Image Study Diesel Power Plants

Study on image and actual potential of engine-based power plants

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Written to order by

KPMG

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1. EXECUTIVE SUMMARY

Today's marketplace for power generation is highly competitive and covers a diverse range of products and technologies. A growing concern about the efficient use of resources and the reduction of emissions is going to have a lasting impact on future developments within the industry.

The main goal of this study, which was conducted by KPMG on behalf of MAN Diesel & Turbo SE, is to investigate engine-based power plants based on four distinct criteria: technological advancement, energy and environmental policy and impact, cost effectiveness, and flexibility. The actual findings are being compared with the current image of the engine technology while competing alternatives such as coal-, nuclear-, or gas turbine-based power plants are looked at as well.

The study shows that there is a very broad spectrum of different factors that needs to be considered when evaluating different power plant options and highlights the importance to make evaluations on a case-by-case basis. Following are some of the key findings of the study.

The most current solutions for engine-based power plants being sold on the market today certainly represent **advanced technology**. However, due to engine's long lifetimes (20 years and above) and the fact that they have experienced continuous advancements over the years, plants in operation today can vary greatly in terms of their technological advancement.

When it comes to **environmental impact**, the ability to run on various fuels (e.g. liquid bio-fuels, gas and oil derivatives), a low water consumption rate for cooling purposes and the option to form hybrid solutions with renewable energy plants (e.g. wind, solar or hydro power) are key advantages of engine-based plants. Nonetheless, the majority of such plants today still run on oil derivatives. And while the use of fossil fuels always produces some amount of emissions, oil derivatives generally create more emissions than alternative fuel types. Hence, the best available technology as well as the best fuel type available should be used when operating fossil-based power plants.

Especially considering the growing concern about the responsible use of resources, engine-based solutions' comparatively high efficiency rates are a certain advantage when it comes to **cost effectiveness**. On the same token, the volatility of the fuel price combined with the significance of fuel costs as a cost parameter can have a considerable impact on long-term calculations for fossil-based electricity generation.

Flexibility in the context of electricity generation and power plants can have various meanings. Engine-based solutions rank highly in this category due to their favorable part load performance, limited susceptibility to external influences and the ability to be located in rather remote areas or islands. Their low water consumption rate, relatively fast construction and expansion times and the ability to run on bio-fuels further add to that.

As far as future developments are considered, a growing concern about the sensible use of resources, the need to continuously reduce emissions and the developing subject of a decentralized energy supply is expected to play an increasingly important role.

2. INTRODUCTION

Objective and Scope

Main Objective

The main goal of this study is to provide fact-based research and analysis on engine-based power plants in order to determine whether or not the evidence matches with the current image of those power plants and the respective technology used. The study was conducted by **KPMG** on behalf of **MAN Diesel & Turbo SE** and highlights areas of interest for project developers, independent power producers (IPP), banks, policy makers, consultants and researchers.

In order to do that, the study focuses on several key areas and benchmarks as defined by MAN Diesel & Turbo SE, the sponsor of this paper. It is not the goal of the study to provide a detailed or comprehensive analysis or to conduct an in-depth technical comparison of different power plant types.

To better illustrate the different areas of investigation, the study is structured around one key and four distinct sub-hypotheses. Each sub-hypothesis was derived from the key hypothesis and covers a different area affecting the image of engine-based power plants. Chapter 4 will cover those hypotheses in detail.

Scope

The market of engine-based power plants covers a wide and diverse spectrum in terms of usage, engine speeds and fuel types. This study sets out to examine only engine-based power plants, which primarily run on oil derivatives, gas, or liquid bio-fuels. This includes medium-speed engines with an output greater than 0.5 MWmech and power plants with a total output of up to 300 MWe. To conduct comparisons, the main focus was on advanced coal-fired power plants, gas turbine power plants (single and combined cycle) and nuclear power plants (generally 2nd generation). The following sections will provide a brief summary of the underlying technology those power plants are based on.

Internal Combustion Engines

Engine-based power plants are generally based on Diesel, gas or dual-fuel internal combustion engines. To develop a better understanding of internal combustion engines, several classification methods can be applied:

By Operation Cycle

Internal combustion engines can be grouped into two main categories of operation cycles, based on the names of their inventors. Within the Diesel cycle, the compression of air and the resulting hot temperatures are used to start the ignition. Within the Otto cycle, that ignition is initiated by spark plugs inside the cylinder or by pilot oil.

By Number of Strokes

Based on the number of strokes in the cycle, there are two and four-stroke engines. Four-stroke engines have an ignition in every other revolution and capture virtually the entire market for power plant applications. Two-stroke engines have one ignition in each revolution and are used selectively in power plant generation.

Engine Speed

Another way to classify the engines in question is by speed. Low-speed engines have a rotation of speed of up to 300r/min and are typically two-stroke engines. Medium-speed engines which this study is primarily focusing on come in between 300r/min and 1000r/min and are mainly four-stroke engines. High-speed engines have a rotation speed above 1000r/min and are four-stroke engines as well.

Gas Turbines

Industrial gas turbines and aero-derivative gas turbines are the two major types of gas turbines available on the market. With industrial gas turbines, hot gases from the combustion chamber are directed into a power turbine that rotates the compressor and the generator. That type of gas turbine is predominantly used in gas-fired turbine-based power plants. Aero-derivative gas turbines, generally falling into a lower to medium output range, are predominantly used for peaking and power reserve applications. Most gas turbine applications are based on natural gas. If fuels other than natural gas are used, maintenance will increase.

Steam Power Plants

The conventional fossil fuel-fired power plants in operation today are based on the Rankine cycle. The basic principle of this cycle is that water is pumped into a boiler in which it evaporates into steam. That steam is then fed into a steam turbine that rotates the generator to generate energy. Based on steam parameters, there are two major types of conventional power plants: subcritical and supercritical plants. Supercritical plants use steam at temperatures of 600-700°C and have an efficiency of 40-45%. Subcritical plants on the other hand use steam at temperatures around 540°C and have an efficiency of 35-40%.

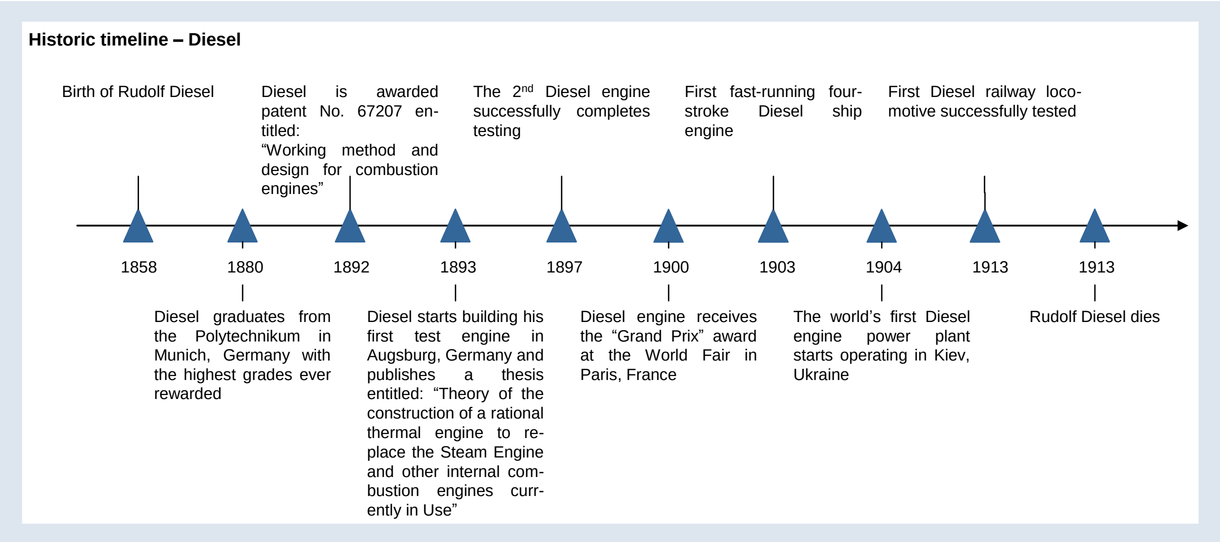
Nuclear Power Plants

Thermal reactors can be classified based on the types of reactor moderator. Moderators are used to reduce the speed of high energy neutrons after the fission. Today, graphite, light water and heavy water moderated reactors are in commercial operation. In the fall of 2009, there were 436 nuclear power plants operating world-wide, producing a combined total of 370.260 MWe. At the same time, another 53 reactors with a combined total output of 47.223 MWe were under construction world-wide.

Historic Developments

When talking about engine technology and engine-based power plants, one name immediately comes to mind – Rudolf Diesel. Diesel, the inventor of the Diesel cycle, is one of the true pioneers in the field of engine development. Born in 1858, his ambitious goal was to replace the omnipresent steam engine. Today, some 150 years later, we know that his invention not only replaced the steam engine and smaller steam turbines back in the day, but also greatly affected the world as we know it today.

