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Project Title:

FLOATING POWER GENERATION PLANT (FPGP)

TEAM MEMBERS:

Luca Mallia-Milanes

Dimitrios Lalaounis

Nikolaos Diakos

Ioannis-Georgios Stamou

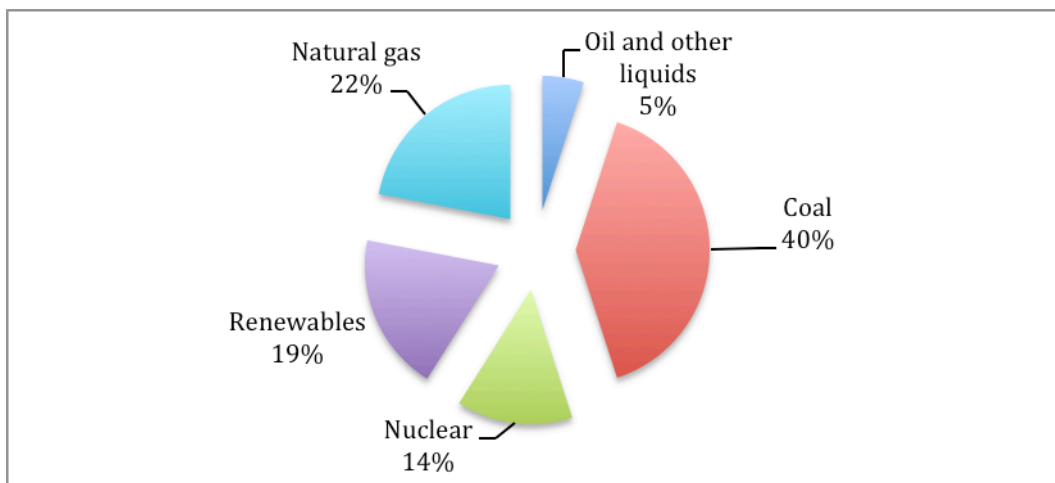
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1 INTRODUCTION

The main sources that are producing the greenhouse gas emissions are electric production, transportation, industry, as well as commercial and residential sources. The electricity sector comprises of different activities from the production up to the distribution of electricity. The main GHG released in this section is the CO₂; moreover, other gases are also released in the electricity sector chain, but the amounts can be considered as negligible.

Liquefied Natural Gas (LNG) provides a solution for reducing emissions from electricity. Energy consumption is steadily increased in recent decades. Total consumption almost doubled between 1990 and 2010. In the upcoming 20 years world demand for electricity is projected to have an average annual growth of 2.4%. Especially in developing countries, where demand is expected to reach 4% of growth per year. There are several ways to produce electricity. The most widely method is using fossil fuels such as coal, oil and gas. Apart from that electricity is also produced from nuclear power plants and renewable sources. The following graph illustrates the electricity production share for the year 2008. (EIA)



Graph 1 Electricity Production Share for the year 2008 (EIA)

As it can be observed, electricity is mostly produced by coal followed by natural gas and renewables sources. According to the projection of EIA, by 2030 use of coal for power generation will be slightly decreased and nuclear as well, while renewable and natural gas sources will be further involved in electricity production industry.

2 SELECTION OF RESEARCH AREA

This design project falls under the **Maritime** sector of the Waterborne transport mode. It is a sector that all the team members are familiar with and well read in, having reached the final year of our MEng degree in Marine Engineering and Naval Architecture at the University of Strathclyde. It is also an industry, which having struggled through the economic crisis, is now recovering and making important inroads into further development. The shipping industry is currently facing an influx of environmental regulations, in an attempt to make the maritime sector a cleaner and more efficient business. With legislation restricting nitrous and sulphur oxides, as well as carbon dioxide and particulate matter, ship owners are looking towards either investing in new technology that can reduce these emission sources, or adopt the use of an alternative fuel, which can perform the same purpose. The alternative fuel which is currently booming in the maritime industry is Liquid Natural Gas (LNG).

The Floating Power Generation Plant design project is most closely related to the Environment and Energy research area, more specifically, **Fuel Infrastructures**. Energy and the environment go hand in hand, with the energy industry continuously developing more environmentally friendly and sustainable sources of power. The FPGP is an installation that provides energy to countries that require an immediate supply of electric power and is based on the use of LNG, which is a cleaner and more efficient fuel. It is primarily an installation that provides emergency relief to countries that are disaster stricken and hence have a shortage of power.

3 JUSTIFICATION OF SUBJECT

The new maritime environment legislation that is being imposed in the shipping industry, poses a number of restrictions to ship owners as to how they design and operate their vessels. There are new regulations on CO₂, NO_x and SO_x emissions that have been imposed by the International Maritime Organisation (IMO).

To comply with the above-mentioned legislation, ship owners can either take certain ship design or operation measures, invest in new machinery that will control emissions or make use of an alternative fuel or even change their trading routes. The use of LNG reduces NO_x emissions and fine particles by around 90% and helps to reduce vessels' carbon footprint, resulting in approximately 15% lower CO₂ emissions. LNG is a cheaper and cleaner fuel, which reduces maintenance costs for ship owners. It is a fuel that is becoming increasingly popular both in the maritime and land based industries.

The above advantages have triggered a substantial interest in LNG, particularly from ship owners. In the last 5 to 10 years, the amount of LNG carriers being constructed has increased rapidly, as are the number of LNG Floating Production Storage and Offloading vessels (FPSOs) and Floating Storage Re-gasification Units (FSRUs). With land-based establishments also converting to LNG based power stations and infrastructure, the Floating Power Generation Plant (FPGP) provides a solution that not only meets the current needs of the market, but also reduces construction time and costs for the customer.

It is noteworthy, that there are currently two billion people all around the world, who have no access to electricity. For that reason, international organizations and governments have set their high priority to tackle this lack of electric power. Moreover, both the increased standards of living for many people as well as the population growth in developing countries result to strong growth in energy demand, where FPGP project might offer a provisional solution.

The primary application of the FPGP concept however, is where it can be used as an emergency relief supply of energy. Specifically, there are various cases of accidents in power generation plants where the power demands, afterwards, were highly increased and instant power sources were required to face these problems. For instance, the disaster in nuclear power station in Fukushima 2011, Japan, had as a result an enormous power struggle of the country. The government is still looking for alternative emergency power sources (i.e. oil, gas and coal) to fire conventional power stations. Another concept of emergency relief is when countries require increased power demands only for a short period of time.

The justification for this project is centered primarily on the additional power needed from certain countries for a restricted time period. This discourages the construction of industrial energy facilities, that would be more expensive and more time consuming as well. Moreover the project promotes the use of a cleaner fossil fuel rather than coal or Heavy Fuel Oil.

4 PROJECT CONTRIBUTIONS

The team aims to build upon the progress already made in the re-gasification sector of shipping and develop it even further through the design of a FPGP. This is an innovative concept and one which can contribute not only to the maritime sector, but the energy industry as a whole. The FPGP will provide electric power to countries which are not in a position to construct their own land based power plants and will provide an emergency relief supply of energy to disaster stricken regions. Specifically, the team hopes to achieve a power generation within the range of 100MW – 300MW, which will contribute to the supply and demand chains of the industry.

5 AIMS OF PROJECT

Below are the objectives of the FPGP project:

- a) Carry out a critical review to establish the needs and availabilities of Floating Storage Regasification Units and Floating Power Generation Plants.
- b) Outline the basic design features of the plant
- c) Select the key features for a more in-depth study
- d) Produce a generated power within the range of 100MW – 300MW
- e) Determine the economic feasibility of the project

6 WHAT IS A FLOATING POWER GENERATION PLANT (FPGP)?

As the name implies, a floating offshore plant is an installation which is stationed away from land and which provides a form of service. Offshore installations are becoming increasingly popular on the market and nowadays come in a variety of forms. In today's industry there are a number of interesting projects that fall under this category. There exist, among others, floating nuclear plants and wind turbine installations, FPSOs, FLNGs, FSRUs and even floating accommodation units. By having these plants offshore, restrictions in size and geographical location, which are often encountered on land based projects, are eliminated. Since there is little or no construction required on the seabed, floating installations pose much less harm to the environment, both for implementation and decommissioning.

On the other hand, although these plants are stationed away from land, they are also ideal to access remote shore-based regions which are otherwise complex or expensive to serve. The distance of these installations from land provides the added element of safety, in that should an accident occur, there is less of a threat to land based establishments and personnel. One floating offshore business in particular that is booming is the power production sector. As the demand for energy rises and conventional oil and gas sources become depleted, developments in design and technology are made that allow the industry to access deeper and more complicated fields.

The concept of a Floating Power Generation Plant builds on the work that has already been done in this sector. It may be thought of as an expansion to Floating Storage Re-gasification Units. The FPGP is an installation that will load Liquid Natural Gas (LNG) from shuttle tankers, vaporize it, and use the fuel to generate electric power. This electricity will then be transmitted ashore to land based establishments. The platform will have the capability of moving around as required from one terminal to another as the supply and demand chains fluctuate. This concept eliminates the requirement for shore based LNG storage tanks, re-gasification equipment and power generation machinery, hence allowing the consumer to make savings in construction time and costs. The FPGP will act as an emergency source of power to countries that require a clean and immediate form of energy. The diagram below gives a pictorial representation of this concept:

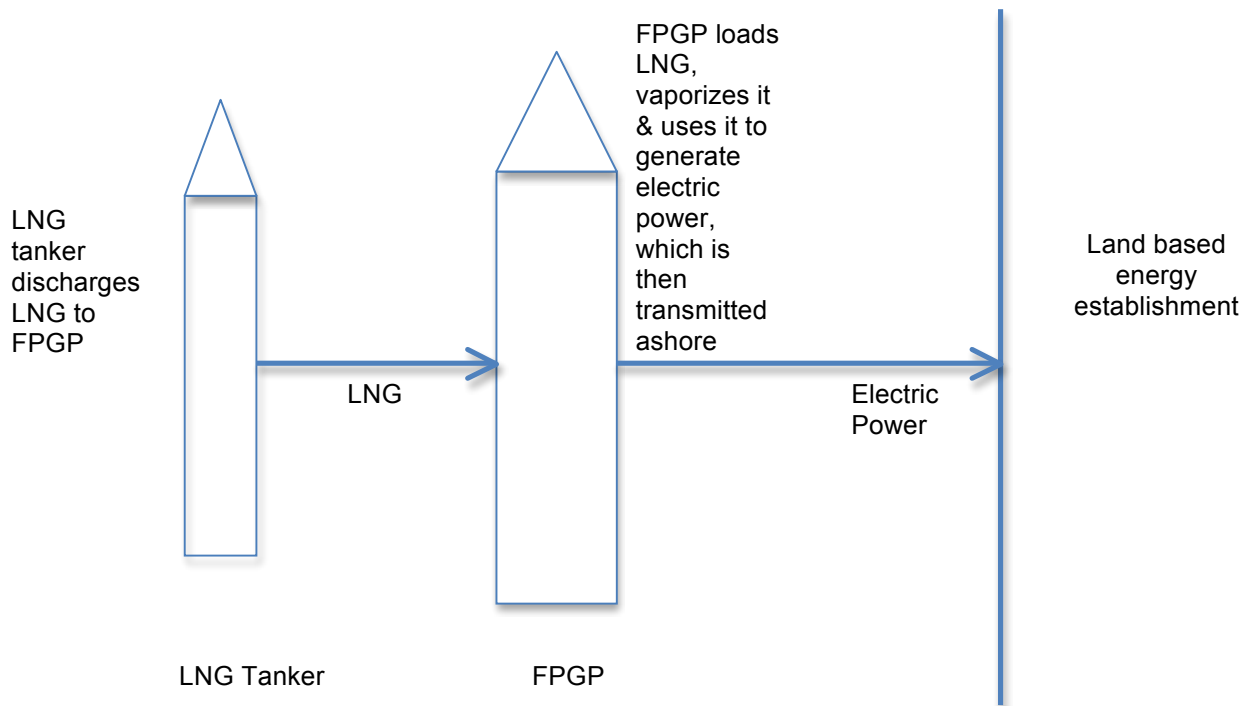


Figure 1 Pictorial Representation of FPSO

It must be mentioned however, that these offshore systems are also associated with their own complications. There is an added element of safety that must be taken into consideration with such installations, due to the nature of the operations and the surrounding harsh environment. Factors such as station keeping, transfer of supplies, output offloading and environmental impact must all be taken into account. These issues are a focal point of the offshore sector, and as the industry grows and develops even further, new designs will come to light that exploit the potential benefits, while keeping the dangers at bay.

