Diploma Thesis

Economic & Technical feasibility Study for the Conversion and operation of Small Scale Compressed Natural Gas Carrier

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Περίληψη

Κύριος σκοπός της τρέχουσας διπλωματικής εργασίας είναι η πρόταση ενός νέου σχεδιασμού πλοίου μεταφοράς συμπιεσμένου φυσικού αερίου, σε εμπορευματοκιβώτια, και η εκπόνησης της αντίστοιχης τεχνικο-οικονομικής μελέτης σκοπιμότητας για την κάλυψη οικιακών αναγκών σε φυσικό αέριο της Θεσσαλονίκης, το οποίο τροφοδοτείται από τερματικό στην Λεμεσό της Κύπρου.

Η μελέτη έχει θεωρηθεί στα δύο ακόλουθα σενάρια:

- ✓ Μελέτη για τον πλοιοκτήτη / διαχειριστή του οποίου το πλοίο θα μεταφέρει το συμπιεσμένο φυσικό αέριο από τον τερματικό σταθμό φόρτωσης στον τερματικό σταθμό παραλαβής.
- ✓ Μελέτη για τον ιδιοκτήτη των τερματικών σταθμών, ο οποίος επιθυμεί να ναυλώσει το πλοίου στον τύπο που έχει προταθεί όπως εξηγήθηκε παραπάνω

Κατ’ αρχήν γίνεται αναφορά στην τρέχουσα κατάσταση της αγοράς Φυσικού Αερίου παγκοσμίως και στην Ελλάδα, στις φυσικές ιδιότητες Φυσικού Αερίου, και ακολουθεί σύγκριση μεταξύ των ιδιοτήτων του υγροποιημένου φυσικού αερίου (ΥΦΑ) & του συμπιεσμένου φυσικού αερίου (ΦΑ). Επιπλέον, πραγματοποιείται σύντομη ιστορική αναδρομή στην ανάπτυξη της αγοράς ΥΦΑ και στην υπάρχουσα υποδομή διαχείρησης συμπιεσμένου ΦΑ στην Ελλάδα.

Το δεύτερο κεφάλαιο παραθέτει ανάλυση της αλυσίδας εφοδιασμού με συμπιεσμένο ΦΑ (μεταφορά, αποθήκευση & διανομή), με έμφαση στους πιθανούς κινδύνους και τα επίπεδα ασφάλειας τη διαδικασίας, και εμπεριέχει παρουσίαση των διαφόρων μεθόδων χειρισμού καθώς και των συναφών πλεονεκτημάτων και μειονεκτημάτων τους.

Το τρίτο κεφάλαιο αποτελεί καταρχήν μια συνοπτική παρουσίαση των κανονισμών κλάσεων γύρω από τα πλοία μεταφοράς συμπιεσμένου ΦΑ, και έπειτα μια παρουσίαση των βασικών υπάρχων πλοίων που μεταφέρουν σήμερα συμπιεσμένο ΦΑ. Συγκεκριμένα αναγράφονται τα βασικά τεχνικά και οικονομικά χαρακτηριστικά τους και στο τέλος του κεφαλαίου, γίνεται και η σύγκρισή τους.

Το τέταρτο κεφάλαιο αναφέρεται στις μεθοδολογικές τεχνικές οικονομικής αξιολόγησης ανάλογων επενδυτικών σχεδίων, με ειδική αναφορά στην χρηματο-οικονομική αξιολόγηση του εν θέματι έργου, τις διαθέσιμες τεχνικές και τα κριτήρια που χρησιμοποιούνται για την οικονομική αξιολόγηση της επένδυσης, την καθαρή παρούσα αξία, το εσωτερικό ποσοστό απόδοσης, το συντελεστή ανάκτησης κεφαλαίου, την περίοδο αποπληρωμής, και τον δείκτη κερδοφορίας.

Στο πέμπτο και τελευταίο κεφάλαιο, η τεχνικο-οικονομική ανάλυση παρουσιάζεται υπό μορφή διαγραμμάτων όπου και υπογραμμίζονται τα συμπεράσματα που προκύπτουν από τη σύγκριση μεταξύ των τιμών πώλησης ΦΑ από το υπό εξέταση έργο με τις τρέχουσες τιμές της αγοράς ΦΑ.

Abstract

The main purpose of this diploma thesis is to propose a innovative design for the transportation of CNG in containers, and the production of the relative techno-economical study for covering the household needs of Thessaloniki, when same is fed by terminal of Limassol in Cyprus.

- ✓ The first focusing on the main concerns of the ship-owner/manager whose vessel will transport Compressed Natural Gas from the loading terminal to the receiving terminal.
- ✓ The second focusing on the implicit interests of the terminal owner who intends to charter the CNG vessel.

In the beginning reference is made to the current state of the Natural Gas market -both globally and locally-, the Natural Gas's physical properties are described, and the properties of LNG & CNG are compared, followed by a brief narrative on the history of the development of the LNG Market and the CNG infrastructure in Greece.

The second chapter contains a brief CNG supply chain analysis (transportation, storage & distribution), elaborating on probable risks and the thereto associated risk factors & security levels in the process, and outlines the handling methods as well as the advantages, and disadvantages of CNG.

The third chapter concerns a brief description in Class Rules which are applied in CNG carrier vessels, and then a presentation for the existing concept designs of CNG transportation in sea, follows. In more detail, the main technical and economical characteristics are included and the chapter's conclusion is a comparison between them.

The fourth chapter elaborates on projects' appraisal methodologies by making specific reference to the available production engineering approaches in use, the various techniques and criteria for the economic appraisals regarding the investing in a project, such as : the Net Present Value (NPV), the Internal Rate of Return (IRR), the Capital Recovery Factor (CRF), the Payback period (PP), and the Profitability Index (PI).

The final fifth chapter includes the project's techno-economic analysis, mainly in the form of charts, and wraps up the conclusions by comparing the project's related NG consumers' end-prices with those prevailing in the current NG market.

1. Introduction

1.1. Current State of Natural Gas Market

It is almost self-evident that in the near future natural gas will become even more dominant as a means of energy supply, due to the ever-rising global socio-political demands for gradual de-carbonization (Stern, 2017). The natural gas is, today, the most sought-after fuel due to its high calorific value, reduced environmental burden, and efficient combustibility. It is being ranked as the cleanest source of energy after renewables, due to its combustion quality and its low content in pollutants. The successful natural gas exploration worldwide shows that there are undoubtedly huge reserves of natural gas available on the planet. The options for transporting gas are either by a network of land-based pipelines and / or by means of LNG tankers in the open seas.

As said, the surging global demands in greener energy supply promote the shift to natural gas which does not leave the shipping sector unaffected. The Liquefied Natural Gas (LNG) has been the focus of global shipping interest as energy transfers dominate global bulk shipping. The need to transport large quantities of natural gas between distant maritime areas has increased the market share for LNG carrying ships in recent years, and there are promising prospects for faster development in this industry. Over the past few years many new LNG vessels have been ordered by both Greek and Chinese shipowners who are leading the way in this fast-growing market segment (Spiers et al., 2019).

As regards its composition, the natural gas is a gas mixture of hydrocarbons. It is extracted from underground cavities and is considered valuable because of its ecological fuel properties. It exists in large stocks which are deemed sufficient for at least another hundred years. The largest gas reserves are found in Russia, which accounts for one-third of the total world stocks, and the Middle East; large quantities of natural gas are found in Iran, Qatar, Saudi Arabia, Nigeria, Algeria, and others (Gkonis, Psaraftis, 2009).

As regards Greece, the country is currently being supplied with gas from three (3) different sources:

a) from Russia (via Bulgaria) via gas pipelines,
b) from Algeria with liquefied petroleum tankers (on the island of Revithousa in the Gulf of Megara) and,
c) since 2007, from Azerbaijan (via Turkey) through gas pipelines.

The natural gas is a natural product found in the Earth's subterranean caverns either alone or co-existing with crude oil reserves. It is a gas whose composition varies according to its source of origin. It is lighter than air (has a specific gravity of 0.59) and odorless, but for leak detection purposes, a substance is added, which gives it a technically characteristic odor (Brenntro, Garcia, Thirion, 2013). The Gas is a mixture of gaseous hydrocarbons, consisting mainly of methane (over

85%), which is the lightest hydrocarbon. Significant amounts of ethane, propane, and butane, as well as carbon dioxide, nitrogen, hydrogen, helium, and hydrogen sulfide, are also present. The gas is very clean, free of impurities, and sulfurous ingredients (Foss, 2012).

The liquefied gas is a state of matter that, at ambient temperature and under atmospheric pressure, would be in gaseous form. Most liquefied gases are hydrocarbons with high calorific value. Because of that and the fact that they are handled in large quantities, it is necessary to take appropriate measures so as to minimize the likelihood of leakage and eliminate potential ignition sources. The most important property of liquefied gas, in relation to pumping and storage, is its vapor pressure. It is the absolute pressure exerted when the liquid is equilibrated with its steam at a given temperature.

The Liquefied Natural Gas is the natural gas that has been cooled to –160°C or 259 degrees Fahrenheit, at atmospheric pressure, a natural state in which it condenses and becomes liquid. Liquefied natural gas is natural gas which has been temporarily converted into liquid form to facilitate its storage and transportation. Liquefied natural gas is odorless as well as colorless, non-toxic, and non-corrosive.

Their liquefaction requires prior treatment of impurities such as water, nitrogen, carbon dioxide, hydrogen sulfide, and other sulfur compounds. By removing these impurities, no solid particles can form during the cooling process of the natural gas. The liquefied natural gas contains mainly methane. After this process, the gas is then concentrated to liquid at near atmospheric pressure (maximum transport pressure of about 25 kPa / 3.6 psi), cooling to about -161°C.

Finally, it should be mentioned, that the liquefied natural gas is not a compressed gaseous matter but a cold liquid which is formed by the application of refrigerants and is not stored under pressure. Liquefied natural gas achieves greater volume reduction than compressed natural gas so that the energy density of the liquefied natural gas is 2.4 times higher than that of the compressed natural gas (CNG), or 60% of that of diesel fuel (Brenntro, Garcia, Thirion, 2013).

As regards the compressed natural gas (CNG), this is being formed by compressing natural gas to less than 1% of the volume it occupies under normal atmospheric pressure. The compressed gas is stored and transported in hard containers, spherical or cylindrical, at a pressure of 200-248 bar. It is used in traditional gasoline engines which have been converted for the combustion of dual-fuel. The number of such vehicles in the world steadily increases, with CNG being regarded as the greenest, i.e. the most efficient, and the least polluting hydrocarbon fuel available. Thus, compressed natural gas is a good solution for quickly selling small quantities over short distances and suitable for transport by tankers not requiring expensive and complex installations & control equipment onboard (e.g., liquefaction and regasification installations) (Foss, 2012).

1.2. The History of LNG & CNG Development

The liquefaction of natural gas, as a scientific process, dates back in the 19th century when the chemist and physicist Michael Faraday experimented with the liquefaction of gases. Liquefied Natural Gas (LNG) proved to be a viable source of energy in 1917, when the first liquefied natural gas plant began operating in West Virginia to store local gas. Then came the creation of the first liquefaction plant built at Cleveland, Ohio, in 1941.

Eighteen years later, in January 1959, the world's first LNG tanker (Methane Pioneer) transported its first liquefied natural gas cargo from Lake Charles, Louisiana, to Canvey Island, United Kingdom. This has proved that large quantities of liquefied natural gas could be safely transported by sea to far off destinations. The ship was a modified WWII Liberty vessel that contained five prismatic aluminum tanks with balsa wood supports, plywood and polyurethane insulation. (Foss, 2012).

In 1961, Britain has signed a 15-year contract to receive about 1 million tons (mtpa) of gas annually from Algeria, the contract taking effect from 1965 onwards. For this reason, the construction of the world's first liquefaction plant was commissioned near Arzew in Algeria that would supply natural gas to UK from the huge natural gas reserves of Sahara. The following year, France signed an agreement to purchase gas from Algeria too (Brenntro, Garcia, Thirion, 2013).

In the late sixties the first exports were made from the US to Asia when the unit located in Kenai, Alaska (which currently has a capacity of 1.3 mtpa) began to ship LNG to Japan for the Tokyo Power Plant TEPCO (Tokyo Electric Power Company). The market for liquefied natural gas has been growing rapidly ever since. In 1972, Brunei became Asia's first natural gas producer, operating a liquefied natural gas plant in Lumut, which now has a capacity of 6.5 mtpa, supplying Korea as well as Japan. Libya's LNG plant at Marsa el Brega began delivering gas to Spain and Italy in the 1970s, signaling the entry of a new producer and two new buyers into the liquefied natural gas global market (Gkonis, Psaraftis, 2009).

The US imports from Algeria were approved in 1972 with Boston's Distrigas signing a pledge to purchase 50 million cubic feet of gas (MMscfd) per day from the Skikda plant for a period of 20 years. 1979 marks first termination of contract LNG: the 15-year contract between Algeria and the United Kingdom has come to an end. Algeria's supply of gas continued during the 1980s, but eventually ended as the North Sea gas production had already begun. During 1979, the market was shaken by price disputes between the US and Sonatrach (the national state owned oil company of Algeria) which eventually led to termination of contracts, the decommissioning of six LNG tankers (three of which were subsequently scrapped) and the shutdown of two of the four US LNG terminals (Foss, 2012).

However, demand for LNG in Asia continued to rise. Thus, Malaysia entered the market for liquefied natural gas in 1983 (initially with a volume contract of 6 mtpa which subsequently increased to 7.5 mtpa). Australia followed in 1989 (similarly with an initial contract volume of 6 mtpa which increased to 7.5 mtpa).

Qatar became the second largest LNG producer in the Middle East with Qatar-gas delivering its first liquefied natural gas shipment in January 1997. Many gas plants have recently been built: Trinidad & Tobago (3 mtpa) started in April 1999, Ras Laffan (6.6 mtpa) in May 1999, Nigeria (5.6 mtpa) in October 1999 and Oman (6.6mtpa) in April 2000. The first offshore, floating liquefied natural gas gasification facility in the Gulf of Mexico began operating in 2005. In addition, the construction of many design approved liquefied natural gas reception terminals is underway. Whilst in 2000 the annual LNG trade had reached 100mt, in 2008 it had exceeded 173mt (Kumara, et al., 2011).

Figure 1. 1 : PROMETHAN for CNG Use in Greece (1)

Although electricity consumption in Europe is completely covered by the existing power plants and the net balance of electrical power is positive, in Greece there is a deficit in electrical power needs which is covered by electrical power imports. In 2017, Greeks consumed 5.287 KWh per person in average, while the corresponding production per capita figure amounted to 4.837 KWh. The difference between consumption and production corresponds to a 450 KWh per capita figure which accounts for approximately 8.5% of the average per capita consumption.

There is also a gap between consumption and production of natural gas, which was expected, seeing that Greece does not produce natural gas and therefore the demand is completely covered by imports. Furthermore, EU cannot produce the consumed amounts of natural gas but has made improvement as far as the natural gas production is concerned. Crude oil production is also zero in Greece and in conjunction with zero natural gas production poses a threat related to energy security, since the total national needs for crude oil are covered exclusively by imports.

Production capacity figure vary according to the different sources available on energy per capita consumption, both for Greece and the other EU member states. The total energy production per capita in Greece comes up to 15.606,19 KWh, a figure broken down to: 4.525,80 KWh of RES per capita, 2.184,87 KWh of hydro production per capita, and 8.895 KWh produced from fossil fuels; meaning that 57% of the total power production comes from fossil fuels, 14% form hydro and 29% from renewable sources of energy, whilst energy production from nuclear technology amounts to zero.

Overall, the European energy percentage values are very similar to the Greek ones; nuclear energy utilization taken apart. EU has set stringent targets for greenhouse gas emissions to be significantly reduced by the years 2020, 2030 and 2050 by all member states. For Greece, the marked reduction in greenhouse emissions resulted from lesser energy consumption attributed to the economic crisis. Though the aforementioned decrease is greater than the EU 28 average, it seems plausible for more regulatory measures in that direction to be put locally in place by the administration for quelling a probable greenhouse gas emissions spike expected when the Greek economy recovers.

Carbon footprint can be defined as the aggregated carbon emissions released into the atmosphere. A possible future reduction on the carbon footprint worldwide constitutes a major challenge. In Greece, the total carbon footprint is measured at 6,26 tons per capita, and when compared to EU’s 5,39 tons per capita, the challenge that Greece has to face can be easily understood. The carbon footprint of Greece consists of 49% of Diesel and gasoline emissions, 8% of natural gas emissions, 39% of coal emissions and 4% of emissions from other sources.

Diesel and gasoline are the major sources of carbon emissions and the reason for almost half of the aggregated carbon emissions in Greece. Natural gas is the only source of energy in which Greece outperforms EU when taking into consideration tons per capita levels of emissions. In particular, Greece emits 35% less carbon dioxide coming from natural gas, in relation to EU, which is approximately 1-ton difference in absolute values. Carbon footprint of coal comes second in absolute values emitted with 2,45 tons. The corresponding number for EU is 1,72 tons of carbon emissions.

As to the developing supply chain of CNG in Greece, the Industrial Area of Sindos was the first region in Greece to be supplied with compressed natural gas (CNG), to the medium pressure network, by PROMETHAN SA. Specifically, on 20/02/2018 PROMETHAN successfully completed the required actions including gas compression (on special vehicles/trailers), safe gas transportation and installation of a mobile decompression unit to feed part of the Industrial Area of Sindos. Thanks to the above feat an uninterrupted supply of CNG was established, ensuring the successful operation of 18 cooperating industries. It should be noted that aforementioned industries cover a significant portion of daily industrial demand in the greater Thessaloniki area. PROMETHAN S.A., has acquired a fleet of specially designed vehicles, equipment and gas compression units, which can operate across the Greek mainland and has established itself as the first company in Greece to have the capability of supplying CNG to industrial and commercial consumers and gas stations located outside the gas pipeline network. All aforementioned achievements clearly depict that a new page for the CNG Market in Greece opens. The next step of the company's development aims Lagadas, Halastra and Koufalia Thessaloniki, to be the first areas exclusively powered by compressed natural gas (CNG).

Figure 1. 2: PROMETHAN for CNG Use in Greece (2)

2. Focus on Natural Gas Supply Chain and the thereto associated aspects

2.1. Supply Chain of Natural Gas

2.1.1. Natural Gas as alternative fuel

Compressed natural gas (CNG) is stored and distributed in hard containers usually of cylindrical or spherical shape at a pressure of 200-248 bar (2900-3600 psi) (Amrouche, et al., 2012), managing to compress natural gas to less than 1% of the volume that it would occupy in normal atmospheric pressure. Compressed natural gas (CNG) can be used as a car fuel, when they are equipped with dual fuel engines (petrol / CNG). Gas vehicles are increasingly used in the Asia-Pacific region (particularly Pakistan and the Indian capital of Delhi), Latin America, Europe, and North America due to continuously rising fuel prices. In response to high fuel prices and global environmental concerns, CNG has also begun to be used by many countries in trucks, public buses, and public trains.

The cost of a possible engine conversion is an important obstacle to the increase of the usage of compressed gas as a fuel and explains why public transport vehicles need to be equipped with dual fuel engines from the get-go. Despite the engine conversion logistics, the number of vehicles using CNG in a global scale has a steady increase of an approximate 30% annual rate (Yarime, 2009). CNG has many advantages – capabilities as follows (Pastorello, Dilara, Martini, 2011):

- ✓ It is the cleanest fuel resulting to lesser vehicle maintenance requirements and longer engine life;
- ✓ CNG vehicles produce the lowest emissions compared to all other engine fuels;
- ✓ Little to no emission production during refueling;
- ✓ Reduced maintenance costs by up to 40%;
- ✓ Natural Gas has a lower price per equivalent gallon of gasoline (on average 15% to 50% cheaper than gasoline);

The advantages and challenges for the use of natural gas over other transportation fuels can be analyzed from an environmental aspect and from a financial point of view, without leaving out of the discussion the significantly evolved role of biomethane as a transport fuel and the affects that this may have (Le Fevre 2014).

Unlike the marine sector, governments worldwide started taken actions in order to reduce the environmental impact of road traffic emissions many years ago. Legislation to improve fuel efficiency (and so reduce CO2 emissions) and limit atmospheric pollution have been introduced by a number of countries and/or cities. The main emphasis of such kind of legislation focused on passing fuel efficiency laws for smaller vehicles, but HGVs were also increasingly subjected to such constrains. Manufacturers have responded to these requirements through improved engine and vehicle design, but the usage of natural gas as a fuel, so as to have a smaller environmental burden is not as clear cut as in the marine sector, particularly since reducing Sulphur emissions are not the main concern when tackling road traffic emissions.

The environmental impact of vehicle fuels are typically measured on the basis of emissions at the well to tank (WTT) and tank to wheel (TTW) stages to provide a holistic ‘well-to-wheel’ (WTW) measure. Natural gas can generally demonstrate a better environmental performance than diesel and petrol, although the means of comparison of the environmental impacts of different fuels is an area of continuing debate and not all studies render the same results.

In particular some studies (for example, Transport and Environment, an organization that has tended to campaign against NGVs 2018) have suggested that the methane leakage problem has not yet been under much scrutiny, as it should have. Methane emissions can potentially impact global warming as much as CO2 emissions and such emissions can be produced at the NG combustion stage, where gas-fired engines are not able to fully combust all the methane subsequently letting it escape into the atmosphere (referred to as 'methane slip').

To add to the aforementioned disadvantage, compressed natural gas (CNG) requires a larger amount of storage space than conventional gasoline vehicles. Since it is a compressed gas and not a liquid, CNG takes up more space when compared to other liquid fuels. Of course, this problem has been solved by CNG vehicles factories by installing the gas tanks under the vehicle bodywork (Amrouche, et al., 2012).

More than 50% of global gas reserves are located in remote areas. For example, most of the gas used in Western Europe is produced in the harsh environment of Siberia or in the Northern Sea. In most cases, the producers ship the gas from the fields of production to the borders of the countries in which it is going to be used. Importers buy the gas under long-term contracts and resell the fuel to local distribution companies as well as to industrial users and power stations directly connected to the distribution system. The domestic and commercial consumers are normally served by local distribution companies.

Natural gas is mainly used for heating; therefore gas demand varies substantially between winter and summer, business days and weekends, or in extreme cases even between day and night (Yarime, 2009). The ratio between summer and winter loads in Europe fluctuates between 1:5 and 1:10. Production, transportation, storage, and distribution facilities must be designed and constructed to handle such load changes. Additionally, gas is stored in underground storage facilities during off-peak times and transported from storage during peak demand periods in winter. Another way of tackling the demand on NG fluctuations is by prissurizing the pipelines themselves in the transmission and distribution systems (Pastorello, Dilara, Martini, 2011).

Of the gas traded at international borders, 75% is distributed via pipelines, and 25% via LNG tankers. The development of gas fields and the construction of the transmission systems from remote fields to the gas importing countries are projects which require particularly high capital expenditures.

2.1.2. Transmission Pipes for the Natural Gas

The transport of large volumes of gas, is best materialized via large diameter pipelines operating under high pressure. The pipes can be up to 1400 mm in diameter and have operating pressures up to 8 MPa with the ability to distribute gas at a range of approximately 1000 km. Unfortunately, these capacities are insufficient to send gas from distant fields to a lot of markets. Therefore, compressor stations must be constructed to increase the gas pressure in the pipeline. Gas compressors are driven by turbines or gas-powered engines achieving greater reliability and lower cost (Amrouche, et al., 2012).

Underwater pipeline system connecting the Northern Sea with mainland Europe is constructed with pipes up to 1000 mm in diameter at a depth of 150 m. Italy and North Africa are connected by 500 mm diameter pipelines at 600 m depths. The high operating pressures of the piping systems firstly require underwater compression stations, which are extremely expensive because they have to be built on platforms and also require measuring stations, so as for sufficient pressure reduction to be ensured, for gas entering the mainland piping network.

2.1.3. The Natural Gas Transportation

Although the energy required to compress NG is substantial, the advantage of volume renders liquefaction economically viable. The NG is transported by double hull vessels specially designed to handle the low temperature of the liquefied natural gas. These tankers are insulated to limit the loss of liquefied gas quantities due to evaporation (Yarime, 2009). These exhaust losses are used to replenish ships' fuel. According to World Gas Intelligence (2008), on a typical trip, it is estimated that about 0.1% - 0.25% of the NG load is evaporates daily, depending on the efficiency of the insulation and the roughness of the trip. In a typical 20-day trip, 2% to 6% of the total NG volume can evaporate.

Three types of LNG tankers are mentioned (Wadud, 2014):
- ✓ Moss design - (44%)
- ✓ Membrane design (51%)
- ✓ Structural prismatic design

The LNG tankers are 300 meters long, 46 meters wide and require a minimum depth of water of 12 meters when fully loaded. There are currently 155 tankers carrying more than 120 million tons of LNG per year. The LNG transportation is often the only way of transporting natural gas from remote production fields to consumption countries. Any cost comparison between LNG and pipeline transportation must, of course, be linked to each individual project requirements. In general, an LNG installation is the only answer when the distance that needs to be covered is very large (Pastorello, Dilara, Martini, 2011).

2.1.4. The Natural Gas Storage

When the NG reaches the terminals, it is transferred to special insulated storage tanks. These tanks can be above or below ground and have very low operating temperatures minimizing the amount of liquid vaporized. If the NG vapors are not released, the pressure and temperature inside the tank increases (Wadud, 2014), on the contrary by technically removing the evaporated gas from the tank, a constant value on both temperature and pressure inside the tank is achieved. This process is known as self-freezing. The evaporated gas is collected and used as a fuel source for the storage facility or for the tanker. When required for use, NG is heated through a heat exchanger, reaching again a gaseous form (Amrouche, et al., 2012).

2.1.5. *The CNG Chain Design Levels*

For the NG supply chain's design, three separate levels with different time frames can be distinguished (Stremerschetal., 2008; Andersson et al., 2010):

- ✓ The first is long term strategic planning. Long-term planning usually involves decisions regarding investments of high necessity and long-term contracts the impact of which will be tangible many years later.
- ✓ The next level of NG chain design is tactical planning. This design is basically a regular scheduling problem with a typical 12-18-month timeframe. When designing the ADP, the goal is to determine the optimal fleet schedule including delivery dates at various terminals/customers. The program should also tackle constraints posed by possible limitations of available NG stocks as well as customer's contract constraints.
- ✓ Finally, there is the Operational Planning phase, which refers to the constant updating of the fleet delivery schedules, due to a variety of financial or other problems along the way.

The production, compression, transportation as well as storage of NG is a particularly capital-intensive project, as large capital expenditures are required to establish the facilities and corresponding transportation network. This favors the creation of long-term contracts with potential customers and reduces the risk of the large initial investment (Tusiani, Shearer, 2007).

2.1.6. *Possible Risks in the NG Supply Chain*

Despite thorough planning, potential dangers of the NG supply chain is an issue of major concern to the NG plant operators. The most possible risks are presented below (Foss, 2003; Balaaura, 2008):

- ✓ Explosion: there is a high possibility of explosion for the tanks when they are to a proximity with a potential source of ignition or when the NG is released uncontrollably under high pressure conditions. For such an abrupt gas release to occur, the containment system must be punctured.
- ✓ A Steam Cloud: as the LNG is discharged from the pressure-controlled environment of the storage tank, it begins to heat up, returning to its initial gaseous state. Initially, the vaporized gas is colder and heavier than the surrounding air, thus creating a mist - a vapor cloud - over the liquified NG. As the gas heats up and mixes with the surrounding air it creates an easily ignitable vapor cloud.