The following graph illustrates some of the major milestones in history of Rudolf Diesel and the development of Diesel engines, which in large parts took place at M.A.N. Maschinenfabrik Augsburg-Nürnberg AG in Augsburg, Germany, today - MAN Diesel & Turbo SE



Graph 1: Historic Timeline

Present Situation

Since its invention in the late 1900’s, Diesel engine technology has become one of the great enablers of the modern world – powering everything from trains to cargo ships, cars to trucks, and through stationary power plants securing the power supply in different locations all around the globe.

Dr. Georg Pachta-Reyhofen,CEO – MAN Diesel SE:

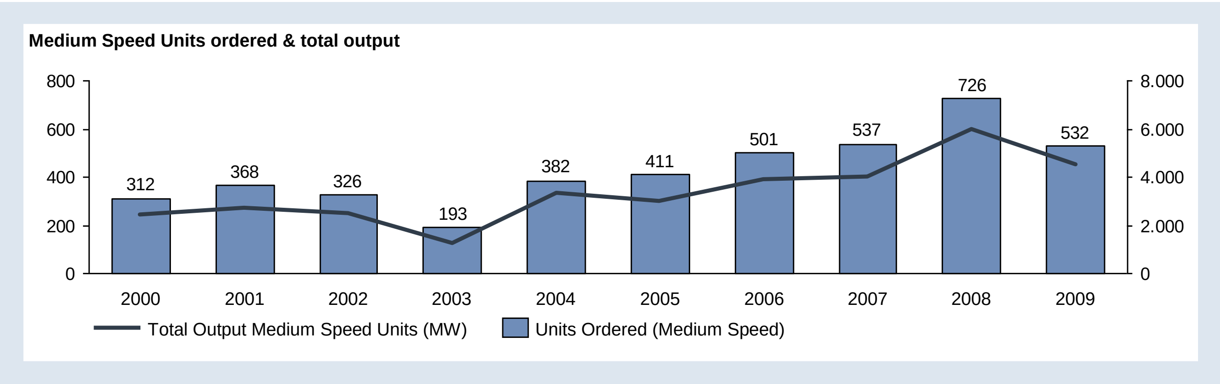
50% of World Trade is powered by MAN Diesel engines

Source: MAN Diesel CEO on press conference 10.09.2007

The market for engine-based stationary power plants has strengthened its solid position over the past several years. Mainly based on medium speed engines, these power plants are usually set up to provide reliable electricity supply in remote locations, developing countries and emerging markets to ensure grid-stability and serve peaking needs, and to provide an independent and reliable energy source for a diverse range of industrial and commercial organizations (e.g. utilities, IPPs, mining & cement companies, paper mills, etc.). While efficiency, flexibility and investment costs are typical key criteria when evaluating engine-based power plants, regulations and environmental aspects are becoming increasingly important. Besides national regulations, guidelines are set by institutions such as the World Bank or the European Union.

Market Information

Graph 2 shows the total number of medium speed units ordered and the total output in MW by medium speed units world-wide (one year covers a June to May reporting period; e.g. 2009 = June 2008–May 2009). By and large, the total MW output of medium speed engines followed a pattern consistent with the total number of ordered units per reporting period. While the order intake grew steadily between 2003 and 2008, it significantly dropped again in 2009. That steep decline of ordered units can largely be attributed to the dramatic economic downturn that started in 2008 and affected economies around the globe. Looking forward, the long-term worldwide energy demand is still expected to grow further, therefore setting positive surrounding conditions for future upward developments within this segment.



Graph 2: Medium Speed Units Ordered & Total Output


562
1268
3
48
PRECAUCION

3. METHODOLOGY AND SOURCES

To compose this study, KPMG has drawn on two proprietary sources of data, as well as information available in the public domain.

KPMG conducted a series of discursive interviews with thought leaders in the academic and research community as well as high ranking representatives of organization and associations in the energy and power generation sector. Interview partners of the academic and research community often owned the chair within their respective research domain. Representatives of organizations and associations often were senior leaders with decision-making power.

The second source is KPMG's in-house expertise in the areas of energy, utilities and manufacturing which were drawn upon in several interview sessions.

4. KEY HYPOTHESIS: ENGINE TECHNOLOGY IS CLEANER AND MORE EFFECTIVE THAN ITS IMAGE

As stated in the introduction, the primary aim of this study is to provide fact-based research and analysis on engine-based power plants, in order to determine whether or not the evidence matches with the current image of those power plants and the respective technology used. The underlying assumption is that in certain cases, engine-based power plants are seen in a light that might not necessarily reflect the actual situation. Guided by this assumption, research and analysis was conducted.

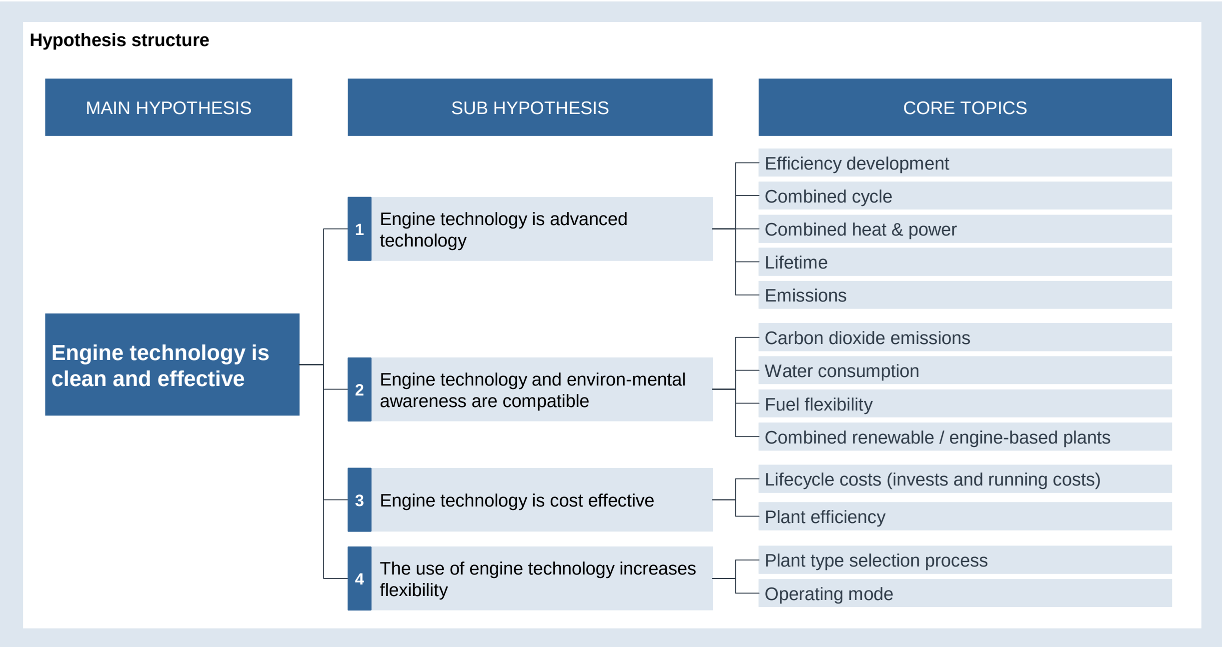
To make the analysis more tangible, we chose to put a main hypothesis at the center of the study, and then derive several key sub-hypotheses from it. The main hypothesis represents the assumption that the image might not be accurate enough and also highlights two key areas of the investigation – environmental impact and effectiveness.

The main hypothesis is:
“Engine Technology is Cleaner and More Effective Than its Image”.

As seen in graph 3, the four sub-hypotheses can be seen as the different pieces of a puzzle, that together form the main hypothesis. They each cover a different aspect of the main statement and help defining the specific areas of research.