7 LITERATURE REVIEW

The following are the main concepts involved in the floating offshore industry, with regards to the energy production sector.

1. Floating Production Storage & Offloading units (FPSOs)
2. LNG Floating Production Storage & Offloading Units (LNG FPSOs)
3. Floating offshore wind energy units
4. Floating nuclear plants
5. Floating Storage Re-gasification Units

7.1 Floating Production Storage and Offloading Units (FPSOs)

7.1.1 Overview

The FPSO is a floating production, storage and offloading vessel, which is designed in order to receive and store the oil or gas produced. The basic design of a FPSO is a ship-shaped vessel with the use of various mooring systems. These vessels are designed in order to provide solutions for both deep-water and ultra-deep fields. Every FPSO is equipped a central mooring system; which compromises of a turret and a swivel stack. The main concept is to allow the structure to rotate freely according to the weather currents; basically, to operate as a weathervane influenced by the wind. The swivel stack enhances the calm flow of the liquid from the turret to the topside structure of the vessel.

The topside structure consists of various compartments; as the crude oil is drawn from the well with the use of flow-lines and passes the turret is drained to the main separator of gas, water and oil. The main separator is divided into 4 main stages; the first stage [1] is the inlet section which ensures the uniform flow distribution across the vessel; and it also considered to be the preliminary gas/liquid separation. The second [2] stage employs the gravity separation function, in which the creation and the fall out of large liquid droplets are achieved. The third [3] stage includes the demisting section where the removal of finer mist particles is completed. The fourth [4] and final stage is the liquid separation section where the mixture is degassed resulting into the separation of the light and heavy liquid phases. Consequently, the gas is separated for power generation, the water is cleaned and sent off-board and the oil is deposit through the oil processing into the cargo tanks.

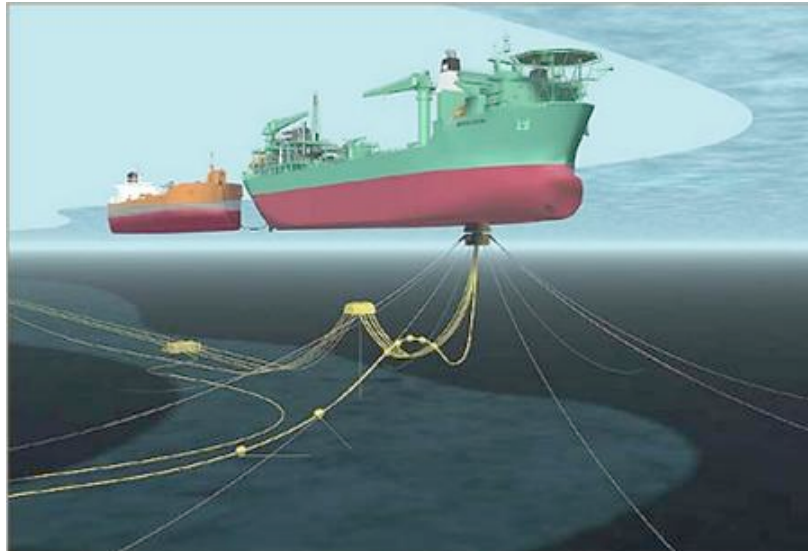


Figure 2 Floating Production Storage & Offloading Unit

Moreover, the stern construction of the FPSO provides the availability of transporting the oil produced to the bow of a shuttle tanker; this process is called tandem loading.

7.1.2 Applications

The first oil FPSO was the Shell Castel build in Spain in 1977. At the present time, more than 200 vessels are considered to be deployed globally. However, the oil FPSO are not build anymore; as a result, the LNG FPSO which work under the same principles of an oil FPSO may be produced to a greater extent.

7.1.3 Merits

The FPSO vessels have the ability to operate where the installation of fixed platform would have been considered as a high risk and not cost-effective; they can operate mainly in deep water locations or in remote places.

The FPSOs have the advantage that they can be considered as recyclable; by lifting the mooring and go to another location; in contrast with the traditional platforms which transportation. As far as the financial benefit is concerned, the initial cost of the investment companies can be decreased by utilizing the conversion of an oil tanker to an FPSO. This conversion is considered to be an easier task comparing with the new-building of a platform. In structural terms the extensive deck area can be utilized for both the required machinery and the needed maintenance processes. The large oil storage below deck is one of the key benefits. However, during the design of an FPSO vessel, it should be noted that the oil and gas development should be far away from the pipeline infrastructure for safety reasons.

7.1.4 Drawbacks

Compared with other tankers (due to the ship-shape hull), the FPSOs have to stay at sea for longer period of time; resulting into dealing with extreme weather conditions for a greater period without the protection of a harbour. Thus, the intact, the damage stability and the sensitivity of the FPSO motions should be given of extra attention. Apart from the extra attention to the construction and mooring design it should be mentioned that the FPSOs have the disadvantage of construction time. Even though,

the conversion is considered to be an easy task for most of the shipyards (comparing the new-building of a traditional platform); the estimated time is calculated to be around to 2 years.

7.1.5 Own view

Due to the instability of oil market and the unsafely weather conditions in the exportation areas the oil FPSO can be considered both cost effective; and safe, in terms of preventing an accident. However, at the present time, the oil industry is constantly decreasing and it is also affected by the stricter regulations; as a result, the LNG industry is arising. Consequently, many LNG FPSOs is expected to be built after the first new-building success.

7.2 LNG Floating Production Storage and Offloading Units

7.2.1 Overview

Similarly to FPSO, Liquefied Natural Gas Floating Production Storage and Offloading or LNG FPSO, is the development on the natural gas when extracted from the seabed. LNG FPSO is a vessel, permanently moored on location where resources of natural gas are established hundrend kilometers offshore. The LNG FPSO is connected with pipes on the seabed then processing, liquefying and storing on the floating facility the LNG. The LNG after is offloads to LNG carriers and transferred directly to the market. The size of such vessel is enormous and since there has not been built any.

The world's first LNG FPSO facility is currently under construction and will be extracting gas in three to four years forward. LNG FPSO is not a new idea, it was first established in 1990, but only recently have technological advantages and economic drivers to become commercial reality. While the natural gas resources have been found in high sea depths, LNG FPSO will be the solution to open new natural gas fields at sea.

An LNG FPSO composed by gas processing and liquefaction equipment as well as storage for the produced LNG. The raw natural gas is transferred from the wells in risers and diverted to the topside where gas processing and liquefaction units are usually installed. The produced LNG is then transferred from there to the storage tanks that are usually situated below deck. Periodically the stored LNG is transferred to LNG carries though offloading equipment. The LNG FPSO employs lot of seafarers so the need of accommodation is required as well. The main structure of LNG FPSO is similar to FPSOs and oil tankers. Additional structure requirements need to be accounted for in the design, due to additional loads of heavily equipment of processing and liquefaction on the topside. Furthermore the mooring system is one of the most important parts of such vessels as soon as the areas that such vessels are operating suffer from very bad weather conditions such as cyclones and monsoons.



Figure 3 LNG Floating Production Storage & Offloading Unit (Prelude)

7.2.2 Applications

The concept of LNG FPSO is under investigation since 90's. The first application of LNG FPSO is now constructed in Korea (SHI) and heads to the Prelude field in Australia (FLNG). Although since there are several resources of Natural Gas in fields far away from shore, several other applications are being considered. The first company that takes the risk of building such vessel is Shell, while previously (2008) Flex LNG has abandon an order of 4 FLNGs stated that it remains commercially untested.

7.2.3 Merits

The main advantage of LNG FPSO is that need 25% less time to been built compared to the inshore liquefaction and storage plants. Moreover the use of LNG FPSO have less impact on the environment as soon as there is no need for pipelines, coastal works and disturbance to the seabed and the land is reduced.

7.2.4 Drawbacks

The high cost of such a plant should be considered as the main disadvantage. There should be sufficient proven reserves so as to generate enough revenue to pay back the cost of such an investment. Moreover the risk of building such innovative concepts that do not currently exist in the market discourage most investors, however there is always a large company that takes that risk as Shell doing with the first LNG FPSO.

7.2.5 Own view

The increasing trade of natural gas in parallel with the strict requirements for cleaner emissions, that LNG can meet, will force the LNG production companies to extrude more difficult resources. Thus, the need for more LNG FPSOs taking place in the market seems to be clear. As soon as the construction of the first LNG FPSO has started only the results will prove how feasible is it and efficient can that be.

7.3 Floating Offshore Wind Energy Generation Units

7.3.1 Overview

Floating offshore wind energy generation unit is an offshore wind turbine installed on a floating structure, which gives the advantage to the turbine to generate electricity by converting the kinetic energy from wind into electric current. Large sea areas with strong and steady winds are available for wind farm development by installing offshore floating wind turbines, or wind parks. Wind is the fastest growing renewable energy source; increasing at an annual rate of 25%; therefore many governments and companies have been directed to the development of an alternative source of power; such as wind energy generation units.

There are various designs of floating offshore wind energy generation unit which depend on the application of each unit. First of all, semi-submersible design concept is widely used in offshore platforms; however the same concept can be used in offshore wind turbines. It is considered as a low-motion concept, where the main structure is being located below the water line, as a result the wave loads can be reduced. Moreover, by using catenary moorings the station keeping is possible to be maintained and the water-plane cross-section area is kept low. On the other hand, Tension Leg Platforms (TLP) is other low-motion design concept, similar to semi-submersible idea but the structure has the difference of excess buoyancy, which is countered by tensioned moorings. Catenary moorings are heavy chains, which provide stiffness by their weight, while in contrast tensioned moorings allow the vessel to move in the surge, sway and yaw directions only and reduce fatigue loadings. The third design concept is based on spar-buoy scenario, where these are large floating vertical-columns where the structure is below the water-line to reduce motion response little payload is needed for offshore floating wind turbines.

