The Ford 2.7 L V6 gasoline engine with fracture-split main bearings was launched in 2014 as the world's first high-volume compacted graphite iron (CGI) gasoline engine. A 3.0 L, 400 hp derivative is used in the new Lincoln Continental.

A LOOK AT COMPACTED GRAPHITE IRON FOR ENGINES

Starting with NASCAR, CGI now finding use in engines from 3.9 to 95 L

Dr. Steve Dawson, president and CEO of SinterCast Ltd., has long been a regular figure around the engine, vehicle and foundry industries extolling the virtues of compacted graphite iron (CGI) for engine use. Dawson joined SinterCast as technical director in 1991, a year after the technology emerged from its R&D origins and began its trek toward becoming a commercial engine components technology.

As such, his insights provide an interesting industry perspective into the growth of CGI over more than 25 years, especially as the trend for more performance and durability from smaller engine packages continues to be driving forces in all kinds of engine design. *Diesel Progress* talked to Dr. Dawson about CGI for engine development in off-highway equipment.

Dr. Steve Dawson is president and CEO of SinterCast Ltd. He said that CGI is significantly stronger and stiffer than gray iron, making it valuable for off-highway engines.

Diesel Progress (DP): Can you recap some of the history of CGI as a technology and SinterCast's involvement with it?

Dr. Steve Dawson: Compacted graphite iron was first observed and documented in 1948. At that time, researchers were trying to improve the strength of normal gray cast iron. They found that adding a small amount of magnesium — about 0.030 to 0.070% — transformed the graphite flakes into spheroidal or nodular particles. That was the discovery of ductile iron.

The researchers also found that when the magnesium addition was too low — about 0.008 to 0.015% — the graphite grew in a compacted or vermicular shape. That was

The SinterCast process control technology has been installed on 44 foundry production lines in 13 different countries. CGI can be produced in existing cylinder block foundries using the same melting and molding techniques.

the discovery of CGI. The researchers filed patents for both CGI and ductile iron on the same date in 1948.

There were some attempts to industrialize CGI, particularly in the 1970s and early 1980s, when the automotive OEMs (original equipment manufacturers) showed interest in the material. Unfortunately, because of the narrow stable range for CGI, these attempts were unsuccessful.

By the time that SinterCast came into the market, there was a healthy skepticism toward CGI and an uphill playing field. SinterCast was formally incorporated in 1983. A professor at the University of Stockholm filed a patent on a measurement and control technology for CGI. The business activities followed around 1990. Initial funding was secured, and a small team of foundry engineers, engine engineers and managers were added and an office was established in Detroit (Mich.).

From 1990 to 1995, we introduced our control technology to the foundries and discussed material properties and engine benefits with the OEMs. Some of the early OEM work started with racing applications, and today all NASCAR engines are CGI. From there, we focused on developing machining solutions to cope with the higher strength of CGI.

In 1999, we had our first CGI cylinder block in series production — the Audi 3.3 L V8 diesel. The next breakthrough was high-volume production commitments from both Ford and Audi for 2.7 and 3.0 L V6 diesels. These engines are still in production, with a combined volume of approximately 400,000 engines per year.

The first commercial vehicle uses started with the introduction of Euro 4 emissions in 2005. Our latest breakthrough, in 2014, was with the start of production of the Ford 2.7 L gasoline engine for the new F-150, giving us our first high volume in the gasoline sector.

On the foundry side, we have installed our CGI process control technology on 44 production lines at foundries in 13 different countries, so the production base is quite broad.

DP: What is the value proposition for CGI for off-highway engines? Is there an impact on weight or emissions?

Dawson: CGI is 75% stronger, 45% stiffer and provides double the fatigue strength. This increase in strength allows for increased peak firing pressure and improved specific performance — horsepower per liter. In off-road applications, CGI is used to increase performance while ensuring durability, such as increasing the power of an existing engine or — in a new design — to get the performance of, say, a 15 L engine from a 13 L package. Most engines are operating near their durability limits, so it isn't possible to make significant steps without resorting to stronger materials.

We have production examples in the off-road sector where gray iron is used for the base engine and CGI is substituted for the high-power versions of the engine. The OEM uses the same foundry tooling and the same machining line but substitutes CGI to improve durability. This is particularly true of cylinder heads for severe-duty marine engines.

