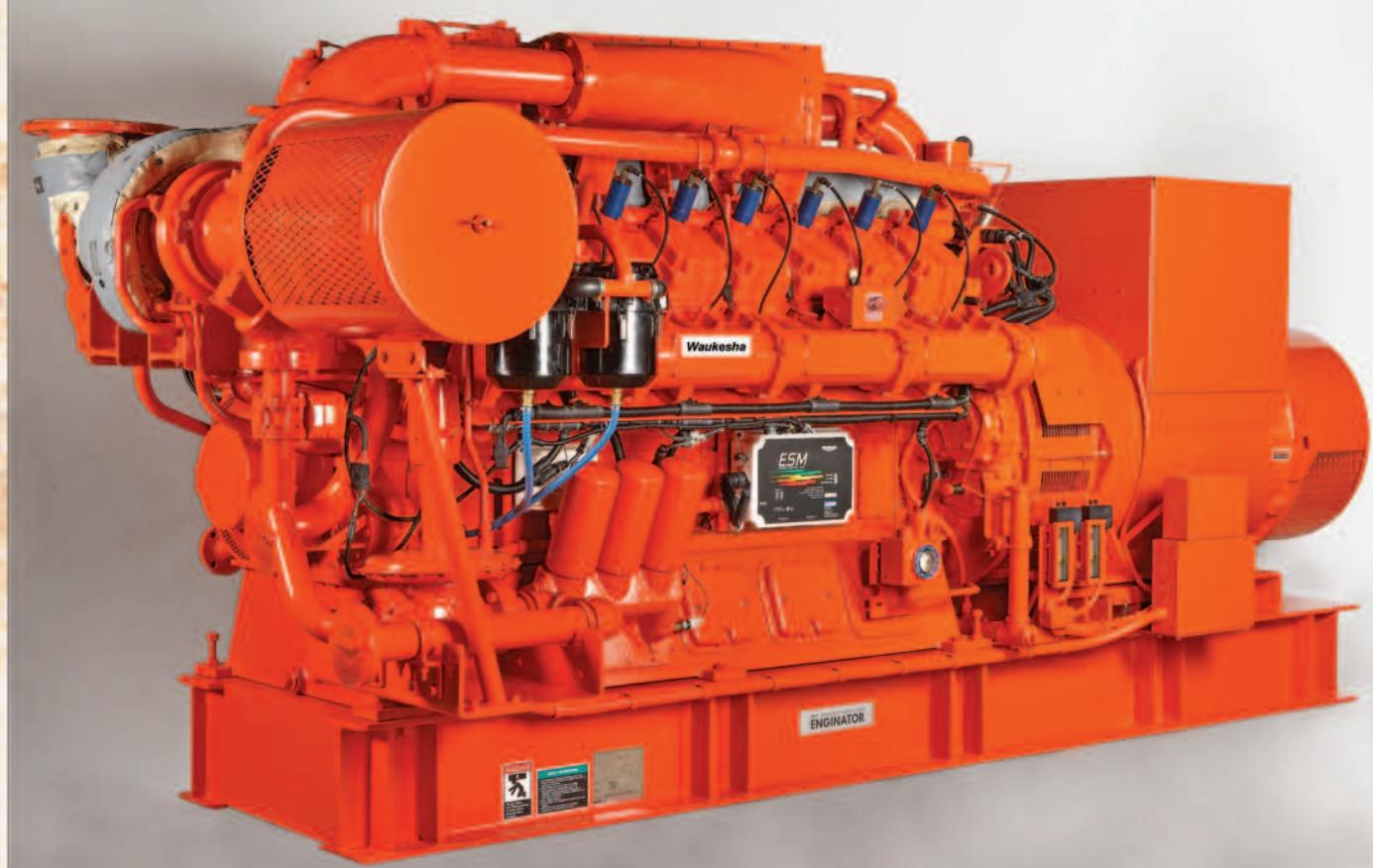
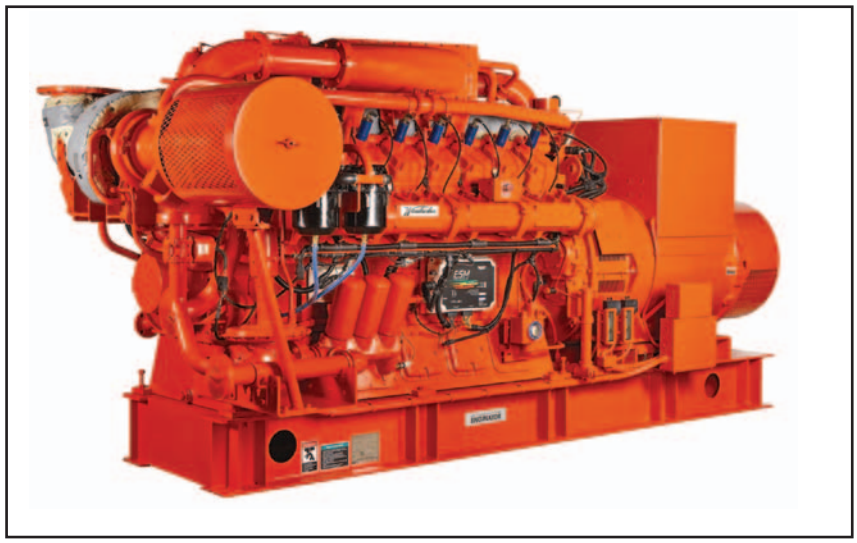
DIESEL & GAS TURBINE WORLDWIDE