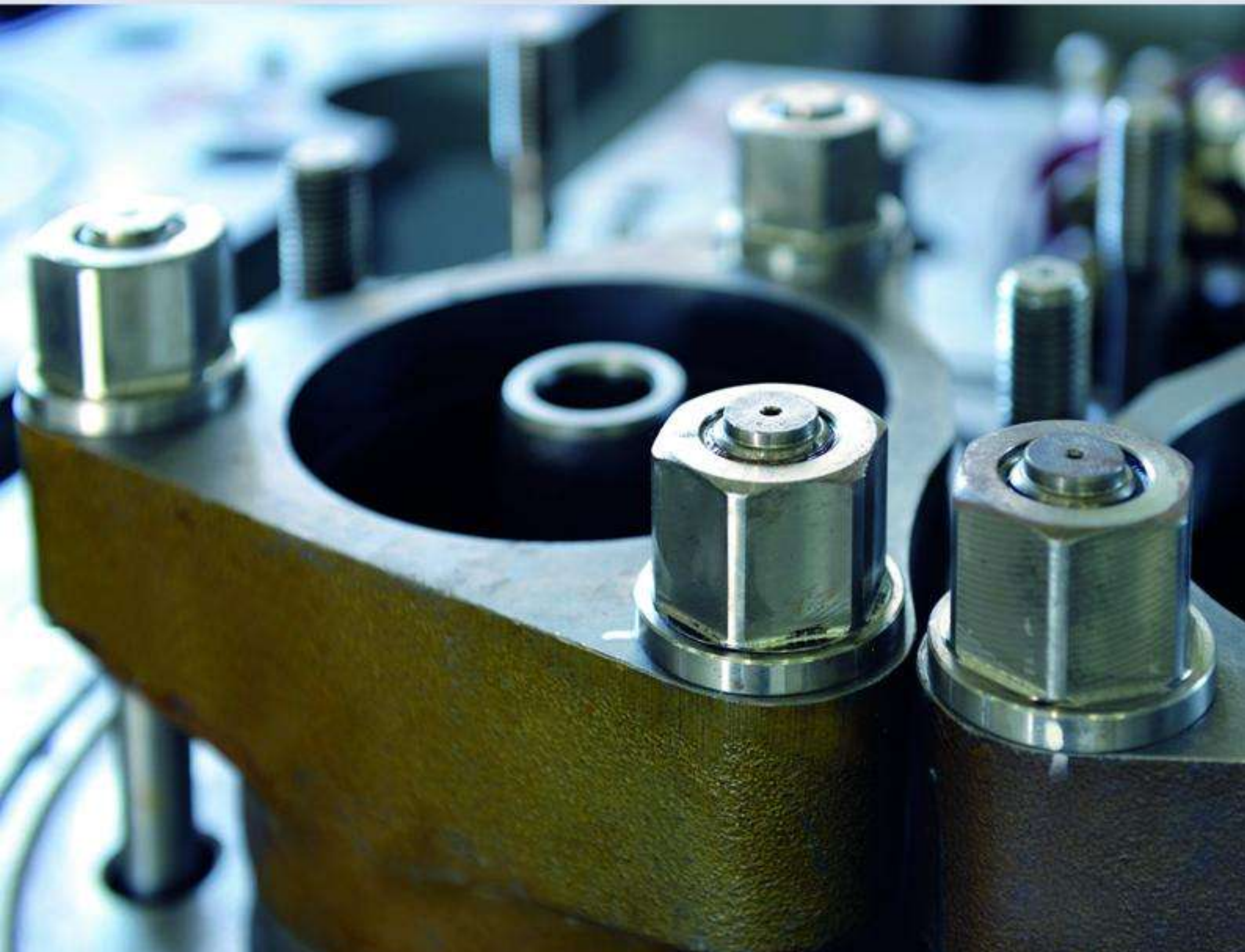
They are as follows:

1. “Engine technology is advanced technology”
2. “Engine technology and environmental awareness are compatible “
3. “Engine technology is cost effective“
4. “The use of engine technology increases flexibility”



Graph 3: Key and Sub-Hypothesis

In the following sections, we will test this statement through the analysis of the four sub-hypotheses mentioned above. Where possible, we will compare engine-based plants with alternative solutions and also provide real-life examples to better illustrate the topic.



5. SUB-HYPOTHESIS 1: ENGINE TECHNOLOGY IS ADVANCED TECHNOLOGY

As illustrated in the introduction, the groundbreaking invention of the Diesel cycle by Rudolf Diesel dates back over 100 years. Since then, the technology has been constantly improved and further developed and it is fair to say that the solutions available on the market today reflect the most current technology that can be used for engine-based power plants.

From an image perspective, people that are directly involved with this subject are well aware of the technology's status. However, people that are not quite as familiar with this topic might not necessarily think that the large engines used in power plants represent advanced technology. That might be due to the fact that the Diesel engine was invented such a long time ago or because some might intuitively associate certain technologies with being advanced or modern while not evaluating other technologies. But from a technical and economical standpoint, such arguments have only limited validity. The following sections will have a closer look at sub-hypothesis 1 and will evaluate the statement from different viewpoints.

Efficiency Development

The thermal efficiency rate of a prime mover is one of the key parameters that can be used for evaluating its performance. And in general terms, it can be defined as the ratio of the mechanical engine output and the fuel input. Over the past several decades, the efficiency of engine-based power plants has continuously increased. This steady improvement is based on technological advancements within a variety of different engine components and has been driven by increasing competitive pressure as well as certain external conditions (e.g. oil crises). The on-going technical developments have led to a point where today, a medium-speed four-stroke engine for example, is able to turn approx. 49% of the energy captured in the fuel into mechanical work (over 50% for low-speed, two-stroke engines; both under ISO conditions). From an efficiency standpoint, considering the different points mentioned above, it can be said that the best available technology on the market today can indeed be regarded as being advanced.

When talking about technological developments and efficiency, especially in light of current environmental and energy policies, the utilization of waste heat needs to be addressed as well. The following paragraphs will do that by having a closer look at so-called combined cycle and co-generation options.

Combined Cycle

While operating Diesel or gas engines, a considerable amount of heat from engine cooling and hot exhaust gases is produced. Rather than releasing that heat into the environment, it is an option to direct it into a heat-recovery system like a steam boiler where it is used to drive a steam turbine that creates additional electrical energy. That process is called combined cycle and the expression is based on the fact that the single cycle of an internal combustion engine (e.g. Diesel cycle) or gas turbine (Joule/Brayton cycle) is now combined with a steam turbine (Rankine cycle). A combined cycle considerably improves the performance of a power plant. In a Diesel combined cycle (engine plus steam turbine), the electrical power output can be raised by 10% without any additional fuel oil consumption. As a result, the plant's total output increases accordingly. Gas turbine combined cycles show even higher numbers when it comes to thermal efficiency and electrical output.

Combined Heat and Power

A combined heat and power (CHP) or co-generation plant also makes use of the waste heat from engine cooling that is created. But rather than using it to generate additional electrical energy, the heat can be used for a district heating or cooling network, municipal facilities, or industrial processes at local companies. Combining a power plant's electrical and heat efficiency in such a way, it is possible for the plant's total efficiency to come close to 90%. When considering the high efficiency and the range of different uses for the combination of heat and electricity, cities and communities, independent investors as well as industrial companies could benefit greatly from such power plants. And looking ahead, the use of those options is expected to further increase in the future. This is partly due to the fact that an increasing number of countries is putting regulations into effect that promote the use of co-generation applications (e.g. Germany's Combined Heat and Power Act).

Case study

The co-generation plant in Mouscron, Belgium, provides a real–life example of how a plant's efficiency can be maximized through the use of combined heat and power.

The plant, operated by the Belgian company Electrawinds NV, is based on large medium-speed diesel engines producing a total electrical output of 17.7 MW.

The total thermal output from exhaust gases and coolant reaches 14 MW.
That thermal energy is used for the local swimming pool and leisure centre as well as space heating and fuel conditioning within the plant itself.

The plant reaches a total efficiency of over 85%.

Especially in today's world, the efficient use of resources is more important than ever. And as the previous two paragraphs have shown, it is possible to further increase the already strong efficiency rate of engine-based plants by the use of combined cycle and co-generation plants. In summary, it can be said that those possibilities help solidify sub-hypothesis 1.

Lifetime

The lifetime of an engine needs to be touched on as well. Low attrition values of crucial engine parts ensure that, especially Diesel engines have a long lifetime. But while an engine's durability and long lifetime generally supports sub-hypothesis 1, it also sheds some light on another aspect related to this subject. It also means that a comprehensive deployment of the newest and most up-to-date versions of the technology can only be achieved at a rather slow rate. The effect is that the long lifetime, which certainly is a positive characteristic, slows down the general adoption rate of the newest technological advancements, simply because there might be no immediate need to replace or upgrade existing units or plants.

Emissions

Lastly, the topic of emissions and emissions-control can add another perspective when evaluating sub-hypothesis 1. This subject is covered in greater detail in chapter 6, but it is also useful evaluating the current status of the technology. In the past, engines used in power plants have seen consistent further development to reduce emissions. Those developments can generally be divided into two major groups: primary/engine-specific measures and secondary/external measures. While the first group includes advancements of certain engine components (e.g. fuel injection), the second group covers all additional advancements (e.g. after-treatment of exhaust gases). Looking ahead, further advancements to reduce nitrogen oxides (NO_x), particle emissions (PM) or greenhouse gases are expected to take place. Similar to the section on efficiency development, the conclusion for this segment strongly depends on the generation of engines or engine-based plants that is being considered. The newest technology available on the market today can certainly be regarded as advanced.

Conclusion sub-hypothesis 1

Several key findings can be derived from the different subjects that were covered within this section. Over the past few decades, engines have experienced a continuous improvement of both their performance and emissions figures. And while people familiar with this subject are well aware of this, others not as familiar with it might have a different impression of engine-based technology. The number of aged products still in operation likely adds to a disparate image as well. That goes to show that there can't be a general or all-embracing answer to sub-hypothesis 1. However, if the newest technology available on the market today is considered, that sub-hypothesis can be regarded as validated.

6. SUB-HYPOTHESIS 2: ENGINE TECHNOLOGY AND ENVIRONMENTAL AWARENESS ARE COMPATIBLE

Of all four sub-hypotheses examined in this study, this one probably creates the widest platform for discussion. That might be due to the fact that people think of fuming old and greasy motors when thinking about Diesel engines or engine-based technology in general. To find out if this picture is actually justified and to shed some light on this topic in general, the following paragraphs have a closer look from an externality perspective.

Externalities, or external costs, arise when the social or economic activities of one group or persons have an impact on another group and when that impact is not fully accounted, or compensated for, by the first group. Measuring and analyzing externalities is an often-discussed and very complex subject. The concept is deeply anchored in economic theory and is becoming increasingly important when evaluating different sources of energy.