- ✓ Fire on the transportation vessel: in the event of a crack near the sides of the ship the NG storage tanks may be punctured, and gas may leak to the sea surface. The NG is lighter than seawater. It floats unmixed on the surface of the water, spreads rapidly and if ignited, the NG pond will burn until all gas has evaporated. The fire can burn through thousands of tons of the NG in a matter of minutes and the thermal radiation can severely injure people and damage the NG facilities.

2.1.7. *Unpredictable Risks in the Natural Gas Supply Chain*

The unpredicted risks differ from the afore-mentioned possible risks in terms of the uncertainty as to whether or when they could occur. General safety rules for the protection of all types of facilities and public buildings, including LNG & CNG terminals apply worlwide. One major danger is that of a possible terrorist attack on the NG transporting ships or onshore/offshore facilities. Following the terrorist attack on September 11th 2001, the international community has raised many concerns that need to be carefully addressed (Paltrinierietal., 2015). When assessing the risk of NG supply chain, companies examine in detail the risk of severe ground movements, earthquakes, and subsequent landslides. The seismic design requirements of installations are described in NFPA Standards 59-A3 of 2001. It must be noted that there are no known incidents of liquefied natural gas leakage from storage tanks due to seismic activity. In fact, in 1995, none of the LNG storage tanks in Kobe, Japan (one of the largest users of liquefied natural gas worldwide), suffered any damage during a 6.8-magnitude Richter earthquake, Japan being one of the most seismically active areas in the world (Foss, 2003).

2.1.8. *Security Levels*

It is a common assumption in the global community that ships carrying natural gas are basically floating bombs and that a possible explosion can result to damages comparable to the destructive force of a small atomic bomb. But in reality, statistics tell a different story. In its liquid form, the gas is not explosive. In order for an explosion to occur, gas must evaporate and mix with other gases (Achniotis, 2012). The security conditions in the LNG/CNG industry are divided into four major levels. The levels are broken down as follows (Amrouche, et al., 2012):

a) Primary Security Level

It is the first stage of security requirements and the most important one. At the primary stage, all the constraints required for the safe storage of LNG are described. Liquefied natural gas, being a cryogenic substance, requires a proper selection of equipment so as for a proper handling operation to be ensured in low temperatures. The materials most commonly used for the storage of NG are high nickel steel, aluminum, and stainless steel. The inner part of the tank is made of 9% nickel steel and is mounted on a foam-like insulation material. Also, the inner wall of the Tank and the outer wall do not come in contact with each-other as an additional measure of insulation.

The storage tanks have undergone extremely precise strength analysis testing to ensure that they withstand the hydrostatic pressure exerted on them from the cargo (BP, 2007). In the case of CNG storage tanks on transport vessels, they are manufactured from stainless steel and iron nickel alloy known as invar. Polyvinyl chloride and perlite foam are used as insulating material. In addition, nitrogen is also used as an inert element, because it does not react with other gases (Flessas, 2009).

b) Secondary Security Level

The secondary level is an extension of the primary level and ensuring a proper isolation in the event of NG leakage. One way to avoid spillage is the construction of a mound around the tanks. Particularly in single-walled tanks, a large ditch is created around the tanks so that in the event of a leak it serves as a barrier and retains the liquefied natural gas. For double-walled tanks, the outer shell is made of 9% nickel and reinforced concrete. In the event of a leak from the inner tank, the exterior is designed to retain liquefied natural gas and its vapor (BP, 2007). Terrestrial plant statistics show that the primary level of safety is working properly since the secondary level has never been activated (Flessas, 2009).

c) Security Systems

As the third level of security, security planning aims at minimizing the leakage of NG and mitigating the consequences of such an occurance. For this reason, all modern NG facilities are equipped with all the necessary security systems such as fire detection and hydrocarbon detection in the ambient environmet. The fire detection systems are mainly located at the top of the tanks but also on the loading-unloading pier and are connected to an alarm ready to initiate a shutdown process in the event of a fire. Hydrocarbon detection systems are located a few meters around the tanks as well as on the pier, and detect, in the event of leakage, the released hydrocarbons. Regular maintenance of these systems is vital to ensure their reliability (Foss, 2003).

d) Site Security

The size of the safe zones are different for ships passing near a liquefaction station opposed to docked ships. Security distances shall be determined by each country’s port authority as well as by the master of the ship. The safe zones for LNG ships have been established for two reasons. First, to minimize the likelihood of a ship collision and secondly to protect staff working on the dock and the nearby facilities (Foss, 2003).

2.2. CNG Handling Methods

Gas can be transported in containers at high pressures, typically 1800 psig for a rich gas (significant amounts of ethane, propane, etc.) to roughly 3600 psig for a lean gas (mainly methane). Gas at these pressures is termed 'Compressed Natural Gas – CNG'. CNG is used in some countries for vehicular transport as an alternative to conventional fuels (gasoline or diesel). CNG filling stations can be supplied through pipeline network but the compressors needed in order to achieve such high pressures can be large, noisy, and expensive to purchase, maintain and operate. The thermodynamics of gas compression (heat generation), and gas expansion (significant cooling), must be considered in any gas processing operation and appropriate heat exchangers used add significantly cost-wise (Yarime, 2009).

Originally, CNG transport containers were heavy walled (and hence heavy weighted) pressure vessels, but recently new lighter designs have been proposed. One design utilizes relatively long lengths of thin-walled tubing (6.25 in. outside diameter with a wall thickness of 0.25 in.) coiled into large diameter reels, termed by the inventors as a Coselle, 'a coil in a carousel' (Pastorello, Dilara, Martini, 2011). The carousel structure is important since it not only protects the pipe from damage, but it also enables stacking of such units, even from 6 to 8 units high.

The inventors initially proposed a Coselle -with a coiled up pipe having a length of 9.6 miles-, which would stand some 11 ft high with a 50 ft outside diameter and 10 ft inside diameter and contain approximately 3 million scf of gas at 3000 psig. The Coselle would be surrounded by many vertical girders so that it would form a large safe pressurized gas containment system. The long-term viability of the coiled tubing under repeated high-pressure loading/unloading conditions is being tested, but no serious difficulties are anticipated. The total weight of pipe and associated structures (perhaps 500 tons) must be transported onboard the vessels along with the gas, but the inventors maintain that the lower fabrication costs for the gas containers render this design attractive. With newer, small sized Coselle Units the inventors target also smaller markets (Wadud, 2014).

An alternative approach, Votrans has designed dedicated transport vessels able to carry straight, long, large diameter pipes in an insulated cold storage cargo containment system. The gas must be dried, compressed and chilled for storage onboard. By carefully controlling the temperature, more gas should be able to be transported at a time. Suitable compressors and chillers required are less expensive than an NG liquefier, and after the Votrans vessel and containment system standardization costs could be further minimized. According to the proposers, corresponding terminal facilities would also be simple and hence would be of low cost (Amrouche, et al., 2012). These CNG systems would make transport possible either for stranded gas (i.e. in places where there is no current market or no pipeline network available) or for smaller quantities of associated gas which cannot be flared or re-injected. The number and size of Coselles or Votrans ships can be scaled to fit demand and would depend on daily production rates from the reservoirs, and weight restrictions of transporters. Case studies by the inventors have shown that large quantities of natural gas (~500 million scf) can be transported to markets at costs substantially below LNG transportation costs over short distances, and probably over longer distance too, if the largest ships are employed. Ships capable of transporting Coselles carrying 1 Bscf CNG and Votrans ships capable of carrying up to 2 Bscf CNG have been proposed (Wadud, 2014).

However, further consideration suggests that it may be a step toward the wrong direction for CNG vessel designers to try and match the sizes of LNG tankers. The CNG ships must tie up to a wharf and deliver liquid into a storage tank for re-gasification over several days per trip. Also, a potential problem could be that ships are required to be fully inspected every 5 years and this is difficult for ships too heavy & large to be dry docked.

Probably the most suitable approach would be the creation of a fleet of smaller ships, perhaps delivering gas daily, directly into the distribution pipeline, with the number of vessels varying depending on the projects demands, or perhaps into a network of backup storage tanks in case a ship is delayed in transit. Such a CNG transportation concept can be very flexible and cope with the needs of many large-scale consumers. This approach can be very attractive to possible investors and help CNG transportation systems rise as a considerable opponent to stand against LNG Tanker owners. As far as intermittent and stranded gas, CNG containment systems (lets say Coselles) can play the role of storage units where the produced gas is cleaned, compressed and stored, until it reaches shipment-worthy levels (Pastorello, Dilara, Martini, 2011).

2.3. Advantages & Disadvantages of the CNG Use

The potential advantages of CNG's use, both environmental and economic, are already recognized on a global level. According to recent estimates, gas-powered cars have reached the promising number of 11.5 million units cars worldwide, with more than 1.5 million gas powered vehicles located in Europe. Economic advantages of using CNG as a fuel are easily understood, as gas prices are a lot lower compared to those of other fuels. Its current price standing at 0.93€/pound, when compared with LPG's 0.77€ per liter may not seem so attractive, but for the same amount of money a CNG powered vehicle can reach 25% longer distances compared to an LPG powered one (Yarime, 2009).

CNG can also be used by some homes and businesses for hot water burners and / or kitchens. The basic advantage for the usage in densely populated areas is the fact that, natural gas is not dangerous, unlike liquefied petroleum gas which may ignite in case of a leak. CNG is light, and in the event of a leakage, it evaporates into the atmosphere (Wadud, 2014).

Natural gas intended for usage in vehicle engines has a higher number of octanes when compared to gasoline and particularly 130 octanes against only 90 octanes. In addition, NG achieves a total combustion because the mixture of gas and air tends to be perfect at any ambient temperature. This results to high torque during acceleration, even at relatively low speeds. Still, according to official figures, 1 kg of gas contains far more energy than 1 liter of other liquid fuels. In detail, 1 kg of natural gas is equivalent to 1.5 liters of gasoline, 1.3 liters of oil and 2 liters of LPG. In fact, CNG powered car owners can achieve 50% - 60% savings on a yearly basis due to lower NG prices (Pastorello, Dilara, Martini, 2011).

It is characteristic that carbon dioxide emissions from natural gas combustion are lower than combined gasoline, diesel, and LPG carbon dioxide emissions. It also reduces emissions of other important pollutants such as nitrogen oxides (NOx). According to international literature, gas engines produce 25% less CO2 than gasoline and 35% less than diesel, while achieving 95% carbon monoxide emissions reduction when compared to gasoline combustion. Also, gas does not contain sulfur, or heavy metals traces and unlike gasoline does not contain toxic lead or benzene additives.

Compressed Natural Gas is also nontoxic or corrosive and does not contaminate groundwater. That is why it poses no such threat to the environment in the event of a major leak, unlike oil spills, for example. Being lighter than air, in the event of a CNG Tank puncture, it simply escapes upwards, diffuses, and dissolves in the atmosphere. As far as the engine's maintenance and projected lifespan is concerned, the combustion gases are non-corrosive and do not damage the metal parts of the engine, neither the exhaust system piping.

As to the disadvantages of the CNG use, the main disadvantage is the cost of converting gasoline engines to be able to burn gas. While many manufacturers -such as Citroen, Fiat, Honda, Mercedes, Peugeot, Renault, Skoda, Toyota, VW, Seat and Volvo- have launched factory-fitted dual-powered vehicles, the Greek market has yet to see these vehicles. Conversion kits usually cost between 2,000 and 2,500 euros and are equipped with bulky tanks that are able to carry only small amount of Gas, with factory conversions being far more reliable (Yarime, 2009).

3. Rules & Regulations for CNG Carriers and Existing CNG Design Concepts

3.1. Classification Rules & Guidelines

This Chapter will provide a very brief description of the rules and guidelines issued by key Classification Societies (all IACS members), while a deep dive in the most important contents of the rules and guidelines is presented in below summary.

For all classification societies, the major aspect/items that guidelines focus separately for this distinct type of vessel, could be summarized to the following:

- ✓ Materials of Construction for Cargo Tanks
- ✓ Arrangement and Location of Cargo Tanks. Cofferdams must separate cargo holds from ER and accommodation for safety reasons. Moreover, CNG carrier is designed in order to survive effects of flooding following assumed hull damage caused by some external force and is given with protection from damage in the case of collision. Thus, a double hull construction both for side shell and double bottom are usually the design concept for a CNG carrier.
- ✓ Scantling and Testing of Cargo Tanks. The design for the hull part of the cargo tanks should be taken into consideration all dynamic and static loads that will be applied during vessel's operating life. For CNG carriers, the dynamic loads due to pressure variations and thermal loads during loading and unloading sequences should be also examined. The mentioned loads in combination with ship motion, vibration and the degradation of material properties with time represent the extreme service conditions the containment system will be exposed to. In respect of the above, the cargo tank shall be designed using special analysis methods and tools to determine stress levels, fatigue life and crack propagation characteristics.
- ✓ Piping system in Cargo area/ Piping Overpressure protection and Vent System
- ✓ Fire protection and Extinction. Specific requirements regarding the fire protection are applied for CNG carriers referring to the following aspects: structural fire preventive measures, but also measures for conformation with the event of a fire such us escape trunks and fire-fighting systems.
- ✓ Control and Monitoring/ Electrical Installations/ Automation
- ✓ Operation Requirements / Use of Cargo as Fuel/ Surveys

3.1.1. American Bureau of Shipping

ABS issued in April 2005 the "Guide for Vessels Intended to Carry Compressed Natural Gasses in Bulk". This guidelines was last updated on March 2018.

Starting point for the guidelines:

- ✓ Rule Requirements for Vessels Intended to Carry Liquified Gases in Bulk" (Part 5C, Chapter 8 of ABS Rules for Building and Classing Steel Vessels)
- ✓ IMO Guidelines for Formal Safety Assessment (FSA)
- ✓ Compliance with ABS Rules for Building and Classing Facilities on Offshore Installations and ABS Rules for Building and Classing Offshore Installations is required for ships with Offshore loading facilities.

Key differences between rules and guides for CNG & other Carriers transporting methane are mainly attributed to:

a) Pressure and Temperature of Cargo carried;
b) Possibility of carrying cargo above main deck;
c) Methods for loading and off-loading the cargo;
d) Venting or Blown don of high-pressure gas (gas dispersion analysis required);
e) Overpressure protection of holds for the case of leakage (relief devices, hatches in each space cover, safe location of discharges from cargo hold space);
f) Occurrence of high pressure (jet) fire from a ruptured pipe;

3.1.2. Bureau Veritas (BV)

BV published in April 2007, a Rule Note NR 517 "Classifications of Compressed Natural Gas Carriers" which forms a set of requirements for ships carrying CNG. The Rule Note is based on the latest editions of BV Rules for the Classification of Steel Ships and IMO IGC Code & Amendments.

Ships which intended for carriage of CNG are to comply with the requirements of latest version of the International Code for the Construction and Equipment of Ships Carrying Liquified Gases in Bulk, including latest amendments and Requirements of Rules Note regarding cargo containment, handling systems and interface between these systems. The remainder of the ship is to comply with the applicable requirements for hull and machinery given in Part B, C and D of Ships Rules.

3.1.3. Nippon Kaiji Kyokai (Class NK)

NKK published in July 2015 "Guidelines for Compressed Natural Gas Carriers" which provide safety requirements for the design and construction of CNG Carriers, based on the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) (Resolution MSC.370(93)) and additional requirements considering hazards arising from handling CNG.

3.1.4. DNV-GL

In January 2003, DNV published its Special Rules providing guidance for CNG Carriers. Latest edition of Rules and Guidelines in "Compressed Natural Gas Tankers", published in October 2015, are incorporated in DNV GL Rules for Classification of Ships as presented in Part 5, Chapter 8.

3.2. CNG Transport Technologies by Sea

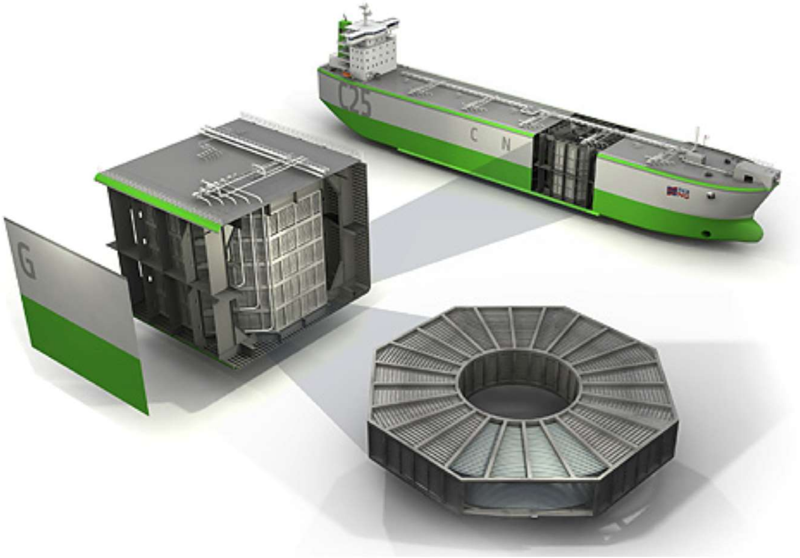
The concept of transport by sea of CNG has a long history, with many different technologies applied over the years with remarkable success. The first test was carried out back in 1965 in the New York Harbour by Columbia Gas Company whose headquarters are in Ohio. The containment method consisted of multiple bottles or cylinders and unfortunately failed, with the main reason being that the weight of the bottles/cylinders, occupied a hefty percentage of the vessel's total loading capacity. Since then, the CNG concept designs have made many steps of improvement mainly due to developed advanced pressure vessels designs, utilizing not only metallic but also composite materials.

The current status of the various Companies and technologies that are attempting to fill the gap between the pipeline and LNG concepts, for the transportation of small and medium volumes of NG are presented below:

1) GEV Canada Corporation (Global Energy Ventures) with two (2) options:
    a. Coselle SeaNG
    b. Optimum Technology
2) EnerSea-VOTRANSTM (Volume Optimized Transport and Storage System), USA
3) Knutsen OAS Shipping (PNG), Norway
4) Trans Ocean Gas Inc. (TOG)
5) TransCanada-GTMTM-Canada
6) Compressed Energy Technology AS (CETech), Norway

3.2.1. GEV Canada Corporation - Coselle® System

The Coselle System was invented by Cran & Stenning Inc., an independent engineering contractor established back in 1966. The creation of a large scale but at the same time compact CNG containment system, is the main principal behind the ''Coselle'' CNG Project and is achieved with the use of pipes. In more detail, the concept for the Coselle system is the formation of HP (high-pressure) gas storage in steel modules (stacks) consisting of high strength steel pipe wound up around a coil, as the name of the system itself betrays (Coselle is a contraction of the words ''COiled pipe in a carouSEL'').



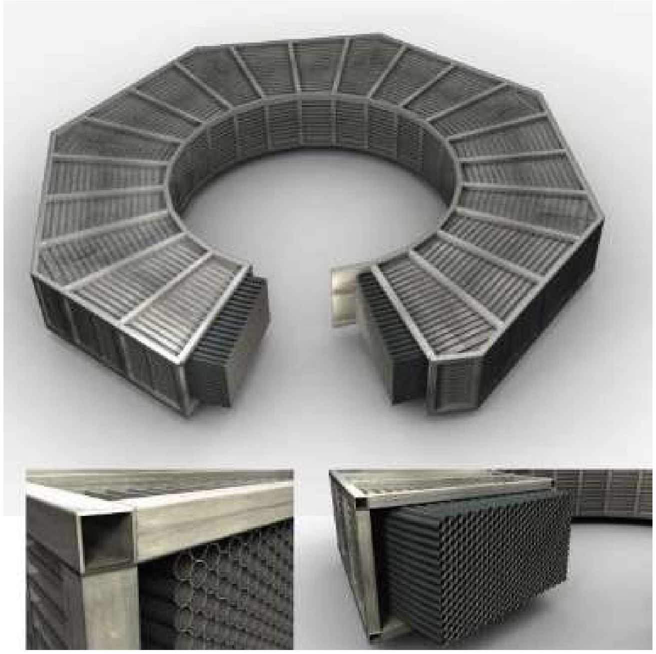
Principal Idea: High-Pressure Gas Storage in Steel Modules (Stacks) Consisting of High-Strength Steel Pipe wound-up around a Coil

Figure 3.1. GEV – Coselle® System

As already mentioned above, the leading goal of the Coselle concept is to capacitate a large volume of CNG, but without utilizing large diameter pressure cylinders. By coiling a series of smaller diameter pipes, the costs per unit volume of storage is lowered, because pipeline technology is tried and tested, and pipelines are manufactured in bulk.

An other benefit is that it overcomes the issues rising from the use of large pressure vessels. Some of the issues are presented below:

- ✓ The strict strength requirements and limits that a CNG cargo containment design shall meet (based on ABS technical paper: bursting, local buckling and collapse, fracture, fatigue, out-of-roughness and corrosion). When the diameter of the cylinders is smaller all the relative design criteria are less challenging.
- ✓ Any new Marine CNG transport concept that requires large diameter pressure vessels, therefore creates an increase on the fabrication costs and concludes also to delays on the production delivery.
- ✓ A manifold consisting of bigger diameter pressurized cylinders, results to a more complex design, that includes more valves, pipe connections, flanges and fittings, leading to a less reliable design with high maintenance needs.
- ✓ When referring to a CNG Carrier we must always keep in mind that the Class Surveyors, the Port State Controls and the Flag Surveyors must be able to easily inspect each of the components consisting the pressure containment system.



Range of Natural Gas Capacities to be transported: 66-531 MMscf
Full ABS Approval on 2006 (first such approval for CNG marine)
Figure 3.2. GEV – Coselle® System Detail

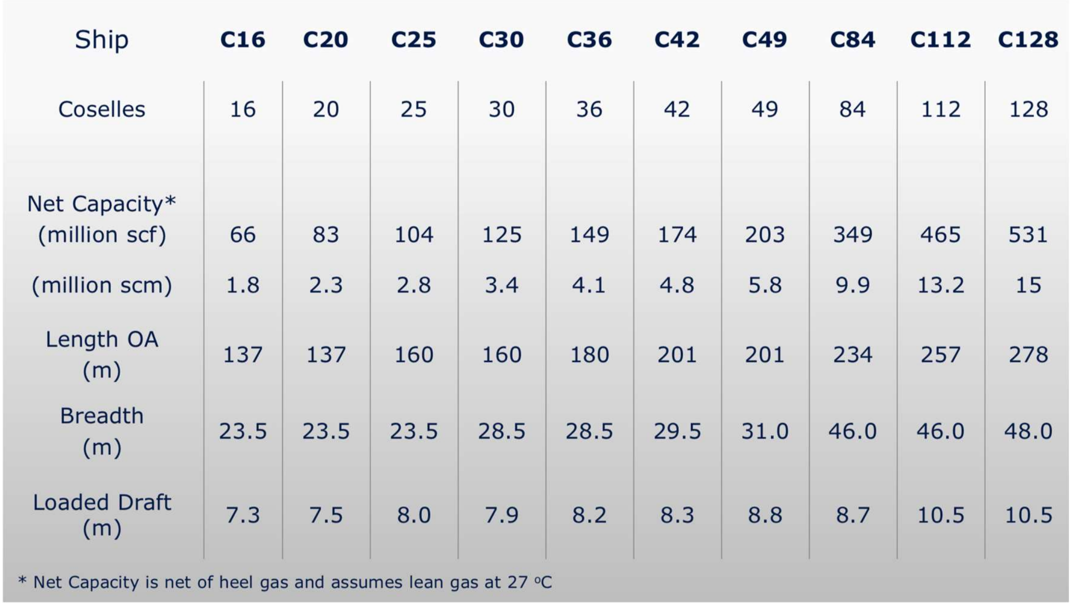
The innovative design of the Coselle concept seems to accommodate all the before-mentioned problems that are applied for large pressure vessels , and thus it stands out as an efficient CNG containment system for ships. Numerically, a typical Coselle is formed by the coiling of approximately 15-17 km of high-strength X70 pipe with outside diameter of 168mm and wall thickness of 6.3mm. The outside diameter of the hole Coselle amounts to about 15 to 20 meters, with a height ranging between 2,5 and 4,5 meters and a weight of up to 550 tonnes. The carousel design provides support and protection for the stacking and transportation and facilitates the inspections by just the use of a special tool, a PIG (Pipeline Inspection Gauge) device.

The Coselle system stores CNG in ambient temperature and under 275 bar pressure. Typically, a single Coselle is capable of carrying approximately 3 MMscf of NG, depending on its dimension and on the temperature, pressure and composition of the transported gas. The capacities transported range between 66 and 531 MMscf.

Actually, a Coselle CNG Carrier is a Bulk Carrier whose holds are loaded with Coselles. The standard Coselle CNG Carrier was developed using a double-hulled Panamax Bulk Carrier with DWT 60,000 ton. For this design, the Coselles are transported in 6 modules in height inside the vessels holds, which constitute 1 Stack (i.e. 1x Stack = 6x Coselles). This standard design can transport a total of 18 Stacks, meaning a total of 108 Coselles per vessel. Assuming that for each Coselle, the containment capability ois about 3 MMscf CNG, we conclude that the total Coselle CNG Carrier transportation capacity is 323 MMscf.

As per the manufacturer, Coselle CNG Carrier has two hundred (200) times greater cargo division than an LNG Carrier and as a result in the event of a major tank damage, the cargo spillage would be remarkably less. Moreover, the Coselle container withstands external impact without rupture many times more than the LNG tank. In addition to the above and for safety purposes, the holds are inerted with nitrogen in order to minimize the probability of fire or explosion. All valves and fittings are installed above cargo hold deck level in order to facilitate the smoother operation from the crew.

As it is easily concluded from the nature of the vessel, the Coselle CNG Carrier is subject to various designs depending each time on the project application. A summary table depicting the range of Coselle concept and respective Coselle CNG Carrier characteristics is presented below.



Ship	C16	C20	C25	C30	C36	C42	C49	C84	C112	C128
Coselles	16	20	25	30	36	42	49	84	112	128
Net Capacity* (million scf)	66	83	104	125	149	174	203	349	465	531
(million scm)	1.8	2.3	2.8	3.4	4.1	4.8	5.8	9.9	13.2	15
Length OA (m)	137	137	160	160	180	201	201	234	257	278
Breadth (m)	23.5	23.5	23.5	28.5	28.5	29.5	31.0	46.0	46.0	48.0
Loaded Draft (m)	7.3	7.5	8.0	7.9	8.2	8.3	8.8	8.7	10.5	10.5

* Net Capacity is net of heel gas and assumes lean gas at 27 °C

Coselle concept vs Coselle CNG Carrier Characteristics

Figure 2.3. GEV – Coselle® System & CNG Carrier Range

The net gas capacities, which are presented in Figure 3.3., are related to load pressures of 275 barg. For projects involving smaller volume and/or distances, the use of a barge with Coselles mounted on top of would be possible.

Coselle design was approved by two of the most prominent Classification Societies, the Det Norske Veritas (DNV) and the American Bureau of Shipping (ABS) after thorough examinations and testing. DNV proceeded to a Phase I, II and III Safety Studies plus a preliminary Hazard Identification Study. ABS proceeded to a Final Hazard Operability Study and a Hazard Identification Study. DNV, came into the conclusion that ''a Coselle CNG ship is at least as safe as other gas ships''. The operating pressure during testing was 275barg (4000psi). The Coselle System complied with all ABS requirements and especially critical fatigue testing overpassed requirements by 300% without failure, which translates into 65000 cycles without failure. A full ABS approval was granted in 2006 (first such approval for CNG Carrier) and in 2009 ABS granted 'Approval in Principe' for the design and operating plans for the C16 Coselle ship.