The structure of an offshore floating wind turbine comprises of three main components, the tower, the rotor and the nacelle. The tower is a steel structure which supports the nacelle and provides access to it. The rotor extracts kinetic energy from the air and converts this into wind into rotational energy in the drive train. While the nacelle converts this rotational energy from the rotor into three phase AC electric energy.



Figure 4 Floating Offshore Wind Turbine Generator Unit (Hywind)

7.3.2 Applications

The world's first operational deep-water floating large-capacity wind turbine is the Hywind, in the North Sea off Norway, in 2009. The Hywind is a 2.3MW turbine which is mounted on a floating tower with a 100-metre deep draft. The application of offshore wind energy generation units has started become more and more popular in the last years, due to the fact that they can produce large amounts of electric power. It is estimated that by 2030 the global production could reach up to 20 GW per year.

7.3.3 Merits

Offshore wind energy generation units are considered as a very promising technology due to the fact that are related to wind, which is a rapidly growing, free, inexhaustible, environmentally friendly and cost effective energy source. Moreover, onshore wind turbines have collected many negative reviews in regards with visual pollution as well as disruptive noise. Floating wind turbines face these problems by allowing wind farms to be pushed offshore and out of sight. Furthermore, there are lower offshore wind turbulences which results that the life of a wind farm or turbine can be expanded up to 25-30 years. Last but not least floating generation units are designed to be assembled in port and towed into position by using barges or tugboats; which results in major cost savings and increased flexibility in construction.

7.3.4 Drawbacks

On the other hand, because this technology is quite new in the industry, there is still a room for improvement either on the design of the structure or the whole efficiency of the generation units. Moreover, the application of these floating wind turbines is limited at a certain level of deep water, for instance 100-150 metres; therefore the installation of these plants in specific areas will be restricted as well.

7.3.5 Own view

Since this technology is related to an inexhaustible energy source such as wind energy, offshore floating wind turbines have the potential to rise in the offshore industry in the near future, although many concepts must be proven before this industry can scale. The potential of each design concept should be consider as well as new design concepts can be developed as well. Floating wind turbines are still years from mass deployment but they can provide a boost change in the wind energy industry.

7.4 Floating Nuclear Plants

7.4.1 Overview

Another idea of floating power plants is using nuclear power. Instead of building nuclear power plants on land and close to the people, an option comes to build a full-sized nuclear power plants on barges and position them offshore. This barge bay be movable or not but definitely should be moored. The electric current can be then transmitted ashore by cables and cover a significant amount of households.

Nuclear power is primary based on the combination of Brayton and Rankine cycles. The fuel that is used in nuclear power is the radioactive uranium. The core of the

reactor consists of a uranium bundle that heats water into steam. The high-pressure steam enters a turbine where it effects its energy to the rotor blades causing the rotor to turn. The rotor is connected with a generator that finally produces electric current. The expanded steam is leaving the turbine is then condensed and pumped back in the liquid form so as to feed the evaporator. The water in the reactor also works as a coolant for the radioactive material, preventing from overheating and melting down.

The main components of such a vessel are the nuclear power plant and the main hull. Although the danger of atomic explosion require the vessel to be designed such that can withstand different catastrophic events such as earthquakes or tsunamis large enough to cast it ashore. Moreover the uranium that is used as fuel should be light enriched, so as to prevent from being stolen and diverted for use in nuclear weapons, according to International Atomic Energy Commission rules

7.4.2 Applications

The idea was first established in 1970s from U.S utility companies but never been applied until the Russian energy company Rosatom has started building the first nuclear power plant named “Academician Lomonosov”. Her technology is based on the construction of nuclear powered icebreakers although she does not have a propulsion plant. The barge will be able to produce 70 Mw of electricity or 300 Mw of heat and additionally will produce water using desalination services capable of supplying 240,000 cubic meters of fresh water per day. The barge is projected to be finalized by 2016 and will be used in remote areas of the north stern Arctic Russia and Far East regions.



Figure 5 Floating Nuclear Plant (Rosatom)

7.4.3 Merits

The main advantage of floating nuclear power plants is the amount of energy that can be produced from just one uranium bundle. Moreover the energy that is produced is totally clean energy as soon as no emissions are produced.

7.4.4 Drawbacks

On the other the main disadvantage of nuclear power plants is the risk of released radioactivity into the environment, which raises health concerns. Moreover uranium is sold only to countries which are signatories of the Nuclear Non-Proliferation Treaty, and which allow international inspection to verify that it is used only for peaceful purposes.

7.4.5 Own view

The use of nuclear power plants is in general very efficient and with no emissions for the environment. Although couple of accidents that have happened in the past has proven that the consequences of one accident on a nuclear plant are so harmful for human's health and the idea is seeing to be abandoned even for shore based power plants.

7.5 Floating Storage Re-gasification Units (FSRUs)

7.5.1 Overview

FSRU vessels are specialized types of mobile offshore units, which are used for the storage and re-gassing of liquefied natural gas (LNG). FSRUs load LNG from shuttle tankers, vaporize it and send it ashore to land based power plants, for use in power generation. They are an important part of the energy supply chain and are becoming increasingly popular due to the recent surge of LNG on the market. Despite its advantages however, the storage and handling of LNG remains a difficulty in the industry.

The design of an FSRU varies according to its application. At present, there are two main concepts that are being applied for FSRUs in the industry. Firstly, an FSRU can be converted from an LNG tanker, with additional re-gasification equipment installed onboard. In this concept, the vessel is still free to roam around from one terminal to another and can even discharge LNG if the demand for gas is low. Alternatively, the LNG carrier can be converted to a standalone FSRU vessel, designed and constructed for a specific location. In this scenario, it is crucial that there is enough demand for gas, since the unit is not as mobile as in the first concept.

The main components of an FSRU include the LNG storage tanks and the re-gasification plant. The type of tank varies from Moss to Membrane, as well as a number of new, innovative designs that are gaining popularity in the market. The re-gasification plant, which is used to vaporize the liquid normally comprises of high-pressure LNG pumps, cryogenic LNG vaporizers and all the associated piping, valves and equipment. The liquid can be vaporized in a number of ways, through the use of steam from boilers for example, or by using a combination of seawater and propane. The design of the mooring system depends on expected weather conditions and the jetty configuration, should the FSRU be placed in a permanent position. Furthermore, additional safety equipment is required due to the high-pressure nature of FSRU operations.



Figure 6 Floating Storage Regasification Unit

7.5.2 Applications

The concepts in which FSRUs are being applied are increasing as the popularity of LNG rises. However, the main applications for these vessels are still in developing countries, where the demand for energy is high and the governments lack the resources and time to construct complete power plants, equipped with LNG storage tanks and a re-gasification facility, which take up the bulk of space. For this reason, FSRUs are also used in countries that have restrictions in the amount of land available.

7.5.3 Merits

Through the use of FSRUs, the land based customer saves on construction time and costs, since there is no requirement for LNG storage tanks and a re-gasification facility. Furthermore, FSRUs boast low emissions due to the burning of natural gas.

7.5.4 Drawbacks

There must be a demand for gas especially if the FSRU is fixed for long periods of time at a particular location. Moreover, the re-gasification process takes a substantial amount of time and is inefficient in certain cases where LNG is burned to create steam for the vaporization process.

7.5.5 Own view

With the increasing popularity of LNG, the demand for FSRUs is set to rise. Different concepts are expected to be developed, with units stationed offshore, at terminals or even free to roam around as required. The efficiency of the vessels can be increased by improving the efficiency of the vaporization process, through the use of waste heat recovery for example.

8 THEMES NEEDING RESEARCH ATTENTION

8.1 Power Generation

The concept of maritime power generation for onshore facilities is a new idea for the shipping industry. Although the idea was first established in the 1970s by US utility companies, it had never come to fruition until the Russian energy company Rosatom began design and construction of their own floating nuclear power plants in 2007. The 2 plants in construction will be able to produce 70 MW of electricity and 240,000 cubic meters of fresh water per day.

However, unlike the floating nuclear power plants, the FPGP of this project will operate on LNG, which means that there are a variety of different issues that must be taken into consideration. These include gas containment, vaporization, propulsion, electric power generation and output offloading. Due to the limited time available for this design project, it would be inefficient to try and tackle every single issue related to the floating power generation plant. Therefore, a number of key issues that the project will focus on are discussed in more detail below.

8.1.1 Trading Area

The first issue that must be tackled for a project of this type is the business case. It is crucial to find a base for the FPGP, around which analysis will be performed in order to extract a suitable power range and key specifications of the installation. In order to narrow down the options, an investigation into the power demand and production of several countries must be carried out. By carefully analysing the options, it will then be possible to select the most adequate region for the FPGP. This may be a hazard-prone area, or even a region that is developing rapidly and is in need of a surge in power for the years to come. This investigation will lead to important information required for the FPGP, such as the power generation capacity required for the installation, and the unit price of electricity needed in order to render the FPGP competitive. This data will provide the platform on which the design decisions will be made.

8.1.2 Gas containment

One of the most important features of the FPGP is the gas containment system. Nowadays there are a number of different designs available to choose from. However, proper analysis must be carried out so as to determine the most suitable tank type for this concept. There are four main containment systems on the market to day, two of which are of the self-supporting type, while the other two are of the membrane type. The most common tank types are the Moss (spherical IMO type B LNG tanks) and Mark III ones but the selection depends on the application. The Moss type tanks are mainly popular because they have no restrictions on cargo filling levels. Also, they have more clearance around the tanks, which makes it easier to carry out any modifications. The membrane type tanks are cheaper and normally related to newer vessels with a more efficient hullform.

The other available designs are the self-supporting prismatic type B (SPB) and the No96 system. The former has only been installed on two vessels but has very beneficial sloshing characteristics, while the latter is of the membrane type. There is also a combined system, called CS1 that is made up of the best Mark III and No96 characteristics.

8.1.3 New build or conversion

A key decision that must be made at the start of the design process is whether to convert the plant from an existing LNG carrier or design it from scratch. The advantage of converting a vessel is that the design and construction process is shorter and less costly, with certain key components readily available, such as the LNG storage tanks and the propulsion system. On the other hand, there might not be a vessel available for conversion, or the ship may be too old or not fit for purpose. Furthermore, depending on the ship set-up, there might not be enough space available for the required vaporization and power generation equipment.

On the other hand, by creating the FPGP from scratch, although the necessary time and expenses are higher, there is greater design flexibility. There are no restrictions on the size of the plant as well as on the type of equipment and machinery used. More modern structural components and equipment can be installed that will allow for a more efficient and environmentally friendly installation. Careful analysis must first be carried out before making this decision. The amount of electric power to be generated and hence the storage space and re-gasification equipment needed must first be determined before making such a selection.

8.1.4 Mooring or dynamic positioning

Another key factor that must be considered in the design stages is how the FPGP will maintain its position. This can be done either through mooring or dynamic positioning (DP). Although it is important to keep these two separate, there also exists thruster assisted mooring (TAM). Whichever choice is made, it is important that the FPGP remains movable.

The feasibility of both systems has to be assessed depending on the conditions and possible locations of the FPGP. In shallow waters, a mooring system is more viable than a dynamic positioning system and vice-versa for deeper waters. This is due to the difference in capital expenditure of the equipment. On the other hand, the operational costs related to dynamic positioning systems are higher due to the increased amount of fuel and power needed to keep the installation in position. Furthermore, although the DP systems are more complex, with more components that can fail, they are also more flexible. Mooring systems pose more restrictions on the plant and are not able to recover from a failure or snap in one of the cables.