The main damages caused by externalities effect human health, crops, materials and the environment in general. And while this subject can be analyzed in many different ways, we chose to focus on two distinct areas to analyze the statement that engine-based technology and environmental awareness can be compatible. On the following pages we will have a closer look at CO_2 emissions and the consumption of water. The second section within this paragraph will focus on fuel versatility and combined renewable and engine-based power plants, all within the context of sub-hypothesis 2.

Carbon Dioxide Emissions

Today, the significant negative impact of carbon dioxide (CO_2) emissions on our climate is widely known. In most developed countries, the largest source of CO_2 emissions is the combustion of fossil fuels. And the process of generating electricity usually tops the list in this category, making it the single largest source of those emissions.

Carbon dioxide emissions are always dependent on the carbon content of the fuel and the efficiency of the technology being used. Table 1 gives an overview of the carbon dioxide emissions of typical fossil-based power plants that are generated during the electricity production process and also puts the emissions in context with the respective plant efficiencies (generally based on state-of-the-art technology).

Carbon Dioxide Emissions of Typical Power Plants

Fuel and Prime Mover	Type	Efficiency (%)	CO_2-Emissions (g/kWh)
Nuclear Power Plants	Light water reactor	~35	0
Natural Gas Plants based on:			
Gas engine	Cogeneration	90	224
Gas turbine	Combined cycle	55	367
Two-stroke dual fuel engine	Single cycle	49	412
Four-stroke dual fuel engine	Single cycle	46	440
Four-stroke gas engine	Single cycle	48	417
Gas engine	Combined cycle	52	388
Distillate Oil Plants based on:			
Diesel engine	Combined cycle	52	513
Diesel engine	Cogeneration	80	333
Two-stroke engine	Single cycle	49	568
Four-stroke engine	Single cycle	47	587
Hard Coal Plants based on:			
Steam turbine	Cogeneration	85	401
Steam turbine	Supercritical	45	757
Steam turbine	Subcritical	38	896

Table 1: Carbon Dioxide Emissions of Typical Power Plants (under ISO conditions)

The table shows that of the four power plant types listed, nuclear power plants rank best in this category, generating virtually no CO_2 emissions during the production process. Of the remaining three plant types, gas plants have the least CO_2 emissions within the respective efficiency range. Coal plants show the highest figure of CO_2 emissions and distillate oil plants rank between those two. The topic of “Carbon Dioxide Capture and Storage” (CCS) is certainly gaining momentum. But while there have been considerable improvements in this field with some demonstration facilities and semi-commercial testing plants, the wide-spread commercial use of the technology is still expected to be more than 10-15 years out in the future. Additionally, the use of CCS is expected to reduce the plant’s net efficiency noticeably. Due to these facts, potential CO_2 emission reductions resulting from the use of CCS were not included.

Looking at the Distillate Oil Plants category, it is important to point out that those numbers are based on the assumption that engines run on distillate oil only. But as the section on fuel versatility will show, engine-based power plants are capable of running on a wide variety of fuels, including different bio-fuels that produce only a fraction of the CO_2 emissions listed in the table above. While bio-fuels are a CO_2-friendly alternative, it needs to be mentioned that the majority of plants run on heavy fuel oil (HFO), a mixture of residue products of the refinery process. And while CO_2 emissions are of course higher with the use of HFO, those residue products can be used to generate electricity instead of being disposed of otherwise. A final point that needs to be mentioned is the fact that CO_2 emissions of a power plant are directly impacted by the plant's efficiency. In this case, the strong efficiency statistics of engine-based plants have a positive impact on emissions.

In general it can be said that as long as fossil fuels are burned, CO_2 emissions will remain a significant factor. Comparing the four plant types listed in light of sub-hypothesis 2, it becomes clear that nuclear power and natural gas plants emit less CO_2 during the production process than the engine-based solutions used for this comparison. From this perspective, sub-hypothesis 2 could not be validated. However, if the use of gas and especially bio-fuels continues to grow and become more widespread, the position of engine-based solutions within this category would improve strongly.

Water Consumption

Fresh water is arguably one of the most precious resources today. And unlike gradually developing environmental concerns, such as the changing climate, water shortages can occur relatively suddenly and effect people and national as well as local economies alike. Unfortunately, the use of water can be a significant factor in energy production. It is used for cooling, fuel treatment, steam production and emissions control technologies and for sanitary purposes.

However, the lion's share of water used in the electricity production process is for cooling purposes. Table 2 lists the cooling water withdrawal and consumption (evaporation to the atmosphere) rates for common thermal power plant and cooling system types. The distinction between withdrawn and consumed water is important, as withdrawn water will be returned to the source again. Consumed water is lost completely in evaporation.

Water Withdrawal and Consumption of Typical Power Plants

Plant and Cooling System Type	Water Withdrawal (l/MWh)	Typical Water Consumption (l/MWh)
Engine-based Power Plants		
Heavy Fuel Oil, radiator cooling	~0	~9
Light Fuel Oil, radiator cooling	~0	~3
Combined-Cycle Plants (Turbine technology)		
Natural gas/oil combined-cycle, once-through cooling	28,390 to 75,708	~378
Natural gas/oil combined-cycle, cooling towers	~870	~681
Natural gas/oil combined-cycle, dry cooling	~0	~0
Fossil Steam Plants		
Fossil/biomass/waste-fuelled steam, once-through cooling	75,708 to 189,270	~1,135
Fossil/biomass/waste-fuelled steam, pond cooling	1,135 to 2,271	1,135 – 1,817
Fossil/biomass/waste-fuelled steam, cooling towers	1,892 to 2,271	~1,817
Nuclear Plants		
Nuclear steam, once-through cooling	94,635 to 227,124	~1,514
Nuclear steam, pond cooling	1,892 to 4,163	1,514 – 2,725
Nuclear steam, cooling towers	3,028 to 4,163	~2,725

Table 2: Water Withdrawal and Consumption of Typical Power Plants

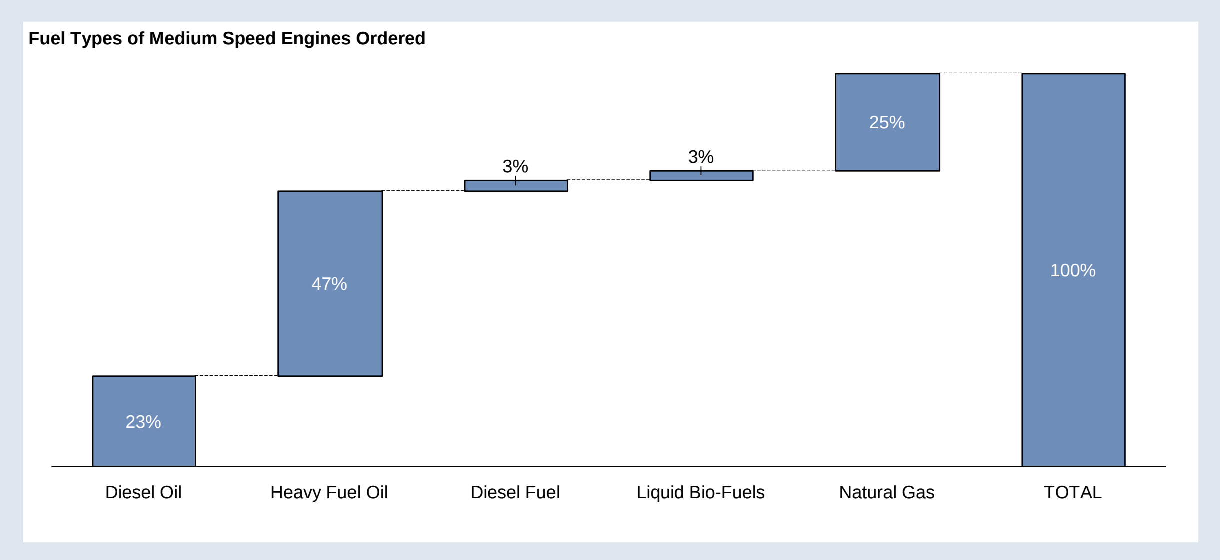
The table shows that when it comes to the use of cooling water – the main driver of water usage within a power plant – engine-based solutions have a clear edge over the other major plant types listed. No other plant type investigated has a lower demand of water for cooling processes. From that perspective, sub-hypothesis 2 can be regarded as validated.

But this does not only mean that engine-based plants use less of the precious resource. It also means that the location to set up the plant does not depend on large and steady water sources such as rivers, thus adding more flexibility when making investment decisions. This topic will be addressed in greater detail in section 8.

Fuel Flexibility

Investigating the second sub-hypothesis is not only possible from an externalities perspective. As already pointed out in the emissions section, the possibility to run on different fuel types is a clear advantage of engine-based power plants. For example, the internal combustion engines this study is focusing on are able to operate with Diesel Fuel, Heavy Fuel Oil (HFO), Natural Gas and liquid bio-fuels (LBF).
In addition to that, there is also the option to operate Dual Fuel engines. Based on the order intake of medium size engines (power class 2-20 MW) from June 2008 to May 2009, Graph 4

illustrates how the different fuel types were distributed.



