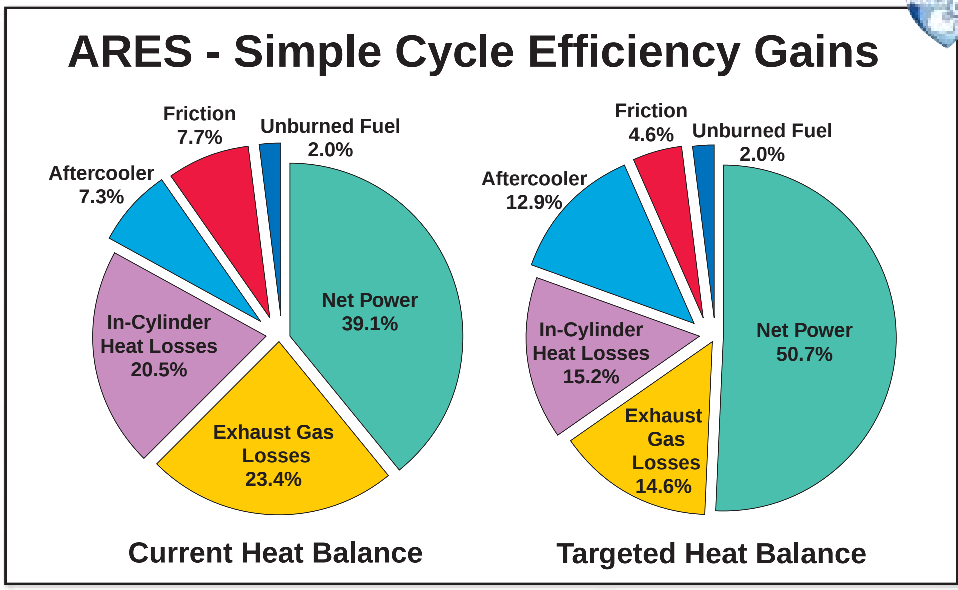

Figure 1

Caterpillar, with the introduction of its 20-cylinder G3520C (see *D&GTW*, April 2003, p.42), has commercialized some of its ARES program technologies. The G3520C's advanced gas engine control (AGEC) module is designed to precisely control fuel flow. The module, which largely came out of the ARES program, is a single-source full engine control package including air-to-fuel ratio control, governing in either isochronous or droop modes, ignition with detonation protection and individual cylinder timing control, plus start/stop logic. The AGEC also includes remote communications and data access, along with diagnostics.

The development of the AGEC control module on the G3520C has also been coupled with further refinements to the cylinder head and air handing system, including turbocharging.

"Technically I would say we're on schedule, perhaps a bit ahead of schedule. We've been able to get some development work done, especially on the G3500C that has helped us to get in line with the upcoming Phase 1 goals," said Gordon Gerber, ARES program manager for Caterpillar. "Phase 2 ARES goals are even more stringent for both efficiency improvements and emissions reductions and we have ongoing research and development plans to meet these targets as well. Phase 3 final goals are currently in the research stage and time will tell on our results for this final stage."

Part of the ARES program involves a high level of research cooperation between industry and universities. Caterpillar, in conjunction with Purdue University, has developed a test rig designed specifically to measure surface friction between piston rings and a cylinder liner.

Cummins has done extensive work on a number of fronts, according to Mark Rosswurm, technical leader for the ARES program. "One area is in the high efficiency air handling system for these engines. As the bmep increases and as the engines get leaner and more efficient there becomes more and more need for high efficiency turbocharging systems. That work has been progressing and it will be spun off to our commercial programs. We've done a significant amount of work in the design and modeling and simulation of the piston for fast heat release. This is also required for very lean, high bmep engines. We've done a lot of work with spark plug erosion characterization and development work on alternative ignition systems that use spark plug energy management to improve the life of the spark plug.

"Life cycle costs are heavily dominated by efficiencies and maintenance costs and these are certainly centerpieces of the overall program goals," Rosswurm added.

Rosswurm noted that Cummins is working closely with Colorado State

Cummins, in conjunction with Colorado State University, is testing diesel pilot injection on a QSK19G gas engine.

University in the design, simulation and actual test of diesel pilot ignition subsystems. "We've also worked with them on developing the combustion test fixture so that we can actually visualize both the spray patterns and also the high temperature ignition event itself."

Meanwhile Caterpillar is working closely with Purdue University on unique friction reduction technology that will modify surfaces on components, such as piston rings and liners, to lower friction without loss of sealing or component life.

Both Caterpillar and Cummins are also continuing their work in homogenous charge compression ignition (HCCI) technology, which might best be characterized as a Phase 3 type of technology. HCCI is not without its challenges. "When you ask the whole cylinder to ignite simultaneously as compared to a regulated flame front, you're dealing with different control issues to manage that combustion correctly. But having done that, you can reach excellent efficiencies and some very, very low NO_x numbers," Gerber said.

Rosswurm echoed the sentiment. "The ability to control the combustion process well enough at these very lean air fuel ratios with HCCI is certainly challenging," he said. "We've made some significant progress in the closed loop control of the combustion process to get the best tradeoffs between high efficiency and very low NO_x."

All three companies also continue their work in reducing friction losses. Waukesha Engine's Director of Marketing John Hoeft explained, "The advantage in friction reduction is that oftentimes what you do to improve efficiency can harm emissions. Friction reduction improves efficiency without harming emissions, so it's one of the few areas you can really go after and focus on and not have some type of emissions tradeoff."

Waukesha's Phase 1 effort is also focusing on improvements in combustion and ignition, and on higher power density. Waukesha's new ESM control system is being used to drive all new ARES technologies, as well as control ignition timing, speed governing, air-fuel ratio control and detonation protection. ESM also provides fault logging, engine diagnostics, and serves as the communication interface for local or remote operation.

Beyond the technical challenges, each of the engine builders acknowledges that there are some pitfalls on the road to Phase 3 completion in 2010. One, the market for distributed generation is not fully developed and there remain barriers and policy inconsistencies. Two, emissions regulations could possibly outpace the ARES program goals. Finally, continued funding of various research programs is essential to achieving ARES milestones.

It's also imperative to reiterate, however, that ARES has already been successful in bringing together the divergent agendas of the various participants, including those of DOE, laboratories, universities and industry.

"It's important to emphasize the DOE leadership in this whole program in bringing us together and organizing us to work toward a common goal with collaborations with the laboratories and universities," Gerber noted. "DOE is bringing the expertise of national labs and universities to the forefront to help develop those subsystems that can best fit the ARES program. Without that type of overall leadership, it would be very difficult for us as individual manufacturers to reach out to these resources."

An instrumented Waukehsa VGF engine with ESM controls at the company's test facility.

For More Information:

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