The main driver in off-road applications is downsizing and power-up while ensuring durability. In parent bore applications, CGI will also have 20 to 30% less bore distortion, allowing for reduced ring tension and reduced friction losses — particularly at cold start — less oil consumption and less blow-by. Engine designers can also expect 1.0 to 1.5 dB(A) reduced noise due to the higher stiffness.

DP: Typically, what engine components do you find CGI used in?

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Dawson: Our series-production components range from 6.0 lb. to 9.9 tons, so there is a lot of variety. The smallest components are turbocharger housings for passenger vehicles, and the largest component is an engine frame for Allen Diesels (formerly Rolls-Royce) for stationary power applications.

The most obvious application for CGI is in cylinder blocks and heads. In cylinder blocks, we routinely realize 10 to 15% weight reduction compared to gray iron while providing improved durability. We also have diesel blocks in series production up to 9.0 L displacement with parent bore. An extension of this is that CGI can be used for midrange and heavy-duty diesel cylinder liners. For cylinder heads, we have series production references from 3.9 to 95 L for utility trucks, tractors, commercial vehicles, mining trucks, stationary power and rail applications.

Other production components include turbocharger housings and exhaust manifolds. We also support the production of CGI piston rings for large stationary engines from 200 to 1000 mm bore diameter for two-stroke marine applications. The top ring is CGI to withstand the high thermal and compression loads while the lower rings are made of gray iron.

Our large-bore piston ring experience has also led to the development of 350 to 980 mm bore diameter cylinder liners, and we have many test liners successfully running in the field with individual piece weights ranging from 2.8 to 11 tons.

DP: Are the sizes of engines in which CGI is used changing? Does market penetration for CGI vary from on-highway to off-highway to stationary or marine? How does use in diesel engines compare to gasoline models?

Dawson: Our current production split is approximately 60% passenger vehicle, 35% commercial vehicle and 5% industrial power. Our production started with diesel engines because the higher combustion pressure requires stronger materials. For passenger vehicles, CGI has effectively become the standard material for vee-configuration diesels.

CGI has made good inroads in commercial vehicles, and most western OEMs now have at least one CGI offering in their lineups. For new designs in the U.S. and Europe, perhaps 25 or 30% of new designs have either the block or head in CGI, sometimes both. As the demand for more performance from smaller packages continues, we feel the application of CGI will grow.

On the industrial power side, we have a lot of successful references, but the volume and penetration are still in the early stages. The most common application for industrial power engines is cylinder heads, where CGI provides improved durability as specific loading is increased. We have production references with Cummins, GE, Jenbacher, MTU and Waukesha.

DP: What are the growth markets for CGI?

Dawson: Commercial vehicles and industrial power applications are obvious growth opportunities for CGI. The material is proven, and there is a clear trend for more performance from smaller engine packages. CGI can contribute to this.

Beyond the mainstream, we are also supporting new engine technologies. For example, together with Engineered Propulsion System (EPS) in Wisconsin, our first aviation diesel is undergoing FAA (Federal Aviation Administration) approvals. It is a 180° "flat vee" with 4.0 L displacement and 100 hp/L.

We are also supporting the development of other small displacement diesels with 100 hp/L, and many of the new horizontal opposed-piston engines have specified CGI for the block and/or liner. There are growth opportunities in new technology as well as conventional technology. dp

