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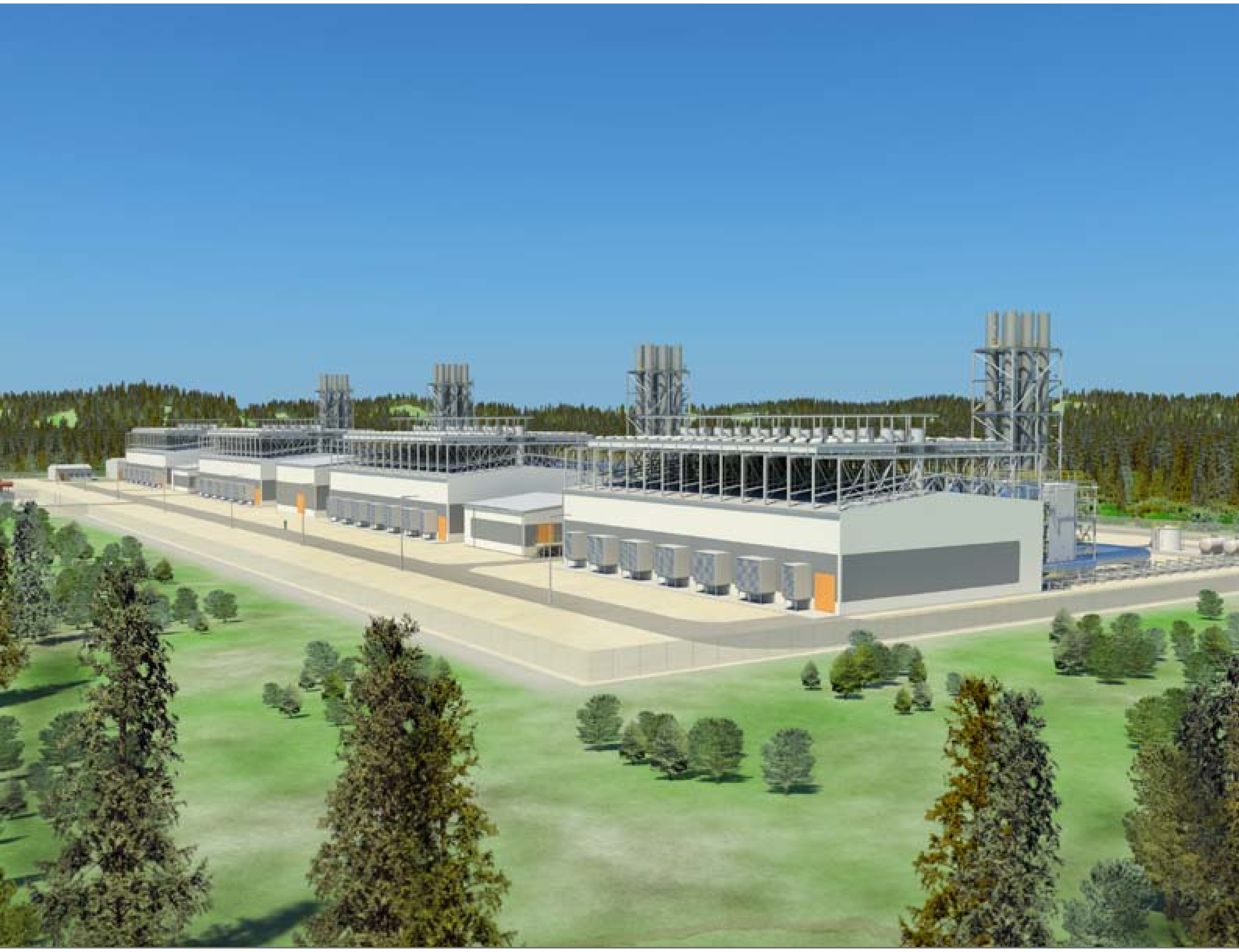

White paper

Combustion engine power plants

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This paper will give an insight into the many unique features that modern combustion engine power plants offer, while enabling valuable flexibility for power generation systems.

1. Modern combustion engines

Today's modern combustion engines are excellently suited for various stationary power generation applications. They cover a wide capacity range, and have the highest simple cycle efficiency in the industry. At the lower end of the range, the power plant can consist of only one generating set, while larger plants can consist of tens of units and have a total output of several hundred megawatts. The largest power stations delivered to date have electrical outputs in excess of 300 MW. Power plants based on combustion engines can, however, be even bigger, simply by adding more generating sets. Today, even 500 MW plants are competitive in applications where flexibility and high efficiency are needed.

A 500 MW Flexicycle™ power plant based on 24 Wärtsilä 18V50SG units in combined cycle.

The combustion engines that are commonly used in power plants are typically based on medium-speed engine technology. The simple cycle outputs of these engines typically range from 1 to 23 MW per unit. Medium-speed engines run at between 300 to 1000 rpm, and the engine and the generator run at the same speed so there is there is no need for a gearbox. The engines are designed according to two different operating process principles, giving them somewhat different characteristics and making them suitable to run on either gaseous or liquid fuels.