Waukesha's New 1.0 MW Workhorse



BY MARK MCNEELY



Waukesha Engine recently entered the commercial demonstration phase of its APG natural gas-fired engine. The new platform, based on the company's VGF Series engines, has been developed in cooperation with the U.S. Department of Energy (DOE) as part of the Advanced Reciprocating Engine Systems (ARES) program.

A New Workhorse for 1.0 MW Power Applications

Waukesha's APG platform designed for higher power density

Waukesha Engine recently entered the commercial demonstration phase of its APG natural gas-fired engine, which will be formally introduced at the Power-Gen International exhibition in Las Vegas, Nevada, U.S.A., in December.

The new platform, based on the company's VGF Series engines, is a culmination of extensive research and product design and has been developed in cooperation with the U.S. Department of Energy (DOE) as part of the Advanced Reciprocating Engine Systems (ARES) program.

Several engines are presently in commercial demonstration (*see sidebar story*). One unit was also paralleled to the local grid and used to provide electricity for the company's Waukesha, Wisconsin, U.S.A., test lab and manufacturing facility.

"Power generation is the largest market for gas engines. It's very competitive and with high expectations in terms of overall performance," said Jim Drees, vice president of product development engineering for Waukesha. "The APG program's goals are to go after the very large segment of the power generation market that demands high efficiency, low emissions and lower operating costs simultaneously. Products that can provide that combination are very active in the market right now."

As a packaged generator set, Waukesha's new APG Enginator is a 16-cylinder, turbocharged, intercooled, lean combustion power generation unit capable of producing 1000 kW at 50 Hz and 1100 kW at 60 Hz — 1500 and 1800 r/min, respectively. Electrical efficiency has been pegged at 42.7% at 50 Hz and 40.5 % at 60 Hz.

The APG engine has a mechanical output of 1036 kW at 50 Hz and 1141 kW at 60 Hz — from a bore and stroke of 152 x 165 mm. The 13 730 kg APG engine features a 428 L lube oil capacity, a single ABB turbocharger design and a two-stage intercooler for improved heat recovery characteristics.

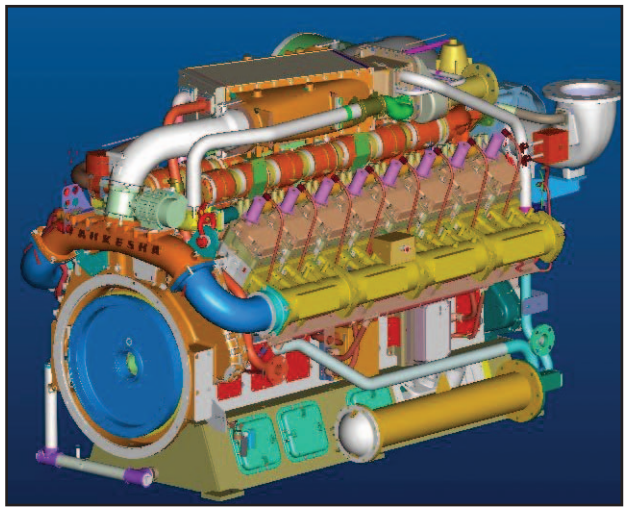
Waukesha's initial ARES program focus has been on developing units in the 1.0 and 1.1 MW output range, which continues to be a very strong node for the power generation market.