8.1.5 Towed or self propelled

The majority of this decision is based on whether the FPGP will be designed from scratch or converted from an LNG carrier. Should the conversion route be selected,

then the most feasible solution would be to make use of the already existing propulsion system on-board. In this case, careful assessment is needed to make sure a carrier with an efficient propulsion system and hull efficiency is chosen, so as to minimise fuel expenses. On the other hand, if the installation is designed from scratch, then it might not be financially feasible to install a brand new propulsion system. However, with so much electric power being generated on board, installing a diesel-electric propulsion system might also be a logical solution.

8.1.6 Re-gasification method

There are two main methods of re-gasification available in the industry – the steam based method and the seawater system. The former is especially used in areas where the US coastguard prohibits the seawater systems. In this case, steam is used to heat up an intermediate medium, which in turn heats up the LNG. The advantage of this system is that the required equipment is relatively small. This is because the heating medium has a high temperature and therefore the heat exchangers installed can be compact and light. However, on the downside, the steam system produces higher CO₂ emissions than other solutions and around 2.5% of the LNG on board is required for steam production.

With the seawater system, propane in its liquid state is heated up with seawater and then used to raise the temperature of the LNG. If the seawater is not hot enough, the temperature can be raised with any other available heat source. Although this system produces fewer emissions than the steam system and does not require use of the on-board LNG, additional high power seawater pumps are needed for the vaporization process. There are also new developments being made in the vaporization market that make use of waste heat recovery methodologies.

8.1.7 Power generation plants

The main scope of the FPGP is to produce electric power for land based establishments. This is why the selection of power plants is of utmost importance. Since LNG is being vaporized and used to generate electricity, there are a few options available on the market to choose from. Dual and tri fuel engines, spark ignited gas engines, gas turbines and fuel cells are all options that may prove to be feasible. Dual fuel engines have a high thermal efficiency and a proven overall efficiency at lower loads. Furthermore, these power plants produce fewer emissions when compared to gas turbines, while the power available from gas turbines depends on the ambient temperature, which is not the case for the engines. Gas turbine systems are also associated with a higher capital expenditure.

On the other hand, gas turbines tend to be smaller and lighter with a very high power to weight ratio. They also produce fewer vibrations and have less moving parts, which means that they are associated with lower lubrication oil costs. Gas turbines also have high operational speeds, as well as higher energy production rates. The decision also has to be made as to how many power plants will be installed and of what rated power they will be. This depends on the electricity demand and gas available for power generation, which are tackled in the primary stages of the design process. It may also

be the case that the optimum solution involves a combination of a number of different power plant systems.

8.1.8 Output product

A decision must be made as to what the FPGP will be able to provide to shore based companies. It will definitely supply electric power. However, it may be logical to design the plant in such a way that it is able to supply an additional form of output. This will be beneficial should the demand for electricity drop for certain periods of time. Additional possible outputs are the supply of gas, as well as fresh water. Analysis will have to be carried out in order to determine whether it is feasible to offload these products. Furthermore, a crucial part of the project is to assess how the outputs should be offloaded, while ensuring a safe and efficient transfer of the product.

9 TRADING AREA

9.1 Global electrical consumption

Consideration must be given to major electrical consumers when locating a floating production plant. A depiction of the energy consumption per person by country on the world's map gives a better illustration on this sector.

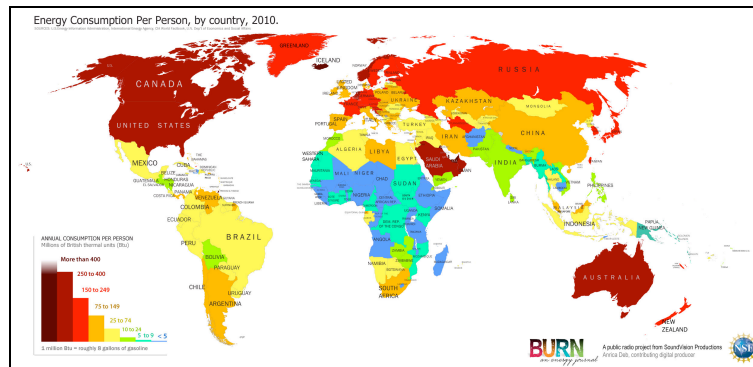


Figure 7 World Map - Energy Consumption per person by country (NSF)

The major consumers seem to be the United States, Canada Australia and Saudi Arabia. Russia, Greenland, Japan, France and Germany are following. Electricity can be transmitted through countries by cables in case of peak loads but when an independent island face such problems the transmission of energy from shore is very difficult. Moreover, developing countries require a quick form of energy until shore based production plants been stored.

9.2 Potential Regions – Potential power

Considering an emergency production power plant, an area surrounded by islands and developing countries would be the most desired region for operation. The potential areas that came under consideration are the Caribbean Sea, the North Sea and the Mediterranean Sea. A summary table with the potential markets as well as the potential power of the FPGP for each region is presented below:

Area	Potential market Countries - Islands	Total Capacity MW	Potential power of FPGP *
The Caribbean Sea	Mexico	62,000	400
	Colombia	13,540	
	Dominican Republic	5,310	
	Jamaica	1,190	
	Haiti	172	
North Sea	Scotland	1,760	200
	Ireland	4,073	
	Isle of Man	200	
Mediterranean Sea	Malta	571	300
	Mallorca	1,497	
	Menorca	247	

Cyprus	1,598
Crete	740
Ibiza	282
Libya	8,907
Algeria	12,000

*The potential power is an outcome of the average produced power in each power station of the country/island

However, it is difficult to obtain specific data regarding power plants on each area and moreover to estimate the accidents that may occur on the plants. On the other hand Mediterranean Sea is an area surrounded by islands that are very attractive to the tourists due to mild weather. Moreover an FPGP can have access to the North Africa's countries that seems to be in high development the last years. Combining the above facts the Mediterranean Sea is the most attractive area for operation of emergency floating production plant.

Although, a project design cannot be based on an emergency market, different scenarios of business case operation are considered. The first scenario is to establish the plant on Malta. The second scenario is examining the feasibility of operation of the plant in Cyprus. The third and last scenario considers the practicability of placing the plant on Crete.

9.2.1 Malta

Malta is situated in the middle of the Mediterranean Sea, half way between Gibraltar and Alexandria, and Sicily and North Africa. The population of Malta is around 420,000 residents as measured in 2012 and the average tourist guest are measure to 12 million all over the year, while most of them visit the island in the summer period.

Malta is covering all the energy requirements from 2 main power stations. The first station produce 304 MW using gas turbines in combined cycles while burning distillate fuels. The second station use 9 units of open cycle gas turbines and produce totally 267 MW. It is obvious that a failure in one of the power station may cause lots of problems on the island. The average tariff for the electricity is 0.170€/kWh.

9.2.3 Cyprus

The third largest Mediterranean island after Sicily and Sardinia is Cyprus. Cyprus is located in the East Mediterranean Basin, 75 kilometers south of Turkey. The population of Cyprus is around 1.1 million residents as measured in 2012 while the tourist arrivals reach 2.4 million per year. Most of the tourist prefers the period of April to September.

Cyprus is equipped with 3 main power station that cover the electricity demand of the island. The main power production plant is found on Vasilikos and is accomplished by steam units, dual fuel engines and a gas turbine. The total power production of the plant is 868MW. Another power station if placed in Dhekelia, and produces 460 MW power using steam turbines. One more power station used generally for peak load is positioned in Moni and can produce 270 MW. The power stations are enough to cover

the whole island demand as well as the peak loads. Even though an accident on summer of 2013 proved that many problems could be caused if a power plant fail to operate. The need of additional power plants does not seem to be required, but an emergency power plant may give solution to failures of existing power plants.

9.2.4 Crete

Crete is the largest island in Greece and the fifth largest in the Mediterranean Sea. Its geographical position is determined between Africa, Europe and Asia. The climate of Crete is mild and its population is around 630,000 residents as measured in 2011 while in summer this value is tripled due to tourists.

Measurements have proved that the annual rise on the electricity demand approaching 7% during the last decade. As most Aegean islands, Crete is not connecting to the mainland grid and thus relies on diesel generation to fulfill its electricity demand. Three main oil fired thermal units produce a nominal capacity of 742 Mw in total. The following graph represents the mean hourly load demand variation all around the year.

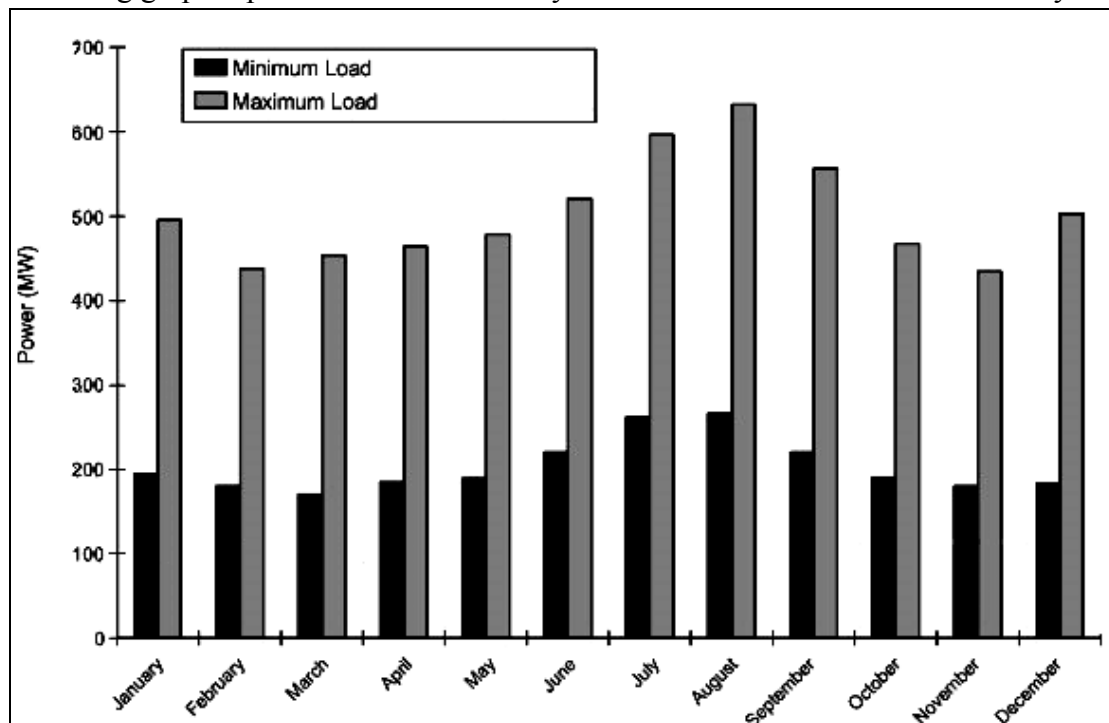


Figure 8 Monthly Variation Load Demand for Crete Island

Moreover, a load demand variation range for daily basis is presented on the next graph.