View inside a combustion engine power plant engine hall.

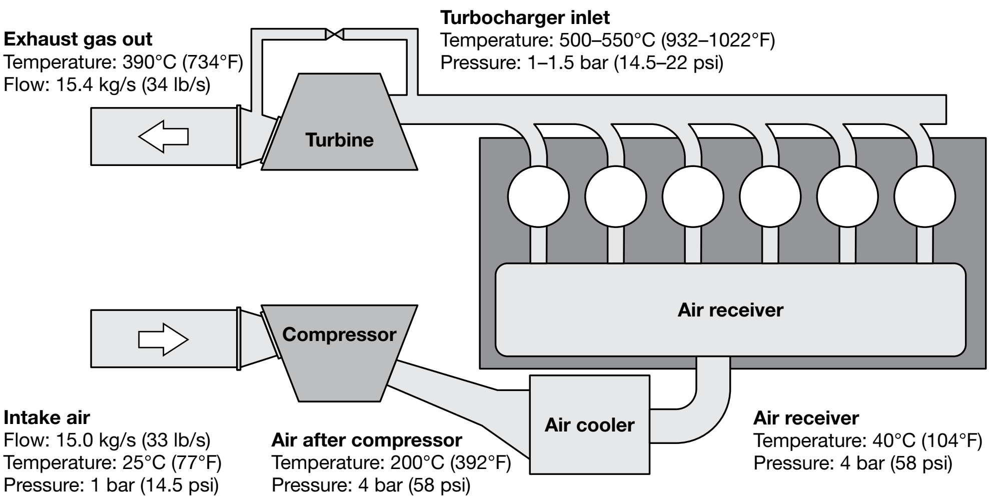
Modern computer controlled combustion engines have many technological advantages over other technologies used for power generation. The following chapter will highlight the most important advantages.

Simple cycle efficiency

The combustion engine's high efficiency is enabled by the characteristics of the combustion process. Combustion takes place in the cylinders at high pressure and high temperature. Modern engines operate at up to 200 bar (2900 PSI) peak cylinder pressure during every combustion cycle. The combustion temperature is optimized for high efficiency and low NO_X emissions.

In an idealised thermodynamic process, a combustion engine would be able to achieve an efficiency rating in excess of 60%. As engine development proceeds, various losses and deviations from the idealised process are minimized, and today modern combustion engines reach 47.5% simple cycle efficiency (heat rate 7187 Btu/kWh), measured at generator terminals.

Modern combustion engines use turbochargers to increase the output and improve efficiency. Turbochargers typically operate at up to 20,000 rpm.

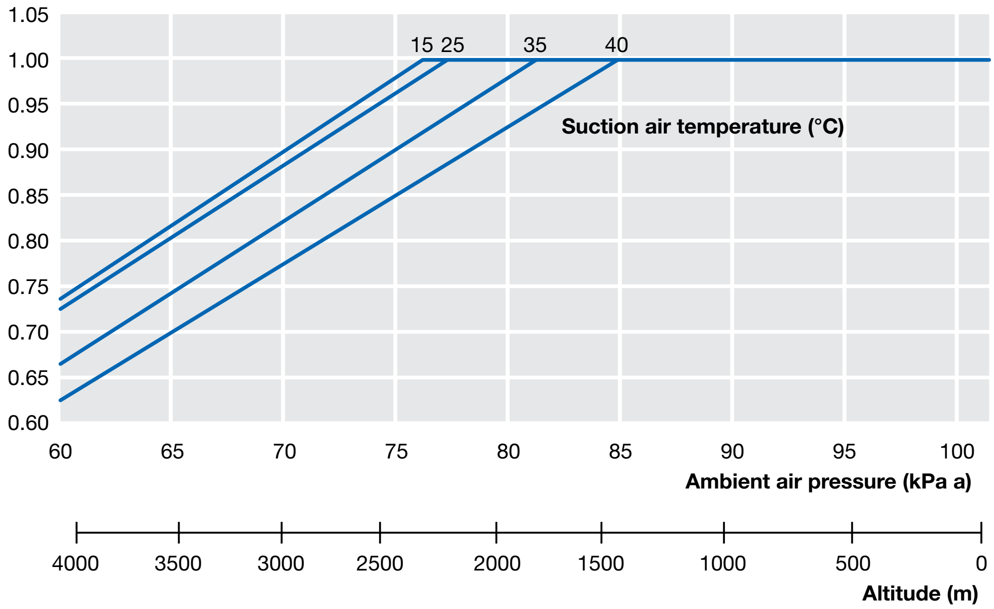


Typical temperatures, pressures and mass flows from a 10 MW combustion engine.

Influence of ambient conditions

A clear advantage of combustion engine technology is the minimal impact of ambient conditions on plant performance and functionality. Turbo-charging and charge air cooling enable the combustion engine power plant´s high electrical efficiency to be maintained at part load.