Graph 4: Fuel Types of Medium Speed Engines Ordered (06/2008 – 05/2009)

With regard to sub-hypothesis 2, two different facts are worth mentioning. Graph 4 shows that today, the vast majority of those engines are running on HFO, which is a mixture of residue products of the refinery process. This means that remnants that would have to be disposed of otherwise can instead be utilized to generate electricity. While this ensures the most efficient use of resources possible, the trade off is that CO_2 emissions are usually highest with the use of HFO.

Also interesting is the fact that those engines can run on bio-fuels as well. While the table shows that the vast majority of engines today still run on the other fuel types listed above, bio-fuels are becoming an increasingly attractive alternative. Key benefit of those fuel types is of course the fact that they are natural and renewable resources. With the growing concern about the changing environment and increasingly strict emissions regulations, bio-fuels are a sustainable alternative that are capable of drastically reducing greenhouse gas emissions. Bio-fuels used today are usually some form of vegetable oil like palm or rape seed oil, recycled bio-fuels like frying fat or certain animal fats. And as with the other fuel-types, bio-fuels are also subject to sometimes significant price fluctuations.

Today, liquid bio-fuels are best suited to power small to mid-size engines-based power plants. Following are two application examples that illustrate how such fuels are used in real-life scenarios.

Case study

Since 2004, the community of Fritzens, Austria, operates a co-generation plant running entirely on used vegetable fats (e.g. frying fat) contributed both from private households and the local gastronomy.

The plant has a thermal efficiency rate of approximately 88% and generates enough electricity to supply 3,500 households.

In addition, part of the plant's thermal output is fed into district heating network and also used for heating purposes at the local sewage plant.

While the power plant in Fritzens provides a rather extraordinary example of how bio-fuels can be used to generate electricity, there is a growing number of successfully operating bio-fuel plants world wide.

For example, the already mentioned power plant in Mouscron, Belgium, runs on a blend of pre-refined vegetable oils and organic fats, producing more than 17 MWe electrical energy.

Another 14 MW of thermal energy are generated from exhaust gases and coolant.

The possibility that engine-based plants are run on liquid bio-fuels shows that there is some truth to sub-hypothesis 2. However, to clearly validate the statement, bio-fuels need to capture a greater overall share of that market, thereby lowering the use of HFO and other fossil fuels that produce CO_2 emissions. If that is not going to happen, sub-hypothesis 2 can not be regarded as fully validated from a fuel-versatility perspective.

Combined Renewable and Engine-based Power Plants

Yet another way to evaluate the second sub-hypothesis is to have a look at how engine-based power plants and renewable energy plants can be combined. One characteristic of some renewable energy plants, especially solar or wind parks is their dependence on external and generally uncontrollable factors like weather conditions. Wind turbines for example need a certain wind speed to produce electrical output. If the air is calm, they are not able to operate.

For those scenarios, a combination of a renewable and an engine-based power plant can provide a very viable solution. Due to its flexibility and fast start up time, an engine-based solution can be used as a back-up in case the renewable energy plant, due to external factors, is not able to generate electricity. This combination is a good example of how renewable and engine-based solution can supplement each other. Another benefit is the fact that engines within such hybrid solutions generally support grid stability and also allow for an intelligent grid management. Following are two real-life examples to better illustrate this possibility.

At the beginning of 2010, the world's largest wind/diesel hybrid power plant is scheduled to start operating on the Caribbean island of Bonaire in the Netherlands Antilles. Designed as an independent power plant generating up to 25 MW of energy, the plant's wind park will be the primary source of electricity generation. The Diesel engines are primarily planned to generate electricity during calm periods, storms and at times of peak demand. Since the project's ultimate aim is to supply the entire island with 100% renewable energy, the Diesel engines will be switched over during the next several years to run entirely on bio-fuels, which will be extracted from algae.

Case study

The city of Garabito, Costa Rica provides another example.

Costa Rica currently generates over three quarters of its electric power via hydroelectric power plants.

Due to seasonal limitations of those power plants – especially during the dry season which spans over several months – Diesel engines will now be used to bridge the shortfall and secure and stabilize the national power system.

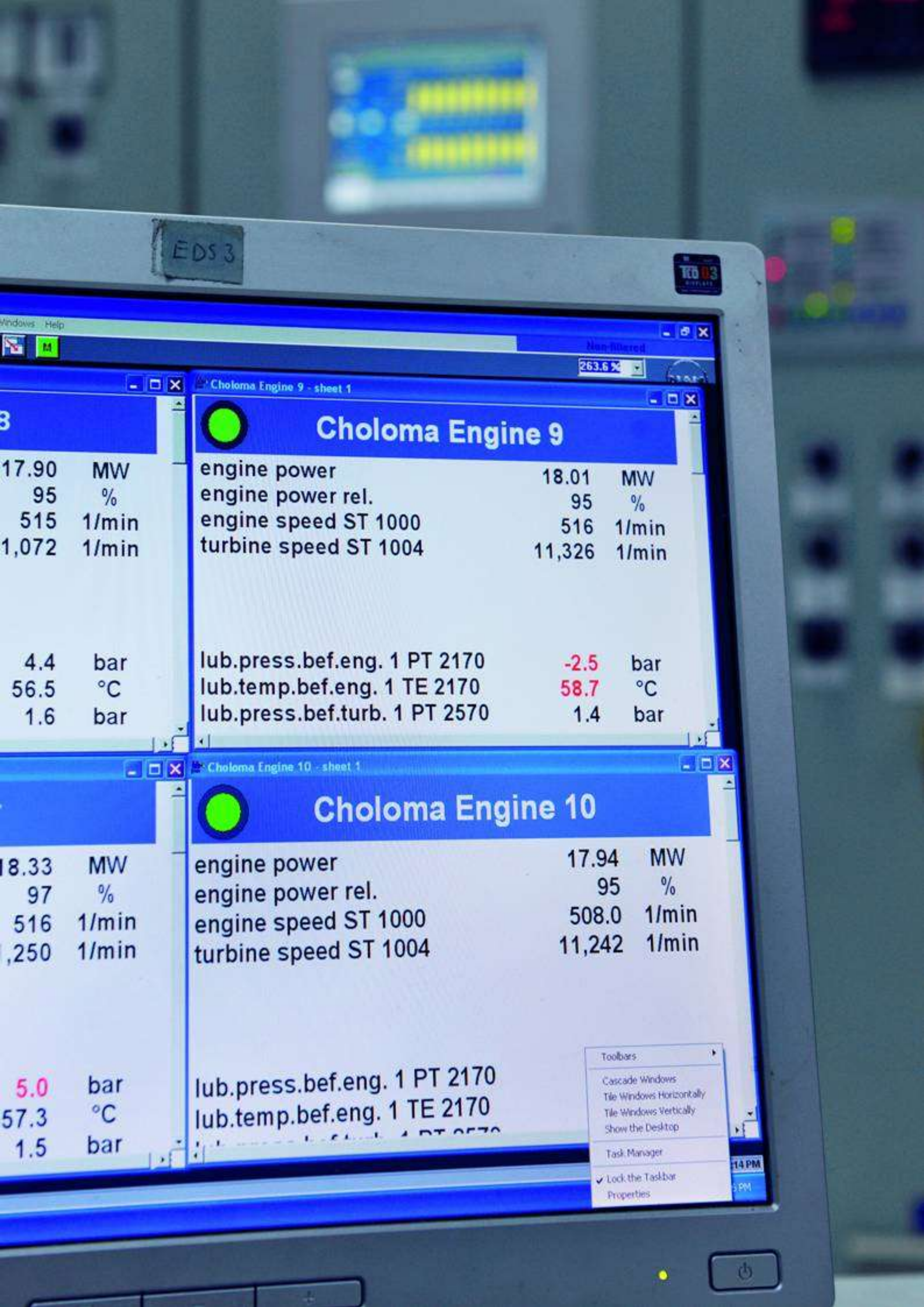
The engine-based peak-load plant will add 200 MW to Costa Rica's national grid, approximately 10% of the nation's total installed electrical capacity.

The installation in Garabito demonstrates that engine-based technology can be utilized to balance fluctuations that can occur with some alternative energy sources.

Such combinations demonstrate that, depending on the circumstances, engine-based and renewable solutions can supplement each other and create a solid business case, also from an environmental perspective. In the main, this supports sub-hypothesis 2.

Conclusion Sub-hypothesis 2

When it comes to preserving the environment, renewable energy sources will always present the most eco-friendly solutions to generate electricity. Looking at this subject from all those different angles – emissions, water consumption, fuel versatility and combinations with renewable sources – has shown that engine-based technology has the potential of presenting viable alternatives that can be compatible with environmental awareness. That is especially the case when looking at the low water consumption figures and the use of bio-fuels. However, other factors like CO_2 and other emissions as well as the predominant use of HFO fuel still speak against that. To sum it up – compatibility with environmental awareness in some categories is possible, but every case/application needs to be judged independently. Our research shows that the general image of engine-based power plants is rather mixed when it comes to environmentally friendliness. Given the findings of this section we can conclude that this image is only partly justified and in general greatly affected by fuel type and emissions.