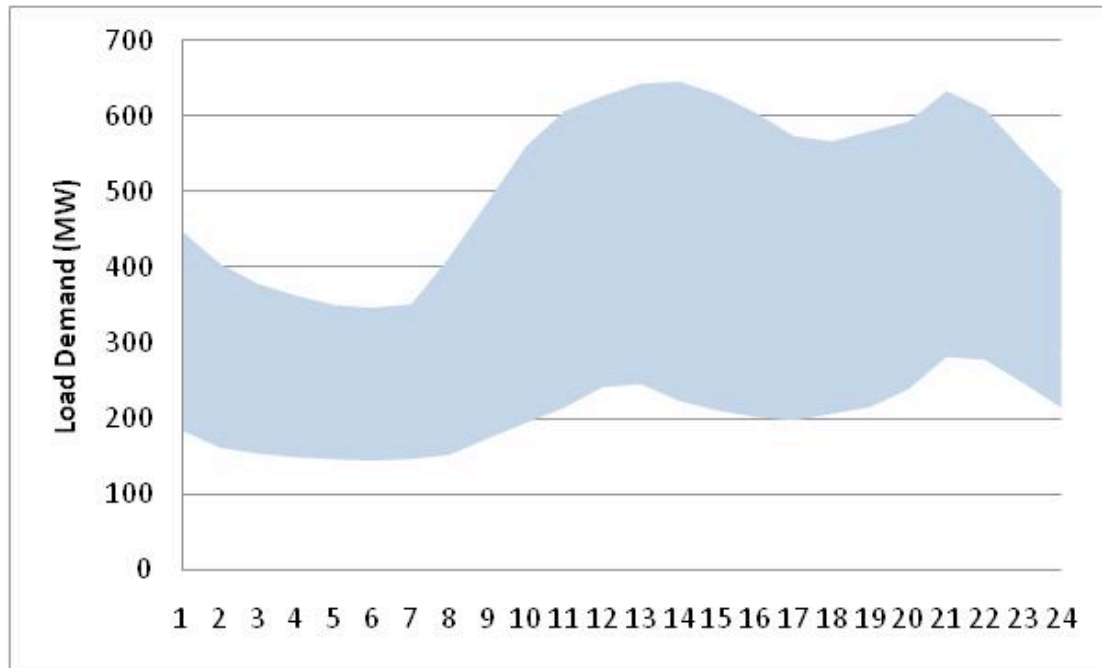


Figure 9 24-hours Load Demand Variation Range for Crete island

The forecast for increasing number of tourist as well as residents on Crete shows that the demand for electricity will be further increased in the future. Based on that several researches have been established for renewable technologies to cover the additional energy demand and the cost of them are presented on the following table. (REGION OF CRETE ENERGY AGENCY)

Description	Energy production (GWh/y)	Cost of the plant (millions €)
Concentrated solar Thermal power plant 38MW	71.1	141
Large Wind with interconnection - 1077MW	2830	2460
Wind - hydro pumped storage: 90MW wind - 75MW hydro	275.3	345
Biomass 8 MW 56.1 24	56.1	24
3000x10kW PVs on roofs - 30MW	45	57
100x80kW PVs on rural land - 8MW	12.8	11.2

9.3 Selected trading area

Considering the above table and the requirement for new project ideas of “European Islands Network on Energy & Environment” the business case of the project will be focused on the island of Crete. The tariff of energy in Crete is found to be 0,12-0,14 € / kWh, consequently the project should be competitive on this price. It is important to stress that the FPGP is an emergency vessel and hence the tariff is not a fundamental part of this design project. However, this analysis was still required to yield a suitable value for power generation and system capability.

10 CONVERSION OR NEW BUILD

One of the primary issues of the project was to explore the possibility of designing the FPGP through a conversion form an existing LNG tanker. This makes the design quicker, more efficient and cost effective, especially considering the restricted time frame. The LNG tanker selected was the British Sapphire. It is one of the larger gas tankers in the fleet and is also a relatively recent build, which makes it fit for purpose. The table below provides the main parameters of the vessel.

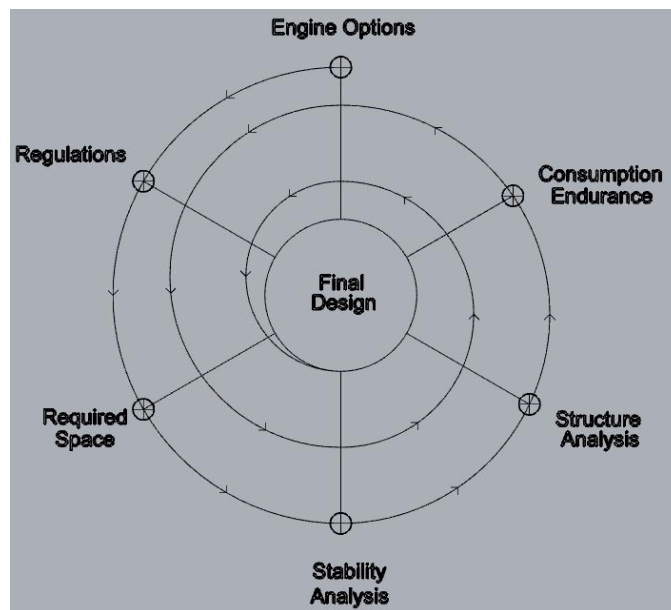
Year built	2008
Length	288.4m
Breadth	44.2m
Deadweight	84,455t
Gas containment system	Membrane type
Diesel generator engines	2 x dual fuel, 11.4MW MCR 2 x dual fuel, 8.55MW MCR

The objective is to identify possible areas for the main conversion equipment, that is the power generation and vaporization machinery. After investigation into the electricity demand of the selected region, it was deduced that the installation would need to provide between 100MW - 300MW of energy. With this in mind, it was decided that conversion is indeed a feasible and viable option, but analysis is required to overcome the issues mentioned in chapter 8.

11 LATEST UPDATES & NEXT STEPS

The critical literature review has been finalized and this allowed for the extraction of key issues associated with the project. An in-depth study of the possible solutions to the issues has begun and is required for the remaining topics. Currently, a study is underway to determine a specific power output that the project would be based on. The aim is obtain as high a power possible within the 100MW – 300MW range, that the vessel can sustain and that is within the required regulations. In order to achieve this power value, a design spiral approach was taken, which includes the following steps:

1. Investigate the maritime market to deduce the different engines and regasification equipment available to meet the requirements of the FPGP.
2. Examine the relevant regulations to understand what is required when converting an LNG tanker and where the additional equipment can be placed on-board.
3. Assess the layout of the vessel to extract different options for machinery positioning.
4. Conduct a stability and structural analysis based on each of the above scenarios to determine whether the vessel can withstand the additional weight.



The above steps were carried out through research and through the application of software programs that are suited for the above requirements, as can be seen in the appendix of this report.

Once the majority of the solutions have been settled, these can then be amalgamated together in the preliminary design. Taking into consideration the time constraints of the project, it will then be necessary to focus on a selection of critical issues for a more detailed design. These are departments that form the skeleton of the FPGP, namely the containment and vaporization of LNG, and the generation and

transmission of electric power. The end of the project plan is dedicated to the delivery of outputs. This includes compiling the project report and highlighting the key aspects of the design work in the final presentation. Below is a detailed plan of the necessary work during the final semester:

11.1 Week 1 (currently underway)

1. Emission regulations
2. Ownership, customer
3. Comparison of 100MW/300MW vessel
4. Prepare basis design study

11.2 Week 2 (currently underway)

1. Power production
 - a. Engines, specifications, position in vessel
 - b. Power output, consumptions
 - c. Power range, peaks, troughs
 - d. Possible hazards, issues and risks affecting vessel and surrounding compartments – vibrations, stability, methane slip, spark ignition, exhaust gases, maintenance
 - e. Engine performance under lower loads, efficiency drops, methane slip change
 - f. Alternatives considered
2. Regasification
 - a. Capacity
 - b. Size
 - c. Specifications, requirements
 - d. Alternatives
 - e. Possible issues, hazards, risks
 - f. Position
 - g. Maintenance

11.3 Weeks 2 – 5 (currently underway)

1. Power transmission
 - a. Concept, how it will be done
 - b. Equipment needed, converters, transformers, cables
 - c. Cable sizes
 - d. Cable strength, stresses from elements
 - e. How output is received at shore, how it will be converted
 - f. Distance required to shore
 - g. Maintenance
 - h. Possible issues, hazards, risks

2. Structural analysis
 - a. Effects of conversion on structure
 - b. Stability with new equipment
 - c. Safety margins, limits of additional equipment & machinery

11.4 Weeks 6 – 8

1. Mooring or dynamic positioning
 - a. How vessel will be moored
 - b. Advantages and disadvantages of each
 - c. Vessel must be as independent as possible
2. Towing or self propelled
 - a. Comparison of the two
3. Maintenance
 - a. Is it an issues
 - b. Will the vessel drydock
 - c. If no drydock, what measures must be taken to keep it in good condition

11.5 Weeks 9 – 12

1. Delivery of outputs
 - a. Final report write-up
 - b. Presentation and preparation for viva

12 REFERENCES

- ¹http://www.dnv.com/industry/maritime/servicessolutions/maritime_environment/co2/
- ²<http://www.lng24.com/en/about-lng/advantages-of-lng/>
- ³<http://www.epa.gov/climatechange/ghgemissions/sources/electricity.html>
- ⁴<http://www.api.org/~media/Files/EHS/climate-change/API-LNG-GHG-Emissions-Guidelines-Pilot-Draft-21JUL2013.pdf>
- ⁵<http://www.epa.gov/climatechange/ghgemissions/global.html#one>
- ⁶<http://www.epa.gov/climatechange/ghgemissions/global.html>
- ⁷<http://www.lngfacts.org/about-lng/environment/>
- ⁸<http://www.iea.org/publications/freepublications/publication/English.pdf>
- ⁹<http://world-nuclear.org/info/Current-and-Future-Generation/World-Energy-Needs-and-Nuclear-Power/#.UmOmY9Jwo4Q>
- ¹⁰<http://theenergycollective.com/lindsay-wilson/279126/average-electricity-prices-around-world-kwh>

13 APPENDICES

13.1 Emission regulations for FPGP

Below is a summary of the emission regulations that the FPGP will have to comply with, both in the case of shore based and maritime regulatory authorities.

Due to the existing strict restrictions for the ship emissions, alternative fuels such as natural gas become more popular. Leading to natural gas used more often as a prime mover in the shipping industry for the sake of completion to the existing regulations. Moreover, it should be mentioned that natural gas is also used since the 19th century for electricity production; nowadays, natural gas has become one of the major sources for electricity generation with the use of gas or steam turbines or dual fuel engines. The LNG combustion even though it is considered to be greener than the HFO, it still has minor environmental impacts; such as the production of nitrogen oxides and carbon dioxides. As stated before, the present project deals with the electricity production on a mobile ship hull structure. Thus, the regulations that the vessel has to comply are investigated in the present section. The existing and future emission regulations will be investigated from two viewpoints based on the operation of the vessel: (a) as a land based power plants and; (b) as the offshore power plant.