diesel Weblink

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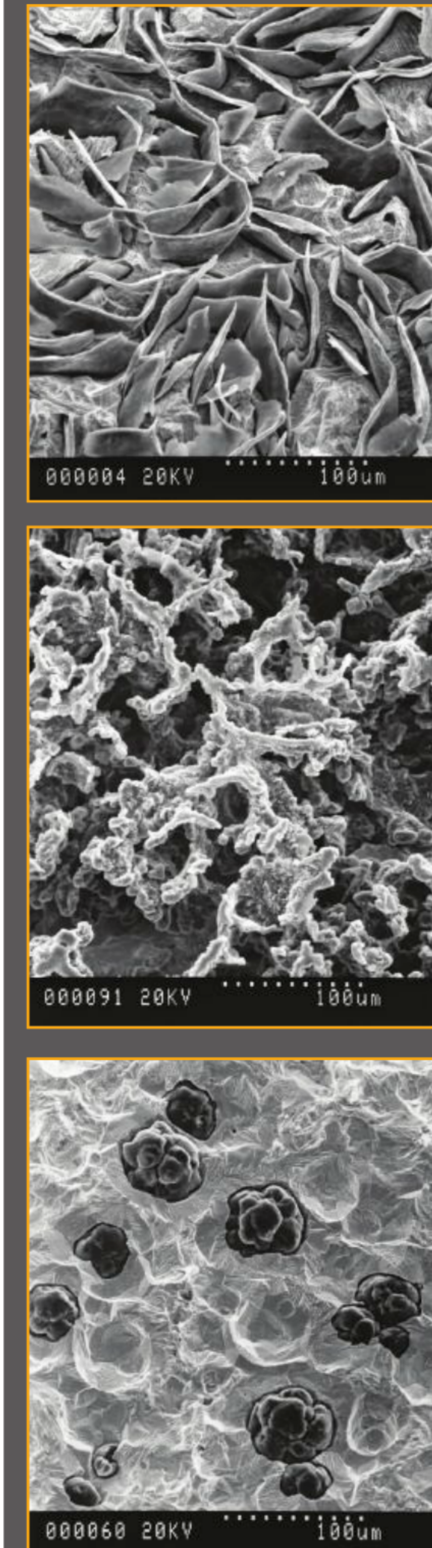
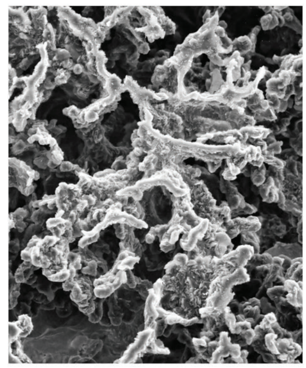
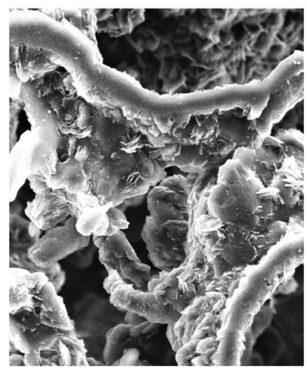


Top to Bottom: gray iron, CGI and ductile iron microstructures. According to SinterCast, the elongated graphite flakes in gray iron provide good heat transfer but reduce strength. The individual spheres in ductile iron provide strength but impair thermal conductivity, the company said. The coral-like compacted graphite microstructure provides strength and heat transfer, SinterCast said.

2016 ENGINE SPECS-AT-A-GLANCE





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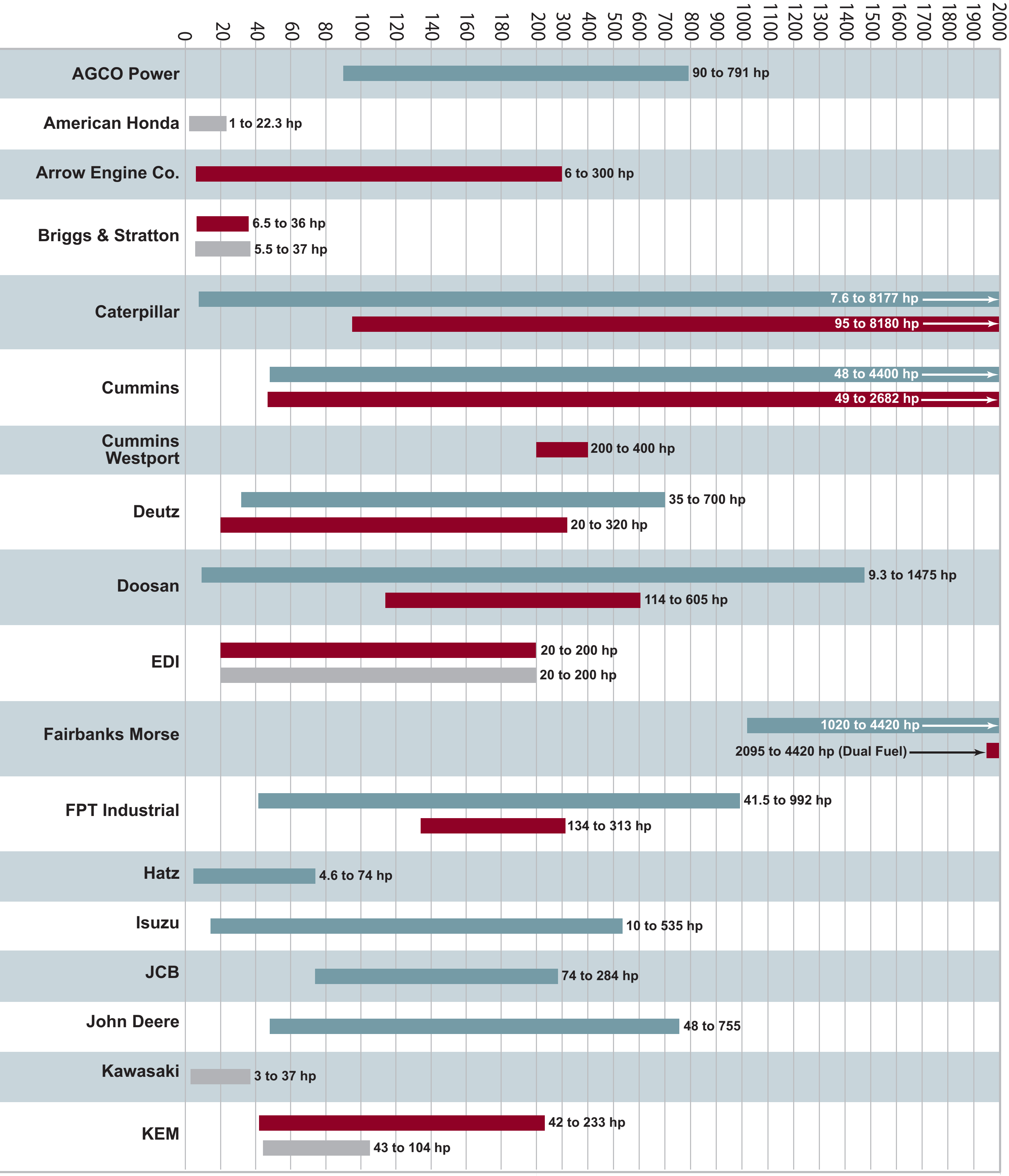