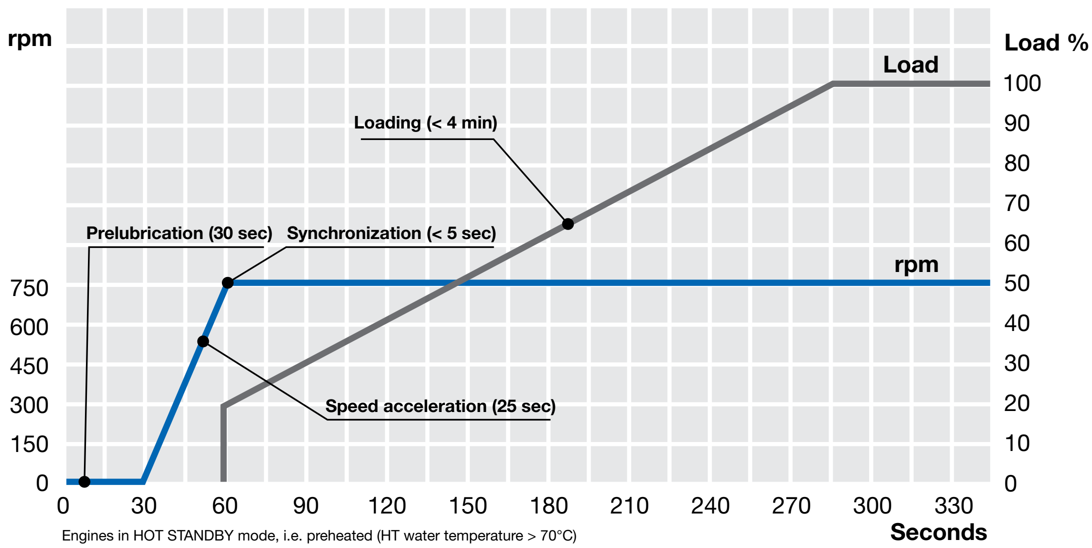
The influence of ambient conditions, temperature and high altitude on the efficiency and electrical output is minimal. Minor derating occurs in extreme conditions, such as temperatures above 40°C (104°F) or an elevation of more than 2000 meters (6562 ft) above sea level. This means that the power and high efficiency are available, when needed, on the hottest summer days.



Derating due to high altitude or high air temperature for a 10 MW gas fired combustion engine.

Frequent fast starts and stops

Modern combustion engines are capable of repeated, fast starts and stops. Pre-heated oil fired combustion engines can be synchronized in 30 seconds and ramp up to full output in 3 minutes. The same procedure takes 5 minutes for gas engines.



A gas fired combustion engine’s start and ramp up time.

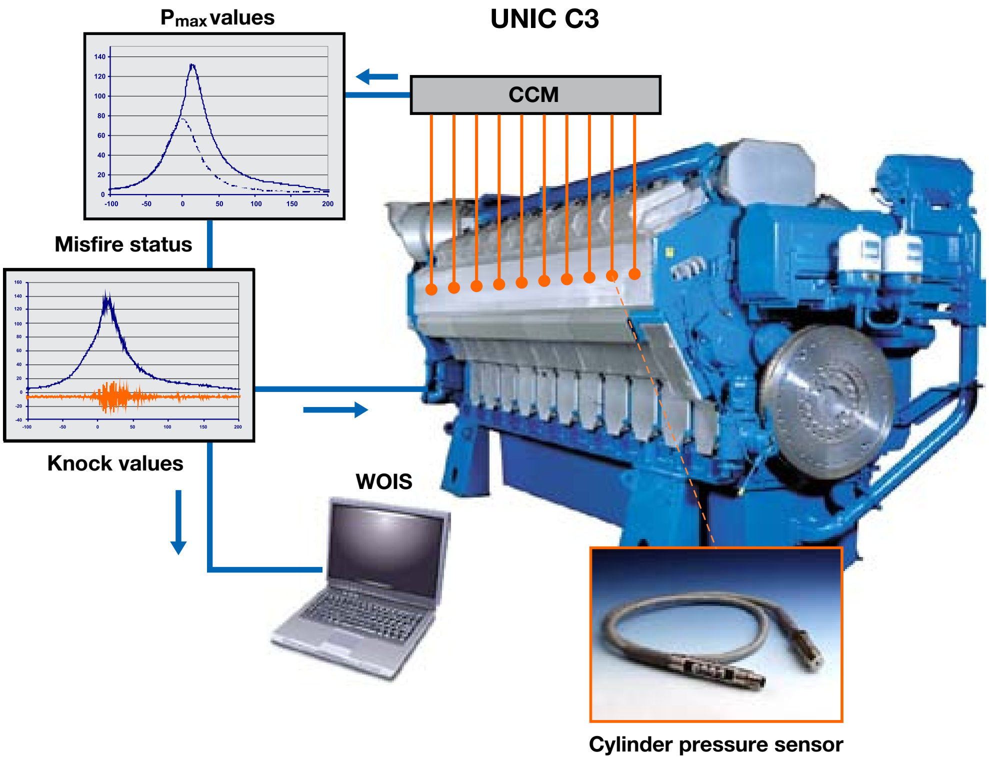
Water consumption

Combustion engine power plants equipped with a closed loop cooling system using radiators, consume a negligible amount of water. This allows the power plants to be located away from the coast, either within a load centre, or out in a desert. When the plant is located at a coastal location, or on a barge, sea water cooling can be used.