(a) Land based power plants

The base case of the project is the operation of the vessel in the Mediterranean region; since, this region includes 25 countries and most of them have their own legislations regarding their power plants, only the European Commission rules are taken into account. The European Commission has entered into force the Directive 2001/80/EC with sets limitations on the emission of certain pollutants into the air and it is referring only to large power plants – greater than 50 MW; this document is known as the LCP Directive. The LCP Directive contains three different provisions referring to power plants according to their date of licensed. However, only the first provision refers to the present project. The first provision states that plants licensed after 26 November 2002 have to comply with emission limit values for SO₂, NO_x and dust fixed in part B of the Annexes III to VII. In the following table a summary of the available limits are illustrated.

Emission limit values for SO₂ – Limit values (mg/Nm³)	
<i>For Gaseous fuels (O₂ content 3%)</i>	
Gaseous fuels in general	35
Liquefied gas	5
Low calorific gases from coke oven	400
Low calorific gases from blast furnace	200
Emission limit values for NO_x (measured as NO₂) – Limit values (mg/Nm³)	
<i>For Gaseous fuels (O₂ content 3%)</i>	
50 to 300 MWth	150
> 300 MWth	200
<i>For Gas Turbines > 50 MWth</i>	
Natural gas	50
Gaseous fuels	120

(b) Offshore power plants

Limits in the air pollution in the global maritime sector have been adopted by the International Maritime Organization (IMO). IMO with the use of the MARPOL Annex VI sets limits on the SO_x and NO_x emissions by the vessels. To begin with the SO_x limits, from the beginning of 2012 the global sulphur cap was reduced by 1%, to 3.5% sulphur content; and will reduce eventually down to 0.5% by the beginning of 2020 with more strict limitations in the Emission Control Areas (ECAs). As far as the NO_x emissions are concerned, they were regulated by three different levels of Tiers based on the date. Tier II represents approximately a reduction of 20% from Tier I; and Tier III a reduction of 80% from Tier I. By applying these limits, scientists expect significant beneficial impacts on the atmospheric environment and human health to be achieved.

However, since the vessel will operate mainly in the Mediterranean area which covers 16 countries of the EU; the stricter limitations provided by EU are investigated. Thus, apart from the global limitations, the European Union took further action not only to reduce emissions but also to resolve the environmental impacts such as the acidification and eutrophication and associated losses in biodiversity. Consequently, the Directive 1999/32/EC was adopted by the European Commission; which establishes limits on the maximum sulphur content of gas oil, heavy fuel oil in land-based applications and as well in marine fuels. These regulations include also fuel-specific requirements for ships calling at EU ports. At this point it should be mentioned that the Directive does not contain any provisions in order to regulate ship emissions of NO_x and PM. Moreover, in 2010 the European Commission decided to adopt the criteria at which the LNG carriers could be consider as an alternative the use of low sulphur marine fuels, with the use of Commission Decision 2010/769/EU. More specific, paragraph 4 states that: “*Liquefied natural gas (LNG) Carriers are frequently fitted with dual fuel boilers, using boil-off gas and heavy fuel oil for propulsion and cargo-related operations.*”

In order to meet the requirements of the Directive most LNG Carriers calling at EU ports could use emission abatement technology employing a mixture of marine fuels and boil-off gas to produce sulphur emissions equal to or lower than 0.1 % sulphur fuel emissions” and paragraph 5: “In the long-term, boil-off gas could be used as a primary fuel at berth, producing lower sulphur emissions than those which would be achieved through the limits on sulphur in fuel specified in the Directive.”

To conclude with, the European Commission allows the LNG carriers to burn the boil off gas when at berth instead of using 0.1 % sulphur fuel and does not provide any specific regulations regarding the emissions of natural gas since it is considered one of the greenest forms of energy. By comparing the two viewpoint it can be stated that the offshore, the project can be considered as an offshore vessel which will be at berth for long-term and to comply mainly with the Commission Decision 2010/769/EU.

Summary of emission regulations that the FPGP will comply with			
Emission	Limit	Remarks	Reference
SO _x	$S_F (\%) M_F \leq 0.1\% M_{F0.1\%}$	S_F(%): percentage of sulphur content per unit of mass of the marine fuel used, M_F: mass of the marine fuel consumed while the ship is at berth in kg, M_{F0.1%}: equivalent mass in kg of a fuel with a sulphur content ≤ 0,1 %. This factor shall be calculated according to the next formula	2010/769/EU
	$M_{F0.1\%} = \frac{(M_{BOG} E_{BOG} + M_F E_F)}{E_{F0.1\%}}$	M_{BOG}: mass of the boil-off gas consumed at berth in kg, E_{BOG}: energy value of the boil-off gas used in MJ/kg, M_F: mass of the marine fuel consumed at berth in kg, E_F: energy value of the marine fuel used in MJ/kg.	2010/769/EU

		$E_{F0.1\%}$: energy value of a marine fuel with a sulphur content $\leq 0.1\%$ in MJ/kg	
	However, it should be mentioned that with the use of LNG the SO _x emissions are reduced or eliminated.		
NO_x	Based on the IMO, NO _x emissions are reduced by around 80-90% comparing with MDO with the use of LNG.		
CO_x	Based on the IMO, the CO _x emissions are reduced by 30% due to the unburned methane (methane slip). However, no specific regulations are available.		
Particulates Matters	Based on the IMO, with the use of LNG the PMs are close to zero; thus, no additional regulations are applied.		

13.2 Ownership and customer allocation

Below is a summary of the ownership possibilities for the FPGP, based on the structure of similar offshore structures and power plants.

An important sector, where further attention must be given, is the matter of the ownership of the floating power generating plant and the customer area where this particular project is directing. There are several cases where similar power plant projects are owned either by a government or by a private company. In order to conclude which solution is the most suitable for the FPGP, the ownership of the largest and biggest power plants (PP) of different setups throughout the world, such as gas PP, coal PP, nuclear PP and offshore wind farms will be investigated. The research will be based on different countries which require and generate huge amount of electricity; therefore the installation and operation of power plants is a necessity. Countries, such as United Kingdom, China, Japan, Russia, and United States of America will be taken into consideration on this matter.

a) Natural Gas Power Plants

As far as the United Kingdom is concerned, the capacity of gas power plants is not significantly large; however it can be said that one of the largest gas power stations is the Seabank Power Station of 1145MW installed capacity in Bristol, England, and is operating under the Scottish and Southern Energy company; which is a public company and Cheung Kong Infrastructure Holding Limited, which is a public limited company. To continue with China, one of the main LNG power plants is located in Fujian with 1560MW installed capacity and the operator is the Fujian Energy Group Company; a private company; whilst another LNG PP with total capacity of 1560MW as well, is operated by CNOOC Gas & Power Ltd; another private company. In Russia the largest gas-fired power station in the world is located in Surgut with total capacity of 5600MW owned by E.ON Russia, a Russian power generation company. Also, the second largest PP in Russia is located in Kirishi with installed capacity of

2600MW where the owner is the OGK-6, another Russian power generation company. To continue with Japan, the second largest gas-fired power station is located in Futtsu, Chiba with capacity of 5000MW and is owned by Tepco, a public Japanese electric utility. At last but not least, in United States the largest natural gas-fired electrical and steam co-generation plant is located in Midland, Michigan with 1560MW installed capacity and the owner is Midland Cogeneration Venture Limited Partnership.

Generally, as it can be obtained is that in gas power plants section the largest station are owned by private companies; however it must be said that there are station which are owned and operated by public companies and governments.

b) Nuclear Power Plants

To move on to nuclear power plants and especially in United Kingdom, in Lancashire a 2400MW capacity station is located operated by EDF Energy, an integrated energy company. Moreover, in China one of the largest nuclear power stations is operated by a private energy company named Qinshan, where 4000MW of installed power can be found. The largest nuclear power station in the world is located in Kashiwazaki, Japan, with installed capacity of 8000MW and is owned and operated by Tepco. In Russia, a 4000MW station is found in Balakovo, where is operated by Rosenergoatom, a public energy utility company. At last in USA, one of the largest stations is located in Arizona with 3875MW capacity which is owned by many energy companies and is operated by Arizona Public Service.

At this stage it has to be mentioned that the first floating nuclear power plant was constructed in Russia and is owned and operated by Rosatom Company, a Russian public energy company. The vessel contains a pair of small nuclear reactor capable of generating up to 70MW of electricity. On the other hand, there are many nuclear-powered submarines which are owned by Russian or U.S. navy which must be taken into consideration as well.

c) Coal Power Plants

To carry on to coal power plants in United Kingdom, a large coal-fired station in Drax of England can be found. The generating capacity equals to 4000MW and the plant is owned nowadays and operated by Drax Power Limited, a private energy company. In China, the second largest coal-fired power station in the world is located with total capacity of 6600MW and is owned by Tuoketuo Power Company; a merger of three separate private companies. In Japan, the largest coal-fired power station is a 4100MW which is owned by Chubu Electric Power Company; a private power generation company. In Ryazan of Russia a large coal-fired station of 3100MW installed capacity is located which is owned by OGK-6 company. Last but not least, a 3500MW of generating capacity power plant can be found in Georgia of United States which is owned by Georgia Power; a public electric utility.

According to the above paragraph, it can be observed that as far as the coal power plants are concerned, the share of the ownership is divided. There are many power stations which are owned and operated by public electric companies; whilst in other cases private companies take charge of the plants.

d) Offshore Wind Farms

To conclude with, the sector of offshore wind farms is similar to FPGP case, where offshore power plants generate power which is transmitted ashore; therefore the ownership shares of these wind farms is crucial. The world's largest wind farm, London Array is installed close to Essex in England with generating capacity of the turbines equal to 630MW. The ownership is shared between three companies; DONG Energy; an energy utility owned by Danish Government, E.ON UK; a public limited English company, and Masdar company; a government owned company of United Arab Emirates. The second largest wind farm, Geater Gabbard, is located near the coast of Suffolk in England and its installed capacity is 504MW; while is owned by Scottish and Southern Energy Company and RWE Npower company; a public limited company.

Therefore; as it is concluded, regarding the offshore wind farms the ownership is shared between governments and public companies. At this point since a general view of the shareholders in different power plant areas is examined, it can be said that the best scenario for a FPGP is to be owned by a merger between a government and public companies, like the case of offshore wind farms. Due to the fact that the main purpose of the operation of FPGP is an emergency relief, a country which faces often and various shutdowns or will need decommissions of the existing power plants, the selection and the purchasing of the FPGP can be a wise choice. Combining this fact; with the ownership of private companies, the customer area can be increased as well as the increased capital cost is split significantly.

To conclude with, as far as the customers area is concerned, since FPGP is primarily operating as an emergency supply vessel, the customers are considered countries or regions which might face electricity supply problems or shutdowns. On the other hand, related to the secondary service of the FPGP; which can operate as a FSRU vessel during its downtime, is able to operate in a trading area where the demand of gas is increasing rapidly and where re-gasification stations are not available.