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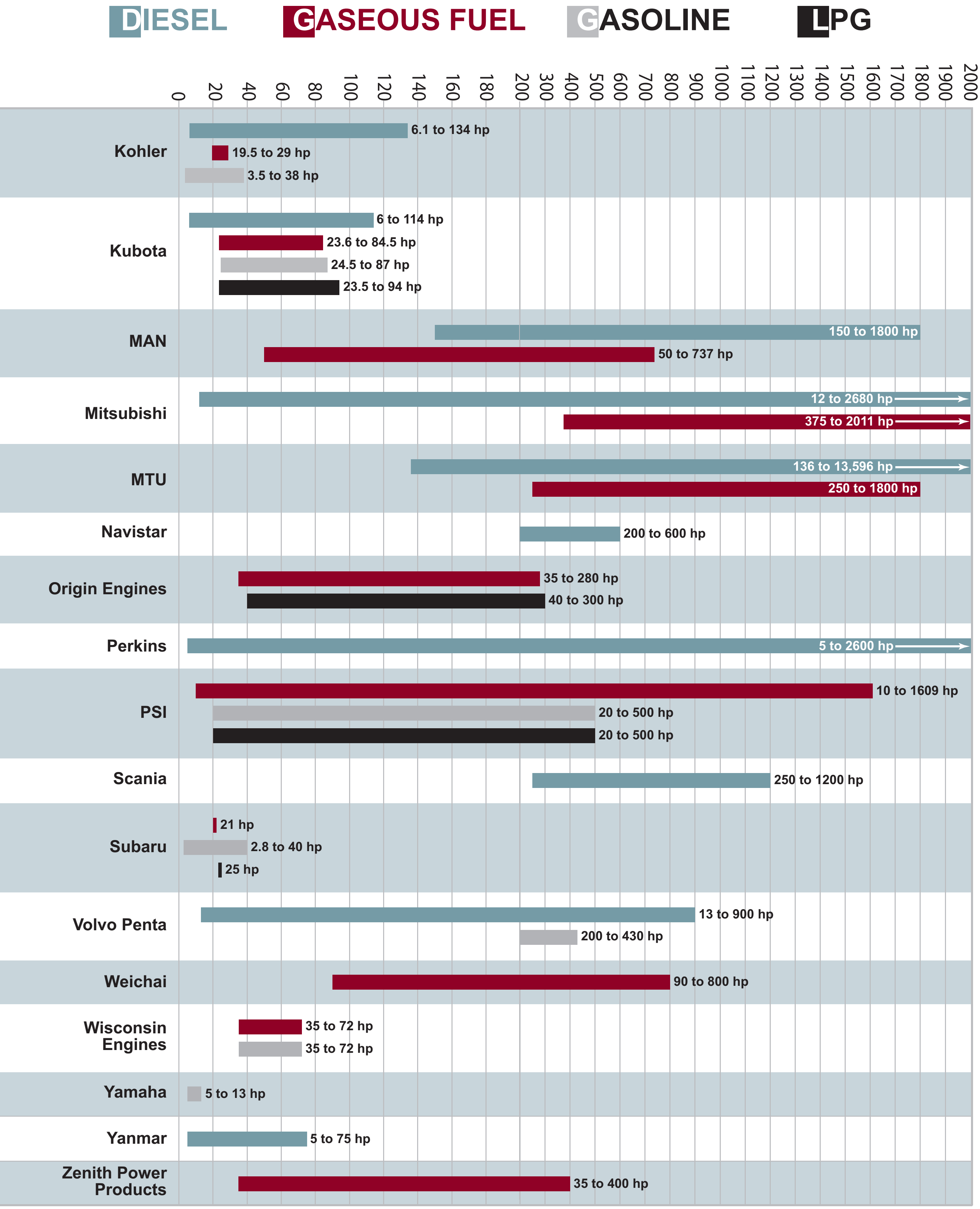