The two main trades that the Coselle CNG Carrier is suitable for, are:

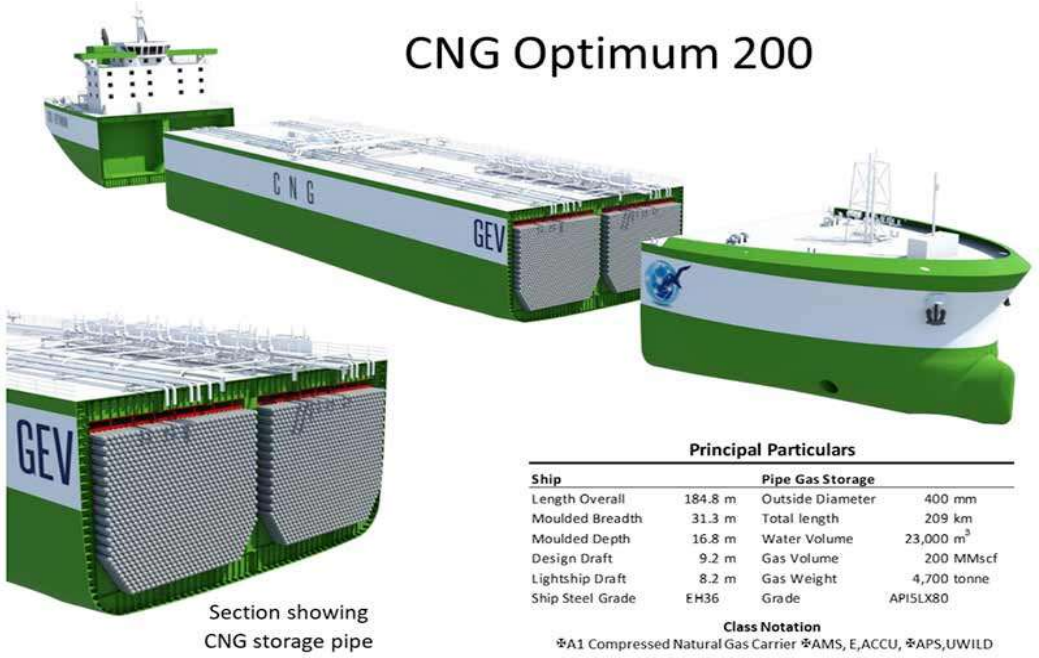
- ✓ The transportation of NG from a producing region to a consumer market separated by sea (for example the Mediterranean Sea, the Black Sea, the Caribbean Sea, the Arabian Sea and the Sakhalin Sea) and
- ✓ The transportation of NG from offshore producing platforms to nearby infrastructure that can forward NG to other markets or use it for other purposes (for example Canada's east Coast, Deepwater and Gas FPSO's).

As per the manufacturer, one (1) of the most significant if not the most important benefit of the Coselle concept, is the fact that it is potentially the least costly gas-delivery containment concept when targeting markets with less than 4,000 kilometres from the gas source.

3.2.2. GEV Canada Corporation - Optimum® Technology

GEV's CNG Optimum vessel is the outcome of twenty (20) years of hard work and research on the development of a low-cost and compact CNG vessel design. The main idea on which the concept was based is the use of close-packed, high strength pipes that run the entire length of the ship's cargo holds.

The long, straight pipes used are hexagonally packed close to each other and laid lengthwise in large open holds locked with a mechanism to clamp the pipes together and take advantage of the resulting friction between the pipes so as to prevent their relative movement. As per the manufacturer, this leads to small sized CNG Carrier vessel which can be loaded and transport large volumes of NG in comparison to their size.



Principal Particulars

Ship		Pipe Gas Storage	
Length Overall	184.8 m	Outside Diameter	400 mm
Moulded Breadth	31.3 m	Total length	209 km
Moulded Depth	16.8 m	Water Volume	23,000 m^3
Design Draft	9.2 m	Gas Volume	200 MMscf
Lightship Draft	8.2 m	Gas Weight	4,700 tonne
Ship Steel Grade	EH36	Grade	API5LX80

Class Notation

✠A1 Compressed Natural Gas Carrier ✠AMS, E,ACCU, ✠APS,UWILD

Principal Idea: Use of Close-Packed, High Strength Pipes through the length of the Cargo Hold, with the use of a Mechanism to Clamp Pipes together.
Figure 3.4. GEV – Optimum® System

This ''friction'' based design on the pipe packing of the vessel had difficulties to meet the international classification rules, since the pipes during voyage would rub together because of vessel's motion as a result of the waves. The Optimum pipes and the new stacking concept subsisted thorough testing from ABS as follows:

- ✓ Pressure test was carried out, to verify that the pipes shall be able to withstand the pressure they are going to be subjected to during operation on the CNG-O-200 ship, also considering a safety margin. The operating pressure of the pipes could reach 3600psi during voyage and the pipelines succeeded the tests, as they withstand more than double the pressure.
- ✓ Bend test was performed to investigate whether the pipes will prevent any relative movement between the pipes, when clamped together inside the cargo holds, and as a result stiffen the ship. The deflection at the midpoint of the pipes was 5.45 mm slightly above the predicted one (5 mm) and this test result proved that the pipes prevent relative movement, because in similar case the deflection has been measured approximately four (4) times larger.
- ✓ The piping arrangement in way of the cargo holds was tested, so as to clarify if the required was achieved. For this testing purpose, a vertical force was applied on the pipes, reflecting the condition of the cargo holds in case a pressure of 10 tons per square meter was implemented. When the pressure reached that levels, a pipe from the middle of the

stack was pulled and being forced to be extracted. The test was successful, thus confirming that the friction developed between the pipes was satisfactory.

- ✓ Cyclic Fatigue Test were carried out which consists of three (3) individual tests:
  - a) Long-term Fatigue Test, that requires for the tested containment vessel to be subject to pressurization (with a range from minimum to operating pressure) for ten (10) times the design life of the ship. The GEV's vessels have a 30year life span, which means that the test should recreate three hundred (300) years, or alteratively two thousand (20000) cycles.
  - b) Notched Burst Test after Fatigue, which requires the containment vessel to be fatigued three (3) times the design life (6000 Cycles) and then to be burst with the aid of a machined notch embedded to give proof for the pipe's ductility. This test carried out upon the completion of the long term fatigue test.
  - c) Cooled Burst Test after Fatigue. This test also requires the specimen to be fatigued for three (3) times the design life. The specimen is then left to cool down, and finally the pipe being burst. In this way a simulation of the Joule-Thompson cooling effect is managed, where gas is escaping through a crack.

After all the above tests were competed, followed by a review of the Safety Study and a Hazard and Operability Analysis, ABS issued an official approval the innovative design in January 2019, and further granting approval for construction of the CNG Optimum ship, thus formally validating the concepts compliance with applicable ABS Regulations and Guidelines.

The close packed pipelines in which the gas is stored inside the Optimum vessel's cargo holds have an external diameter of about 0.4 meters, a total length of 207 kilometers and their material is high strength steel API5LX80.

The gas is stored in ambient temperature avoiding a cooling procedure and liquid-push systems and in HP (high pressure) which get overs the 250 bar. It can reach to a capacity of cargo up to 450MMscf. Both the vessel and the containment system can be fully constructed in a conventional shipyard, and not specialized facility is needed. The vessels design satisfies all classification requirements for a CNG ship.

As per the manufacturer, the most important benefit of the Optimum vessel is that the ratio of cargo holds versus gas stored inside for a conventional CNG Carrier is about 8:1 and for the Optimum vessel is 3:1. The maker insists that the capital and operational costs of choosing the Optimum Technology CNG Carriers over previous CNG transportation concepts are significantly less, extending the range of CNG competitiveness up to four thousand (4,000) kilometers.

The manufacturer pursues the following markets for the development of the Optimum Technology concept:

- a) UK and Europe,
- b) Indian subcontinent,

c) South East Asia,
d) Australasia and
e) Middle East

As a key event, in March 2019, GEV signed a Heads of Agreement (''HOA'') with the National Iranian Gas Company (''NIGC'') for the installation of compression and berthing facilities at the Port of Chabahar, Iran, permitting CNG to loaded sequentially on to a fleet of six (6) CNG Optimum 200 ships delivering gas equivalent to the West Coast of India.

Coselle SeaNG Optimum Technology emphasises that CNG in general has significantly lower costs than LNG or pipelines when the served region occupies a distance of about 500 to 2,500 kilometers.

Figure 3.3. GEV – Coselle® vs Optimum® Concept Detail

3.2.3. EnerSea – VotransTM

EnerSea Transport LLC founded in 2001, with headquarters in Houston Texas, partnered with Kawasaki Kisen Kaisha Ltd (''K'' Line) and the shipbuilder Hyundai Heavy Industries Co. (HHI). Together all the above, they introduced an innovative concept for the marine transport of CNG named VotransTM, which stands for Volume Optimized Transportation System. EnerSea is the owner and manager company of the Votrans offshore & onshore gas supply and delivery terminals.

VotransTM concept aims to tackle some of the most important obstacles companies deal with, when evolving transportation means of NG under high pressure with:

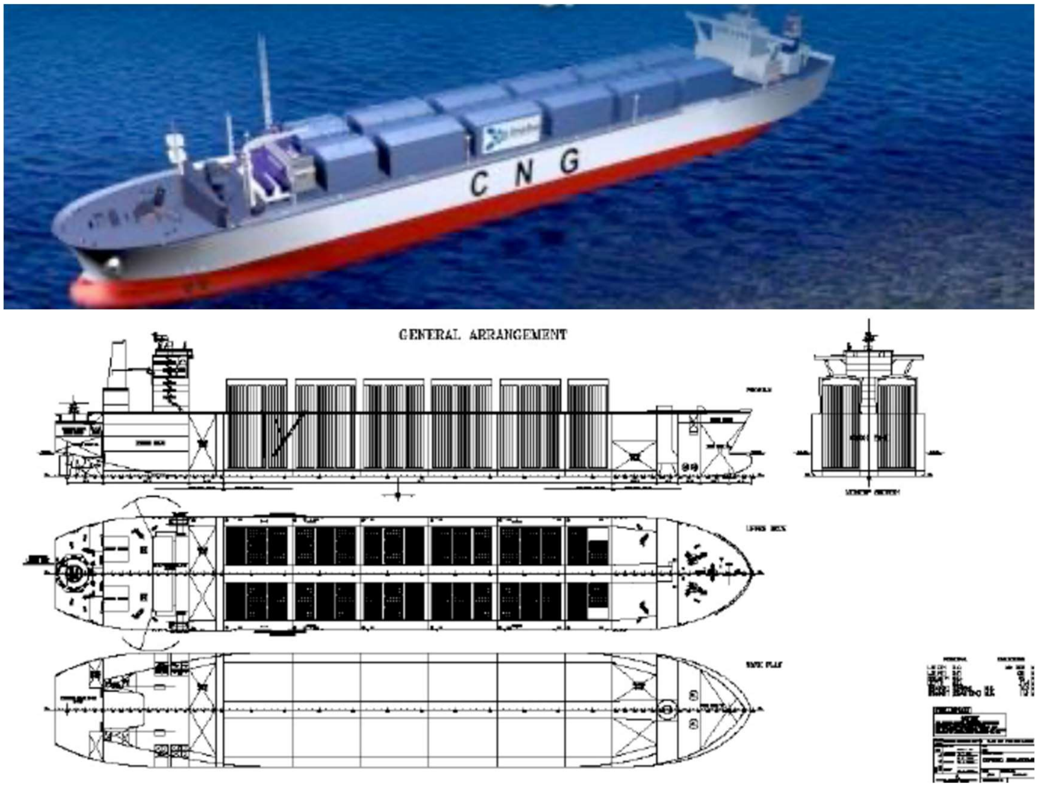
a) optimization of the gas cargo/ containment weight ratio;
b) avoidance of pressure transient conditions during gas loading;

c) minimization of the heel pressure so as to maximize the net CNG cargo capacity;

When NG is compressed to a pressure that get over the 70 bar, it exhibits non-perfect gas properties. For non-perfect gas, the ''Ideal Gas Law'' can be adjusted with the introduction of the compressibility factor (whose symbol is ‘’z’’). Thus, the expression P*V=z*R*T is revised as reported, where R is a constant, P stands for pressure, V for Volume and T for Temperature.

VotransTM concept recognized the dependence between the weight of the containment system and the z-factor effect in gas storage design. Depending on the composition of the transported gas, the system is designed to operate at the minimum compressibility factor for the gas. A temperature and pressure combination can be calculated and selected, in which the mass of the stored compressed NG is upmost in comparison to the weight of the containment system. When the temperature of the stored gas is low (lower than zero degrees Celsius), bigger gas quantities can be compressed into long tubular containers. VotransTM concept typical operation conditions are 125 bars & -30^o C. The purpose is to reduce the operating pressure that the system is operated and thus reduce the thickness of the walls on the containment cylinders (resulting lower production costs) without reducing the transportation capacity of the vessel.

EnerSea uses a patented liquid displacement system in order to monitor and control the pressure and temperature values of the gas during the whole process and the transfer of cargo into and from the cargo tanks. The cargo containment system comprises from many sets of cylinders configured into multiple tanks and tiers.



Principal Idea: Several Cylinder, configured in Tank Modules on a common Manifold under Pressurized Environment
Figure 3.4. GEV – VortransTM Concept

After the stage of compression and chilling, the gas is inerted into the vessel's containment system, flowing against a pressurized ethylene glycol/ water mixture (similar to antifreeze). The loading procedure progresses from one cylinder module to the next until all cylinders are filled. This operation is a closed loop process, in which the ethylene glycol/water solution is stored onboard in a designated tank, that requires eight (8) to ten (10) percent of the total containment system capacity. The same method is applied during cargo unloading, but for this case the ethylene glycol/ water solution is pumped in the cylinders and the gas is pumped out. In line with the manufacturer, by applying this controlled method of cargo handling, the VotransTM concept gains the below listed profits:

- ✓ the operational conditions are stable, and as a result the gas is allowed to maintain its dense phase during the whole process,
- ✓ the concept can find application to a wide range of gas compositions (rich gas with low temperature compressibility characteristics can be stored at lower pressure than lean gas in even lighter and less costly containment cylinders),
- ✓ an easily controlled loading and unloading cargo rate, by controlling the flow rate of the glycol/ water pumps,
- ✓ the use of the ethylene glycol/water solution as a piston during offloading prevents auto-cooling and drop out of natural gas during offloading,

- ✓ the back-pressure control when loading the cargo into the cylinders, which helps in the avoidance of temperature extremes caused by auto-refrigeration & heat of compression effects,
- ✓ low cost for liquid pumping in comparison to other CNG concepts,
- ✓ the use of a displacement fluid allows for lower residual gas volumes (2-5%) against 10-15% for conventional high-pressure blow-down systems.

The main principal idea in which the vessel design is based on is that several cylinders are manifolded together in a common pressure environment and controlled by the same valves, configured in tanks.

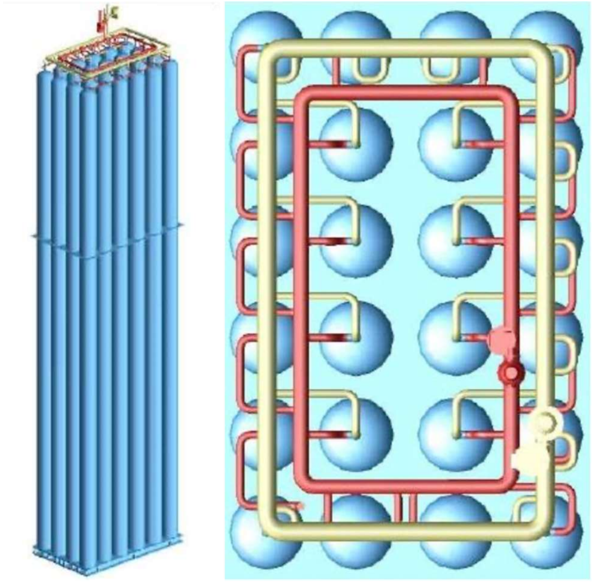


Figure 3.7. EnerSea – VotransTM Tank Module (courtesy EnerSea)

The main challenge of this concept is the design and specification of a ship able to transport 700MMscf of lean gas, which roughly is equivalent to 75000 m3 of CNG. The vertical cylinders have all manifold connections at the top of the tanks. The cargo containment systems consists of one hundred (100) cylinder modules, grouped in twelve (12) separate holds which are inerted with hydrogen for safety purposes. Each module is comprised by twenty-four (24) cylinders with the below geometrical and material characteristics:

a) Outside Diameter: 1,1-1,2 meters
b) Length: 24-36 meters
c) Wall Thickness: 0,022-0,025 meters
d) Material: API 5L X80 grade Carbon Steel

The cargo spaces are insulated by polyurethane foam in order the temperature to be kept in low levels, and over-pressurization of the cylinders because of heat ingress to be avoided. A denser layer of foam material also supports the weight of the tank modules.

The cargo handling system is positioned forward to the cargo block. For safety purposes, cargo handling process shall be away for accommodation block, thus an internal submerged turret loading/ offloading has been adapted for VotransTM concept. The design can accommodate loading/unloading at jetty or buoy system as well as uninterrupted loading or delivery. Furthermore, VotransTM concept ships can be configured to include dynamic positioning systems for connection to an efficient bow loading system, limiting the time needed for loading and unloading.

In order to expand to a wider range of clients, EnerSea has developed a range of vessels (different sizes and classes), which include the V600 and V1000 (600-1000MMscf), and as a result smaller or larger transport needs can be accommodated and the specific project requirements can be adapted each time. A horizontal pipe configuration could also be contemplated.

In continuation of the above, EnerSea Barge Concept that also uses the VotransTM concept technology targets gas delivery needs of about 10 to over 100 MMscf for transport distances that range from 50 to 75 miles. The Barge Concept design on which the company focuses, is the Articulated Tug-Barge design (ATB), where the tug is directly connected to the barge, achieving better characteristics in speed, efficiency and manoeuvring characteristics when in open seas. The CNG Barges can be constructed in almost every conventional yard worldwide, providing greater flexibility for project timing and cost competitiveness compared to the larger CNG Carrier vessels.

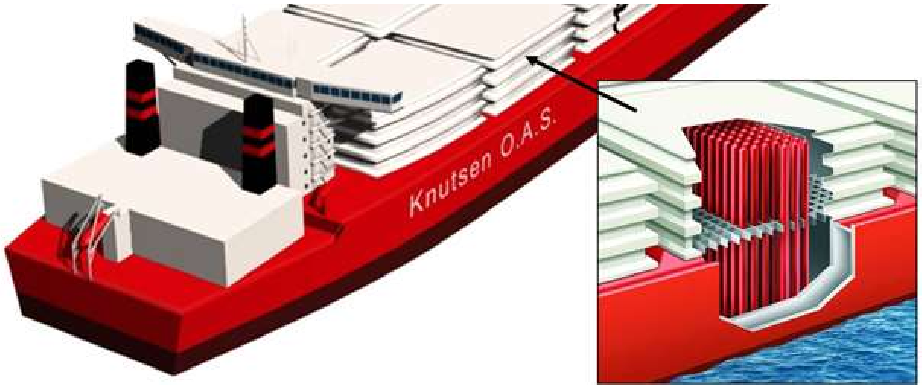
EnerSea together with Kerr-McGee Corporation took the lead to carry out a feasibility study of an innovative ultra-deep-water field development. The Gas Production and Shuttle (GPSSTM) system eliminates the infrastructure traditionally required for remote gas field development (ultra-deep-water pipelines, dedicated Floating Production Units etc). The GPSSTM fleet vessels have raw gas production and gas handling facilities onboard. The Shuttle vessel concept also serves as a storage facility for gas and liquids and, when filled to capacity, disconnects from its production buoy/mooring to deliver the gas to market.

EnerSea has completed a two and a half years research for developing a prototype testing program, witnessed and approved by ABS. This program confirmed that VotransTM containment concept was functional and operational in both a normal and a vigorous case operating scenario. With this program, it was also ensured that the materials used for the containment cylinders were capable for marine use. Approval in Principle an operating plan for the V800 V VotransTM concept vessel finally granted from ABS in 2003. ABS also confirmed that the EnerSea CNG barge system concept is within the AIP granted for V800 VotransTM concept ship.

VotransTM concept system aims to accommodate production rates in a range from 150 to 700 MMscf/d (54000 to 255000 MMscf/y) and for distances from 250 to 3000 nautical miles. Moreover, the barge concept and smaller vessel designs enable to accommodate inshore coastal markets and smaller annual production rates.

3.2.4. Knutsen PNG®

Knutsen OAS Shipping AS co-operated with Det Norske Veritas and with Europipe GmbH for the development of the PNG (Pressurized Natural Gas) system. The main principle on which the PNG® concept was developed, is to apply HP (high-pressure) gas pipeline standards (in accordance with DNV standard ''DNV-OS-F101-Submarine Pipeline Systems'') to the design of vertical CNG cylinders and simultaneously maintain an ambient temperature on the stored gas. By using the modern risk and reliability based DNV Submarine Pipeline Standard, the total weight of the cylinders' steel is reduced to 50% in comparison to the weight that the cylinders would have in case the International Gas Code (IGC) standard was used.



Principal Idea: Vertical Cylindrical Tanks of Modified Steel X80 under Ambient Temperature and 205bar Pressure
Figure 3.8. Knutsen – PNG® Concept

The main characteristics of the Vertical PNG® Cargo Tank Cylinders are the following:

- ✓ Operating Pressure: 250 Barg
- ✓ Heel Pressure: 20-30 Barg
- ✓ Cylinder Height: 18-36 meters
- ✓ Diameter: about 1 meter
- ✓ Steel Quality: Modified High Strength Steel (X80)
- ✓ Wall Thickness: 33.5 millimetres
- ✓ Operating Temperature: -25 to 50 Degrees Celsius

- ✓ 40 Year Lifetime

The cylinder tanks underwent a full-scale fatigue and burst testing. The purpose of the testing was to ensure:

- ✓ that the cylinder wall, end caps and welding have sufficient reliability against fatigue,
- ✓ that after two times the number of pressure-induced stress cycles of the design lifetime, the cylinder still has sufficient burst resistance, and
- ✓ that the system specifications are still valid with respect to accumulation and disposal of liquids.

The burst and the fatigue tests were both carried out with water in a concrete reinforced pit at the Mannesmann Research institute in Duisburg, in Germany. After the initial 4,000 fatigue load cycles, it was noticed that the burst capacity of the cylinders had not been reduced. A burst occurred only when the pressure reached 472 bars, which corresponds to 1,8 times the design pressure of the cylinder. During the full-scale fatigue tests, two different fatigue failures occurred. The first failure appeared after more than thirty thousands (30,000) cycles just across a regional weld. The second one was a fracture that occurred in the middle of a longitudinal weld after forty thousands (40,000) cycles. Both failures were caused by defects that will not be presented in the PNG® tank when filled up with a dry gas. In conclusion, both tests were considered successful, as the cylinders demonstrated fatigue capacities of 15 and 20 times the design life of 40 years respectively and the material demonstrated sufficient ductility as no unstable crack propagation or fracture occurred.

In respect of the above, an Approval in Principal for the design and fabrication of the containment system has been granted by DNV. Finally, a formal approval has been issued by DNV to Europipe GmbH as a qualified supplier of PNG® cylinders in compliance with the DNV Class Rules for Compressed Natural Gas Carriers.

For the design of the marine transportation vessel Knutsen OAS Shipping was supported by Class DNV and some independent consultants, over and above the input from several top ranked shipbuilding yards and the Europipe GmbH input for the cargo containment system. Knutsen OAS Shipping was able to price the vessels to a detailed level, enabling them to define the unit cost for NG transportation by PNG® concept vessel.

In general, the PNG® vessel is a hybrid between an ordinary crude oil tanker and a CNG container ship. Two (2) different types of vessels were developed:

a) Offshore loading and discharging PNG® vessel
b) Small terminal to terminal type PNG® vessel

The offshore loading type vessel came from Knutsen OAS prior experience with operation of oil shuttle tankers. The vessel can apply a Submerged Turret Loading (STL) system from advanced production and loading (APL) systems for gas. Other types of offshore loading systems have also been examined and evaluated and some of them have been used for offshore loading and/ or discharging. The vessel has been designed, including a specific area to facilitate the above systems with adequate space for additional facilities that could be used either for gas processing or compression.

The standard type offshore loading vessel has the carrying capacity of 2,672 PNG® cylinders with a height of about 36 meters, that corresponds to 794MMscf. The operating pressure is 250barg. The vessel has the following geometrical characteristics: length is abt. 280 meters, beam 54 meters and depth of 29 meters.

The small type PNG® vessel has a carrying capacity of about 660 cylinders approx. equivalent to 70MMscf. A larger PNG® vessel capable of transporting about 1,200 MMscf has also been developed. This vessel will be capable to achieve sailing speeds of about 17.5 knots and serve large volumes and/or long-distance deliveries. Considering the previously mentioned, it is understood Knutsen OAS has developed a generic design applicable to a large quantity of volumes and distances. These vessels are planned to be fuelled with natural gas, thus offering an environmentally friendly footprint.

In order to address the cargo containment hazards and assist to the further development of the Knutsen PNG® ship, a concept risk assessment was performed in compliance with IMO Code MSC72/16. The scope of the assessment was to determine whether the concept design was feasible and to propose measurements for the reduction of the hazards, and thus to ensure that the risks where as low as reasonably practicable (ALARP). The risk assessment concluded that in the preferred design solution the cargo deck piping shall be located in inert ducts on the upper deck ensuring the avoidance of a jet fire from deck piping leaks to escalate and to impair cargo holds and valves. The total results end up that nominal risks on the PNG® vessel are within the region of, or better than, LNG vessels.

As pee the manufacturer, one of the main advantages for the PNG® system, is the fact that the quality of gas that can be transported by the PNG® vessel is almost identical to the gas qualities which are transported through pipeline systems. In addition, PNG® vessels have the capability of transporting even richer gas quality. This would probably make PNG® vessel more inviting for markets that require the transport of smaller volumes but for long voyage distances. Case studies led to the conclusion that voyages which are characterized for distances of about 100-3,000 nautical miles and volumes of 150-500MMscf/d , the use of a PNG® vessels might be more profitable in comparison to pipelines or LNG Carriers. In respect of the above it is clear that the PNG Concept is currently in an active phase of development both technically and commercially.

3.2.5. Trans Ocean Gas

Trans Ocean Gas Inc. of ST. John’s Newfoundland in Canada (TOG) is a privately-owned company pioneer in its field, i.e. the natural gas transportation technologies development. The CNG containment method that company developed is based on the use of composite pressure vessels (CPV). CPVs have been proven safe and reliable in the defense and aerospace industry since 1970's, in the offshore oil ang gas industry and in recent years in the gas vehicle industry (public transportations). The CPVs introduced by TOG are Fibre Reinforced Plastic (FRP) pressure vessels, weighing approximately 30% less than the traditional steel ones. The company owns the patent rights for storing and transporting natural gas by road, rail and sea, with FRP pressure vessels.