13.3 Regasification equipment

a) Background

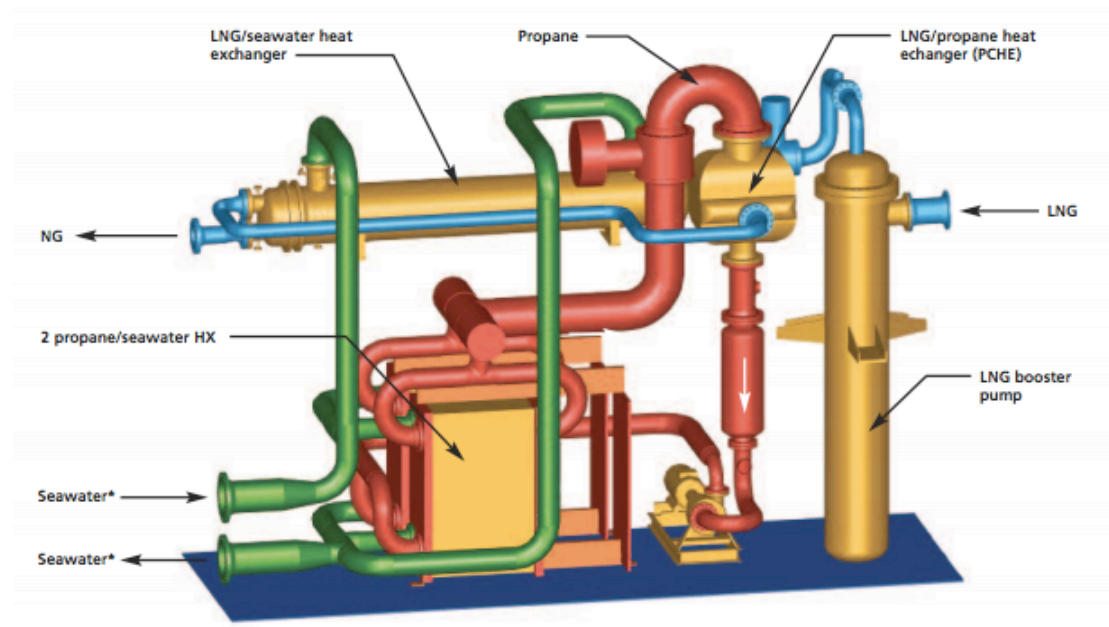
The regasification system is the machinery required to vaporize the LNG held in the storage tanks. This process is fundamental to the operation of the FPGP and is required to obtain Natural Gas (NG), which will be transferred to the engines for electric power generation. There are 2 main varieties of regasification systems on the maritime market at present and the basic principal is the same in both cases. In general, the vaporization system handles 3 different mediums – the LNG/NG, an intermediate medium that is used to heat the LNG, and a medium that is used to raise the temperature of the intermediate substance. This exchange of heat is done through a combination of heat exchangers, piping and pumps, all of which are combined into a single system, the output of which is natural gas, exiting from the export manifold.

As mentioned above, there are 2 main types of regasification systems, the steam based type, that uses a water glycol mixture as an intermediate heating medium, and a seawater based system, which uses propane as the intermediate medium. These 2 systems are summarized in the table below:

Steam based	Seawater based
LNG is pumped through a shell and tube heat exchanger and is heated by a glycol water mixture, which in turn is heated by steam in a compact heat exchanger. Natural gas is then passed through the export manifold.	LNG is heated by propane from -160 to -10 degrees Celsius in a compact printed circuit heat exchanger. It then passes through a shell and tube heat exchanger that further heats the LNG to 6 degrees Celsius.
These systems are generally more compact than the seawater based equipment, since the heat exchangers are smaller due to the use of a high temperature medium (steam). On the other hand, they are less efficient and more costly, since around 2% of the LNG on board must be burned in the boilers to produce steam for the vaporization process.	The seawater is also used to raise the temperature of the propane in titanium semi-weld plate heat exchangers. The propane, which was used to heat the LNG at a temperature of around 0 °C and a pressure of 4.7 bar (gas form) exits at a temperature of around -5 °C (liquid form) after heating the LNG. It is therefore necessary to re-heat the propane back to its original form, through heat exchange with seawater.
The seawater based systems, although not as compact, still have manageable footprints and are more efficient, without the requirement for steam production.	The use of an intermediate medium is crucial as the seawater might freeze if it is in direct contact with LNG, which in turn could cause severe damage to the equipment.

b) Chosen system

Taking into account the above information, a seawater system was chosen for the FPGP, due to the higher efficiency and lower expenses. A diagram of the equipment is shown below:



The maximum natural gas required for electric power generation on board is approximately 1,500 tonnes per day. The above system is able to generate up to 5,000 tonnes per day. The complete system weighs 70 tonnes, with a footprint of 10.5m long by 6.1m wide by 8.0m high, and outputs NG at 6°C, with a pressure of up to 103 bar.

13.4 Power generation equipment

The power production is the most basic function of the FPGP. The selection of the power plant of a FPGP is probably the most important part of the design. Considering a conversion of an LNG carrier to a FPGP one of the main parameters of the design is already fixed, the storage capacity of the tanks. Although due to the limited space for the location of the engines even the capacity of the tanks may be reduced. The storage capacity is straight forward influenced to the autonomy of the vessel involving as well the consumption of the engines. Moreover the key factors that should be examined for the final selection of the power plant of the vessel can be categorized as follows:

- Specific Fuel/Gas Consumption
- Range of Operation / Instant Acceleration
- Necessary Space
- Weight
- Reliability
- Maintainability

The necessary space and the weight are considered to be the most critical parameters considering the conversion of an LNG carrier. Several scenarios of engine combination will be examined for the initial step and the establishment onboard should be verified by the stability analysis as well as the detailed description of their location onboard the vessel.

a) Type of Engine

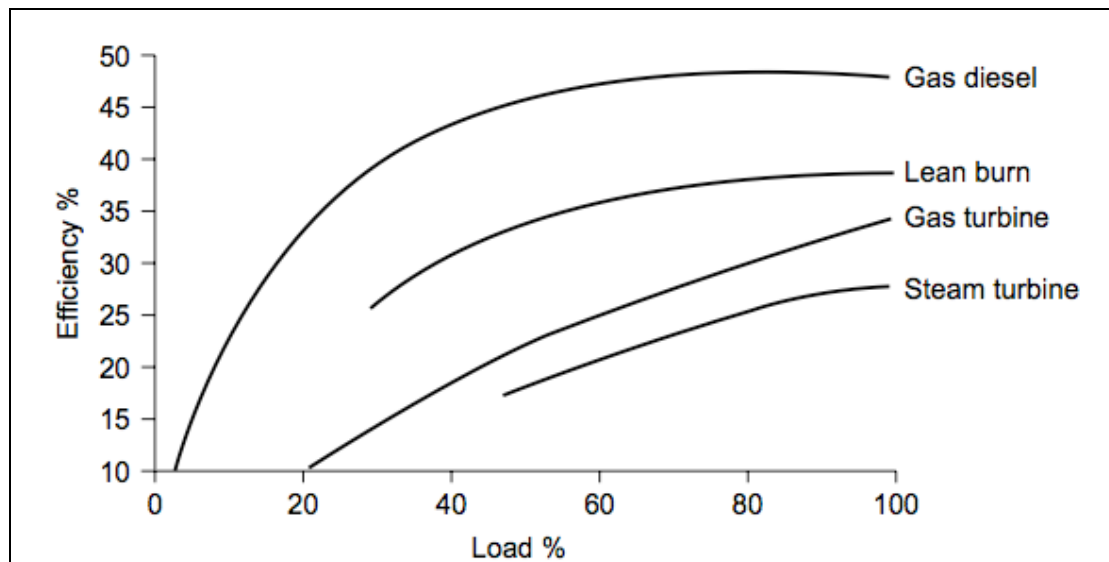
As it is been already clear the engines will be using Natural Gas as fuel and this is another parameter that is already been fixed for the selection. Although the existence on the market of engines that can operate in gas mode and fuel mode, gives even more flexibility on the engine selection. There are 3 different options of engines that will be examined for electricity generation.

The first option is considered to be the Gas Turbines, which can be further extended to combined cycle using a steam turbine in a waste heat recovery system in order to capture more energy from the high temperature exhaust gases and produce electricity as well. Unfortunately Gas turbine are characterized by low thermal efficiency and highly influenced by the temperature of the inlet temperature. In order to achieve the highest efficiency of gas turbines the operational profile of the load must be steady and moreover on the maximum output capacity. Combination with waste heat recovery using steam turbine for electric production may allow the gas turbines to reach the 48% thermal efficiency. There are several output gas turbines on the market and the maximum that have been constructed by now is a 340MW power by Siemens. Although such sizes are enormous for a floating establishment other models can be used for the FPGP.

Another option for generator set burning Natural Gas is the spark-ignition lean-burn gas engines. This type of engine is based on the well-known Otto cycle with mixture compression and external ignition. The gas is supplied to the cylinder in a variety of pressures depending on the load of the engine, while the maximum pressure of the gas may reach 4.5 bars. The maximum power output gas engine that can be found on market is the 18V50SG engine from Wartsila that proves an output of 18MW.

The third type of engine that is examined for electrical power generation is the dual fuel engine. Dual fuel four stroke engines can be run in either gas mode or liquid-fuelled mode. In gas mode the engine is operating according to the lean-burn Otto principle, but instead of spark plug for ignition the lean air-gas mixture is ignited by a small amount of diesel fuel. In diesel mode, the engine operates according to the normal diesel concept using traditional jerk pump fuel injection. The gas pressure in the engine is less than 4 bar at full load. The main advantage of dual fuel engines compared to spark ignited gas engines is their ability to operate in diesel or even on HFO that gives the operator the reliability of burning cheaper fuel when no restrictions are presented and moreover due to the fact that storage of LNG requires 3 times more space than diesel oil or HFO. The largest Dual Fuel engine was officially launched by MAN and can reach the power of 18MW.

Following to the description of the operation of the three different type of engines a comparison graph of the thermal efficiency for the range of load of the engines is illustrated below:



Resulting a market research the engines that will be examined for the power plant are summarized on the following tables:

Gas Fired Engines

		100%			Dimensions				
Manufacturer	Model	Power	Heat Rate	Consumption	Length	Height	Width	Weight	Efficiency
	-	kW	kJ/kWh	g/kWh	m	m	m	ton	
Watsila	9L34SG	4340	7843	166.37	10.4	3.84	2.78	77	45.9%
	16V34SG	7740	7819	165.86	11.3	4.24	3.3	120	46.0%
	20V34SG	9730	7779	165.02	12.89	4.44	3.3	130	46.3%
	18V50SG	18320	7411	157.21	18.8	6.34	5.33	360	48.6%
Rolls Royce	B35:40V16AG	7700	8065	171.08	11.507	5.58	3.3	105	44.6%
MAN	20V35/44G	10335	7618	161.60	13.97	4.54	3.845	144	47.3%

Dual Fuel Engines

		100%			Dimensions				
Manufacturer	Model	Power	Heat Rate	Consumption	Length	Height	Width	Weight	Efficiency
	-	kW	kJ/kWh	g/kWh	m	m	m	ton	
Watsila	20V34DF	8730	8031	170.36	12.89	4.4	3.3	130	44.8%
	18V50DF	16638	7489	158.86	18.78	6.02	4.09	335	48.1%
MAN	18V51/60DF	18000	7260	154.01	13.64	5.52	4.7	265	49.6%