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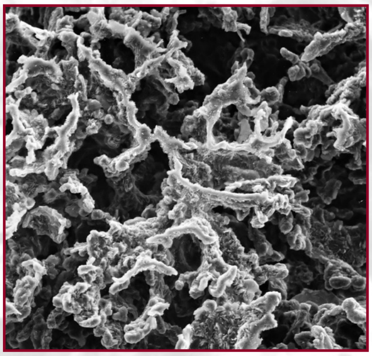
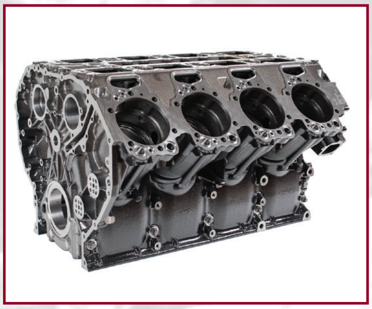
SinterCast-CGI Cylinder Blocks and Heads

SinterCast is the world's leading supplier of process control technology and solutions for the reliable high volume production of Compacted Graphite Iron (CGI).

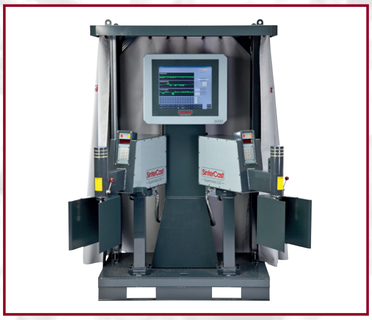
With 44 installations in 13 countries, SinterCast's foundry partners deliver CGI cylinder blocks and heads, bedplates, exhaust manifolds and turbocharger housings to the global passenger vehicle, commercial vehicle, construction, agriculture, marine, mining and locomotive markets.



STRENGTH & DURABILITY
+75% Tensile Strength
+45% Elastic Modulus
+100% Fatigue Strength



ENGINE PERFORMANCE
10-20% Weight Reduction
5-10% Size Reduction
10-20% Power-up (kW/litre)
1-2 dB Noise Reduction



PROVEN RELIABILITY
>75,000 Cylinder blocks/month
2.7-100+ litre Displacement
High Volume Diesel & Petrol References

COMPACTED GRAPHITE IRON BENEFITS

1. WEIGHT REDUCTION
2. DOWNSIZING
3. POWER INCREASE
4. DURABILITY INCREASE
5. NOISE REDUCTION
6. FRACTURE SPLIT MAIN BEARINGS
7. REDUCED THREAD ENGAGEMENT
8. INCREASED CYLINDER PRESSURE
9. LESS BORE DISTORTION
10. REDUCED RING TENSION
11. LESS OIL CONSUMPTION
12. LESS BLOW-BY EMISSIONS
13. IMPROVED WEAR RESISTANCE
14. CLEANER AS-CAST SURFACES
15. THERMAL EXPANSION SAME AS GRAY IRON
16. CAST IN EXISTING GRAY IRON TOOLING
17. SECONDARY WEIGHT REDUCTION
18. PROVEN HIGH VOLUME MACHINING
19. 100% RECYCLABLE
20. ASTM, ISO & SAE STANDARDS

INCREASE PERFORMANCE AND DURABILITY
REDUCE SIZE AND WEIGHT
USE CGI

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