Combustion engines, gas operation

Modern gas fired combustion engines are designed to operate on natural gas (NG) or associated gas (AG), and are able to operate on low pressure gas. A gas pressure of just 5 bar(a) (73 PSI) is required, enabling the power plant to be located even where the pipeline gas pressure is low.

In modern lean-burn gas engines, natural gas and air are pre-mixed before entering the cylinders. The optimal air to fuel ratio (lambda) of around 2.2, is the key to controlling the combustion temperature, which enables high efficiency and minimal NO_X emissions. The lean air to fuel ratio is achieved by pressurising air with turbo chargers to around 3 bar, after which the air is intercooled before being fed to the cylinders for combustion. The charge air pressure is controlled with a waste gate valve to match different ambient conditions.



Modern combustion engines are equipped with computerized control systems.

Modern gas fired engines are controlled using sophisticated computerised combustion control systems. The control system continuously monitors engine parameters, such as load, speed, cylinder exhaust gas temperature, and cylinder pressure. This enables the control system to detect detonation and misfiring, and to continuously adjust the lambda value and ignition timing to be optimal for each individual cylinder on every cycle. The control system adjusts the charge air pressure and cylinder specific gas control valves so that the lambda value is kept at the desired level.

Igniting the lean air fuel mixture requires high energy. Combustion engines using gas as the only fuel use spark plugs, located in a pre chamber, to ignite the air fuel mixture.

Combustion engines, dual fuel operation

Dual fuel combustion engines use a pilot fuel to ignite the air fuel mixture. The pilot fuel quantity is only approximately 1% of the total fuel energy input at full engine load. Dual fuel combustion engines can operate on a wide variety of fuels, including light fuel oil (LFO) and heavy fuel oil (HFO). The engines can transfer from gas to liquid fuel oil operation, or vice versa. This can be done at any load, instantaneously and automatically, for example in the event of an interruption to the gas supply.

The Sangachal power plant in Azerbaijan has a total output of 308 MW and consists of 18 Wärtsilä 18V50DF engines. The power plant uses natural gas when available, but can switch over to using HFO or LFO when needed.

Combustion engines, liquid fuel operation

Oil fired combustion engines operate according to the compression ignition process. The fuel is instantly ignited as a result of the high temperature produced by the compression, and thus there is no need for an external ignition source.

The traditional fuel for oil fired combustion engines is LFO. Oil fired engines are also able to operate on HFO, crude oil (CRO), fuel water emulsions (FWE) and liquid biofuels (LBF) with minor on-site pre-treatment. Even poorer fuel qualities, e.g. refinery residuals, can be used.

Oil fired engines can be converted to operate on gas, for example, in cases where a gas infrastructure becomes available at a later point in time.

Low and controllable emissions

Natural gas fired engines typically generate lower carbon dioxide (CO_2) emissions than oil and coal plants, due to the lower carbon content per fuel energy input and the high engine efficiency. Gas operation produces fewer nitrogen oxide (NO_X) emissions than liquid fuel operation. The engines can be optimized to achieve very low NO_X levels of a maximum of 45 ppm vol, dry, at 15% O_2. Tuning the engine is a balance between NO_X emissions and having the highest possible efficiency. Similar efficiency optimized engines reach NO_X levels of a maximum of 90 ppm vol, dry, at 15% O_2. The NO_X level can be reduced to meet any environmental requirements by installing SCR (selective catalytic reduction) systems.

The Humboldt power plant, located in Eureka, California, consists of 10 Wärtsilä 18V50DF gas engines and has a total output of 162 MW. The dual fuel (DF) engines are able to operate on light fuel oil as back-up. The plant is equipped with SCRs and is capable of meeting the strict Californian emission requirements in both gas and liquid fuel mode.

The burning of clean natural gas produces insignificant levels of sulphur dioxide (SO_2) and particulate matter (PM) emissions.

Today there are several technologies available for controlling combustion engine exhaust gas emissions. All emissions requirements can be met by installing secondary emission control equipment. The need to install equipment for emissions reduction is highly dependent on local regulations, the type of engine technology, and the fuel quality used. With SCR technology NO_X levels of 5 ppm, vol, dry at 15% O_2 can be attained.