EDS 3
Choloma Engine 9 - sheet 1
Choloma Engine 9
engine power 18.01 MW
engine power rel. 95 %
engine speed ST 1000 516 1/min
turbine speed ST 1004 11,326 1/min
lub.press.bef.eng. 1 PT 2170 -2.5 bar
lub.temp.bef.eng. 1 TE 2170 58.7 °C
lub.press.bef.turb. 1 PT 2570 1.4 bar
Choloma Engine 10 - sheet 1
Choloma Engine 10
engine power 17.94 MW
engine power rel. 95 %
engine speed ST 1000 508.0 1/min
turbine speed ST 1004 11,242 1/min
lub.press.bef.eng. 1 PT 2170
lub.temp.bef.eng. 1 TE 2170
Toolbars
Cascade Windows
Tile Windows Horizontally
Tile Windows Vertically
Show the Desktop
Task Manager
Lock the Taskbar
Properties

7. SUB-HYPOTHESIS 3: ENGINE TECHNOLOGY IS COST EFFECTIVE

Having examined the technology itself and its compatibility with environmental criteria, we will now take a closer look at the subject from an economical perspective. As with the previous sections, there exist plenty of economical and more finance-driven ways how one could evaluate engine-based plants and other alternatives. To keep the evaluation as straightforward as possible, this section mainly focuses on two main areas: the plant's lifecycle costs and its electrical efficiency. Both of them serve as key benchmarks in this area.

Lifecycle Costs

Lifecycle costs can generally be defined as the sum of all recurring and non-recurring costs over the full life time of a product, structure, service or system. In the case of power plants, costs in the areas of investment, operations and maintenance (O&M) as well as fuel are key parameters that influence total lifecycle costs. While there might be additional costs that can be a factor as well, these three major cost types are generally considered to be the key drivers of lifecycle costs.

To shed some additional light on this topic, Table 3 takes a closer look at costs for engineering, procurement & construction (EPC), as well as investment costs and fixed and variable operations and maintenance costs for various plant types. For this example, investment costs were calculated as the sum of the EPC price, owner's costs (e.g. site works, office/administration buildings, fuel tanks, connection fees of pipelines and de-rating costs at actual site conditions) and interest during construction. Fixed operation & maintenance costs include costs for operations personnel, taxes, insurances, and other services. Variable O&M costs include scheduled maintenance, start-up costs, material costs (e.g. lubricating oil) and CO_2 emission costs. Fuel costs will be the subject of a separate paragraph in this hypothesis 3 - chapter.

Investment Costs, Fixed and Variable Operations & Maintenance Costs of Different Plant Types

Plant Type	EPC Price (€ / kWe)	Investment cost (€ / kWe)	Fixed O&M costs (€ / kWa)	Variable O&M costs (€ / MWh)
Oil-fired Plants				
Diesel engine 160 MW HFO	840	991	18,4	26,3
Diesel engine 160 MW LFO	648	756	7,8	24,2
Gas-fired Plants				
Aero derivative gas turbine 160 MW	720	1036	12,7	24
Combined heat & power 160 MW	792	999	12,6	11,9
Gas turbine combined cycle 330 MW	840	1244	17,5	17,8
Industrial gas turbine 110 MW	480	752	15,8	25,6
Fossil Steam Plans				
Coal 500 MW	1440	1794	19,3	28,1
Nuclear Plants				
Nuclear 1500 MW	2400	3205	28,2	6,8

Table 3: Investment Costs, Fixed and Variable Operations & Maintenance Costs of Different Plant Types

Assumptions:

- Please note that the price of the turnkey plant was calculated at ISO conditions of 15°C, but the investment costs were adjusted to reflect site conditions of 30°C
- Gas engines and gas-fired gas turbines use lownox-combustion systems and do not need after-treatment of exhaust gases. HFO Diesel engine plants have a selective catalytic reduction denox-system. LFO Diesel engines and gas turbines do not have denox-systems as they are assumed to operate for less than 1000 hours annually
- Gas-fired gas turbines use lownox-combustion systems (no after-treatment needed); HFO engine plants have selective catalytic reduction denox-system; LFO diesel engines and gas turbines have no denox-system
- CO_2 costs have been calculated using a price of 25€/ton for CO_2

The above table shows that of the listed power plant types, oil-fired engine-based plants show the lowest overall investment costs, closely followed by gas-fired plants. Coal and nuclear power plants show significantly higher investment costs on a Euro per kWe basis. The fact that engine-based plants can have comparatively low investment costs is accompanied by their construction time which generally does not exceed one to one and a half years, depending on the size of the plant. EPC costs, which are by definition part of the investment costs, are lowest in the gas and oil-fired plants categories and significantly higher for nuclear and coal-based plant options.

When looking at the fixed and variable O&M costs, the results of the listed plant types are not as coherent. Here, the spread of results indicates that those costs are strongly dependant on a variety of different factors, thus preventing a general comparative statement to be made. Therefore, meaningful comparison can only be carried out on a case-by-case basis.

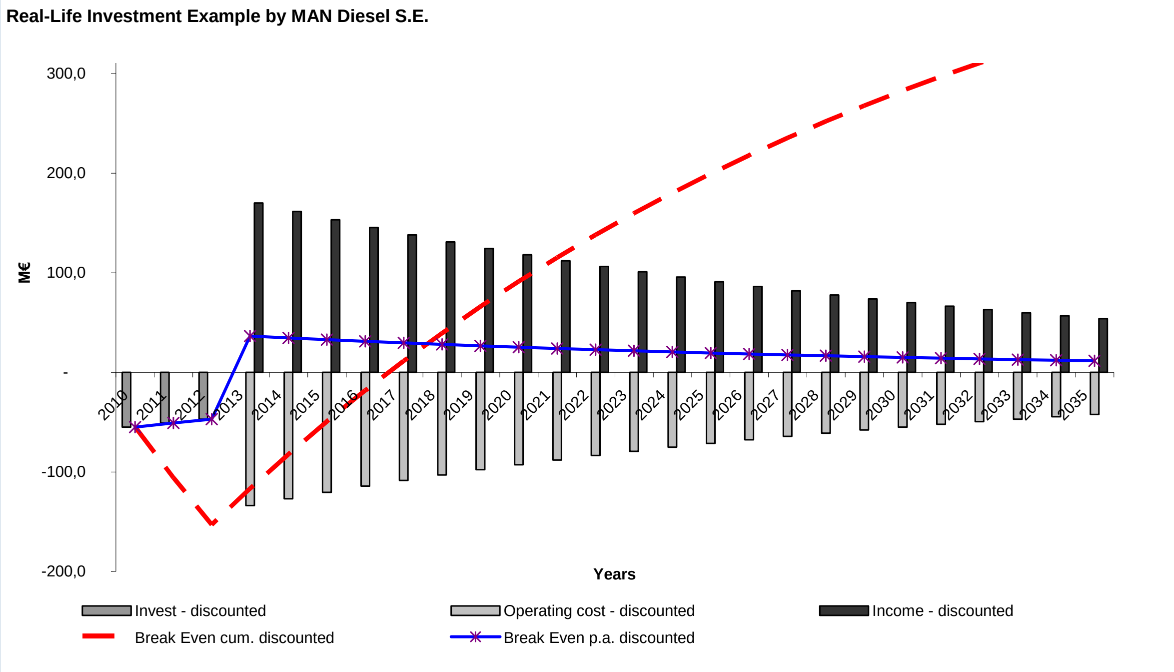
To get an impression of how construction-related costs have developed over the past several years, the IHS/CERA Power Capital Costs Index (PCCI) offers some useful information. It tracks the costs of building coal, gas, wind and nuclear power plants (it is indexed to the year 2000 and costs are associated with the construction of a portfolio of 30 different power generation plants in North America). In the second quarter of 2009, the index registered 217 index points, indicating that a power plant that cost $100 million in 2000 would, on average, have cost $217 million in the second quarter of 2009. Since the introduction of the index in the year 2000, it continuously increased until the first quarter of 2008. Since then, the costs captured by the index are trending downward. Especially since the beginning of 2009, this downward trend was caused by significantly lower prices for steel, copper and petroleum and affected all power plant types covered by the index.

Fuel costs, the third component of lifecycle costs covered in this study is a significant cost parameter. In the case of engine-based solutions it is important to mention that it is the most volatile parameter which usually makes up the lion's share of the plant's total lifecycle costs. The development of oil prices over the past several years has proven how fast and sometimes unexpectedly prices can change. To a certain extent, it is of course possible to compensate such price fluctuations with long-term purchasing or fuel supply agreements. However, looking at the full life time of a power plant, the general volatility of the fuel price makes long term projections very difficult and is of course able to impact a plant's profitability.

Looking at table 3, a final point needs to be made considering the end of a power plant's life time. While there is of course the option to make an investment in order to extend its operating life, one of the benefits of modern engine-based plants is that they can be fully disassembled again within a reasonable amount of time.

In light of sub-hypothesis 3, the analysis above has shown that investment costs are generally lowest with engine-based power plants. When it comes to operation and maintenance costs however, it is very difficult to determine a low cost leader, as the variety of different cost influencers calls for a case-by-case analysis. Fuel costs generally make up most of the plant's lifecycle costs and fuel prices can be rather volatile. In light of those findings, it is not possible to fully verify sub-hypothesis 3 or to make a general statement including all engine-based plants.