The primary concept scheme of the TOG cylinders was given the name Type-4, competed the rail and road transportation. The cylinders are made up from a laminate shell made by winding high-strength carbon fibre around high-density polyethylene (HDPE) liner, that redound to the grade of safety the system has over steel systems especially for the cases that the transported natural gas includes corrosive contaminants. The containment design is completed with the addition of two corrosion resistant stainless-steel port boss at both ends of each cylinder.

The design as per above description was lightly change when was to serve the transportation of large quantities of natural gas via the sea. For this use, the material of laminate shell is replaces with HDPE, but it is wrapped with continuous lengths of high strength fibreglass. With this material and design adjustments, the containment cylinders may weight significantly more than the carbon fibre wrapped cylinders, but the production cost is decreased approximately by fifty (50) percent. This new design is able to withstand about 750bar of pressure. The allowable operating pressure is 250bar, thus meaning the safety factor applied by TOG design is three (3). The operating temperature that it can cope with , is within the range between -40 and 40 deg. Celsius.

TOG developed two different ship concepts so as to convert a conventional container into a CNG Carrier Vessel, based on the type of the cargo containment. The two (2) types of Multi-Element Gas Containers (MEGC) proposed by the company are:

a) The 40-ft ISO Shipping Container MEGC
b) The Modular Cassette System

The first concept consists of eight (8) large cylinders with an outside diameter each of 0.5 meters, protected inside an insulated 40-foot shipping container. Each MEGC has a capacity of about 225 MMscf of CNG at a pressure of 250bar and in ambient temperature. Actually cargo capacities can be deviated depending on different combinations of temperature, pressure and/ or cargo composition.For example, at a temperature of -30 deg. Celsius with a lean cargo, a capacity of about 335 MMscf could be achieved, or a rich cargo at 25 deg. Celsius will achieve a capacity of 268 MMscf. The shipping container vessel has net weight about 16 tons.

The second containment system, which seems to be more popular among the marine industry, is manufactured in modular cassettes, in order to facilitate the installation. Steel truss frames are used to house, in vertical orientation, the cylinders. Each cassette can accommodate a number of FRP cylinders. The cassettes are then stowed on top of each other and form a gas containment module. Two steel manifolds are connected for pressure vessel, one on the top of them and the one on the bottom respectively. The entire frame including the top and bottom manifolds form a storage unit. The cassette frame design has the following advantages:

- ✓ It restricts the potential for ship produced forces into the gas containment system and help isolate the gas containment system from hydro-dynamic movements and vibrations.
- ✓ It allows visual inspection (steps are also provided on the steel frames allowing inspection at every cylinder).
- ✓ It facilitates maintenance procedures for each cassette. The removal or installation of a cassette can take place without disturbing bordering cassettes.
- ✓ It provides the ability to extract natural gas liquids (NGL's) at any point during the voyage. It is noticed that NGL's are typically propane, butane, pentane and hexane.

The containment cylinders forming the cassettes have an outside diameter of abt. 1m and a length of 5 m.

Both containment methods have approximately the same cargo capacity capabilities.

Figure 3.9.1 Trans Ocean Gas Concept - MEGC

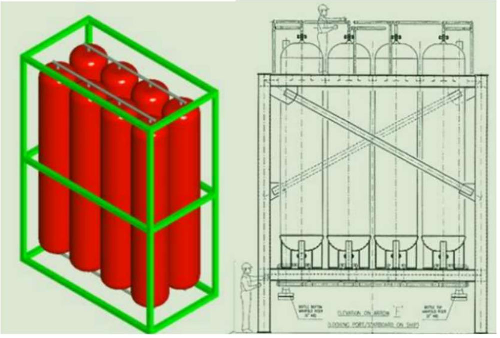


Figure 3.9.2 Trans Ocean Gas Concept – Modular Cassette System both figures courtesy Trans Ocean Gas Inc.

The development status is still considered early and preliminary, since specific ship concept designs in which the above containment systems will be adjusted have not been yet adopted, but TOG is thinking of the idea of installing the MECG Modules or 40-ft containers on a barge or a retrofitted container vessel. No further information regarding the way the pressurized gas will be handled during loading or offloading procedures has not been acknowledged by the company.

ABS granted approval in principal to the TOG concept, in September of 2003.

As per TOG some of the possible applications for the TOG MECG are the transport of natural gas from an offshore marine location or from a pipeline-restricted well, the transport of associate gas from flaring restricted areas and the transport of natural gas coming from a well that is on the stage of testing.

3.2.6. TransCanada CNG Technologies

In 2006 TransCanada CNG Technologies Ltd. cooperated with Overseas Shipholding Group Inc. (OSG) for the commercialization of a new technology for the CNG transportation. According to the agreement, OSG would have the rights to operate and own a new type of CNG Carrier, that would utilize TransCanada's patented Gas Transport Modules (GTM) for the storage of the transported CNG. This partnership created the TransCNG International (TCI).

TransCanada's concept is based on the utilization of a proprietary composite reinforced steel pressure container system manufactured under license from NCF Industries Inc. For the purpose of manufacturing the GTM an appropriate facility has been built in the Port of Saint John, New Brunswick, in Canada.

The containment system contains following materials resin, glass fibre, steel pipe and steel heads, among others. The steel shell formed from high tensile alloy (HSLA) pipeline pipe, is welded to a thicker steel head with a tapered transition piece. The shell is then over-wrapped with the high-performance laminate, extending past the transition, resulting a hoop reinforced pressure vessel.

In essence, GTM is a pressure vessel made of steel and then wrapped circumferentially exteriorly with a layer of composite material acting as a reinforcement. This reinforcement increases the weight of the cylinder about twenty percent (20%), adding to the pressure vessel's capability by one hundred percent (100%). Totally, compared to an all steel pressure vessel with the same standards, a Gas Transport Module weight is less approximately forty percent (40%) less. This is not a novel technology, as it is already in use for underground gasoline storage tanks, , mountain climber's oxygen tanks & CNG vehicle fuel tanks, fireman's breathing tanks and others.

The principal dimensions and operating characteristics of the GTM are:

- ✓ Outside diameter: 1 meter
- ✓ Length: 24 to 30 meters
- ✓ Service Pressure: 306 bar (or 3000 psi)
- ✓ Carrying capacity: 0,2 MMscf

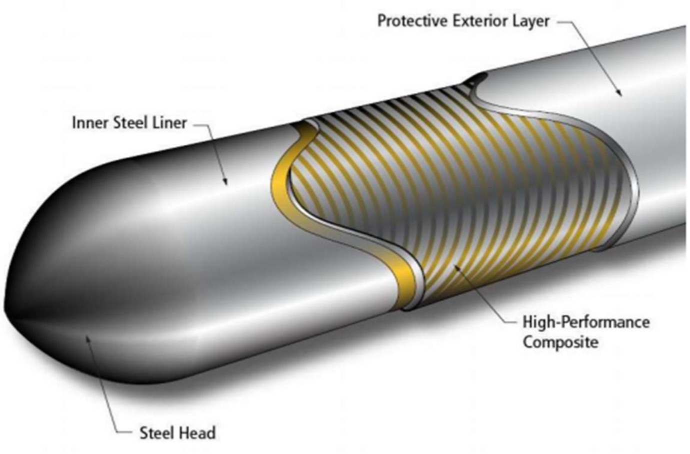


Figure 3.10. TransCanada GTM Concept
Courtesy TransCanada

Firstly, TransCanada's concept was intended for use in small vessels or even barges that would have a cargo capacity of between thirty-five (35) and one hundred (100) MMscf. The company itself claims to have investigated (in-house) models of vessels with carrying capabilities that range between one hundred (100) and one thousand six hundred (1,600) MMscf, which roughly represents a carrying capacity of about five hundred (500) to eight thousand (8,000) GTMs. For the above vessel concepts, the natural gas will be transported in pipelines with the length varying between 12,4 to 36,6 meters and with an outside diameter of about 1,04 meters. The environmental condition is defined with temperature of the cargo will be close to ambient and the pressure set at about 210 bar.

In the concept of the GTM system, several vessels will transit between the loading and unloading area continuously and one ship will be docked at the loading site and one at the unloading area. The filling process simulates the filling of a CNG tank inside a vehicle, but in a more large scale, a compressor that supplies the CNG to the vessel through high pressure loading connections, is also utilized.

In 2003 Approval in Principle for ocean going vessels was issued from Lloyd's Register and full approval of the ship design will be granted when each project is finally identified. The cylinders developed by NCF and that will contain the CNG have already been fully approved. Furthermore, granted conditional approval for inland barge operation has been granted from Classification Society American Bureau of Shipping .

The basic targeted Markets in accordance with TransCanada's initial assessment, are for low enough volumes (less than 200 MMscf) and short distances (less than 500 nautical miles).

3.2.7. Compressed Energy Technology AS

Compressed Energy Technology (CETech) is a company created in 2004 currently on the phase of developing and commercializing a innovative concept for the transportation of CNG from offshore fields to various terminals. The company is equally owned by the below three partners:

a) Statoil
b) Canadian-owned Teekay Shipping Corporation
c) Norwegian company Leif Hoegh & Co

Along with the aid from DNV, the three partners have been pursuing this project since 2002.

CETech concept design is trying to use composite materials for the fabrication of the containment cylinders, instead of the traditional high strength steel. The cylinders are currently in the process of in-depth testing, in order the final composition to be determined and to develop a fabrication method suitable for such large-scale production.

Approval Certificate from DNV has been acquired for developed CNG Concept.

Two Concepts developed:

A. Vertical, whose main characteristics listed below.

- Vertical Arrangement of cylinders built of composite material (OD=3m, L=30m) with gas stored at 150bar and ambient temperature.
- No insulation adopted for cylinders.
- Gas handling system considered during loading/offloading.
- Cargo Capacities: 250-500MMscf

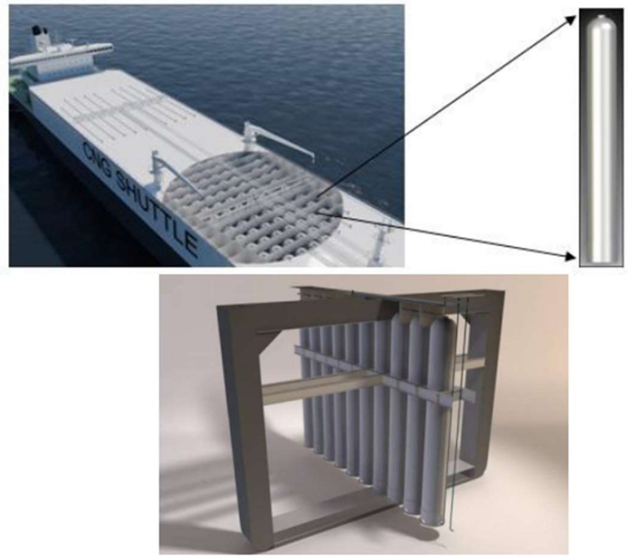


Figure 3.11. CETech Vertical Concept courtesy CETech

B. Horizontal, whose main characteristics listed below.

- Horizontal Arrangement of pipes made of X-80 HSS, OD=1.2m, L= 200m, wall thickness 36mm, cargo capacity 300-1200MMscf

Figure 3.12. CETech Longitudinal Concept
courtesy CETech

CETech is working simultaneously on two different vessel designs:

- ✓ The CNG Shuttle, that will be able to supply natural gas from a producing location to a receiving terminal pipeline or to supply associated gas from an oil producing unit to a receiving/processing terminal,
- ✓ The Shuttle Producer, the design of which targets areas that will require both production and offtake of oil and associated gas. As it is clearly understood the Shuttle Producer will be able to simultaneously transport oil and compressed natural gas.

The idea on which the designs for both concepts have been based on is the separation of the CNG storage system from the CNG Carrier vessel's hull.

The CNG Shuttle design itself is separated in two different concepts, which are mainly deviated with respect to the orientation of the containment cylinders. In the first design a vertical cylinder containment arrangement is used whereas the second concepts based on a horizontal pipe system. The main characteristics of each containment system design are presented in the following summary table.

Characteristics		Configurations	
		Vertical	Horizontal
Containment Cylinder	Outside diameter (m)	3	1.2
	Length (m)	30	200
	Pipe Material	-	HT Steel X-80
	Wall Thickness	-	36
Carrying Capacity (MMscf)		250-500	300-1,200
Operating Pressure (Barg)		150	250
Operating temperature (deg. C)		25	-

Table 3.1. CETech Configurations Comparison
courtesy CETech

Further to the above designs, CETech together with Hexagon Lincoln from Lincoln Nebraska, research the possibility for utilizing the TITAN compressed NG modules for the development of a CNG Carrier design.

The TITAN cylinders, consist of a HDPE liner, a filament wound carbon fibre/ epoxy composite shell, constituting the main structural element of the container, and an outer shell of polyurethane coating. The cylinder’s total weighing is calculated about seventy five percent less than the equivalent steel cylinders.

The two companies are contemplating the conversion of an existing vessel so as to be able to transport approximately 150 containers (TITANTM4), each container equipped with four (4) TITAN cylinders. As a result, the proposed design concept would have a transport capacity of about 50 MMscf at an operating pressure of 250 barg.

Approval in Principal has been granted by Det Norske Veritas (DNV) for the developed CNG Concept and the ISO container modules are already ABS certified for onshore and offshore/ marine transportation of Compressed Natural Gas.

As per the company their CNG design's target is a transport market serving a range between 300 to 2000 nautical miles with a respective production rate of 18000 MMscf/y and 100000 MMscf/y. In such combinations of transport5ation distances and production volumes their design is considered to be gainful.

3.2.8. *Comparison of CNG Carrier Concepts*

Item	Characteristics	GEV Canada Corporation Coselle® System	GEV Canada Corporation Optimum® Technology
1	Type of Containment	Coiled X-80 steel pipe forming a carousel	API 5LX80 steel pipe
2	Arrangement	Coselles® in C.H.	Horizontal in C.H.
3	Gas Pressure (bar)	200-275	200 - 250
4	Gas Temperature (deg.°C)	Ambient	Ambeint
5	Cargo/ Container (weight ratio)	0.12 - 0.18	0.40
6	Development stage	Advanced Concept Stage	Advanced Concept Stage for 200 MMscf
7	Transport Capacity (MMscf)	65 - 530	200 - 450

Table 3.2. Comparison of CNG Carrier Concepts

Item	Characteristics	Enersea Vortrans™	Knutsen PNG®
1	Type of Containment	X-80 steel cylinders	X-80 steel cargo tank cylinders
2	Arrangement	Vertical tank modules or horizontal pipes	Vertically stacked
3	Gas Pressure (bar)	125	250
4	Gas Temperature (deg.°C)	Minus 30	Ambient
5	Cargo/ Container (weight ratio)	0.35 – 0.39	0.21
6	Development stage	Advanced Concept Stage	Concept Stage
7	Transport Capacity (MMscf)	75 - 1000	70 – 1200

Table 3.2 (continue). Comparison of CNG Carrier Concepts

Item	Characteristics	Trans Ocean Gas	TransCanada CNG Technologies
1	Type of Containment	Composite HDPE and fiberglass cylinders (MEGC)	Composite Reinforced Steel GTMs

2	Arrangement	Container of modular cassettes with vertical cylinders	GTMs stacked
3	Gas Pressure (bar)	250	206
4	Gas Temperature (deg.°C)	Ambient / minus 30	Ambient
5	Cargo/ Container (weight ratio)	0.34 – 0.47	1.5
6	Development stage	Concept Stage for MEGC Container only	Concept Stage
7	Transport Capacity (MMscf)	255	12 - 100

Table 3.2 (continue). Comparison of CNG Carrier Concepts

Item	Characteristics	CETech
1	Type of Containment	Composite or X-80 steel pipe
2	Arrangement	Vertical / Horizontal
3	Gas Pressure (bar)	150 – 250
4	Gas Temperature (deg.°C)	Ambient / minus 30
5	Cargo/ Container (weight ratio)	0.70 (composite) / 0.24 (X-80 steel)
6	Development stage	Concept Stage
7	Transport Capacity (MMscf)	250 – 500 (composite) 300 – 1200 (steel)

Table 3.2 (continue). Comparison of CNG Carrier Concepts

4. Financial Appraisal Model

4.1. Chapter's Introduction

The specific chapter deals with the analysis of the Project Appraisal Methodology which is presented in detail, in the following pages, making special reference to the Financial project Appraisal, the various techniques and criteria for the financial appraisal for investing in a project: the Net Present Value (NPV), the Internal Rate of Return (IRR), the Capital Recovery Factor (CRF), the Payback period (PP) and the Profitability Index.

4.2. Definitions & Characteristics of the Financial Project Appraisal

The development of a business, even its ability to remain competitive and ultimately to survive in a competitive market, depends on the degree upon which it seeks ideas to create new products, to improve existing ones or to minimize its operating costs (Brigham, Ehrhardt, 2006). The process of deciding on strategic investments, it involves the identification, evaluation, and choice between the alternative projects, which are likely to have a major impact on the business's competitive advantage (Keat, Young, 2003).

An investment is utilizing monetary means taken from the company's available funding sources in acquiring assets, which are intended to remain in the business for a long period of time. The decision for an investment can affect the company on three levels, the activities in which it is involved, i.e. the products and services it offers, the geographical area and the way in which it operates. The need for a strategic investment decision making process thus becomes more than obvious. If the investment proves successful, the business will enjoy great strategic and operational advantages. On the other hand, if the investment turns out to be wrong, either a great opportunity for business development will be lost, or the business will have wasted significant resources without reaping any benefits (Freeman, 2003).

According to Sakkas (2002), the financial project appraisal, is an extremely complex process which by its own nature is intertwined with a significant degree of uncertainty and inherent risks. The financial project appraisal is a small part of the whole process, which revolves around the concept of investment cash flows and is a useful analytical tool.

The financial project appraisal as a whole is based on the deep understanding of the company and its business environment (market) as well as on issues of strategy that the company, in a subjective way, poses. For example, the expediency of developing a new generation of products or services (e.g. third generation mobile services) is made with assumptions and strategic considerations that are difficult to substantiate (Girola, 2005). That is, the financial project appraisal is necessarily based on too many economic, commercial, and productive assumptions.

It includes the following two main procedures, (a) the identification of all income (inputs) and expenses (outputs), related to the investment (cash flow analysis) and (b) the use of methods and criteria, based on which the above inputs and outputs can be evaluated (capital budgeting decision methods) (Brigham, Ehrhardt, 2006).

The first process, the identification of the expected income and expenses of the investment, it is the most difficult, involves the greatest uncertainty about the conclusions of the evaluation and involves people of various specializations, in order to design the necessary "working cases". The second process has a detailed character, which aims to process the data and assumptions of the first phase. However, it is worth noting that the financial evaluation of an investment helps and does not determine the relevant business decision (Freeman, 2003). When considering investing in an investment program, a company has to make two types of decisions:

a) the former refers to one accepting or rejecting the investment plan, and
b) the second in the way of financing the investment program.

The process of deciding on a strategic investment, includes all the financial elements that one encounters in the process of a cost-benefit analysis. The four stages of such a process include the identification of alternative investments, the quantitative analysis of cumulative cash flows, the qualitative analysis of items not included in the cash flows and the final decision to accept or reject the investment. These four stages are interrelated and there should be no final decision without due consideration being given to each one of them. The identification of alternative investments is related to the needs that the company has, and which must be met in order to strengthen its position in relation to the competition (Davis, 2002).

Business organizations have resources for investment, which fall into three broad categories (Girola, 2005):

- ✓ Investments for replacements and improvements of fixed assets, which have been devalued. The initial idea for such investments usually comes from people who use these fixed assets and can immediately understand their problems.
- ✓ Investments to expand the activities of an enterprise, either to meet growing market needs or to increase market share. The idea for these investments comes from opportunities offered by the external environment and usually comes from senior management.
- ✓ Investments related to strategic moves of the company. These investments are examined in depth and essentially concern the survival of the company. The idea comes from senior management.

Once the brainstorming phase has been completed, some alternative investment plans should be considered in relation to the financial impact they will have on the organization if implemented.

In order to examine the financial implications, it is necessary to gather information on both the cost of the investment and the financial benefits that will result from its successful implementation. The company's financial records for past investments and discussions with the competent staff & the company’s managers are useful for investments related to improvements and replacements of fixed assets or expansion of the organization. However, in the case of strategically important investments, due to their difficulty and the fact that they occur only once, this information is of minor importance and the internal and external environment of the company should be carefully considered in order to gather the necessary data. It is necessary to study the market conditions and the movements of the competitors in order to assure the executives that the investment will be in the interest of the company and to compare the possible benefits that its successful implementation will bring in opposition to the benefits of the alternative plans (Davis, 2002).

4.3. The Net Present Value (NPV)

The Net Present Value is based on the technique of discounted cash flows. This method shows the contribution of the investment to the value of the business. The process, at first, involves the establishment of the present value of cash outflows and inputs by discounting them on the capital cost of the investment. These cash flows are then added algebraically, and their sum is the Net Present Value of the investment. Alternatively, the net present value of an investment program, is equal to the present value of the expected cash flows (outflows and inputs) discounted at an interest rate proportional to the investment risk (Brigham, Ehrhardt, 2006).

This method takes into account the time value of money, discounts the weighted average cost of capital and is expressed in monetary amounts while relying on the degree of return of the investment plan and the requirements of the company's shareholders. One disadvantage of the criterion is the assumption that the weighted average cost remains constant throughout the investment. The formula for the Net Present Value of an investment project is as follows:

$$NPV\left(i,N\right)=\sum_{t=0}^{N}\frac{R_t}{\prod_{k=0}^{t}(1+i_k)}$$

where:

i_t: It is the discount rate in a given time period t. When referring to the present (reference year=year 0), t=0, so $i_0=0$. Discount rate is a rate in which cash flows are discounted in order to find present value.

N : It is the number that shows the economic life of the investment in years. Economic life is the expected period of time during which an asset is useful to the average owner. The economic life of an asset could be different from its actual physical life.

R_t: It is the net cash flow=cash inflow-cash outflow in a given time period t. When in present (t=0), then $R_0<0$, because a large amount of money is spent at the beginning of the investment creating an initial outflow.

In the above equation, CFt is the net recurring cash flow during period t, k is the capital cost of the investment plan and n is its duration. If the Net Present Value is positive (greater than zero), then the investment plan must be accepted. If the firm accepts a program with a positive net present value, then the cash flow of the program yields an additional return on demand (i.e., the investment generates more money than is required to cover the cost of the investment), which leads to an increase in of the company's market capitalization and this cash surplus belongs exclusively to the shareholders. Therefore, the investment in question improves the financial position of the shareholders (Keat, Young, 2003).

If the Net Present Value is equal to zero, then the investment program is marginal. If the company accepts a program with zero net present value, then the size of the company increases, but not its value. Net Present Value equal to zero means that the inflows from the investment are just enough to cover the cost of the invested capital (investment cost) and to provide the shareholders with the required degree of return for this capital. If the Net Present Value is negative (less than zero), then the investment plan should not be accepted. If the company accepts a program with a negative net present value, then both its size and market value are reduced (Freeman, 2003).

4.4. The Internal Rate of Return (IRR)

The Internal Rate of Return is defined as the discount rate that equals the present value of the cash inflows that will result from the investment to the present value of the outputs required for its implementation. If the Internal Rate of Return resulting from the equation of discounted cash inflows and outflows is greater than the capital cost of the investment, then the investment should be accepted. Otherwise, the investment plan is rejected (Davis, 2002).

The Internal Rate of Return on Invested Capital is essentially the expected return on investment. Internal efficiency is the interest rate that equates the present value of cash flows with the initial cost. The method recognizes the time related value of money and offers a security measure to evaluate the return related to the risk of each investment program. However, it does not provide a precise picture on the full contribution of the investment, but a relative one, since future flows should be estimated. The equation on the basis of which the Internal Rate of Return of an investment is obtained is:

If i_t = i =constant, then NPV(i)=$\sum_{t=0}^{N} \frac{Rt}{(1+i)^t}$

If NPV(i)=0 then i=IRR

Where CFt is the net revised cash flow during period t, IRR is the required Internal Rate of Return on the investment plan and n is its duration. Therefore, if the Internal Rate of Return is greater than the capital cost of the investment, then the investment program must be accepted and there will be a surplus which will remain in the possession of the shareholders, after the investment costs are repaid.

Therefore, the acceptance of a plan with an Internal Rate of Return greater than its capital cost, implies an increase in the wealth of shareholders. If the Internal Rate of Return is equal to the cost of capital of the investment, then the investment plan is marginal while if the Internal Rate of Return is less than the cost of capital of the investment, then the investment plan should not be accepted (Keat, Young, 2003).

4.5. The Capital Recovery Factor (CRF)

For special cases of investments where in year 0 capital K is disbursed and henceforth the net income per period is E, the criterion of the capital recovery rate (CRR) can be used. The CRF is directly related to the size of capital needs for the initial investment & the expected net annual income from the latter, as shown below:

$$CRF = \frac{IRR * (1 + IRR)^{N}}{(1 + IRR)^{N} - 1}$$

or $$CRF = \frac{E}{K}$$

where:

E: the cash flow for each time period (as defined, it is the same every time period t)
K: the initial cash outflow which is necessary to run the project.

4.6. The Payback Period (PP)

The Payback Period (PP) is a very common criterion, which is related to how fast (in time) an investment "makes its money". It is defined as the number of years until the net return on investment equals its initial cost. According to this criterion, the investment with the shortest repayment period is preferred. It is obvious that from an economic point of view this criterion is not so serious. It ignores the time value of money and the scale of the investment (Davis, 2002).

4.7. The Profitability Index (IP)

The equation from which the Efficiency Index is derived is the following:

$$PI = \frac{PRESENT\ VALUE\ OF\ FUTURE\ CASH\ FLOWS}{INITIAL\ INVESTMENT\ REQUIRED} = 1 + \frac{NET\ PRESENT\ VALUE}{INITIAL\ INVESTMENT\ REQUIRED}$$

As mentioned before, it is the current worth of future cash flows at a discount rate. The difference between NPV and PV is that in the second, the initial sum of money being invested is not taken into account. Hence, the mathematical formula that relates these two is the following:

$$PV = NPV + INITIAL\ INVESTMENT$$

An investment is accepted from a financial point of view, if its Profitability Index is higher than the unit. The method of the Profitability Index is closely related to the Net Present Value approach, since for example, if the present value of cash flows exceeds the initial investment, the net present value will be positive and the Profitability Index will be greater than one, which means that the investment should be accepted (Davis, 2002).