The engines will be shipped with ESM (engine system manager) controls, Waukesha's successful engine control and diagnostics system. ESM integrates air-fuel ratio control, spark timing control, speed governing, knock detection, start/stop control, diagnostic tools, fault logging, engine safeties, an engine service program and ignition power module diagnostics. The ESM also includes an electronic service program (ESP) and E-Help program.

"The DOE funding, which began in mid-2001, helped us to investigate more advanced technologies," Drees said. "During those first two years, we assessed a number of different concepts for ignition systems and several alternatives for combustion systems, which were key criteria within the ARES development program. We built prototypes — parts and subsystems — and tested them. Our findings helped us identify the technologies that would meet the ARES program requirements and that were ready to take into production."

The result of these development processes is the APG's new high-energy ignition system, fast burn rate, and a new high-efficiency turbocharger, which move Waukesha into a higher level of advanced lean-burn combustion.

The ARES program identified increasing power density as an important criterion for achieving high efficiency for a gas engine, therefore, it was a key objective in the development of the APG, Drees said. Waukesha met that



A color rendering showing the flywheel end of Waukesha Engine's new APG engine.

objective by designing the APG to carry a 40% higher power output than the current VGF product family.

The APG's higher power density also required a totally new air handling system, from intake through exhaust, to handle higher air flow, Drees said.

The fast combustion that delivers improved efficiency, combined with the higher power density, places an extra strain on the load-carrying components of the engine's powertrain. Both faster burn rates and higher power density lead to high peak cylinder pressures. The higher peak cylinder pressures of the APG required a new crankshaft and crankcase to meet the required durability at the new conditions. The crankshaft throw was increased 10 mm to 125 mm to provide the required strength. The material was also upgraded to provide additional strength.

A 10 mm larger throw diameter and higher loading forced the redesign of the VGF connecting rod. The increase in big end diameter of the connecting rod required an increase in the split angle to maintain good serviceability. Extensive finite element analysis was used to optimize the strength, while minimizing the rotating weight of the rod. To improve the connecting rod and the piston load carrying capability, a teepee style design was used on the pin bore. This allows for maximum surface area for the highly loaded rod and piston bores.

The APG cylinder head was a clean sheet design constrained only by the bolt pattern, push tube location, and jacket water feed passages from the VGF. The APG cylinder head system was made structurally stronger by finite element analysis optimization of the load columns and water passage coring. Computational fluid dynamics (CFD) simulation was used to optimize the cooling of the new cylinder head. Both the intake and exhaust ports were optimized for low flow losses, which contribute to the overall high efficiency.

Longer cylinder head cap screws are used to provide better clamping. An all-new overhead design using a rocker arm housing was developed to deliver optimal valve train performance. This connection between the cylinder head and the rocker arm housing is sealed using a patented multi-material gasket.

Different turbocharger arrangements were also closely scrutinized in the concept and design stage. "As you go to higher BMEPs, the turbocharger has to work harder and its efficiency becomes a more significant contributor to overall engine performance," Drees said. It is also a key contributor to reaching the ultimate ARES goal of 50% thermal efficiency. Ultimately, the Waukesha team settled on a single larger turbocharger, which was a departure from past designs, which used two turbochargers, one for each bank of cylinders.

"We've also been working with MIT (Massachusetts Institute of Technology) and CSU (Colorado State University) on friction reduction in the power cylinder component," Drees continued. "MIT has received an award from DOE and they are doing testing on a VGF engine at Colorado State. We've been part of that for several years now. There's the mechanical side of the friction, but there's also the pumping side, which is another focus of the ARES program. During the APG development program, Waukesha's most extensive use of CFD was to optimize the flow paths to reduce pressure drop across the engine. The less pressure drop there is through these components, the less work is required by the piston and the turbocharger to move the air and thus more power goes to the crankshaft."

Drees said that CFD work in engine design has traditionally been used for modeling the cylinder head design, such as intake and exhaust air handling characteristics. "But we treated every component in the system as significant. We really looked at the intake manifold and the exhaust manifold, their diameters, every bend radius and the geometry of the turns. So essentially we studied the air flow from the air cleaner all the way to the exhaust stack."