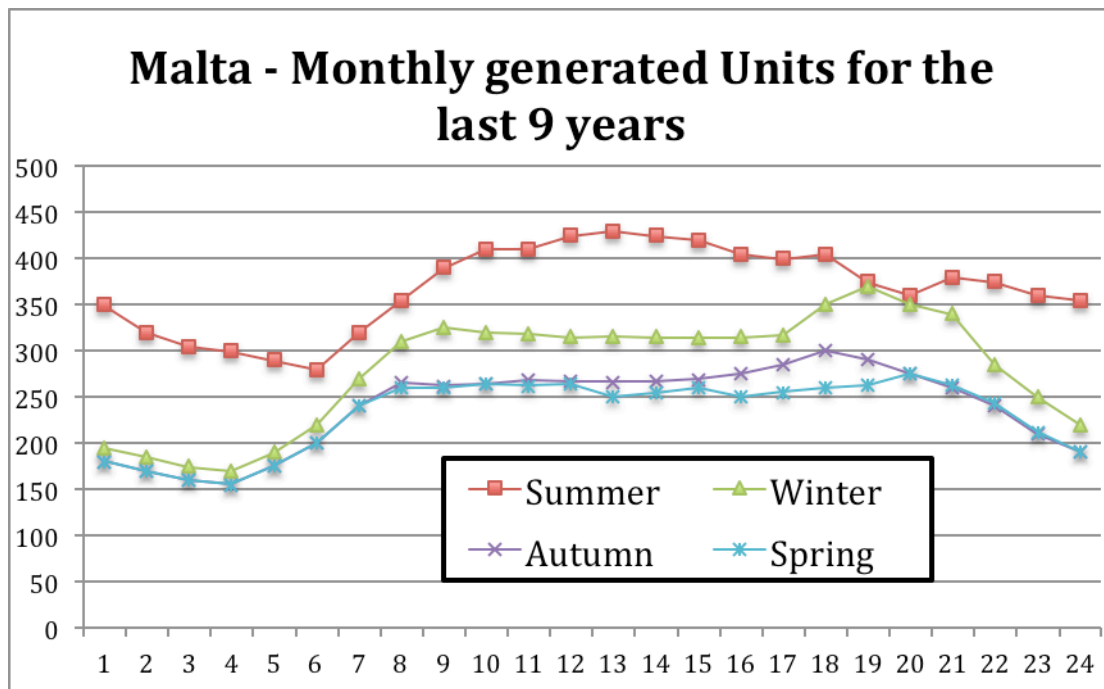
*fuel consumption must be added 1g/kWh

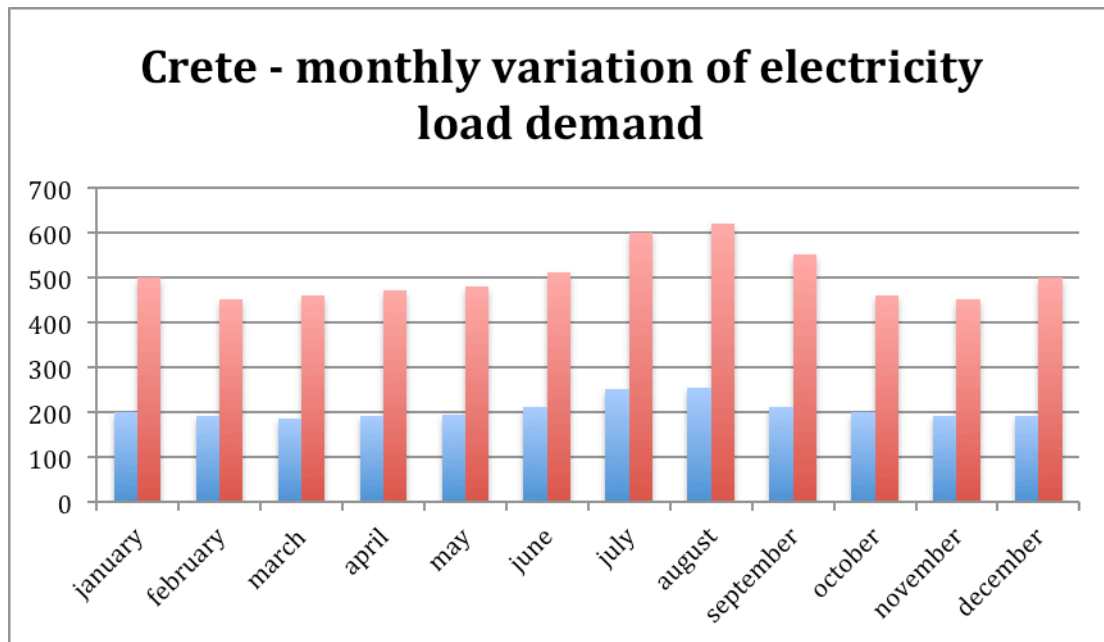
Gas Turbines

		100%			Dimensions				
Manufacturer	Model	Power	Heat Rate	Consumption	Length	Height	Width	Weight	Efficiency
	-	kW	kJ/kWh	g/kWh	m	m	m	ton	
Rolls Royce	MT30	33000	9758	207	16.15	4.52	3	105	36.9%
	WR-21	20000	9428	200	14	4.5	3	91	38.2%
General Electric	LM500	4200	12241	259.67	7.14	2.39	2.39	27	29.4%
	LM2500plus	29000	9343	198.19	14.38	3.99	3.12	95	38.5%
	LM6000	42800	8900	188.80	16.5	4.9	4.36	151	40.4%
Solar	TITAN130	15000	10230	217.01	14	3.3	3.2	86	35.2%
	TITAN250	21745	9260	196.43	18.1	3.6	3.4	129	38.9%
Siemens	SGT400	12900	10355	219.66	14.5	3.9	2.85	90	34.8%
	SGT500	19100	10664	226.21	21.3	5.1	4	98	33.8%
	SGT600	24700	10533	223.44	18.7	7.8	4.1	120	34.2%
	SGT800	47500	9557	202.73	24.5	3.7	4.7	168	37.7%
Combined Cycle (2+1)		135000	9900	210.01					36.4%

Existing Onboard									
		100%			Dimensions				
Manufacturer	Model	Power	Heat Rate	Consumption	Length	Height	Width	Weight	Efficiency
	-	kW	kJ/kWh	g/kWh	m	m	m	ton	
Watsila	12V50DF	11400	7150	151.67	10.465	5.5	3.8	175	50.3%
	12V50DF	11400	7150	151.67	10.465	5.5	3.8	175	50.3%
	9L50DF	8550	7150	151.67	10.8	4.5	3.1	148	50.3%
	9L50DF	8550	7150	151.67	10.8	4.5	3.1	148	50.3%
		39900							

From the data collected by various potential customers it is found that the domestic electricity consumption varies throughout the day. Some typical examples of possible customers in the Mediterranean Sea are presented on the following graphs.





As it can be observed in the midday and midnight there is an almost steady need of electric power, while there are also some peak loads for a small time throughout the day. In order a power plant to cover the different loads while operating in the minimum possible consumption of the engines and without damaging the engines, combination of different power output engines can be used. Moreover as long as there is a minimum load requirement that remain steady, the advantage of the gas turbine to produce steady power on high efficiency can be used at that point. Considering the above, a minimum power output can be covered by an arrangement of 2 Gas Turbines in a combined cycle with a steam turbine producing steady power continuously. Moreover set of dual fuel engines and sets of gas-ignited engines are examined on the scenarios. Apart from the power output combination the most efficient cooling system should be examined so as to have pair of engines combined on the same cooling system. Different scenarios of 200MWe and 300MWe have been examined and presented below:

Scenario 1 - 1 Combined Cycle - 8 Dual Fuel Engines								
		Power	Heat Rate	Consumption	Length	Height	Width	Weight
		kW	kJ/kWh	g/kWh	m	m	m	ton
Gas Turbine	SGT600	24700	10533	223.4	18.7	7.8	4.1	120
	SGT600	24700	10533	223.4	18.7	7.8	4.1	120
Steam Turbine		20995						60
Dual Fuel	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
Existing	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	Total:	211767				Added weight		2160

Scenario 2 - 1 Combined Cycle - 4 Dual Fuel Engines								
		Power	Heat Rate	Consumption	Length	Height	Width	Weight
		kW	kJ/kWh	g/kWh	m	m	m	ton
Gas Turbine	SGT800	47500	9557	202.7	24.5	3.7	4.7	168
	SGT800	47500	9557	202.7	24.5	3.7	4.7	168
Steam Turbine		40375						80
Dual Fuel	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
Existing	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	Total:	210195				Added weight		936

Scenario 3 – 1 Combined Cycle - 6 Gas Ignited Engines								
		Power	Heat Rate	Consumption	Length	Height	Width	Weight
		kW	kJ/kWh	g/kWh	m	m	m	ton
Gas Engines	18V50SG	18320	7411	157.2092234	18.8	6.34	5.33	360
	18V50SG	18320	7411	157.2092234	18.8	6.34	5.33	360
	18V50SG	18320	7411	157.2092234	18.8	6.34	5.33	360
	18V50SG	18320	7411	157.2092234	18.8	6.34	5.33	360
	18V50SG	18320	7411	157.2092234	18.8	6.34	5.33	360
	18V50SG	18320	7411	157.2092234	18.8	6.34	5.33	360
Gas Turbines	SGT600	24700	10533	223.4	18.7	7.8	4.1	120
	SGT600	24700	10533	223.4	18.7	7.8	4.1	120
Steam Turbine		20995						60
Existing	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	Total:	220215				Added weight		2460

Scenario 4 - 1 Combined Cycle - 10 Dual Fuel Engines								
		Power	Heat Rate	Consumption	Length	Height	Width	Weight
		kW	kJ/kWh	g/kWh	m	m	m	ton
Gas Turbine	SGT800	47500	9557	202.7	24.5	3.7	4.7	168
	SGT800	47500	9557	202.7	24.5	3.7	4.7	168
Steam Turbine		40375						60
Dual Fuel	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
	20V34DF	8730	8031	170.4	12.89	4.4	3.3	130
Existing	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	Total:	310023				Added weight		2926

Scenario 5 - 2 Combined Cycles - 6 Dual Fuel Engines								
		Power	Heat Rate	Consumption	Length	Height	Width	Weight
		kW	kJ/kWh	g/kWh	m	m	m	ton
Gas Turbine	SGT800	47500	9557	202.7	24.5	3.7	4.7	168
	SGT800	47500	9557	202.7	24.5	3.7	4.7	168
Steam Turbine		40375						
Gas Turbine	SGT400	12900	10355	219.7	14.5	3.9	2.85	90
	SGT400	12900	10355	219.7	14.5	3.9	2.85	90
Steam Turbine		10965						
Dual Fuel	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
	18V50DF	16638	7489	158.9	18.78	6.02	4.09	335
Existing	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	12V50DF	11400	7150	151.7	10.465	5.5	3.8	175
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	9L50DF	8550	7150	151.7	10.8	4.5	3.1	148
	Total:	311868				Added weight		2526

Verification of space – weight

All the above-suggested scenarios should be confirmed that could be positioned on board vessel taking into account the space required for the engines and the additional equipment needed (pumps, heat exchangers, etc.) as well as the stability of the vessel.

13.5 Vessel modelling

The diagram below shows a model of the basis ship to be converted, designed using the *Rhino* software package. The next step is to fit the additional topside weights, before analysing the stability of the converted ship.