Maintenance of combustion engines

The maintenance of combustion engines is today easy, and most routine inspections and maintenance measures can be quickly performed by operating personnel while the engine is in operation.

Proper maintenance ensures high reliability and availability of the power plant. Operational statistics prove that power plants achieve a plant availability of 95%, plant reliability of 97%, and starting reliability of 99%. The highest availability numbers are reached with OEM’s operation and management agreements.

Inspections can easily be carried out by the power plant crew and the OEM’s technical advisor. Standard workshop tools are typically sufficient for inspections.

For combustion engines there is no equivalent operating hours (EOH) calculation. The maintenance schedule is not affected by frequent starts and stops, fuel, or trips as modern combustion engines have the capability to stop and start without limitations or maintenance impact, while at the same time reducing emissions and fuel consumption.

The condition of modern combustion engines can be monitored continuously by a condition based maintenance system to extend inspection intervals.

The hours presented below are thus the actual fired hours of the engine.

Operation hours	Event	Estimated duration
Routine checks	Checking of filters, lubricating oil, cooling water	During operation
8000 h	Minor inspection	2 days
12 000 h	Minor inspection	3 days
16 000 h	Intermediate inspection (cylinder head & bearings)	9 days
24 000 h	Minor inspection	4 days
32 000 h	Intermediate inspection (connecting rod screw change)	10 days
48 000 h	Major inspection (crank shaft inspection)	10 days

Typical inspection schedule, two 12 hour shifts (example).

Part	Repair interval (h)	Replacement interval (h)
Piston (piston rings)	16 000 – 24 000	60 000 – 100 000 (16 000 – 24 000)
Cylinder liner & head	16 000 – 24 000	60 000 – 100 000
Inlet valve	16 000 – 24 000	32 000
Exhaust valve	16 000 – 24 000	16 000 – 24 000
Bearings	16 000 – 24 000	16 000 – 32 000
Gas valves	8 000	16 000
Pre chamber	16 000 – 24 000	32 000 – 48 000

The major component repair and replacement intervals for combustion engines (example).

2. Features of combustion engine power plants

Combustion engine power plant solutions have many unique features compared to power plants based on other technologies.

Flexible plant sizes

Investments in combustion engine power plants can easily be made in several steps. There are several sizes of engine generating sets available. The number of units can be chosen to match the needed power, see chart below.

		Number of units (CC = Combined Cycle)					
	Type	1	6	16	16+CC	24	24+CC
Gas engines Output in MW	Wärtsilä 20V34SG	9.7	58	155	169	233	253
	Wärtsilä 18V50SG	18.5	111	296	322	444	486
Liquid fuel engines Output in MW	Wärtsilä 20V32	8.9	53	142	155	214	233
	Wärtsilä 20V46F	22.4	134	358	391	538	586

Examples of power plant configurations based on different numbers of engines and the same with combined cycle. Outputs in MW.

The initial investment can, for example, be for 6 units having an output of 18 MWe per unit. The decision to invest in additional units can be made at any time later. Heat recovery steam generators (HRSG) and steam turbines can also be installed later to close the cycle for combined cycle application.

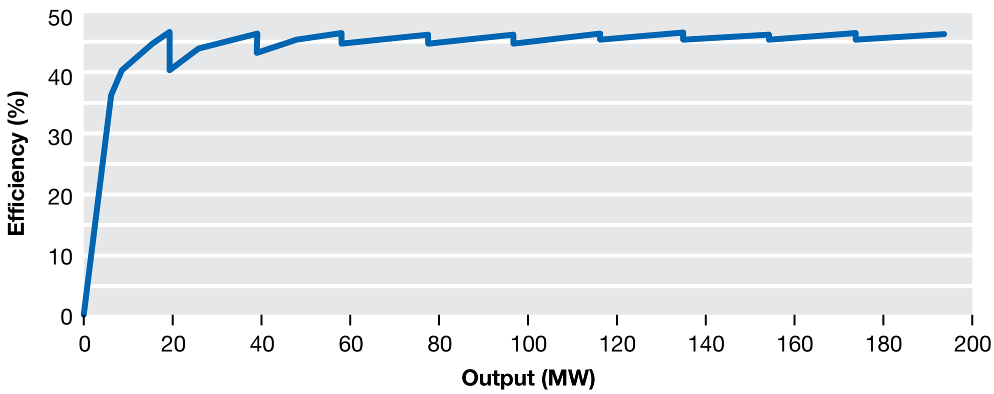
A 322 MW Power Plant based on 16 Wärtsilä 50SG engines and steam turbine combined cycle (Flexicycle), 296 MW from engines and 26 MW from steam turbine. The investment and construction can be made in several steps and the combined cycle can be added later on. In this example there is space reserved in the engine hall for two additional units.

The modular concept also enables easy and repeatable installation work.

Combustion engine power plants can be architecturally designed to blend into urban areas.

Multiple independent units

As power plants typically consist of several generating sets, the excellent fuel efficiency can be maintained across a wide load range also at part load operation. The plant can be operated at all loads with almost the same efficiency.