5. Techno-Economic Feasibility for a CNG Transport Model

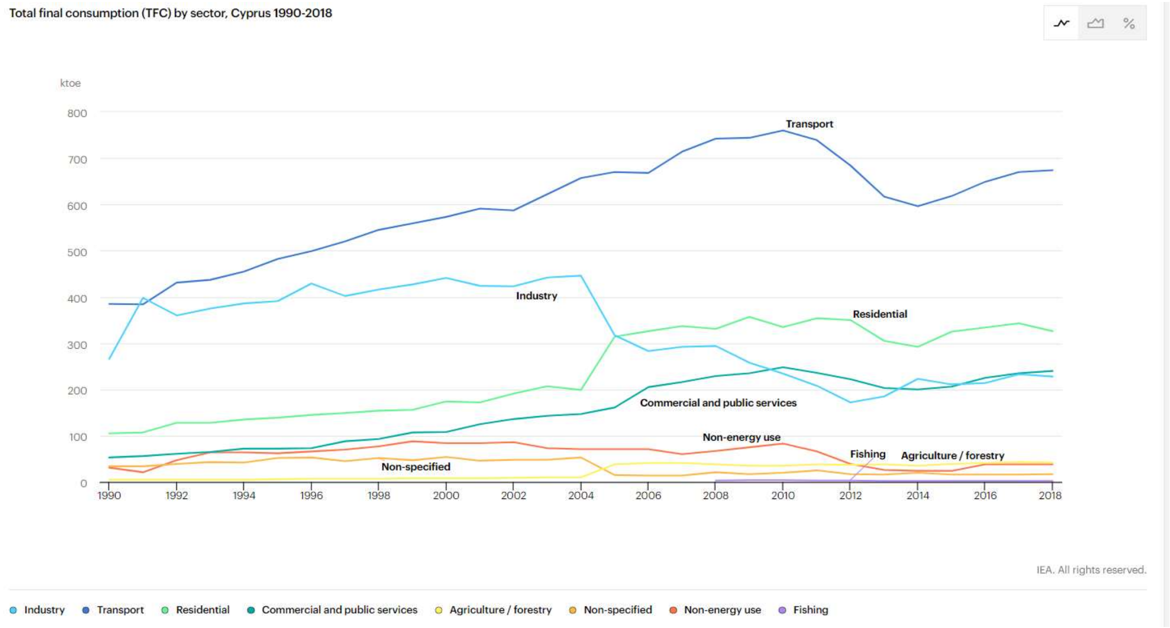
5.1. Chapter Introduction

In the following chapter an economic and technical feasibility of the partial accommodation of the Natural Gas needs of Cyprus will be presented. The CNG marine transport model consists of a Modified General Cargo vessel that will be able to transport Compressed Natural Gas via specially designed containers from an assumed feed terminal located in Thessaloniki, Greece to an assumed receiving terminal located in Limassol, Cyprus. The model covers a distance of 669,7 nautical miles (Marine Traffic – Voyage Planner) and has a constantly changing capacity of Natural Gas per year, based on Thessaloniki's NG energy demand. The techno-economic feasibility will include two different viewpoints, the first one is based on the Ship Owner/Operator the vessel of whom will transport the Compressed Natural Gas from the loading terminal to the receiving terminal and the second of the Ship Owner and the Charterer willing to charter the modified General Cargo vessel.

5.2. Input Data & Assumptions

The economic and technical feasibility study that is carried out in the current diploma thesis is based on the assumption that the construction of the two (2) under investigation vessels is approximately three (3) years. In continuation, the life span of the specific project will be twenty (20) years specifically extended from 2020 to 2042.

Moreover, the demand for Cyprus is considered based on the available information from ''International Energy Agency, Cyprus - Countries & Regions - IEA. Based on the Table 3.1. the Total Energy Demand in 2018 is depicted to be 1567 ktoe which is equal to 18224210000 kWh. For the feasibility study it is assumed a rise of demand about 10% until 2023. The NG Market is assumed to serve a 5,5% of the Total Energy Sector and in order to have a safe approach in regard to the share of demand satisfied with CNG, is 20% of the NG demand in Cyprus, as the rest will be covered from LNG. Finally, a yearly growth 2% is assumed and the results for the demand are presented in Table 5.2 which summarizes the demand of Natural Gas that is going to be served through our project).



Total final consumption (TFC) by sector, Cyprus 1990-2018

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Table 5. 1: Calculated gas demand for selected industrial customers

Demand of Natural Gas in Cyprus			Precentage of Demand accomodated by CNG	Demand accomodated in our case Study	Demand accomodated in our case Study
Year	kWh	MMscf	-	kWh	MMscf
2020	Vessel & Infastructure ongoing				
2021					
2022					
2023	1103825578	3663,597095	20%	220765115,672226	732,72
2024	1125902090	3736,869036	20%	225180417,985670	747,37
2025	1147978601	3810,140978	20%	229595720,299115	762,03
2026	1170055113	3883,41292	20%	234011022,612559	776,68
2027	1192131625	3956,684862	20%	238426324,926004	791,34
2028	1214208136	4029,956804	20%	242841627,239448	805,99
2029	1236284648	4103,228746	20%	247256929,552893	820,65
2030	1258361159	4176,500688	20%	251672231,866337	835,30
2031	1280437671	4249,77263	20%	256087534,179782	849,95
2032	1302514182	4323,044572	20%	260502836,493226	864,61
2033	1324590694	4396,316513	20%	264918138,806671	879,26
2034	1346667206	4469,588455	20%	269333441,120115	893,92
2035	1368743717	4542,860397	20%	273748743,433560	908,57
2036	1390820229	4616,132339	20%	278164045,747004	923,23
2037	1412896740	4689,404281	20%	282579348,060449	937,88
2038	1434973252	4762,676223	20%	286994650,373893	952,54
2039	1457049763	4835,948165	20%	291409952,687338	967,19
2040	1479126275	4909,220107	20%	295825255,000782	981,84
2041	1501202787	4982,492049	20%	300240557,314227	996,50
2042	1523279298	5055,763991	20%	304655859,627671	1011,15

Table 5. 2: Calculated gas demand for selected commercial customers

The transportation of the Natural Gas from the terminal in Thessaloniki to Cyprus, will be handled for our under investigation CNG vessel which carries CNG in containers. For this purpose, a General Cargo vessel with an appropriate capacity which was selected from a range of different sizes. Specifically, between the available vessel sizes and corresponding capacities, a General Cargo vessel with 7,500-10,,000 DWT has been selected as it closely matches our CNG project specifications. The service speed for the vessel will be assumed to be 12.5knots with an average fuel consumption of 8,295 t/day.

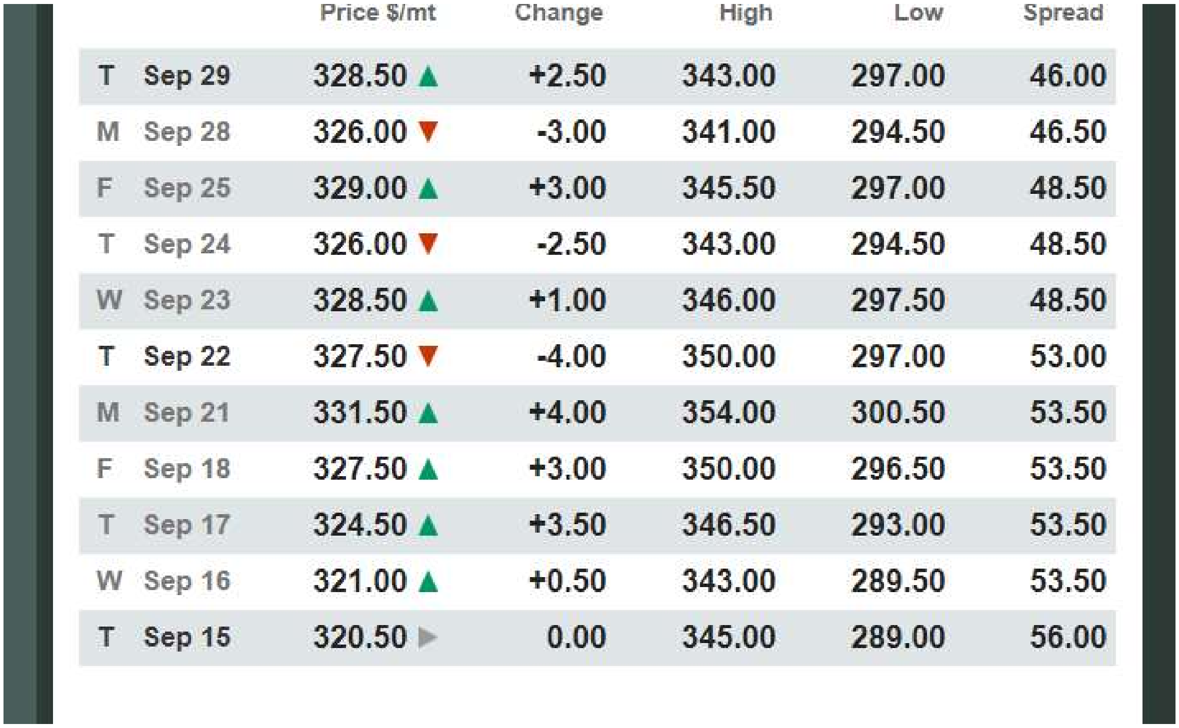
The CNG vessels' total cycle time for the voyage that is going to be traveled is approximately 114 hours, as shown in the below breakdown list:

- ✓ 2 hours of loading time
- ✓ 54 hours of sailing to the receiving terminal
- ✓ 1 hour of mooring and connecting
- ✓ 2 hours of discharging
- ✓ 54 hours of sailing back to the loading terminal
- ✓ 1 hour of mooring and connecting

As a result, it is understood that in order to facilitate Thessaloniki with a constant supply of CNG, two (2) CNG carrying vessels are needed.

The approach for the vessel's capital cost will be in line with the calculation method as proposed by David Stenning (Coselle CNG: Economics and Opportunities, 2000). For this purpose, the initial cost of a General Cargo Vessel with the capacity as selected above, will be adjusted incorporating the additional cost for the containers and the relevant equipment needed for transporting, handling and storage the CNG containers. Following these steps, it is noted that a general cargo with transporting capacities serving our needs, i.e. 7,500-10,000 DWT) is considered to have a capital cost approximately ten (10) million US Dollars. It is assumed that the modifications which are necessary in order the vessel to be capable for CNG containers' transportation is about the half price of the New Building General Cargo. As a result, the total capital cost for each of the two under study vessels is estimated fifteen (15) million US Dollars.

For the economic and technical feasibility study, the following input data are also considered for the capex and opex in order cash flow to be determined yearly. Firstly, the Capital expenditure of the project is assumed to be paid in three installments, 40% in 2020, 40% in 2021 and finally 20% of the ships' total cost in 2022. Moreover, in the context of the present study, it is assumed that the vessels' operational costs are equal to 2% of the capital cost. As a result, the operational costs for both vessels are deemed 600,000 US Dollars and the terminal fees are assumed 20,000 euros per Berth. An other important operation cost in also the fuels needed for the vessels' voyages for which the prices for VLSFO are retrieved from [Piraeus Bunker Prices - Ship & Bunker (shipandbunker.com)]() as summarized in Table 5.3.



		Price $/mt	Change	High	Low	Spread
T	Sep 29	328.50 ▲	+2.50	343.00	297.00	46.00
M	Sep 28	326.00 ▼	-3.00	341.00	294.50	46.50
F	Sep 25	329.00 ▲	+3.00	345.50	297.00	48.50
T	Sep 24	326.00 ▼	-2.50	343.00	294.50	48.50
W	Sep 23	328.50 ▲	+1.00	346.00	297.50	48.50
T	Sep 22	327.50 ▼	-4.00	350.00	297.00	53.00
M	Sep 21	331.50 ▲	+4.00	354.00	300.50	53.50
F	Sep 18	327.50 ▲	+3.00	350.00	296.50	53.50
T	Sep 17	324.50 ▲	+3.50	346.50	293.00	53.50
W	Sep 16	321.00 ▲	+0.50	343.00	289.50	53.50
T	Sep 15	320.50 ▶	0.00	345.00	289.00	56.00

Table 5. 3: VLSFO Price-Ship & Bunker

Certainly, the under study vessels are deviating from conventional CNG carriers, with respect to the containment system. In this respect, containers cost shall be also included. Firstly, the quantity of containers that fill the cargo hold capacity and serve the market's needs shall be calculated. Considering that an average container capacity is 89 TEU and TITAN4 containers, which are used in the current study, are double in length, it is estimated that approximately forty-five (45) TITAN4 containers per roundtrip are needed. Moreover, four (4) sets of 45 TITAN4 containers are assumed to be used for a constant provision of Natural Gas to be ensured. The information for the containers' price, capex and opex should remain enclosed due to legal binding with the production company.

5.3. Case Study A – Ship Owner/ Operator Scope

In Case Study A, the economic and technical feasibility study and the project are carried out in view of the Ship Owner/Operator scope and willing to build the General Cargo vessels and accommodate the needs of the project in CNG. The minimum charging price of Natural Gas to the receiving Terminal was calculated so as the Net Present Value (NPV) of the project to be equal to zero for three different discount rates (i=6%, 8%, 10%).

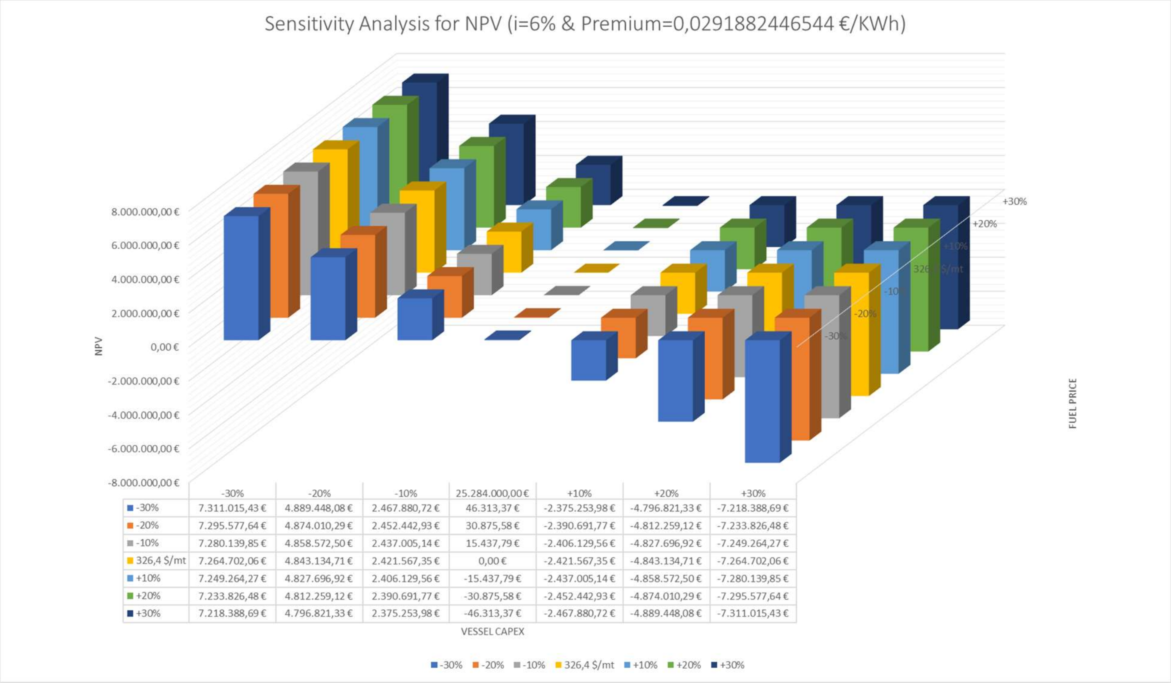
For this case study, the costs which have been taken into consideration capital cost for building the vessels, capital cost for acquiring the TITAN4 containers, terminal fees per year and operational costs for the vessels and containers. Regarding the fuels needed to serve the specific market which serves, the round trips needed to cover demand needs per year were calculated and taking into consideration typical values for Main Engine Consumption and VLSO price, the final costs were calculated.

The methodology adopted for the feasibility study can be described as follows. By adding the costs which have been listed above, and dividing the summary with the quantity of Natural Gas delivered to the terminal of Limassol. The minimum price for the Natural Gas transportation in €/KWh was calculated, so as the NPV to be zero. The same method was followed for three different discount rates i=6%, 8% & 10% and the result for the price for each case is as shown below:

- ✓ For i=6%, the minimum premium was found to be 0,0291882446544 €/KWh
- ✓ For i=8%, the minimum premium was found to be 0,03518210463487 €/KWh
- ✓ For i=10%, the minimum premium was found to be 0,04184213406814 €/KWh

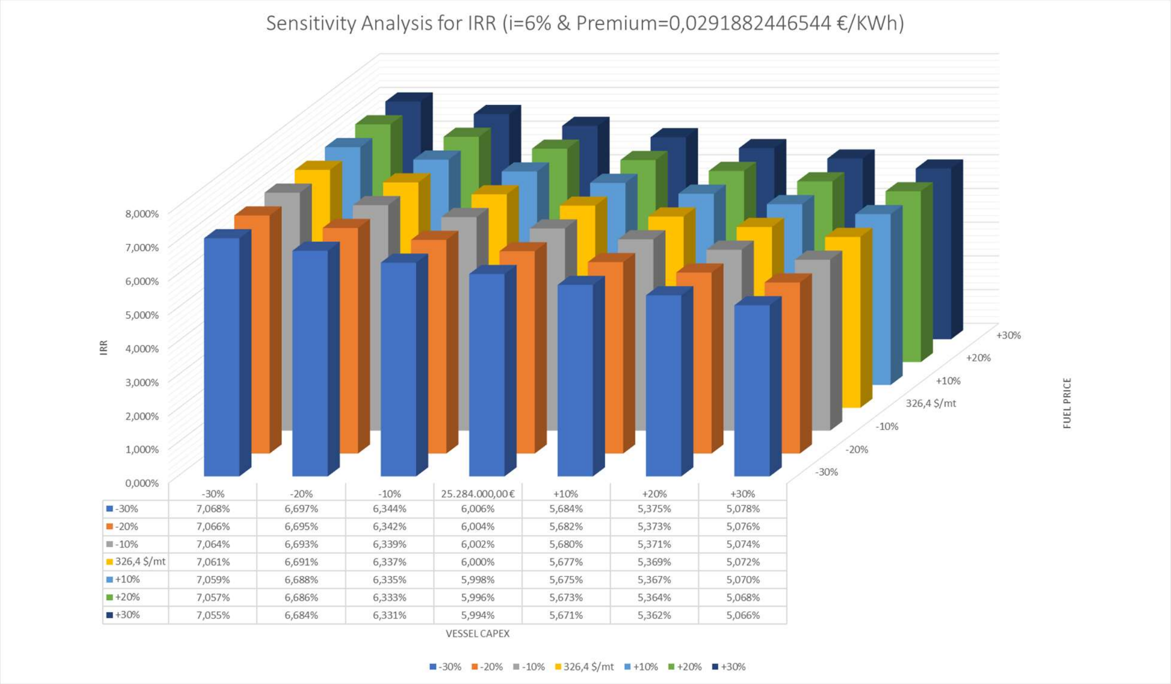
Following the above results, the price was taken into consideration to the study in order the actual NPV and IRR to be calculated. The new price is multiplied with the amount of Natural Gas in order the positive financial flow to be included. To conclude the first case study a sensitivity analysis followed, for the NPV and IRR values of the project, by fluctuating the vessels' CAPEX and Fuel Price from -30% of the current prices to +30%.

The results are presented diagrammatically in Charts 5.1 to Chart 5.6.



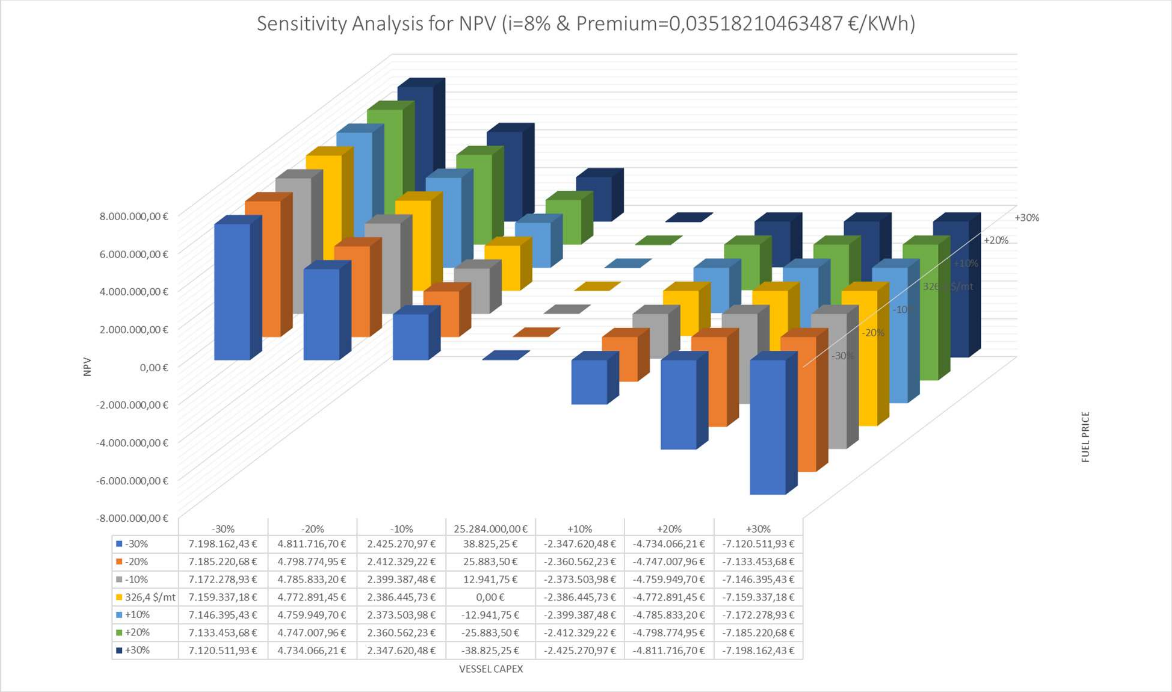
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	7.311.015,43 €	4.889.448,08 €	2.467.880,72 €	46.313,37 €	-2.375.253,98 €	-4.796.821,33 €	-7.218.388,69 €
■ -20%	7.295.577,64 €	4.874.010,29 €	2.452.442,93 €	30.875,58 €	-2.390.691,77 €	-4.812.259,12 €	-7.233.826,48 €
■ -10%	7.280.139,85 €	4.858.572,50 €	2.437.005,14 €	15.437,79 €	-2.406.129,56 €	-4.827.696,92 €	-7.249.264,27 €
■ 326,4 $/mt	7.264.702,06 €	4.843.134,71 €	2.421.567,35 €	0,00 €	-2.421.567,35 €	-4.843.134,71 €	-7.264.702,06 €
■ +10%	7.249.264,27 €	4.827.696,92 €	2.406.129,56 €	-15.437,79 €	-2.437.005,14 €	-4.858.572,50 €	-7.280.139,85 €
■ +20%	7.233.826,48 €	4.812.259,12 €	2.390.691,77 €	-30.875,58 €	-2.452.442,93 €	-4.874.010,29 €	-7.295.577,64 €
■ +30%	7.218.388,69 €	4.796.821,33 €	2.375.253,98 €	-46.313,37 €	-2.467.880,72 €	-4.889.448,08 €	-7.311.015,43 €

Chart 5. 1: Sensitivity Analysis for NPV (i=6% & Premium=0,0291882446544 €/Kwh)



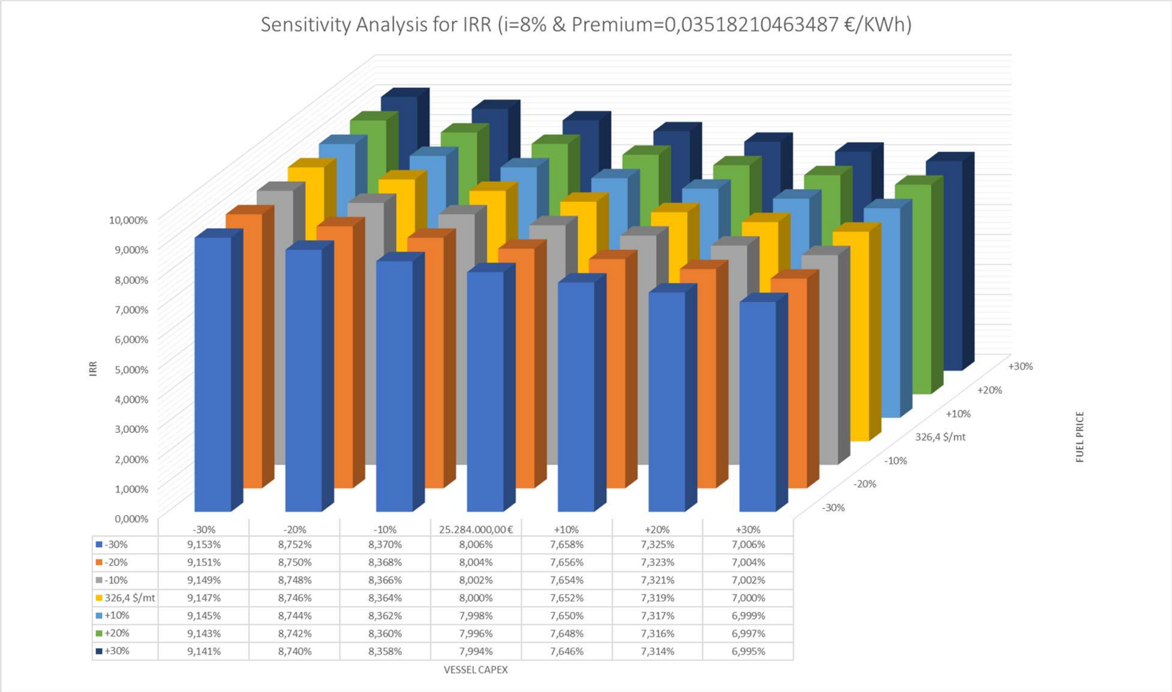
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	7,068%	6,697%	6,344%	6,006%	5,684%	5,375%	5,078%
■ -20%	7,066%	6,695%	6,342%	6,004%	5,682%	5,373%	5,076%
■ -10%	7,064%	6,693%	6,339%	6,002%	5,680%	5,371%	5,074%
■ 326,4 $/mt	7,061%	6,691%	6,337%	6,000%	5,677%	5,369%	5,072%
■ +10%	7,059%	6,688%	6,335%	5,998%	5,675%	5,367%	5,070%
■ +20%	7,057%	6,686%	6,333%	5,996%	5,673%	5,364%	5,068%
■ +30%	7,055%	6,684%	6,331%	5,994%	5,671%	5,362%	5,066%

Chart 5. 2: Sensitivity Analysis for IRR (i=6% & Premium=0,0291882446544 €/Kwh)