To make this topic more tangible, graph 5 illustrates a real-life investment example kindly provided by MAN Diesel & Turbo SE. It shows that the main factors, investment and operating costs and typical income, discounted and cumulated on a 25-years perspective. As already pointed out in the text, these investment cases are typically characterized by a rather short investment period (in this example, 3 years) and therefore the possibility to reach the break even point within few years, making it an interesting investment case. Due to difficulties in predicting all the cost and income factors over a 25 years-period, this investment case shows a linear development. Nevertheless, it perfectly supports the findings, discussed above.



Graph 5: Real-Life Investment Example by MAN Diesel & Turbo SE

Graph 5 is based on the following key assumptions:

Key assumption parameters for the Real Life Investment Example

Key assumption parameters					
First Year	2013	Operating Hours	7500	Investment	750 €/kW
Discount Rate	8%	Load	100%	Fuel Price	29 €/MWh
Escalation	2,5%	Plant Output	220 MW	FOM	18 €/kWa
Operation	Base Load	Efficiency	45%	VOM	29 €/MWh
Electricity Price	120 €/MWh				

Table 4: Key Assumption for Real-Life Investment Example provided by MAN Diesel & Turbo SE

Plant Efficiency

Lastly, a plant's efficiency ratio provides another important indicator of its cost effectiveness. The electrical efficiency is the ratio of the generator output measured in MWe and the fuel input measured in MWth. If the net efficiency of a plant needs to be determined, the plant's auxiliary power consumption would have to be subtracted from the generator output first. Also to be considered are the at-site conditions that can affect a plant's electrical output. Those conditions can be ambient temperature, altitude, part load operation mode, system deterioration, etc.

Power Plant Efficiencies

Plant Type	Net Plant Efficiency (%)
Oil-fired Plants	
Two-stroke Diesel engine 150 MW HFO	49
Four-stroke Diesel engine 160 MW HFO	43
Four-stroke Diesel engine 160 MW LFO	41
Four-stroke Diesel engine 160 MW LBF	41
Gas-fired Plants	
Aero derivative gas turbine 160 MW	38
Gas turbine combined cycle 330 MW	49
Industrial gas turbine 110 MW	31
Fossil Steam Plans	
Coal 500 MW	40
Nuclear Plants	
Nuclear 1500 MW	35

Assumptions

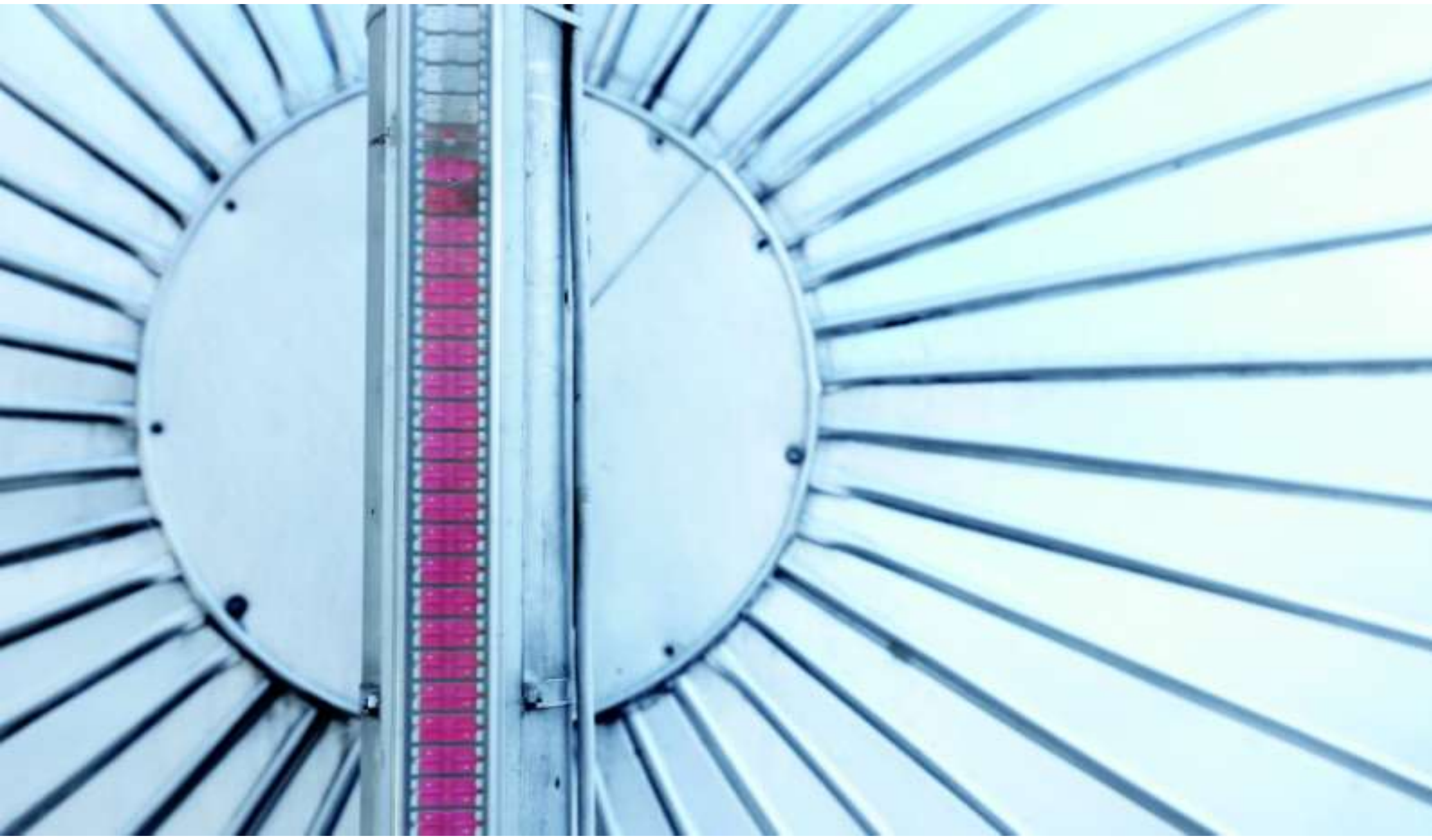
- Please note that calculations are assuming southern European conditions at the plant site (30°C ambient temperature, site at 100 m above sea level).
- The values of the listed engines and gas turbines are based on the values of the products of two large international manufacturers in that field.

Table 5: Power Plant Efficiencies (under ISO conditions

Mainly using the same examples as in the section on lifecycle costs, table 5 compares the efficiency ratios of different power plant types. The table does of course not provide a comprehensive list of all variations within a given power plant category, but provides a good selection of real life examples to better illustrate the topic.

The findings above show that the efficiency values of engine-based plants range between 40-47%. While the values of plants based aero derivative gas turbines range between 35-40%, plants based on industrial gas turbines come in between 25-35%. Comparing plants based on Diesel and gas engines shows that they have roughly the same efficiency values at the same sizes. The evaluated coal and nuclear power plants came in at 40% and 35%, respectively. The different results show that engine-based solutions have the highest efficiency ratios of the alternatives compared. Please note that this assessment does not include co-generation or combined cycle power plants.

Examining the different power plant types from an electrical net efficiency perspective showed that engine-based technology is highly competitive. From that point of view, sub-hypothesis 3 can be regarded a valid statement.



Conclusion Sub-hypothesis 3

Looking at the two main categories examined above – lifecycle costs and net plant efficiency – it can be said that engine-based power plants can indeed be cost effective solutions. It is of course always necessary to examine alternatives on a case-by-case basis, but the analysis of this chapter has shown several areas that support sub-hypothesis 3. These mainly include the areas of investment costs and electrical efficiency. Speaking against sub-hypothesis 3 are the findings that fuel costs are a very significant cost parameter and that fuel prices relevant for fossil fuel-based power plants are generally subject to fluctuations.

8. SUB-HYPOTHESIS 4: THE USE OF ENGINE TECHNOLOGY INCREASES FLEXIBILITY

The fourth and last sub-hypothesis states that engine technology increases flexibility. To examine this statement, we had a closer look at two different stages from a plant owner/investor perspective – the time period before the plant type is chosen and the period when the plant is completely set up and commercially operating.

Selection Process

The process of selecting the appropriate power plant type is a long and highly complex undertaking, with a multitude of different criteria and parameters to consider. Those factors cover all kinds of different areas like financing, electrical supply agreements, site conditions, fuel availability and fuel supply agreements, or environmental aspects. And together, they define how flexible one can be when choosing a certain plant type.

While some factors might be the same for all plant types, others might be very plant-specific. The following paragraphs do not aim to examine all those different factors. The goal is to investigate whether engine-based solutions are or are not able to increase flexibility during this stage.

As seen in section 6, a plant's water consumption for cooling during operating mode can be very significant. Because of that, access to a large and reliable source of water is an important criterion when deciding on a certain prime mover technology. That is also why many power plants can be found near rivers or other considerable sources of water. But as table 2 indicates, engine-based plants use significantly less water than the other major plant types listed. As a result, access to such a water source is not a relevant factor for operating those plants. The fact that the decision can be made independently of the water supply certainly adds flexibility to those evaluating different options in countries or areas where water supply is scarce.