Power plants based on multiple units achieve high efficiency throughout the entire load range.

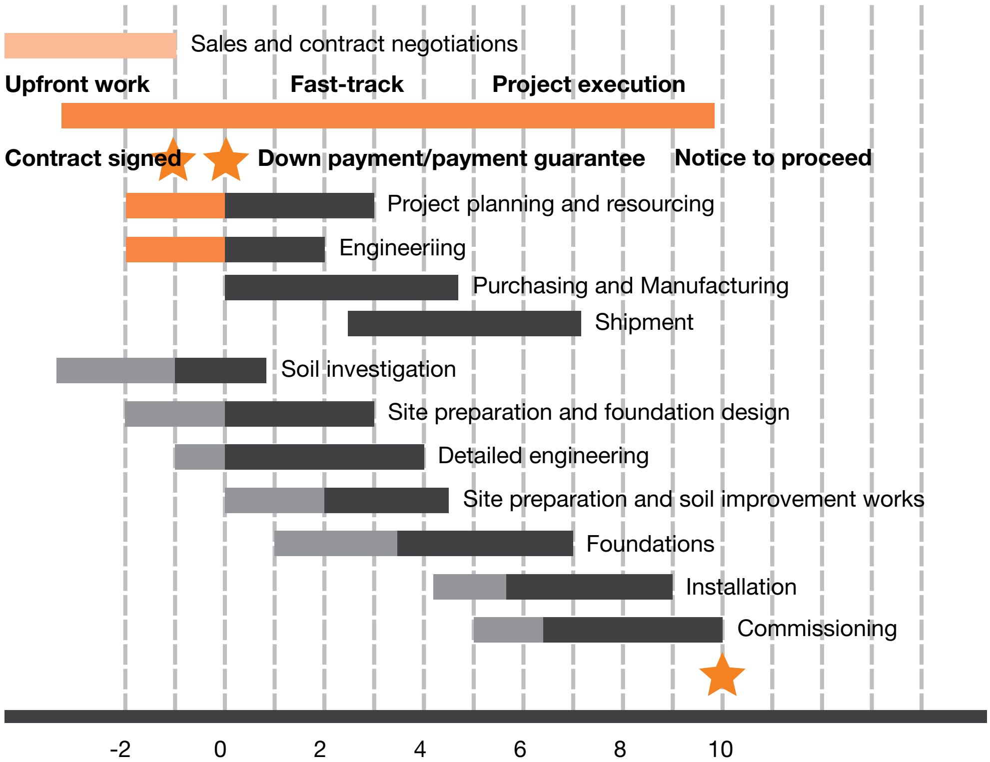
If operating one or several generating units at part load, there is an in-built spinning reserve in the load range from 30..100% for each unit.

Start-up, synchronisation and loading

Fast start-up, synchronisation, and quick loading are valuable benefits for power plant owners. Quick synchronization (30 seconds) is especially valuable for the grid operator, as these plants are the first to synchronise when an imbalance between supply and demand begins to occur. System operators benefit from the possibility to support and stabilize the grid in many situations, such as peaking power, reserve power, load following, ancillary services including regulation, spinning and non-spinning reserve, frequency and voltage control, and black-start capability.

Fast track EPC project delivery

Combustion engine power plant construction projects can be executed with fast delivery schedules. EPC (engineering, procurement, construction) power plant construction projects can take as little as 10 months from the notice to proceed to final handing over. As an example, the 102 MW Dohazari power plant in Bangladesh was delivered in only 10 months.



Example schedule for Fast Track Project.

3. Applications for flexible power plants

Decentralised or distributed, modular combustion engine power plants can be used in a variety of applications from grid stability management, peak and intermediate load, to base load operation. The plants can be located close to the consumption centres, thereby reducing transmission losses. These solutions offer high efficiency in varying ambient conditions, while providing unique operational flexibility.

Grid stability management

Utilities, system operators, and regulators are increasingly faced with the challenge of balancing power systems in an optimal way. Power grids typically see significant load variations during the day and between seasons. The system capacity is typically a mix of power plants dedicated for base load, intermediate load and peak load. Combustion engine power plants are, however, able to handle many functions in power systems, which have traditionally been managed by separate dedicated power plants applying different technologies.

The wide load range, in combination with the high efficiency at different loads and the fast starts and stops, that combustion engine power plants can offer, make them highly valuable assets to a system dispatcher. To date there are more than 1000 Wärtsilä power plants installed operating as grid stability, peaking and stand-by power plants.