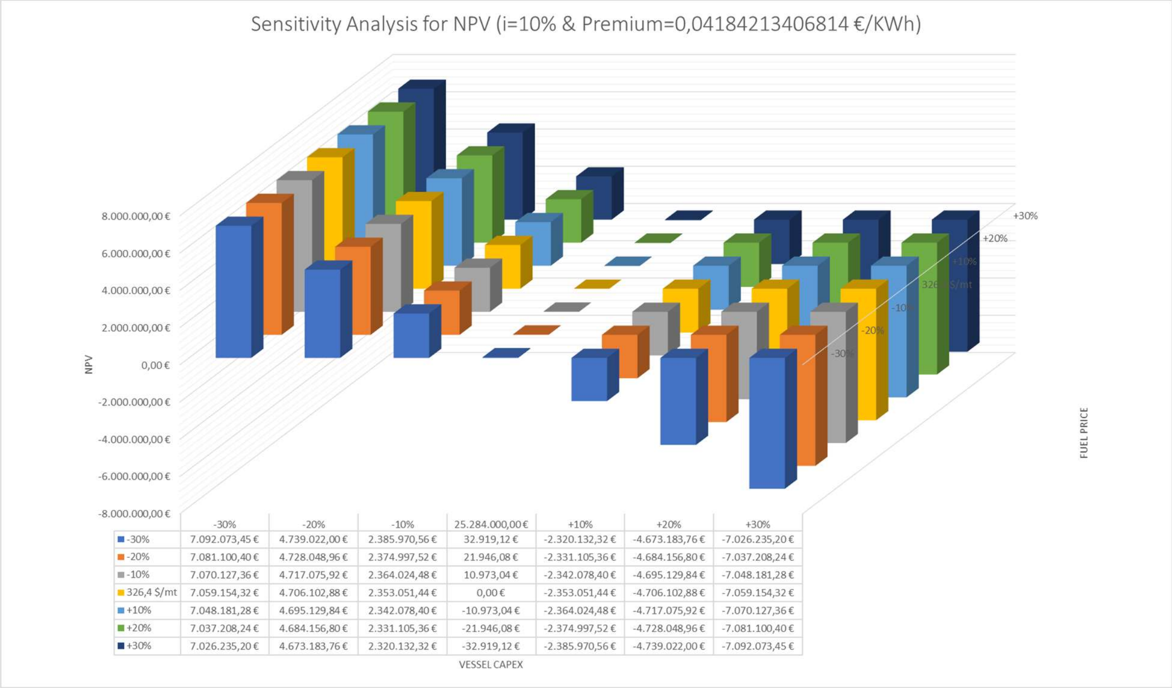
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	7.198.162,43 €	4.811.716,70 €	2.425.270,97 €	38.825,25 €	-2.347.620,48 €	-4.734.066,21 €	-7.120.511,93 €
■ -20%	7.185.220,68 €	4.798.774,95 €	2.412.329,22 €	25.883,50 €	-2.360.562,23 €	-4.747.007,96 €	-7.133.453,68 €
■ -10%	7.172.278,93 €	4.785.833,20 €	2.399.387,48 €	12.941,75 €	-2.373.503,98 €	-4.759.949,70 €	-7.146.395,43 €
■ 326,4 $/mt	7.159.337,18 €	4.772.891,45 €	2.386.445,73 €	0,00 €	-2.386.445,73 €	-4.772.891,45 €	-7.159.337,18 €
■ +10%	7.146.395,43 €	4.759.949,70 €	2.373.503,98 €	-12.941,75 €	-2.399.387,48 €	-4.785.833,20 €	-7.172.278,93 €
■ +20%	7.133.453,68 €	4.747.007,96 €	2.360.562,23 €	-25.883,50 €	-2.412.329,22 €	-4.798.774,95 €	-7.185.220,68 €
■ +30%	7.120.511,93 €	4.734.066,21 €	2.347.620,48 €	-38.825,25 €	-2.425.270,97 €	-4.811.716,70 €	-7.198.162,43 €

Chart 5. 3: Sensitivity Analysis for NPV (i=8% & Premium=0,03518210463487 €/Kwh)



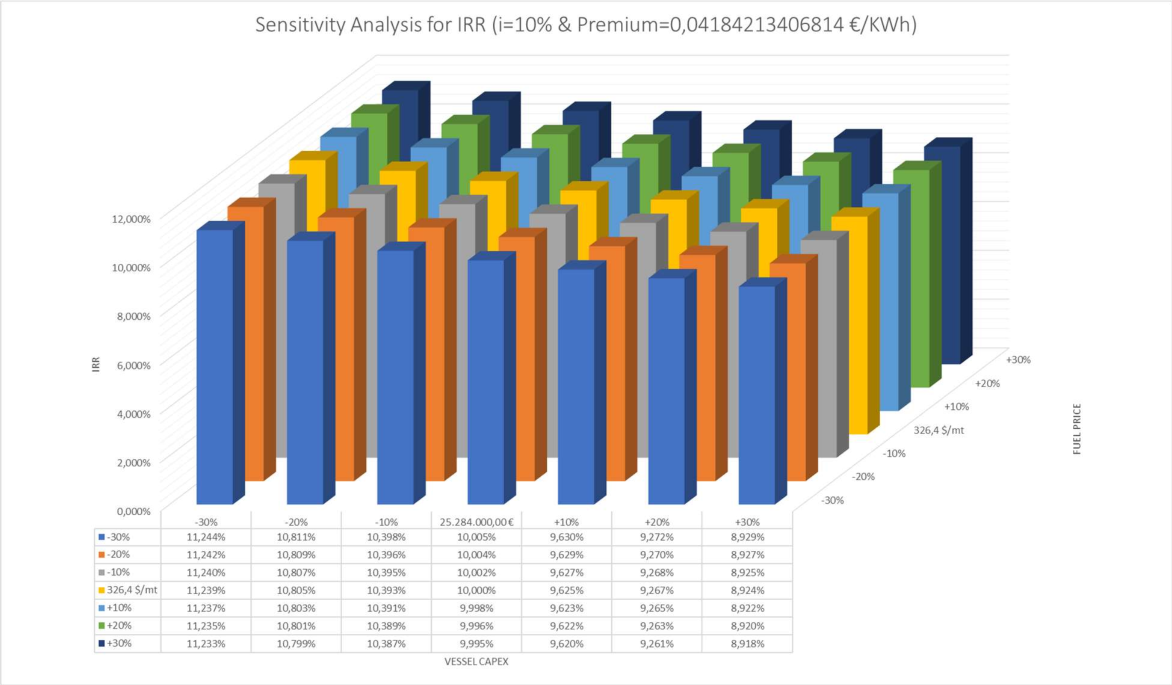
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	9,153%	8,752%	8,370%	8,006%	7,658%	7,325%	7,006%
■ -20%	9,151%	8,750%	8,368%	8,004%	7,656%	7,323%	7,004%
■ -10%	9,149%	8,748%	8,366%	8,002%	7,654%	7,321%	7,002%
■ 326,4 $/mt	9,147%	8,746%	8,364%	8,000%	7,652%	7,319%	7,000%
■ +10%	9,145%	8,744%	8,362%	7,998%	7,650%	7,317%	6,999%
■ +20%	9,143%	8,742%	8,360%	7,996%	7,648%	7,316%	6,997%
■ +30%	9,141%	8,740%	8,358%	7,994%	7,646%	7,314%	6,995%

Chart 5. 4: Sensitivity Analysis for IRR (i=8% & Premium=0,03518210463487 €/Kwh)



	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
-30%	7.092.073,45 €	4.739.022,00 €	2.385.970,56 €	32.919,12 €	-2.320.132,32 €	-4.673.183,76 €	-7.026.235,20 €
-20%	7.081.100,40 €	4.728.048,96 €	2.374.997,52 €	21.946,08 €	-2.331.105,36 €	-4.684.156,80 €	-7.037.208,24 €
-10%	7.070.127,36 €	4.717.075,92 €	2.364.024,48 €	10.973,04 €	-2.342.078,40 €	-4.695.129,84 €	-7.048.181,28 €
326,4 $/mt	7.059.154,32 €	4.706.102,88 €	2.353.051,44 €	0,00 €	-2.353.051,44 €	-4.706.102,88 €	-7.059.154,32 €
+10%	7.048.181,28 €	4.695.129,84 €	2.342.078,40 €	-10.973,04 €	-2.364.024,48 €	-4.717.075,92 €	-7.070.127,36 €
+20%	7.037.208,24 €	4.684.156,80 €	2.331.105,36 €	-21.946,08 €	-2.374.997,52 €	-4.728.048,96 €	-7.081.100,40 €
+30%	7.026.235,20 €	4.673.183,76 €	2.320.132,32 €	-32.919,12 €	-2.385.970,56 €	-4.739.022,00 €	-7.092.073,45 €

Chart 5. 5: Sensitivity Analysis for NPV (i=10% & Premium=0,04184213406814 €/Kwh)



	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
-30%	11,244%	10,811%	10,398%	10,005%	9,630%	9,272%	8,929%
-20%	11,242%	10,809%	10,396%	10,004%	9,629%	9,270%	8,927%
-10%	11,240%	10,807%	10,395%	10,002%	9,627%	9,268%	8,925%
326,4 $/mt	11,239%	10,805%	10,393%	10,000%	9,625%	9,267%	8,924%
+10%	11,237%	10,803%	10,391%	9,998%	9,623%	9,265%	8,922%
+20%	11,235%	10,801%	10,389%	9,996%	9,622%	9,263%	8,920%
+30%	11,233%	10,799%	10,387%	9,995%	9,620%	9,261%	8,918%

Chart 5. 6: Sensitivity Analysis for IRR (i=10% & Premium=0,04184213406814 €/Kwh)

5.4. Case Study B – Ship Owner & Ship Charterer Scope

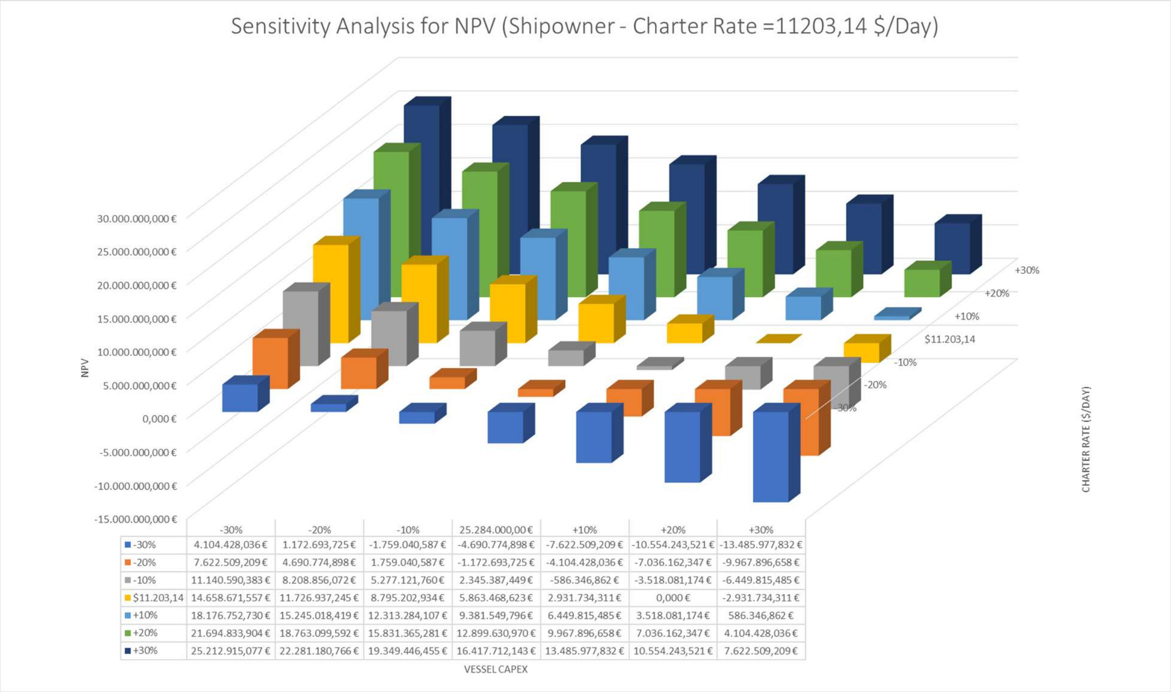
In the second case study the project was examined from the scope of the Ship Owner willing to build the modified General Cargo vessels and then charter them to a Ship Operator that will use them to accommodate the needs of the project.

Firstly, the Required Frate Rate (RFR) of the two vessels was calculated, so as a minimum Charter Rate to be identified. By adding up the capital cost for building the vessels and the operational costs of the vessels and retract them from RFR an NPV equal to zero for three different discount rates (i=6%, 8%, 10%) was calculated. Following the provided results, it was also assumed that the charter rate for the vessels increased by 20%. The initial and final results for RFR are presented in the below table.

i (%)	RFR ($/ Day)	1.2 x RFR ($/ Day)
6	9.335,949932157	11.203,1399185884
8	10.840,3366458738	13.008,4039750486
10	12.495,1741022749	14.994,2089227299

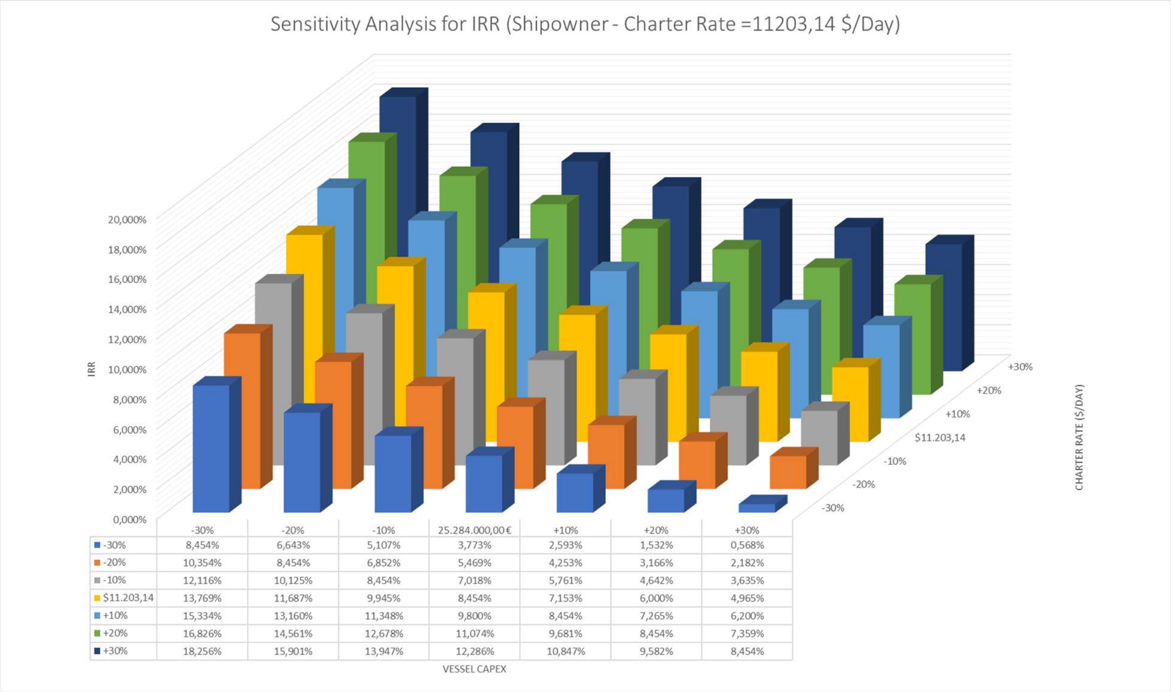
The calculation for the NPV and IRR for the Ship Owner, taking into account the newly estimated Charter Rates, was conducted and a sensitivity analysis followed by fluctuating the CAPEX and Charter Rates from -30% of the current prices to +30%.

The results are presented diagrammatically in Charts 5.7 to Chart 5.12.



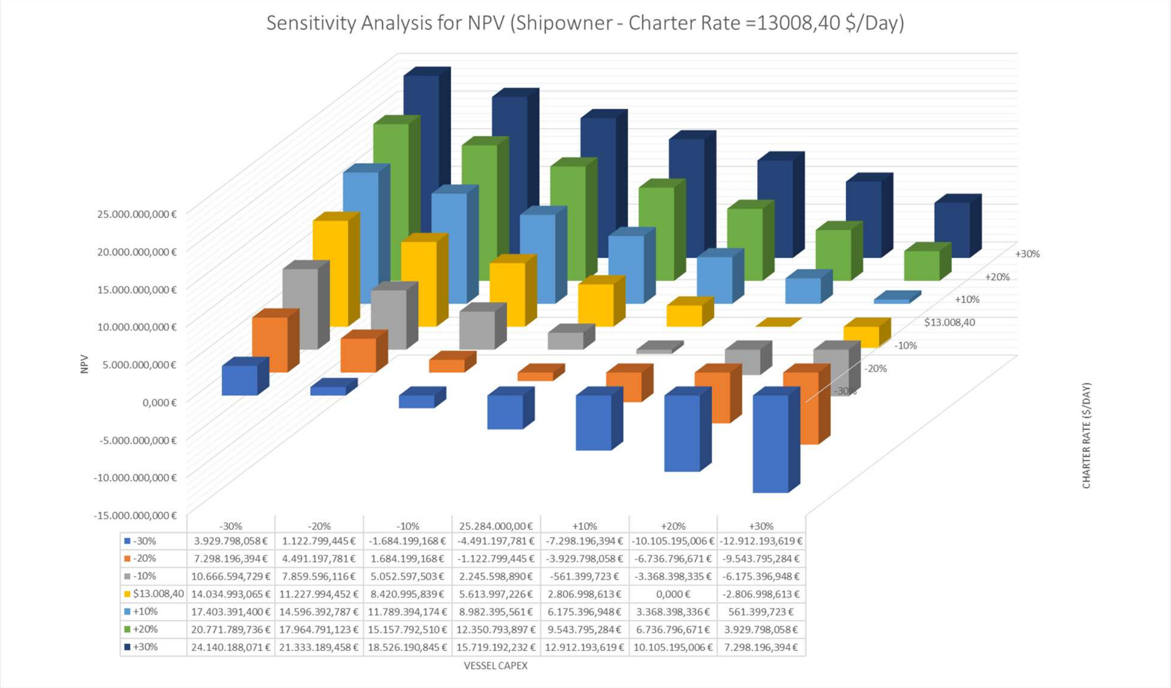
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	4.104.428,036 €	1.172.693,725 €	-1.759.040,587 €	-4.690.774,898 €	-7.622.509,209 €	-10.554.243,521 €	-13.485.977,832 €
■ -20%	7.622.509,209 €	4.690.774,898 €	1.759.040,587 €	-1.172.693,725 €	-4.104.428,036 €	-7.036.162,347 €	-9.967.896,658 €
■ -10%	11.140.590,383 €	8.208.856,072 €	5.277.121,760 €	2.345.387,449 €	-586.346,862 €	-3.518.081,174 €	-6.449.815,485 €
■ $11.203,14	14.658.671,557 €	11.726.937,245 €	8.795.202,934 €	5.863.468,623 €	2.931.734,311 €	0,000 €	-2.931.734,311 €
■ +10%	18.176.752,730 €	15.245.018,419 €	12.313.284,107 €	9.381.549,796 €	6.449.815,485 €	3.518.081,174 €	586.346,862 €
■ +20%	21.694.833,904 €	18.763.099,592 €	15.831.365,281 €	12.899.630,970 €	9.967.896,658 €	7.036.162,347 €	4.104.428,036 €
■ +30%	25.212.915,077 €	22.281.180,766 €	19.349.446,455 €	16.417.712,143 €	13.485.977,832 €	10.554.243,521 €	7.622.509,209 €

Chart 5. 7: Sensitivity Analysis for NPV (Shipowner – Charter Rate=11.203,14 $/Day)



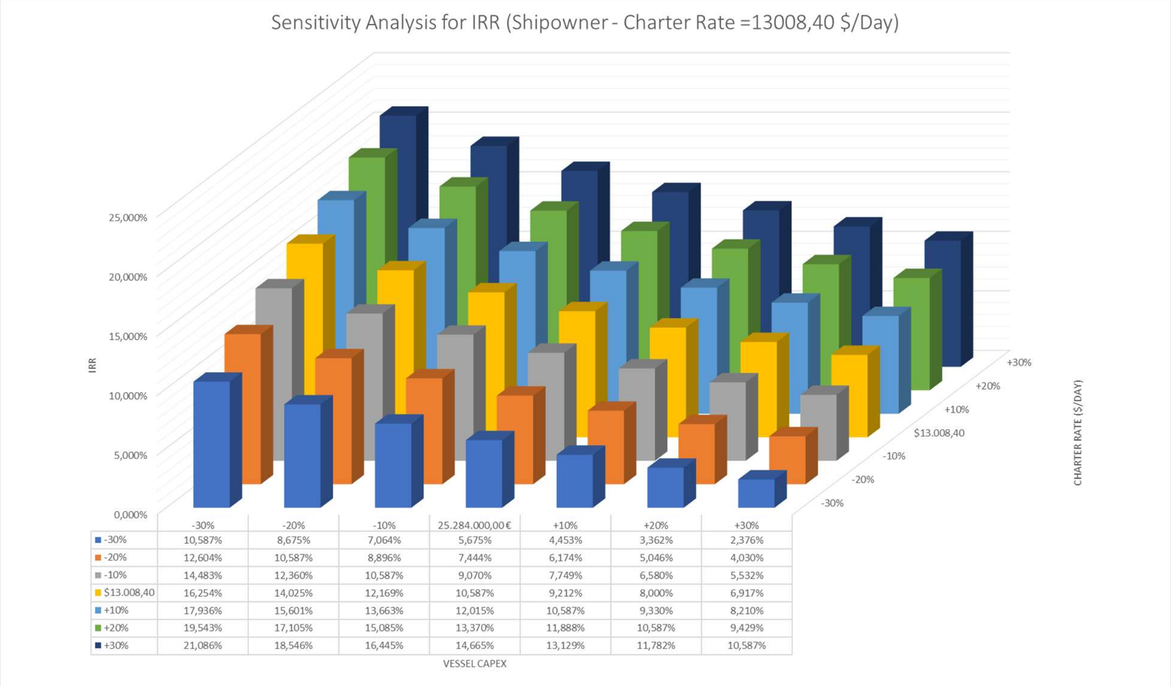
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	8,454%	6,643%	5,107%	3,773%	2,593%	1,532%	0,568%
■ -20%	10,354%	8,454%	6,852%	5,469%	4,253%	3,166%	2,182%
■ -10%	12,116%	10,125%	8,454%	7,018%	5,761%	4,642%	3,635%
■ $11.203,14	13,769%	11,687%	9,945%	8,454%	7,153%	6,000%	4,965%
■ +10%	15,334%	13,160%	11,348%	9,800%	8,454%	7,265%	6,200%
■ +20%	16,826%	14,561%	12,678%	11,074%	9,681%	8,454%	7,359%
■ +30%	18,256%	15,901%	13,947%	12,286%	10,847%	9,582%	8,454%

Chart 5. 8: Sensitivity Analysis for IRR (Shipowner – Charter Rate=11.203,14 $/Day)



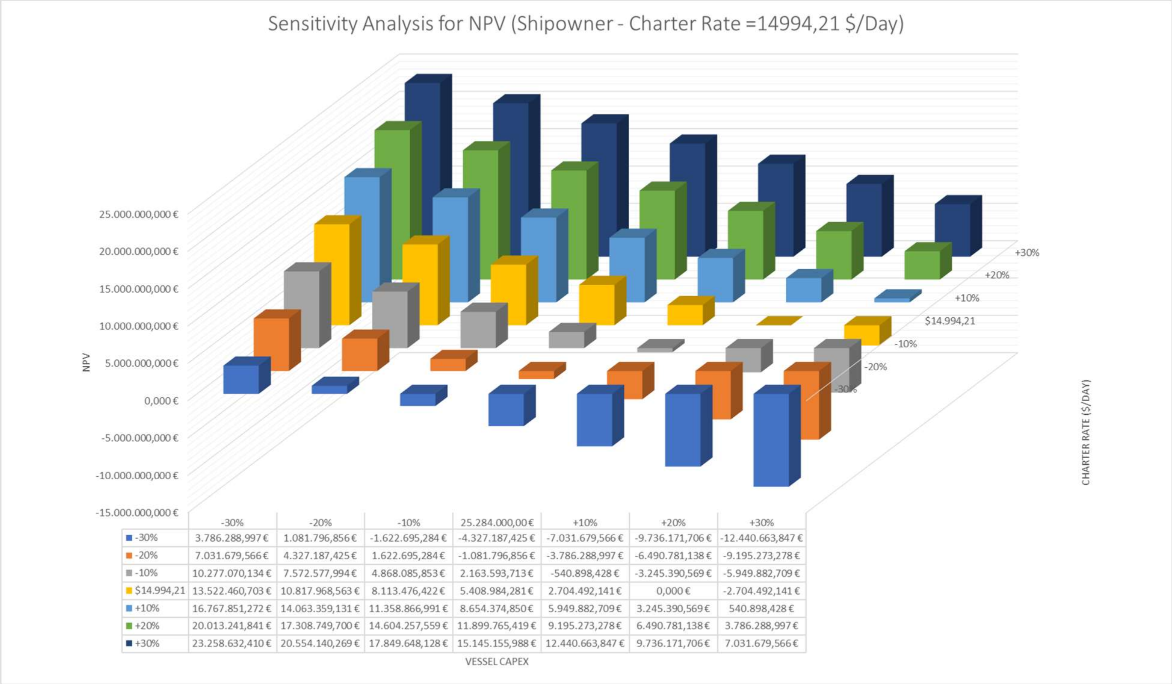
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	3.929.798,058 €	1.122.799,445 €	-1.684.199,168 €	-4.491.197,781 €	-7.298.196,394 €	-10.105.195,006 €	-12.912.193,619 €
■ -20%	7.298.196,394 €	4.491.197,781 €	1.684.199,168 €	-1.122.799,445 €	-3.929.798,058 €	-6.736.796,671 €	-9.543.795,284 €
■ -10%	10.666.594,729 €	7.859.596,116 €	5.052.597,503 €	2.245.598,890 €	-561.399,723 €	-3.368.398,335 €	-6.175.396,948 €
■ $13.008,40	14.034.993,065 €	11.227.994,452 €	8.420.995,839 €	5.613.997,226 €	2.806.998,613 €	0,000 €	-2.806.998,613 €
■ +10%	17.403.391,400 €	14.596.392,787 €	11.789.394,174 €	8.982.395,561 €	6.175.396,948 €	3.368.398,336 €	561.399,723 €
■ +20%	20.771.789,736 €	17.964.791,123 €	15.157.792,510 €	12.350.793,897 €	9.543.795,284 €	6.736.796,671 €	3.929.798,058 €
■ +30%	24.140.188,071 €	21.333.189,458 €	18.526.190,845 €	15.719.192,232 €	12.912.193,619 €	10.105.195,006 €	7.298.196,394 €

Chart 5. 9: Sensitivity Analysis for NPV (Shipowner – Charter Rate=13.008,40 $/Day)



	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	10,587%	8,675%	7,064%	5,675%	4,453%	3,362%	2,376%
■ -20%	12,604%	10,587%	8,896%	7,444%	6,174%	5,046%	4,030%
■ -10%	14,483%	12,360%	10,587%	9,070%	7,749%	6,580%	5,532%
■ $13.008,40	16,254%	14,025%	12,169%	10,587%	9,212%	8,000%	6,917%
■ +10%	17,936%	15,601%	13,663%	12,015%	10,587%	9,330%	8,210%
■ +20%	19,543%	17,105%	15,085%	13,370%	11,888%	10,587%	9,429%
■ +30%	21,086%	18,546%	16,445%	14,665%	13,129%	11,782%	10,587%