The APG is also the first time that Waukesha has used two-stage intercool-

Performance Figures

	60 Hz	50 Hz
Speed	1800 r/min	1500 r/min
kW_e	1100	1000
kW_b	1141	1036
Mechanical Efficiency(%)*	42	42.7
Electrical Efficiency(%)*	40.5	41.2
BMEP (bar)	15.8	17.2
NO_x Emissions (TA Luft)**	1.34 g/kWh	1.6 g/kWh

*With motor driven water pumps, 54°C intercooled water, .8 pf, ISO 3046
**1/2 TA Luft Available

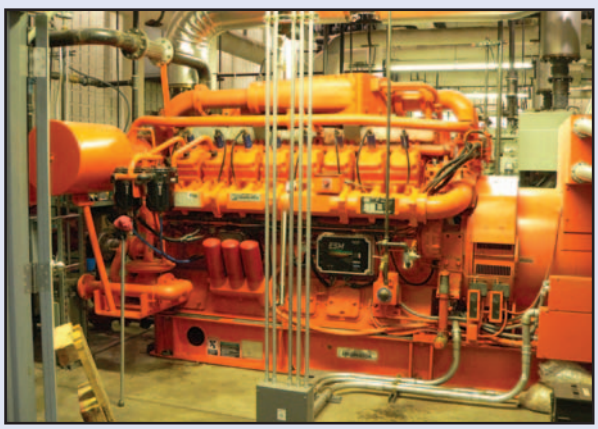
The APG cylinder head was a clean sheet design constrained only by the bolt pattern, push tube location and jacket water feed passages from the company's VGF engine series. Both the intake and exhaust ports were optimized for low flow losses, which contribute to the overall high efficiency.

ing, important to customers who want to recover the most total energy possible, typically in CHP applications. This is significant because new engine designs like the APG have higher power densities and the auxiliary cooling circuit has more available heat, Drees said.

"Another feature of this engine is the overall reduction of heat rejection. This engine uses dry exhaust manifolds, as well as a higher standard jacket water temperature to help reduce the heat loss. We designed the APG to drive as much energy as possible to the crankshaft and optimize the amount of recoverable energy in the form of heat," he said.

"With the APG, we have a one megawatt product with six to seven points higher thermal efficiency," Drees said. "This is a very significant operating improvement for our customers whose largest operating cost is the fuel they use."

Real-Time Demo at U.S. Manufacturing Plants



As part of its commercial demonstration phase, Waukesha Engine has placed two APG Enginators at two manufacturing plants in Ohio, U.S.A.

Two of Waukesha's new APG Enginator gen-sets are currently running under base load conditions at two manufacturing facilities in Mansfield, Ohio, U.S.A. These two units have been part of Waukesha's commercial demonstration phase for the APG platform, which began earlier this year and includes other test engines.

Jay Plastics and Broshco Fabricated Products, both owned by Jay Industries, are each running one of the 1100 kW Enginators, according to Mark Amicone, maintenance manager at Jay Plastics Division.

The APG units have been added to the two facilities' existing lineup of five other gen-sets. Typically the company runs its gen-sets strategically to stabilize and reduce its energy costs in a market where variable real-time pricing creates significant swings in those costs.

Amicone acknowledged that some allowances have been made to accommodate a demonstration installation of the APGs.

"We are using both engines in base load functions. Since we are billed at the real-time price of electricity, on days where the price is higher than the cost of generation we create savings for our company," he said. The cost of running the new engines 24 hours a day, including non-peak operation, for Waukesha testing purposes is minimal, he said, because the new engines are much more efficient than the company's other generators.

"The Broshco Fabricated Products Division is fully set up for heat recovery, so the off-peak operation is break even," Amicone noted. "At the Jay Plastics Division we are in the process of installing absorption cooling to utilize the waste heat and increase our savings.

"The test engines have been online since midspring. The efficiency has been upward to 40% better than our present units," Amicone explained. "This was just as promised."

Amicone also noted that the engines have had downtime as the Waukesha APG team has made modifications and tried out new parts and software. "We expected this. One of the better functions is that it requires less power to cool the engine and every little bit of savings helps."

The Broshco site uses full heat recovery from the engine jacket water and exhaust. This was pre-existing at that site and the new APG unit was installed to utilize the same. Most of the heat is used to displace fire tube boilers used in the process heating of the facility's electro-coat and powder coat finishing lines. The remaining energy is used to provide heated make-up air in the cooler months.

Jay Industries has been generating electricity at the Jay Plastics site for eight years and for three years at Broshco metal fabrication site. Ballard Engineering Inc., of Rockford, Illinois, U.S.A., has provided project engineering for the various Waukesha engines at both sites.

"We started with natural gas-driven chillers and grew to power generators. At first, it was more of a savings in the electric costs, but as the natural gas pricing has risen we find it is a good way to keep our utility costs more consistent," Amicone said.