Wind enabling

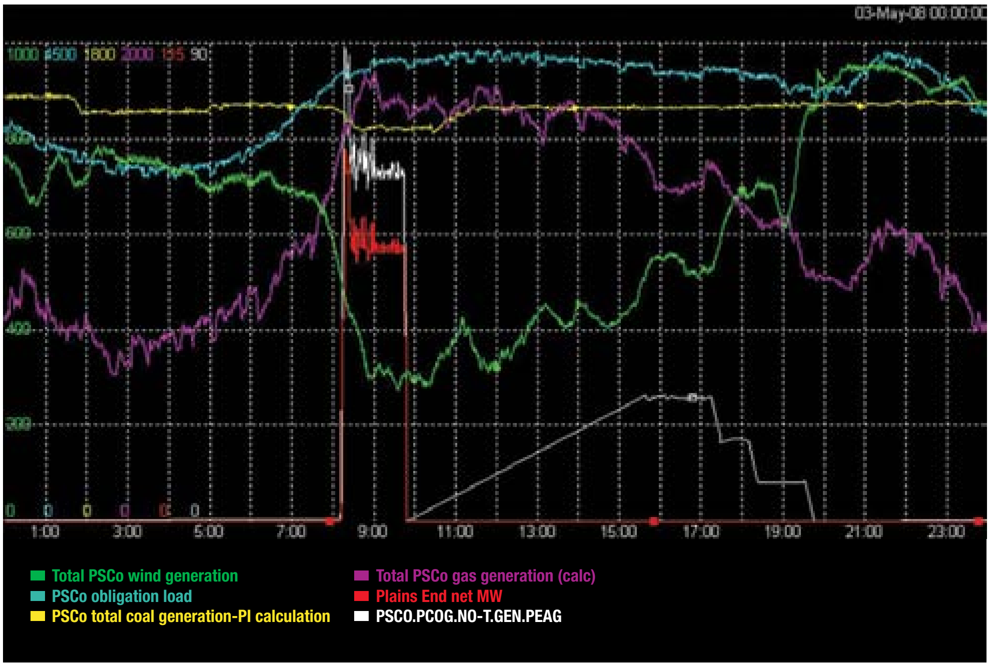
Power grids will see more and more wind power generation in the future. Wind power is, however, similar to solar power, and by nature non-dispatchable. The dynamic features of modern combustion engine power plants are outstandingly well suited to supporting grid systems that require flexibility to cope with daily load fluctuations, or that have a significant installed base of non-dispatchable power.

The Plains End I and II grid stability power plants are located in COLORADO, USA and consist of 20 x Wärtsilä 18V34SG engines and 14 x Wärtsilä 20V34SG engines with a total output of 231 MW. The gas fired power plant was delivered in two phases, 2002 and 2008.

Flexible base load

Combustion engine power plants can be optimized for different applications, but the plants are also capable of handling many tasks in a power system. The high simple cycle efficiency and proven reliability make them very suitable for flexible base load operation. The high output and efficiency can be achieved even in the most challenging locations and conditions, including hot climates and high altitudes.

A considerable number of combustion engine power plants are following load profiles that classify them as base load power plants, i.e. running more than 6000 hours per year. More than 1550 Wärtsilä base load plants produce 22300 MWe



A screen shot from the Colorado Dispatch Center, Xcel Energy, USA. The green curve illustrates how wind generation drops from 700 MW to 350 MW during one morning hour. The red and white curves show how gas engine based grid stability power plants are started, providing fast reaction to the change.

of power around the clock in 135 countries around the world. In many cases the plants operate more than 8000 hours per year, through all seasons, in highly varying ambient conditions, and even using very poor fuel qualities.

The Lufussa Pavana III base load power plant is located in Honduras and consists of 16 Wärtsilä 18V46 engines having a total output of 273 MWe.

As an example of their inherent reliability, combustion engines based on the same technology are also powering ships sailing the world's oceans, for which the reliability requirements are obviously high. Their reliability is also a key reason why combustion engines are chosen to drive pumping units for crude oil pipelines and for gas compression applications.

The Lufussa Pavana III base load power plant is located in Honduras and consists of 16 Wärtsilä 18V46 engines having a total output of 273 MWe.

4. The Flexicycle™ power plant

In typical power systems, the base load generation capacity consists of large centralised coal and/or nuclear power plants alongside combined cycle gas turbines (CCGT) with long ramp-up and ramp-down times. Intermediate operation is typically handled by combined cycle gas turbines. The reserve and peaking capacity is based on less efficient smaller generating units that are expensive to operate.

The Flexicycle™ solution combines the advantages of a flexible simple cycle plant, with the superb efficiency of a combined cycle plant, in a unique way. Flexicycle™ power plants can be optimized for different outputs in the 100 to 500 MW range. This power plant solution is based on gas fired combustion engines and a steam turbine combined cycle. Each engine is equipped with a waste heat recovery steam generator. The power plant has one common steam turbine with a condenser. The power plant cooling is typically arranged so that the combustion engines are cooled with closed loop radiators, and the steam cycle with cooling towers.

The Flexicycle™ power plant solution's two-in-one characteristic makes it a very competitive solution for handling a grid system's intermediate load. Depending on the power system's capacity mix, the Flexicycle™ power plant can also be the best choice for base load generation, thanks to the high combined cycle efficiency. In the Flexicycle™ concept, the unique dynamic features of combustion engines are maintained as the combined cycle can be shut on and off individually for each generating set.