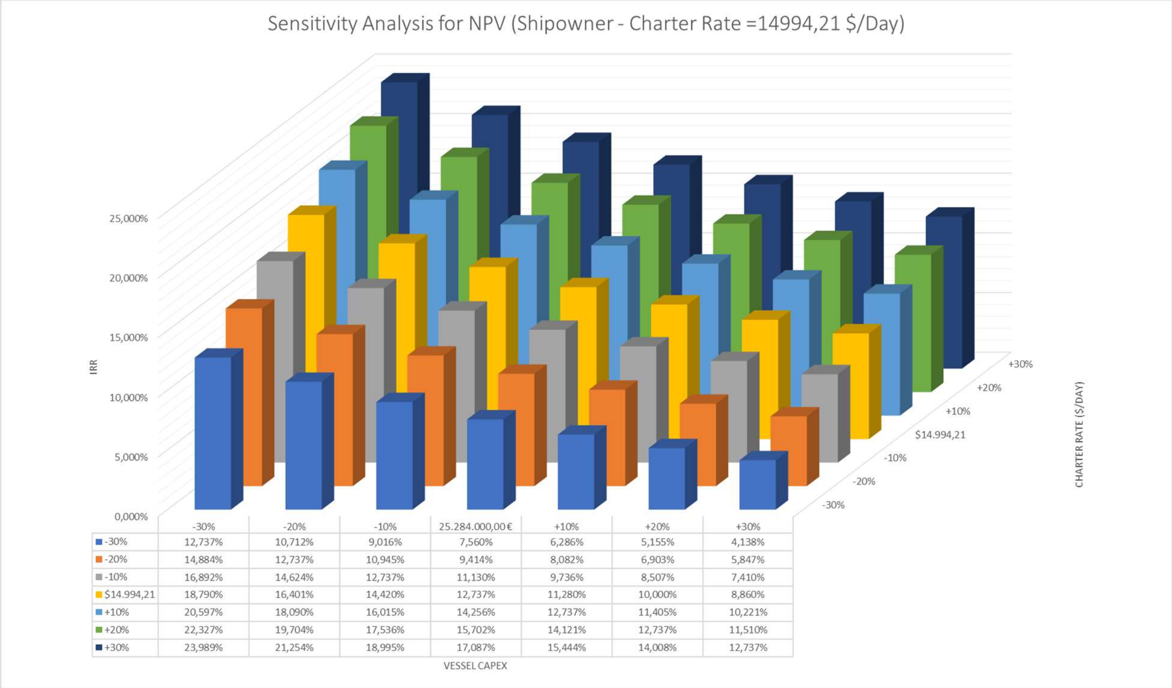
Chart 5. 10: Sensitivity Analysis for IRR (Shipowner – Charter Rate=13.008,40 $/Day)



	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	3.786.288,997 €	1.081.796,856 €	-1.622.695,284 €	-4.327.187,425 €	-7.031.679,566 €	-9.736.171,706 €	-12.440.663,847 €
■ -20%	7.031.679,566 €	4.327.187,425 €	1.622.695,284 €	-1.081.796,856 €	-3.786.288,997 €	-6.490.781,138 €	-9.195.273,278 €
■ -10%	10.277.070,134 €	7.572.577,994 €	4.868.085,853 €	2.163.593,713 €	-540.898,428 €	-3.245.390,569 €	-5.949.882,709 €
■ $14.994,21	13.522.460,703 €	10.817.968,563 €	8.113.476,422 €	5.408.984,281 €	2.704.492,141 €	0,000 €	-2.704.492,141 €
■ +10%	16.767.851,272 €	14.063.359,131 €	11.358.866,991 €	8.654.374,850 €	5.949.882,709 €	3.245.390,569 €	540.898,428 €
■ +20%	20.013.241,841 €	17.308.749,700 €	14.604.257,559 €	11.899.765,419 €	9.195.273,278 €	6.490.781,138 €	3.786.288,997 €
■ +30%	23.258.632,410 €	20.554.140,269 €	17.849.648,128 €	15.145.155,988 €	12.440.663,847 €	9.736.171,706 €	7.031.679,566 €

VESSEL CAPEX

Chart 5. 11: Sensitivity Analysis for NPV (Shipowner – Charter Rate=14.994,21 $/Day)



	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
■ -30%	12,737%	10,712%	9,016%	7,560%	6,286%	5,155%	4,138%
■ -20%	14,884%	12,737%	10,945%	9,414%	8,082%	6,903%	5,847%
■ -10%	16,892%	14,624%	12,737%	11,130%	9,736%	8,507%	7,410%
■ $14.994,21	18,790%	16,401%	14,420%	12,737%	11,280%	10,000%	8,860%
■ +10%	20,597%	18,090%	16,015%	14,256%	12,737%	11,405%	10,221%
■ +20%	22,327%	19,704%	17,536%	15,702%	14,121%	12,737%	11,510%
■ +30%	23,989%	21,254%	18,995%	17,087%	15,444%	14,008%	12,737%

VESSEL CAPEX

Chart 5. 12: Sensitivity Analysis for IRR (Shipowner – Charter Rate=14.994,21 $/Day)

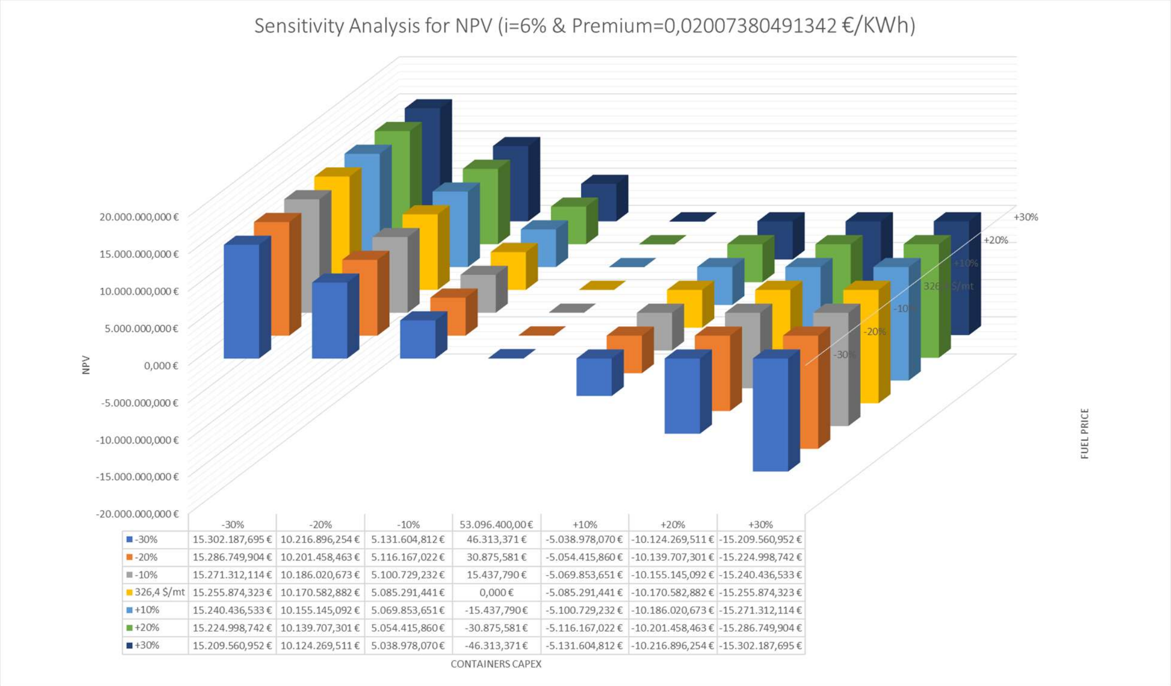
Now, the methodology is as per for the Case A. For the charteter the costs which have been considered are the capital costs for acquiring the TITAN4 containers, the operational costs for the containers, terminal fees per year. Moreover, the necessary round trips were calculated based on each year's demands and considering Main Engine consumption and VLSFO price the fuel costs were computed.

By adding up the costs and dividing them with the NG quantity delivered to the receiving terminal in Thessaloniki, the cost of the transported Natural Gas in €/KWh was estimated. In the above price a minimum premium was added, and the new price was multiplied with the amount of Gas delivered and the projects income was calculated, so as the NPV to be null. The same method was followed for three different discount rates i=6%, 8% & 10%, using the three different charter rates.

- ✓ For i=6%, the minimum premium was found to be 0,02007380491342 €/KWh.
- ✓ For i=8%, the minimum premium was found to be 0,02414386810096 €/KWh.
- ✓ For i=10%, the minimum premium was found to be 0,02866446557018 €/KWh.

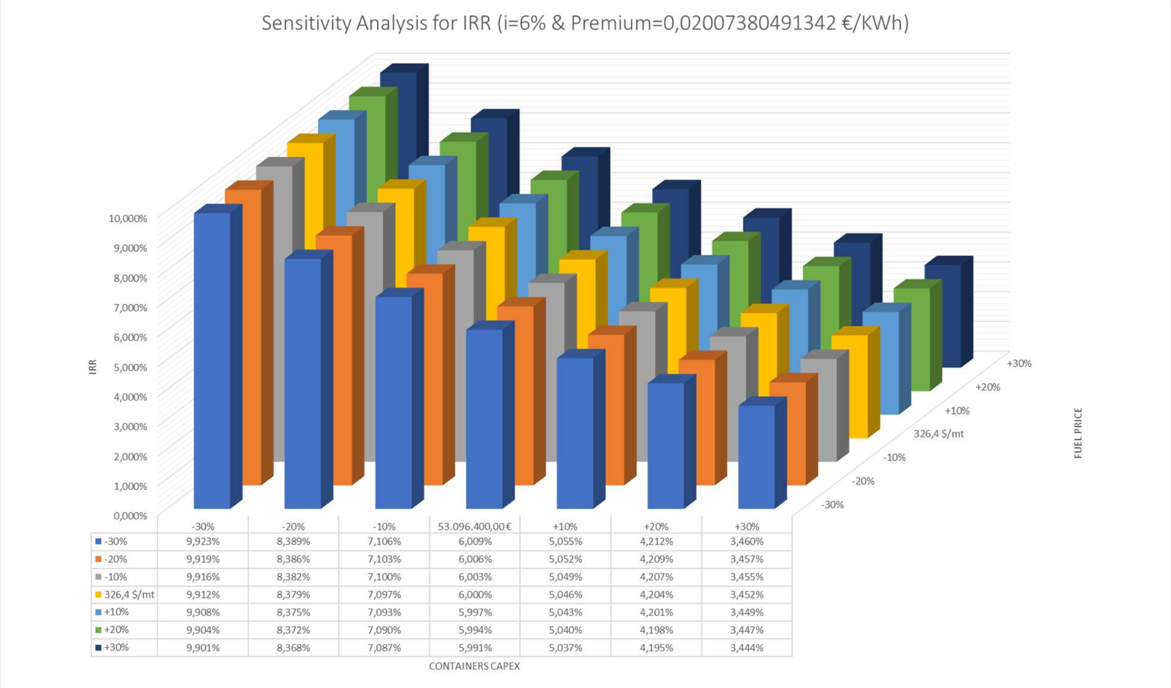
To conclude the second case study a sensitivity analysis followed, for the NPV and IRR values of the project, by fluctuating the containers'CAPEX and Fuel Price from -30% of the current prices to +30%.

The results are presented diagrammatically in Charts 5.13 to Chart 5.18.



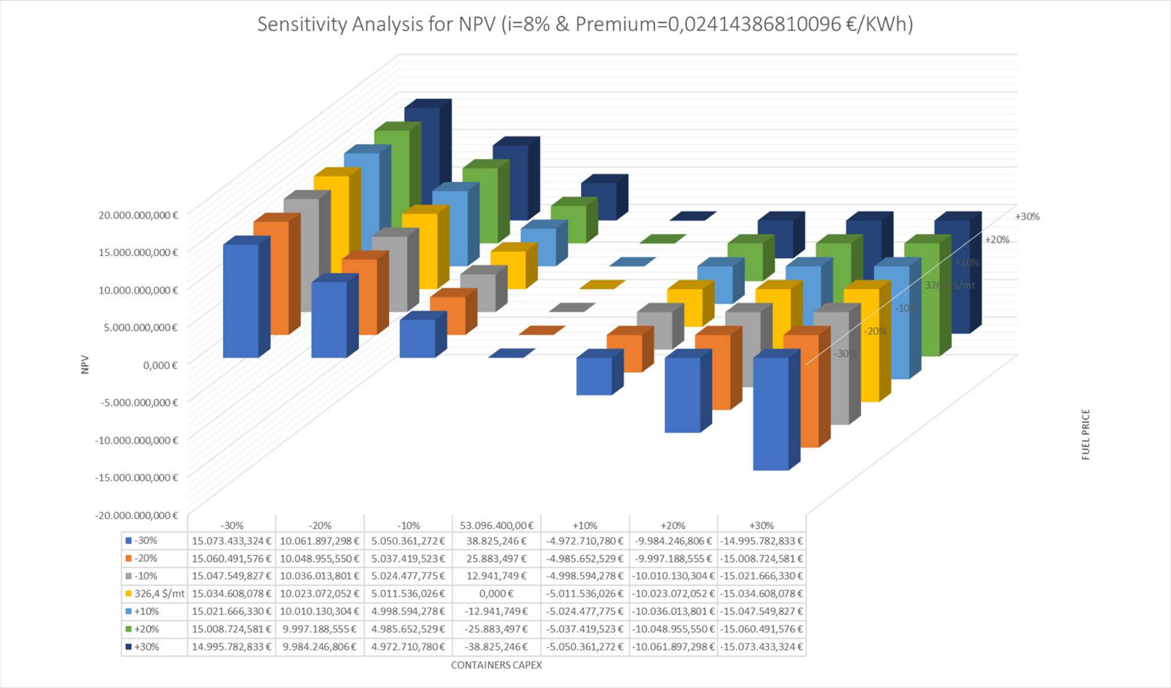
	-30%	-20%	-10%	53.096.400,00 €	+10%	+20%	+30%
-30%	15.302.187,695 €	10.216.896,254 €	5.131.604,812 €	46.313,371 €	-5.038.978,070 €	-10.124.269,511 €	-15.209.560,952 €
-20%	15.286.749,904 €	10.201.458,463 €	5.116.167,022 €	30.875,581 €	-5.054.415,860 €	-10.139.707,301 €	-15.224.998,742 €
-10%	15.271.312,114 €	10.186.020,673 €	5.100.729,232 €	15.437,790 €	-5.069.853,651 €	-10.155.145,092 €	-15.240.436,533 €
326,4 $/mt	15.255.874,323 €	10.170.582,882 €	5.085.291,441 €	0,000 €	-5.085.291,441 €	-10.170.582,882 €	-15.255.874,323 €
+10%	15.240.436,533 €	10.155.145,092 €	5.069.853,651 €	-15.437,790 €	-5.100.729,232 €	-10.186.020,673 €	-15.271.312,114 €
+20%	15.224.998,742 €	10.139.707,301 €	5.054.415,860 €	-30.875,581 €	-5.116.167,022 €	-10.201.458,463 €	-15.286.749,904 €
+30%	15.209.560,952 €	10.124.269,511 €	5.038.978,070 €	-46.313,371 €	-5.131.604,812 €	-10.216.896,254 €	-15.302.187,695 €

Chart 5. 13: Sensitivity Analysis for NPV (Charterer – i=6% & Premium=0,02007380491342 €/KWh)



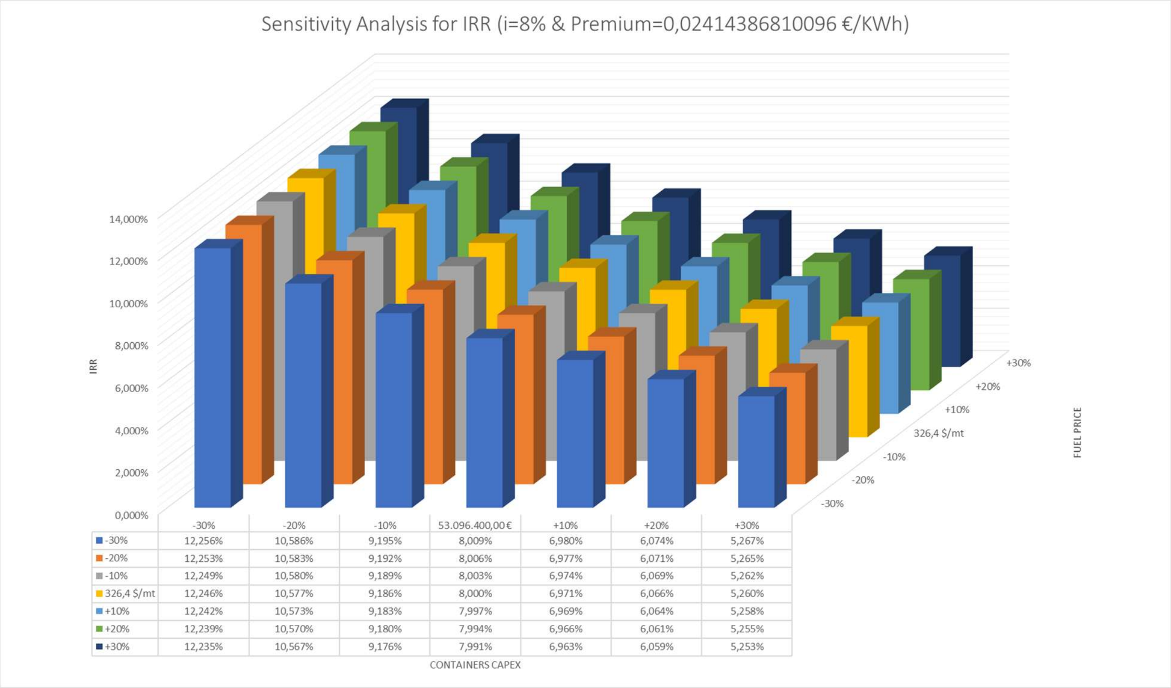
	-30%	-20%	-10%	53.096.400,00 €	+10%	+20%	+30%
-30%	9,923%	8,389%	7,106%	6,009%	5,055%	4,212%	3,460%
-20%	9,919%	8,386%	7,103%	6,006%	5,052%	4,209%	3,457%
-10%	9,916%	8,382%	7,100%	6,003%	5,049%	4,207%	3,455%
326,4 $/mt	9,912%	8,379%	7,097%	6,000%	5,046%	4,204%	3,452%
+10%	9,908%	8,375%	7,093%	5,997%	5,043%	4,201%	3,449%
+20%	9,904%	8,372%	7,090%	5,994%	5,040%	4,198%	3,447%
+30%	9,901%	8,368%	7,087%	5,991%	5,037%	4,195%	3,444%

Chart 5. 14: Sensitivity Analysis for IRR (Charterer – i=6% & Premium=0,02007380491342 €/KWh)



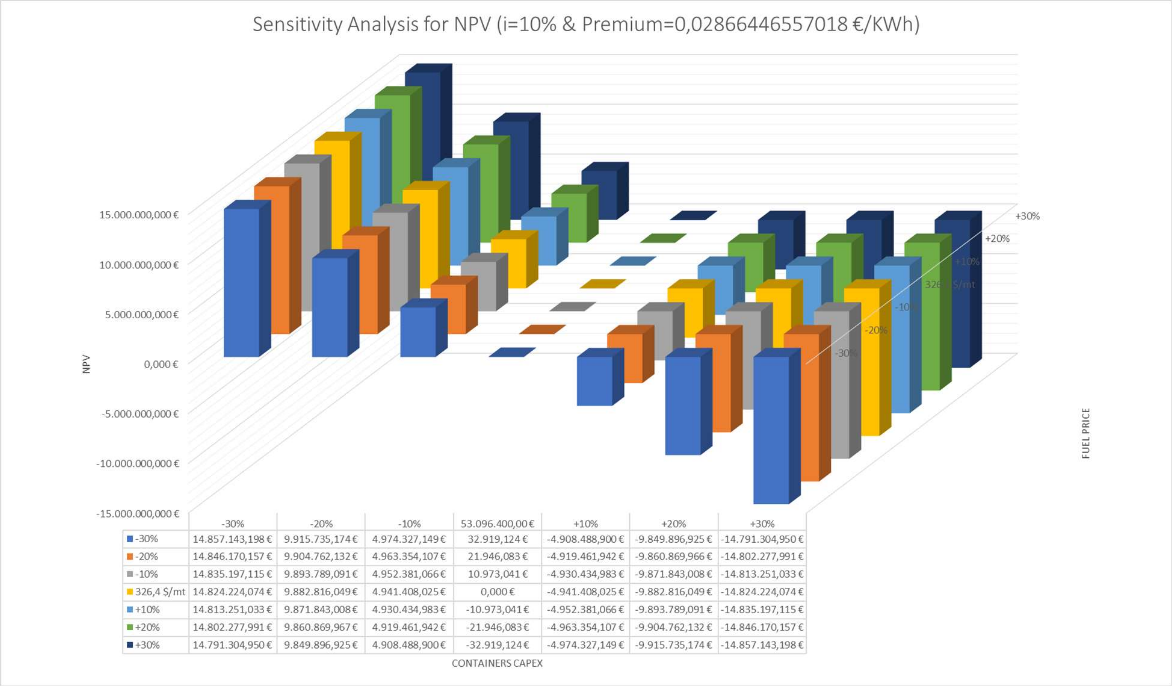
	-30%	-20%	-10%	53.096.400,00 €	+10%	+20%	+30%
■ -30%	15.073.433,324 €	10.061.897,298 €	5.050.361,272 €	38.825,246 €	-4.972.710,780 €	-9.984.246,806 €	-14.995.782,833 €
■ -20%	15.060.491,576 €	10.048.955,550 €	5.037.419,523 €	25.883,497 €	-4.985.652,529 €	-9.997.188,555 €	-15.008.724,581 €
■ -10%	15.047.549,827 €	10.036.013,801 €	5.024.477,775 €	12.941,749 €	-4.998.594,278 €	-10.010.130,304 €	-15.021.666,330 €
■ 326,4 $/mt	15.034.608,078 €	10.023.072,052 €	5.011.536,026 €	0,000 €	-5.011.536,026 €	-10.023.072,052 €	-15.034.608,078 €
■ +10%	15.021.666,330 €	10.010.130,304 €	4.998.594,278 €	-12.941,749 €	-5.024.477,775 €	-10.036.013,801 €	-15.047.549,827 €
■ +20%	15.008.724,581 €	9.997.188,555 €	4.985.652,529 €	-25.883,497 €	-5.037.419,523 €	-10.048.955,550 €	-15.060.491,576 €
■ +30%	14.995.782,833 €	9.984.246,806 €	4.972.710,780 €	-38.825,246 €	-5.050.361,272 €	-10.061.897,298 €	-15.073.433,324 €

Chart 5. 15: Sensitivity Analysis for NPV (Charterer – i=8% & Premium=0,02414386810096 €/KWh)



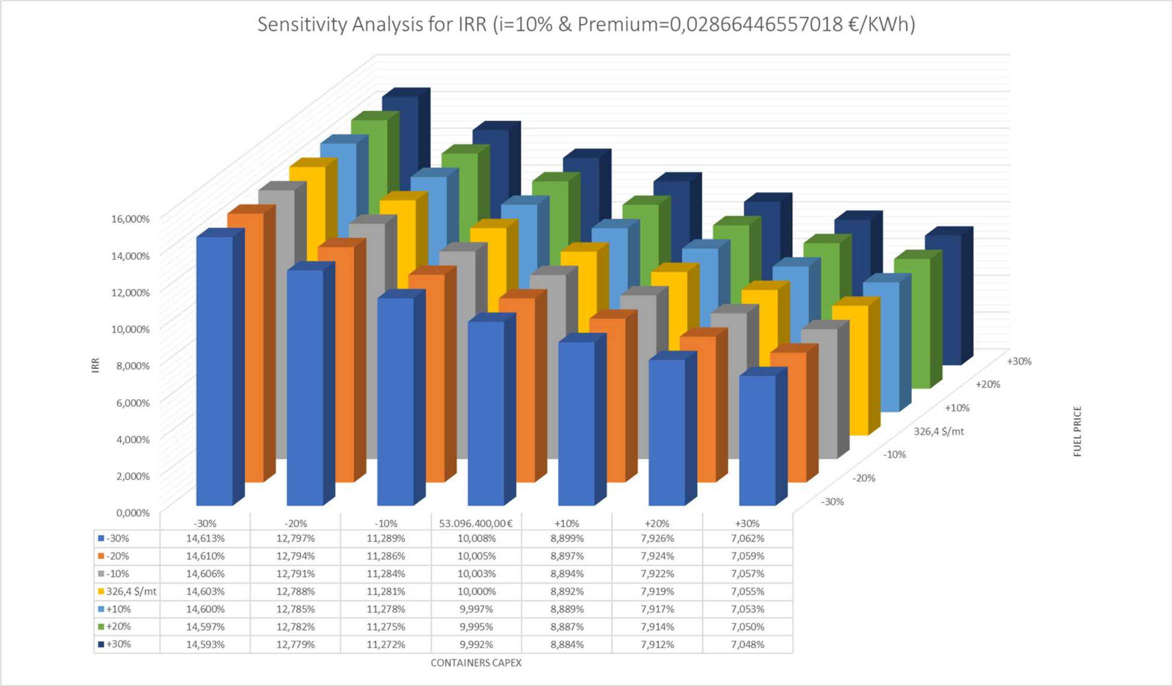
	-30%	-20%	-10%	53.096.400,00 €	+10%	+20%	+30%
■ -30%	12,256%	10,586%	9,195%	8,009%	6,980%	6,074%	5,267%
■ -20%	12,253%	10,583%	9,192%	8,006%	6,977%	6,071%	5,265%
■ -10%	12,249%	10,580%	9,189%	8,003%	6,974%	6,069%	5,262%
■ 326,4 $/mt	12,246%	10,577%	9,186%	8,000%	6,971%	6,066%	5,260%
■ +10%	12,242%	10,573%	9,183%	7,997%	6,969%	6,064%	5,258%
■ +20%	12,239%	10,570%	9,180%	7,994%	6,966%	6,061%	5,255%
■ +30%	12,235%	10,567%	9,176%	7,991%	6,963%	6,059%	5,253%

Chart 5. 16: Sensitivity Analysis for IRR (Charterer – i=8% & Premium=0,02414386810096 €/KWh)



	-30%	-20%	-10%	53.096.400,00 €	+10%	+20%	+30%
■ -30%	14.857.143,198 €	9.915.735,174 €	4.974.327,149 €	32.919,124 €	-4.908.488,900 €	-9.849.896,925 €	-14.791.304,950 €
■ -20%	14.846.170,157 €	9.904.762,132 €	4.963.354,107 €	21.946,083 €	-4.919.461,942 €	-9.860.869,966 €	-14.802.277,991 €
■ -10%	14.835.197,115 €	9.893.789,091 €	4.952.381,066 €	10.973,041 €	-4.930.434,983 €	-9.871.843,008 €	-14.813.251,033 €
■ 326,4 $/mt	14.824.224,074 €	9.882.816,049 €	4.941.408,025 €	0,000 €	-4.941.408,025 €	-9.882.816,049 €	-14.824.224,074 €
■ +10%	14.813.251,033 €	9.871.843,008 €	4.930.434,983 €	-10.973,041 €	-4.952.381,066 €	-9.893.789,091 €	-14.835.197,115 €
■ +20%	14.802.277,991 €	9.860.869,967 €	4.919.461,942 €	-21.946,083 €	-4.963.354,107 €	-9.904.762,132 €	-14.846.170,157 €
■ +30%	14.791.304,950 €	9.849.896,925 €	4.908.488,900 €	-32.919,124 €	-4.974.327,149 €	-9.915.735,174 €	-14.857.143,198 €

Chart 5. 17: Sensitivity Analysis for NPV (Charterer – i=10% & Premium=0,02866446557018 €/KWh)



	-30%	-20%	-10%	53.096.400,00 €	+10%	+20%	+30%
■ -30%	14,613%	12,797%	11,289%	10,008%	8,899%	7,926%	7,062%
■ -20%	14,610%	12,794%	11,286%	10,005%	8,897%	7,924%	7,059%
■ -10%	14,606%	12,791%	11,284%	10,003%	8,894%	7,922%	7,057%
■ 326,4 $/mt	14,603%	12,788%	11,281%	10,000%	8,892%	7,919%	7,055%
■ +10%	14,600%	12,785%	11,278%	9,997%	8,889%	7,917%	7,053%
■ +20%	14,597%	12,782%	11,275%	9,995%	8,887%	7,914%	7,050%
■ +30%	14,593%	12,779%	11,272%	9,992%	8,884%	7,912%	7,048%

Chart 5. 18: Sensitivity Analysis for IRR (Charterer – i=10% & Premium=0,02866446557018 €/KWh)

5.5. Conclusions for Scenarios considered in Feasibility Study

5.5.1. Conclusions for Case Study A

After reviewing Charts 5.1 to 5.6 and tables in ANNEX A the following information can be deducted:

a) Fuel Price fluctuations have a minor impact on the NPV of the project, whereas it is more sensitive to the vessel's CAPEX.
b) A possible investor (Ship Owner/Operator) may be interested on the project, when taking into consideration the NPV, only for a capital expenditure on the vessel 10% below from our starting point estimation. So, with a CAPEX of 22.755.600€ and below. The same is applicable for all three discount rates (6%, 8% & 10%).