Another factor is that stationary engine-based plants are rather compact and do not have a large real estate footprint, thus adding additional flexibility when it comes to determining the proper site of a new plant. It is also beneficial when it comes to meeting electricity demands smaller than 100 MW, like it often is the case in more remote or developing regions. In those cases, engine-based plants have the highest potential to be set up right where they are needed, to serve range of different customers from independent power producers to communities to companies (e.g. mining). Proof for that is the wide range of different, engine-based plants within that MW-range that can be found world-wide in remote or inaccessible areas. Generally, state-of-the art plants of that kind can be set up rather quickly within 12-18 months. Only comparable gas-turbine power plants could be set up within a similar time frame. Both nuclear and coal-based solutions will take significantly longer, but those plant types generally produce a much higher MW output as well. Looking past the operating life of an engine-based plant, another advantage is that they can be fully dismantled again.

The above mentioned flexibility does not only apply to remote locations. It also offers the possibility to set up smaller sized plants in more urban or industrial areas. In that case, the close proximity to the electricity and heat consumers would not only result in a reduction of energy losses but also reduce the need for transmission lines and heat pipes. If the plant would be located in a more urban environment, it is important to point out that its noise emissions would become a more significant factor.

Operating Mode

Depending on the primary purpose of the power plant, flexibility during operation mode can be an important factor. One way to measure this would be to look at the plant's part load performance. Generally, the main purpose of large nuclear and coal-fired power plants today is the provision of base load electricity. In those cases, part load performance is not such a critical factor. When looking at smaller power plants, plants similar to the ones described in the previous section, it becomes clear that different requirements apply. For those smaller plants it can be very important to be able to frequently alter the plant's performance while still maintaining a high net efficiency. In those cases, medium and low speed engine-based plants show a noticeably better part load performance (between 50%-100% load) than for example gas or steam turbines. A significant reason for this is the fact that many stationary engine plants usually consist of several engines that can, depending on the current electricity demand, be independently managed by starting and stopping them. This adds considerable flexibility during the operation mode. It also means that it is possible to add further engines and increase the plant's total capacity in the future if need be. This possibility enables the owner of an engine-based power plant to increase its capacity in a fast, economical and demand-driven fashion.

While a power plant's ramp rate, meaning its possible change of output within a 60 second time span, might not serve as a direct measure of flexibility, it indicates how promptly the plant's performance can be adjusted if need be. Table 6 lists the maximum ramp rates of different, to the network connected power plant types. Comparing the different ramp rates shows that engines together with aero derivative gas turbines have the best performance in this category. While industrial gas turbines still rank relatively closely behind that group, steam and nuclear power plants come in last. The faster ramp rates of engines both in emergency and in normal operation show that adjustments can be made rather quickly, thus allowing for more flexible decisions.

Maximum Ramp Rates of Different Power Plant Types

Prime Mover	Maximum Ramp Rate (%/min)	
Diesel engines	**Emergency**	**Normal**
Emergency	100	6
Gas engines	**Emergency**	**Normal**
Emergency	20	6
Aeoro derivative gas turbines	**Emergency**	**Normal**
Emergency	20	6
Industrial gas turbine	8	
Steam turbine	**Coal-fired**	**Lignite-fired**
Coal-fired	2-4	1-2
Nuclear plant	1-5	

Table 6: Maximum Ramp Rates of Different Power Plant Types

The first paragraphs of this section have shown that many small to medium sized engine-based plants can be located in remote areas, close to their respective end consumers. With these varying locations oftentimes come varying external conditions like ambient temperature and pressure. And depending on their value, these parameters can have a significant impact on a plant's performance.

When comparing engine and gas turbine-based plants, presumably the two plant types best suited for situations as described above, it can be said that the performance of gas turbines continually decreases the higher the altitude is. Gas engines on the other hand generally show no decline in performance even above an altitude of 2,000 meters. When looking at the ambient temperature, the picture is not quite as clear. In conditions between minus 30°C and plus 15°C, gas turbines actually have a better performance than engines. However, once temperatures are above 15°C, engines show the superior performance. It is important to note that over the span of minus 30°C and plus 50°C, the performance of gas turbines continuously declines. Engines on the other hand show a constant performance over the entire temperature range up to plus 30°C. Only after that their performance starts declining slowly.
The ability of engines to operate under varying external conditions without a major impact on

performance certainly is an indicator of flexibility. It allows investment decisions to be made more independently of such limiting external factors.

Even though the topic of fuel flexibility was already covered in section 6, it needs to be touched on again when trying to answer the question whether engine-based plants increase flexibility or not. The engines this study is covering are capable of running on various types of different fuels, including oil derivatives, natural gas and liquid bio-fuels. Gas turbines or other alternative technologies covered in this study show less versatility when it comes to running on a wide variety of fuels.

This capability allows for many different options and shows that engine-based solutions can be very flexible when it comes to the choice of fuel.

Conclusion Sub-hypothesis 4

The findings of this section have demonstrated that engine-based power plants rate highly when it comes to flexibility. Whether it is during the plant type selection process (e.g. independence of water sources, ability to be located in remote areas) or during the operation mode (e.g. ramp-up or part load performance, external influences, fuel flexibility), engine plants by and large present flexible solutions that are capable of adapting to different requirements. Based on our research we can conclude that engine-based solutions are generally seen as rather flexible solutions. Therefore, image and reality do match up in this case.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9. CONCLUSION

As stated at the beginning of this study, its main goal was to provide fact-based research and analysis on engine-based power plants and investigate how the evidence matches with the current image of those power plants and the technology used. At the center of the study was the hypothesis that engine technology – in a power plant-context – is cleaner and more effective than its image. Rather than working off a checklist to cover all the necessary aspects, four very distinct sub-hypotheses, each covering a different area with relevance to the subject, were evaluated.

Hypothesis 1: Engine Technology is Advanced Technology

The analysis has shown that it is rather difficult to find a general answer to this statement. As the technology has been constantly worked on and improved over the last several decades, there is a wide range of engines and engine-based power plants operating today. That range of course affects the technical image people have. However, it can be said that the newest technology that is currently being sold on the market supports the sub-hypothesis in question. Looking forward, especially in light of the growing world-wide concern about the use of resources, combined cycle and especially co-generation plants will gain more importance due to their higher efficiency numbers.

Hypothesis 2: Engine Technology and Environmental Awareness are Compatible

There is no doubt that environmental awareness is becoming an increasingly important factor in today's world. Evaluating engine-based plants in light of sub-hypothesis 2 has shown that especially the low water consumption rate as well as the ability to operate on a wide range of liquid fossil and renewable fuels validates the statement. Another supporting fact is that engine-based solutions can be combined with renewable energy technologies (e.g. wind, solar or hydro power plants) as a form of hybrid solution to ensure a consistent electricity output. In terms of future growth, hybrid solutions and the use of bio-fuels show strong potential – from an economical, environmental and image perspective. Research indicates that the current image appears to be rather mixed when it comes to environmental friendliness. A significant factor contributing to that is the predominant use of heavy fuel oil and the emissions that come with its use. That clearly speaks against sub-hypothesis 2.

Hypothesis 3: Engine Technology is Cost Effective

While it is certainly always necessary to examine different power plant alternatives on a case-by-case basis, the evaluation of engine-based plants from a cost effectiveness perspective has shown that there are several areas that validate sub-hypothesis 3. Two of the most important ones include the plant's high electrical efficiency and the overall investment costs. The biggest downside, however, lies in the volatility of the fuel price, which of course is a factor for all fossil-fuel based plants, and the fact that fuel costs generally constitute the most significant part of the ongoing operating costs of engine-based power plants. Also to be considered are future environmental policies that may be put in place.

Hypothesis 4: The Use of Engine Technology Increases Flexibility

In the context of engine-based power plants, flexibility can be measured in a variety of different ways. Based on the criteria that have been evaluated in section 8, it is fair to say that sub-hypothesis 4 is by and large valid. The engine-based power plants within the scope of the study generally do not need to be located next to a large water source and are perfectly suited to generate electricity in rather remote areas or islands. They also show a favorable performance when it comes to part load efficiency, sensitivity to external influences (e.g. ambient temperature, pressure) and fuel flexibility.

The study has also highlighted that there is a wide range of different factors that need to be considered when evaluating engine-based power plants or possible alternatives.

It showed that it is important to make evaluations on a case-by-case basis, always considering a plant operator's needs, local conditions, available alternatives, fuel choices, financing options or energy and environmental policies.

Looking ahead, a growing concern about an efficient resource use, reduction of emissions and the subject of a decentralized energy supply will play an increasingly important role.

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Source overview Tables and Graphs

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Statement CEO MAN	MAN Diesel CEO quote	Press conference 10.09.2007
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Graph 3	Key and Sub-Hypothesis	Author definition
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Table 2	Water Withdrawal and Consumption of Typical Power Plants	EPRI, „Water & Sustainability“, 2002, p. viii Wärtsilä In Detail, issue 1/2008 MAN Diesel SE
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