Simple cycle mode – superior for ancillary services

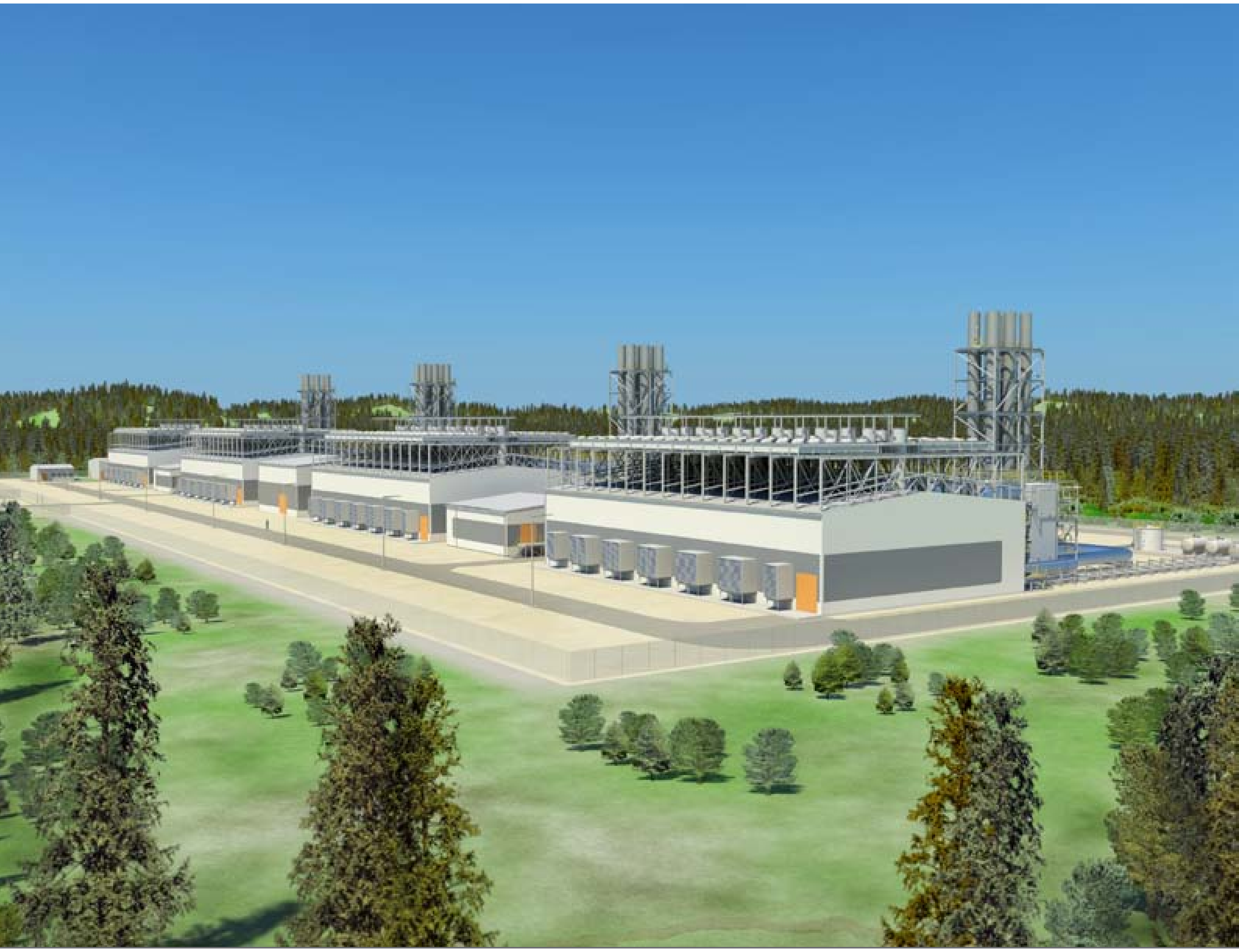
- 10 minutes to full load, 1 minutes to stop
- 45.8 % efficiency, 7860 Btu/kWhe
- Unlimited starting and stopping with no impact on maintenance schedule

Combined cycle mode – for competitive base load power

- 50.0 % efficiency, 6829 Btu/kWhe
- 45 minutes to full efficiency
- Switch back to simple cycle on the run

Efficiencies and heat rates are given as plant net at site conditions.

The 500 MW Flexicycle™ power plant based on 24 Wärtsilä 18V50SG units and a steam turbine combined cycle.



Wärtsilä is a global leader in complete lifecycle power solutions for the marine and energy markets. By emphasising technological innovation and total efficiency, Wärtsilä maximises the environmental and economic performance of the vessels and power plants of its customers. Wärtsilä is listed on the NASDAQ OMX Helsinki, Finland.