5.5.2. Conclusions for Case Study B

After reviewing Charts 5.7 to 5.18 and tables in ANNEX C the following information can be deducted:

<u>Shipowner Viewpoint</u>

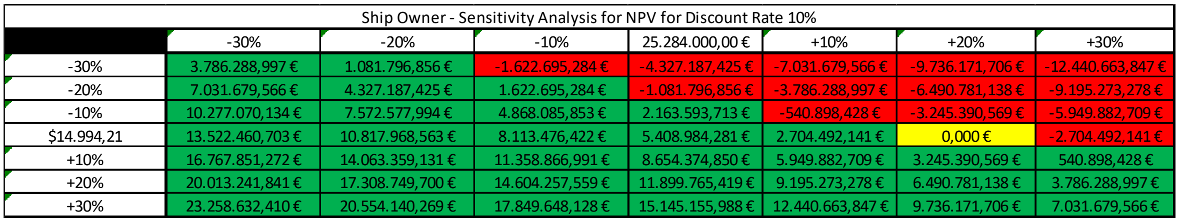
In case the Charter rate is 10% higher than the projects starting point estimation, then a possible investor (Ship Owner) may be interested on the project, when taking into consideration the NPV, even with a 30% higher CAPEX. The same is applicable for all three interest rates (6%, 8% & 10%).

Ship Owner - Sensitivity Analysis for NPV for Discount Rate 6%							
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
-30%	4.104.428,036 €	1.172.693,725 €	-1.759.040,587 €	-4.690.774,898 €	-7.622.509,209 €	-10.554.243,521 €	-13.485.977,832 €
-20%	7.622.509,209 €	4.690.774,898 €	1.759.040,587 €	-1.172.693,725 €	-4.104.428,036 €	-7.036.162,347 €	-9.967.896,658 €
-10%	11.140.590,383 €	8.208.856,072 €	5.277.121,760 €	2.345.387,449 €	-586.346,862 €	-3.518.081,174 €	-6.449.815,485 €
$11.203,14	14.658.671,557 €	11.726.937,245 €	8.795.202,934 €	5.863.468,623 €	2.931.734,311 €	0,000 €	-2.931.734,311 €
+10%	18.176.752,730 €	15.245.018,419 €	12.313.284,107 €	9.381.549,796 €	6.449.815,485 €	3.518.081,174 €	586.346,862 €
+20%	21.694.833,904 €	18.763.099,592 €	15.831.365,281 €	12.899.630,970 €	9.967.896,658 €	7.036.162,347 €	4.104.428,036 €
+30%	25.212.915,077 €	22.281.180,766 €	19.349.446,455 €	16.417.712,143 €	13.485.977,832 €	10.554.243,521 €	7.622.509,209 €

Table 5. 4: Shipowner – Sensitivity Analysis for NPV (discount rate 6%).

Ship Owner - Sensitivity Analysis for NPV for Discount Rate 8%							
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
-30%	3.929.798,058 €	1.122.799,445 €	-1.684.199,168 €	-4.491.197,781 €	-7.298.196,394 €	-10.105.195,006 €	-12.912.193,619 €
-20%	7.298.196,394 €	4.491.197,781 €	1.684.199,168 €	-1.122.799,445 €	-3.929.798,058 €	-6.736.796,671 €	-9.543.795,284 €
-10%	10.666.594,729 €	7.859.596,116 €	5.052.597,503 €	2.245.598,890 €	-561.399,723 €	-3.368.398,335 €	-6.175.396,948 €
$13.008,40	14.034.993,065 €	11.227.994,452 €	8.420.995,839 €	5.613.997,226 €	2.806.998,613 €	0,000 €	-2.806.998,613 €
+10%	17.403.391,400 €	14.596.392,787 €	11.789.394,174 €	8.982.395,561 €	6.175.396,948 €	3.368.398,336 €	561.399,723 €
+20%	20.771.789,736 €	17.964.791,123 €	15.157.792,510 €	12.350.793,897 €	9.543.795,284 €	6.736.796,671 €	3.929.798,058 €
+30%	24.140.188,071 €	21.333.189,458 €	18.526.190,845 €	15.719.192,232 €	12.912.193,619 €	10.105.195,006 €	7.298.196,394 €

Table 5. 5: Shipowner – Sensitivity Analysis for NPV (discount rate 8%).



Ship Owner - Sensitivity Analysis for NPV for Discount Rate 10%							
	-30%	-20%	-10%	25.284.000,00 €	+10%	+20%	+30%
-30%	3.786.288,997 €	1.081.796,856 €	-1.622.695,284 €	-4.327.187,425 €	-7.031.679,566 €	-9.736.171,706 €	-12.440.663,847 €
-20%	7.031.679,566 €	4.327.187,425 €	1.622.695,284 €	-1.081.796,856 €	-3.786.288,997 €	-6.490.781,138 €	-9.195.273,278 €
-10%	10.277.070,134 €	7.572.577,994 €	4.868.085,853 €	2.163.593,713 €	-540.898,428 €	-3.245.390,569 €	-5.949.882,709 €
$14.994,21	13.522.460,703 €	10.817.968,563 €	8.113.476,422 €	5.408.984,281 €	2.704.492,141 €	0,000 €	-2.704.492,141 €
+10%	16.767.851,272 €	14.063.359,131 €	11.358.866,991 €	8.654.374,850 €	5.949.882,709 €	3.245.390,569 €	540.898,428 €
+20%	20.013.241,841 €	17.308.749,700 €	14.604.257,559 €	11.899.765,419 €	9.195.273,278 €	6.490.781,138 €	3.786.288,997 €
+30%	23.258.632,410 €	20.554.140,269 €	17.849.648,128 €	15.145.155,988 €	12.440.663,847 €	9.736.171,706 €	7.031.679,566 €

Table 5. 6: Shipowner – Sensitivity Analysis for NPV (discount rate 10%).

Charterer Viewpoint

a) Fuel Price fluctuations have a minor impact on the NPV of the project, whereas it is more sensitive to the containers' CAPEX.

b) A possible investor can be interested on the project, when taking into consideration the NPV, only for a capital expenditure on the containers 10% below from our starting point estimation. So, with a CAPEX of approximately 48.000.000€ and below. The same is applicable for all three discount rates (6%, 8% & 10%).

6. General Conclusions and Further Study

The aim of this diploma thesis is to examine the potential significance of the (Compressed Natural Gas) CNG solution, the creation of an initiative type of ship that could be supplied with CNG being a part of a CNG supply chain. For this respect, above technical document focuses in the applicable rules for CNG carriers, the design characteristics of existing CNG concept designs and key components of CNG vessels and upon this presentation, the diploma thesis focuses in the techno economical study for the proposed design of a vessel which carries CNG in containers, in order to capacitate the needs of NG in Cyprus. Our approach on estimating the NG needs of Cyprus has as follows:

- ✓ From the Total Energy Demand in Cyprus (International Energy Agency, Cyprus - Countries & Regions - IEA, 2018) we assumed a 10% rise until 2023 and from which we assumed to capacitate with NG a 5,5%.
- ✓ From the total NG Demand, we also assumed that only 20% will be accommodated from CNG and the rest 80% from LNG.

In order to transport CNG from Thessaloniki to Limassol, we estimated that the use of two Modified General Cargo vessels (7500-10000 DWT each) with an assumed average speed of 12,5 knots each is necessary. The assumed CAPEX for each vessel was 10 million US Dollars with an OPEX of 2% of the CPAEX.

The Case Study was divided in two separate parts:

a. Ship/Owner Operator Scope
b. Ship Owner & Ship Charterer Scope

In the first case study we assumed that an Owner/Operator will accommodate the needs of the project in CNG transportation. By adding up the costs and dividing them with the delivered amount of NG we estimated the minimum CNG transportation cost to which we added a minimum premium so as to conduct a sensitivity analysis on the NPV and IRR of the project by fluctuating the CAPEX and Fuel Prices.

In the second case study the project was examined from the scope of the Ship Owner willing to build the modified General Cargo vessels and then charter them to a Ship Operator that will use them to accommodate the needs of the project. Firstly, the Required Frate Rate (RFR) of the two vessels was calculated, so as a minimum Charter Rate to be identified, which was afterwards increased by 20%. A sensitivity analysis on the NPV and IRR of the project by fluctuating the CAPEX and the Charter Rate was conducted. By adding up the costs and dividing them with the delivered amount of NG we estimated the minimum CNG transportation cost to which we added a minimum premium so as to conduct a sensitivity analysis on the NPV and IRR of the project by fluctuating the CAPEX and Fuel Prices.

The general conclusion on the project is that it is highly Capital oriented because minor fluctuations on the required CAPEX can totally derail the outcome of the project and the required NG Prices, in order to consider the project viable/feasible.

Further Study

Several extensions to the proposed Design for CNG transportation are possible and are being considered for further research. One major issue that will determine study's results is the containers' cost and size for the most accurate and beneficial stowage arrangement inside cargo hold in order the complete volume to be filled. Finally, the model prepared for this analysis could include further operational considerations, such as the cost for self-cargo loading unloading equipment, cost considered for compressing the NG etc.

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Annex A: Excel Calculations for First Case Study

Year	N	i1	i2	i3	Demand in KWh	Stock of NG for Next Year (KWh)	Round Trips	Capex	Opex	Terminal Fees pes Year (Euros)	Fuel Cost per Year (Euros)	Sum of Costs (Euros)	Sum of Cost (Euros / KWh)	Charging Price to Receiving Terminal for i1 (Euros/KWh)	Charging Price to Receiving Terminal for i2 (Euros/KWh)	Charging Price to Receiving Terminal for i3 (Euros/KWh)	Income (for i1)	Income (for i2)	Income (for i3)	Rt (i1)	Rt (i2)	Rt (i3)
2020	0	0,06	0,08	0,10	Construction of vessels and Terminals ongoing			31352160	0	0	0	31352160	-	-	-	-	0	0	0	-31352160	-31352160	-31352160
2021	1	0,06	0,08	0,10				31352160	0	0	0	31352160	-	-	-	-	0	0	0	-31352160	-31352160	-31352160
2022	2	0,06	0,08	0,10				15676080	0	0	0	15676080	-	-	-	-	0	0	0	-15676080	-15676080	-15676080
2023	3	0,06	0,08	0,10	220765115,672226	1979900	104	0	1567608	4160000	1144374,067	6871982,067	0,030851339	0,0600395839597876	0,0660334439402576	0,0726934733735276	13254645,7	14577880,89	16048183,06	6382663,631	7705898,823	9176200,991
2024	4	0,06	0,08	0,10	225180417,985670	2010035	107	0	1567608	4280000	1177384,858	7024992,858	0,030654021	0,0598422658470976	0,0658361258275676	0,0724961552608376	13475306,44	14825006,33	16324714,54	6450313,579	7800013,475	9299721,686
2025	5	0,06	0,08	0,10	229595720,299115	1848156	109	0	1567608	4360000	1199392,051	7127000,051	0,03052851	0,0597167546316863	0,0657106146121563	0,0723706440454263	13710711,29	15086875,89	16615990,15	6583711,242	7959875,842	9488990,097
2026	6	0,06	0,08	0,10	234011022,612559	1878290	111	0	1567608	4440000	1221399,245	7229007,245	0,030407522	0,0595957663429564	0,0655896263234264	0,0722496557566964	13946066,23	15348695,53	16907215,83	6717058,98	8119688,284	9678208,582
2027	7	0,06	0,08	0,10	238426324,926004	1716412	113	0	1567608	4520000	1243406,438	7331014,438	0,030290816	0,0594790608255090	0,0654729208059790	0,0721329502392490	14181373,88	15610467,89	17198394,23	6850359,444	8279453,452	9867379,793
2028	8	0,06	0,08	0,10	242841627,239448	1746546	115	0	1567608	4600000	1265413,632	7433021,632	0,03017817	0,0593664146304076	0,0653602746108776	0,0720203040441476	14416636,73	15872195,44	17489527,83	6983615,1	8439173,811	10056506,2
2029	9	0,06	0,08	0,10	247256929,552893	1584667	117	0	1567608	4680000	1287420,826	7535028,826	0,030069375	0,0592576195872754	0,0652514795677454	0,0719115090010154	14651857,07	16133880,49	17780618,92	7116828,246	8598851,661	10245590,09
2030	10	0,06	0,08	0,10	251672231,866337	1614802	119	0	1567608	4760000	1309428,019	7637036,019	0,029964237	0,0591524815203830	0,0651463415008530	0,0718063709341230	14887037,04	16395525,16	18071669,64	7250001,025	8758489,144	10434633,62
2031	11	0,06	0,08	0,10	256087534,179782	1452923	121	0	1567608	4840000	1331435,213	7739043,213	0,029862574	0,0590508190920656	0,0650446790725356	0,0717047085058056	15122178,65	16657131,48	18362681,99	7383135,44	8918088,262	10623638,78
2032	12	0,06	0,08	0,10	260502836,493226	1483057	123	0	1567608	4920000	1353442,406	7841050,406	0,029764218	0,0589524627589780	0,0649463227394480	0,0716063521727180	15357283,77	16918701,29	18653657,85	7516233,361	9077650,887	10812607,45
2033	13	0,06	0,08	0,10	264918138,806671	1321179	125	0	1567608	5000000	1375449,6	7943057,6	0,029669009	0,0588572538285492	0,0648511138090192	0,0715111432422891	15592354,14	17180236,37	18944598,97	7649296,54	9237178,77	11001541,37
2034	14	0,06	0,08	0,10	269333441,120115	1351313	127	0	1567608	5080000	1397456,794	8045064,794	0,029576799	0,0587650436045905	0,0647589035850605	0,0714189330183305	15827391,41	17441738,35	19235506,99	7782326,618	9396673,552	11190442,2
2035	15	0,06	0,08	0,10	273748743,433560	1189434	129	0	1567608	5160000	1419463,987	8147071,987	0,029487448	0,0586756926123826	0,0646695525928526	0,0713295820261226	16062397,12	17703208,76	19526383,45	7915325,136	9556136,774	11379311,46
2036	16	0,06	0,08	0,10	278164045,747004	1219569	131	0	1567608	5240000	1441471,181	8249079,181	0,029400825	0,0585890698947459	0,0645829298752159	0,0712429593084859	16297372,72	17964649,06	19817229,79	8048293,538	9715569,879	11568150,61
2037	17	0,06	0,08	0,10	282579348,060449	1057690	133	0	1567608	5320000	1463478,374	8351086,374	0,029316808	0,0585050523716246	0,0644989123520946	0,0711589417853645	16532319,56	18226060,6	20108047,38	8181233,183	9874974,229	11756961
2038	18	0,06	0,08	0,10	286994650,373893	1087824	135	0	1567608	5400000	1485485,568	8453093,568	0,02923528	0,0584235242565957	0,0644173842370657	0,0710774136703357	16767238,92	18487444,67	20398837,49	8314145,35	10034351,1	11945743,92
2039	19	0,06	0,08	0,10	291409952,687338	925946	137	0	1567608	5480000	1507492,762	8555100,762	0,029156132	0,0583443765244874	0,0643382365049574	0,0709982659382274	17002132	18748802,46	20689601,32	8447031,241	10193701,69	12134500,56
2040	20	0,06	0,08	0,10	295825255,000782	956080	139	0	1567608	5560000	1529499,955	8657107,955	0,029079262	0,0582675064249578	0,0642613664054278	0,0709213958386978	17236999,95	19010135,1	20980340,01	8579891,991	10353027,15	12323232,05
2041	21	0,06	0,08	0,10	300240557,314227	794202	141	0	1567608	5640000	1551507,149	8759115,149	0,029004572	0,0581928170374715	0,0641866770179415	0,0708467064512115	17471843,82	19271443,68	21271054,63	8712728,67	10512328,53	12511939,48
2042	22	0,06	0,08	0,10	304655859,627671	824336	143	0	1567608	5720000	1573514,342	8861122,342	0,028931972	0,0581202168636213	0,0641140768440913	0,0707741062773613	17706664,63	19532729,2	21561746,19	8845542,288	10671606,85	12700623,84

NPV=	0,000 €	0,000 €	0,000 €
IRR=	6,000%	8,000%	10,000%

			Remarks
7109262 scf of NG =	2141779	KWh	https://www.convert-me.com/en/convert/energy/mscfgas/mscfgas-to-kwh.html?u=mscfgas&v=7.109
Terminal Fees	20000	Euros	
Fuel consumption per roundtrip	40	t	Approximate consumption in tons
Fuel Prices	326,4	$/mt	https://shipandbunker.com/prices/emea/medabs/gr-pir-piraeus
Minimum Premium for i1	0,02918824465440	Euros/KWh	Minimum premium on the NG transportation cost in Euros / KWh, in order for the NPV to be equal with zero
Minimum Premium for i2	0,03518210463487	Euros/KWh	
Minimum Premium for i3	0,04184213406814	Euros/KWh	
Capex for Vessels	25284000	Euros	1 US Dollar = 0,8428 Euros
CAPEX for Titan Containers	53096400	Euros	

Annex B: Excel Calculations for Second Case Study

	Year	N	i1	i2	i3	Capex	Opex	Income (for i1)	Income (for i2)	Income (for i3)	Rt (i1)	Rt (i2)	Rt (i3)
SHIPOWNER	2020	0	0,06	0,08	0,10	10113600	0	0	0	0	-10113600	-10113600	-10113600
	2021	1	0,06	0,08	0,10	10113600	0	0	0	0	-10113600	-10113600	-10113600
	2022	2	0,06	0,08	0,10	5056800	0	0	0	0	-5056800	-5056800	-5056800
	2023	3	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2024	4	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2025	5	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2026	6	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2027	7	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2028	8	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2029	9	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2030	10	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2031	11	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2032	12	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2033	13	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2034	14	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2035	15	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2036	16	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2037	17	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2038	18	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2039	19	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2040	20	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2041	21	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
	2042	22	0,06	0,08	0,10	0	505680	2871943,59	3334726,04	3843790,448	2366263,59	2829046,04	3338110,448
										NPV=	0,000 €	0,000 €	0,000 €
										IRR=	6,000%	8,000%	10,000%

	Year	N	i1	i2	i3	Capex	Opex	Income (for i1)	Income (for i2)	Income (for i3)	Rt (i1)	Rt (i2)	Rt (i3)
SHIPOWNER (120% RFR)	2020	0	0,06	0,08	0,10	10113600	0	0	0	0	-10113600	-10113600	-10113600
	2021	1	0,06	0,08	0,10	10113600	0	0	0	0	-10113600	-10113600	-10113600
	2022	2	0,06	0,08	0,10	5056800	0	0	0	0	-5056800	-5056800	-5056800
	2023	3	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2024	4	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2025	5	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2026	6	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2027	7	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2028	8	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2029	9	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2030	10	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2031	11	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2032	12	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2033	13	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2034	14	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2035	15	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2036	16	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2037	17	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2038	18	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2039	19	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2040	20	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2041	21	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
	2042	22	0,06	0,08	0,10	0	505680	3446332,308	4001671,248	4612548,537	2940652,308	3495991,248	4106868,537
										NPV=	5.863.468,623 €	5.613.997,226 €	5.408.984,281 €
										IRR=	8,454%	10,587%	12,737%

	Year	N	i1	i2	i3	Demand in KWh	Stock of NG for Next Year (KWh)	Round Trips	Capex	Opex	Terminal Fees pes Year (Euros)	Fuel Cost per Year (Euros)	Charter Rate for i1 (Euros/Year) = 120 * RFR (for i1)	Charter Rate for i1 (Euros/Year) = 120 * RFR (for i2)	Charter Rate for i1 (Euros/Year) = 120 * RFR (for i3)
CHARTERER	2020	0	0,06	0,08	0,10	Construction of vessels and Terminals ongoing			21238560	0	0	0	0	0	0
	2021	1	0,06	0,08	0,10				21238560	0	0	0	0	0	0
	2022	2	0,06	0,08	0,10				10619280	0	0	0	0	0	0
	2023	3	0,06	0,08	0,10	220765115,672226	1979900	104	0	1061928	4160000	1144374,067	3446332,3080360	4001671,2476124	4612548,5372280
	2024	4	0,06	0,08	0,10	225180417,985670	2010035	107	0	1061928	4280000	1177384,858	3446332,3080360	4001671,2476124	4612548,5372280
	2025	5	0,06	0,08	0,10	229595720,299115	1848156	109	0	1061928	4360000	1199392,051	3446332,3080360	4001671,2476124	4612548,5372280
	2026	6	0,06	0,08	0,10	234011022,612559	1878290	111	0	1061928	4440000	1221399,245	3446332,3080360	4001671,2476124	4612548,5372280
	2027	7	0,06	0,08	0,10	238426324,926004	1716412	113	0	1061928	4520000	1243406,438	3446332,3080360	4001671,2476124	4612548,5372280
	2028	8	0,06	0,08	0,10	242841627,239448	1746546	115	0	1061928	4600000	1265413,632	3446332,3080360	4001671,2476124	4612548,5372280
	2029	9	0,06	0,08	0,10	247256929,552893	1584667	117	0	1061928	4680000	1287420,826	3446332,3080360	4001671,2476124	4612548,5372280
	2030	10	0,06	0,08	0,10	251672231,866337	1614802	119	0	1061928	4760000	1309428,019	3446332,3080360	4001671,2476124	4612548,5372280
	2031	11	0,06	0,08	0,10	256087534,179782	1452923	121	0	1061928	4840000	1331435,213	3446332,3080360	4001671,2476124	4612548,5372280
	2032	12	0,06	0,08	0,10	260502836,493226	1483057	123	0	1061928	4920000	1353442,406	3446332,3080360	4001671,2476124	4612548,5372280
	2033	13	0,06	0,08	0,10	264918138,806671	1321179	125	0	1061928	5000000	1375449,6	3446332,3080360	4001671,2476124	4612548,5372280
	2034	14	0,06	0,08	0,10	269333441,120115	1351313	127	0	1061928	5080000	1397456,794	3446332,3080360	4001671,2476124	4612548,5372280
	2035	15	0,06	0,08	0,10	273748743,433560	1189434	129	0	1061928	5160000	1419463,987	3446332,3080360	4001671,2476124	4612548,5372280
	2036	16	0,06	0,08	0,10	278164045,747004	1219569	131	0	1061928	5240000	1441471,181	3446332,3080360	4001671,2476124	4612548,5372280
	2037	17	0,06	0,08	0,10	282579348,060449	1057690	133	0	1061928	5320000	1463478,374	3446332,3080360	4001671,2476124	4612548,5372280
	2038	18	0,06	0,08	0,10	286994650,373893	1087824	135	0	1061928	5400000	1485485,568	3446332,3080360	4001671,2476124	4612548,5372280
	2039	19	0,06	0,08	0,10	291409952,687338	925946	137	0	1061928	5480000	1507492,762	3446332,3080360	4001671,2476124	4612548,5372280
	2040	20	0,06	0,08	0,10	295825255,000782	956080	139	0	1061928	5560000	1529499,955	3446332,3080360	4001671,2476124	4612548,5372280
	2041	21	0,06	0,08	0,10	300240557,314227	794202	141	0	1061928	5640000	1551507,149	3446332,3080360	4001671,2476124	4612548,5372280
	2042	22	0,06	0,08	0,10	304655859,627671	824336	143	0	1061928	5720000	1573514,342	3446332,3080360	4001671,2476124	4612548,5372280

Year	Sum of Costs for i1 (Euros)	Sum of Costs for i2 (Euros)	Sum of Costs for i3 (Euros)	Sum of Costs for i1 (Euros / KWh)	Sum of Costs for i2 (Euros / KWh)	Sum of Costs for i3 (Euros / KWh)	Charging Price to Receiving Terminal for i1 (Euros/KWh)	Charging Price to Receiving Terminal for i2 (Euros/KWh)	Charging Price to Receiving Terminal for i3 (Euros/KWh)	Income (for i1)	Income (for i2)	Income (for i3)	Rt (i1)	Rt (i2)	Rt (i3)
2020	21238560	21238560	21238560	-	-	-	-	-	-	0	0	0	-21238560	-21238560	-21238560
2021	21238560	21238560	21238560	-	-	-	-	-	-	0	0	0	-21238560	-21238560	-21238560
2022	10619280	10619280	10619280	-	-	-	-	-	-	0	0	0	-10619280	-10619280	-10619280
2023	9812634,375	10367973,31	10978850,6	0,044053216	0,046546376	0,049288872	0,0693626770129332	0,0734327402004732	0,0779533376696932	15312859,41	16211387,38	17209377,61	4334008,81	5232536,78	6230527,003
2024	9965645,166	10520984,11	11131861,39	0,043485752	0,04590901	0,048574614	0,0686484187284453	0,0727184819159853	0,0772390793852053	15458279,62	16374778,15	17392728,18	4326418,228	5242916,758	6260866,786
2025	10067652,36	10622991,3	11233868,59	0,043124796	0,045503591	0,048120284	0,0681940892997802	0,0722641524873202	0,0767847499565402	15657071,05	16591540,14	17629449,97	4423202,464	5357671,554	6395581,386
2026	10169659,55	10724998,49	11335875,78	0,042776848	0,045112781	0,047682327	0,0677561321027787	0,0718261952903187	0,0763467927595387	15855681,76	16808121,41	17865991,05	4519805,98	5472245,628	6530115,265
2027	10271666,75	10827005,69	11437882,98	0,042441216	0,044735806	0,047259873	0,0673336778154056	0,0714037410029456	0,0759243384721656	16054121,35	17024531,55	18102360,99	4616238,37	5586648,578	6664478,019
2028	10373673,94	10929012,88	11539890,17	0,042117259	0,044371942	0,046852113	0,0669259175902019	0,0709959807777420	0,0755165782469620	16252398,73	17240779,5	18338568,75	4712508,563	5700889,33	6798678,576
2029	10475681,13	11031020,07	11641897,36	0,041804377	0,044020519	0,046458293	0,0665320978855181	0,0706021610730581	0,0751227585422781	16450522,24	17456873,57	18574622,62	4808624,877	5814976,204	6932725,254
2030	10577688,33	11133027,27	11743904,56	0,041502012	0,043680908	0,046077711	0,0661515158179665	0,0702215790055065	0,0747421764747265	16648499,63	17672821,51	18810530,37	4904595,071	5928916,957	7066625,812
2031	10679695,52	11235034,46	11845911,75	0,041209642	0,043352524	0,04570971	0,0657835149757885	0,0698535781633285	0,0743741756325485	16846338,14	17888630,59	19046299,24	5000426,39	6042718,835	7200387,494
2032	10781702,71	11337041,65	11947918,94	0,040926781	0,043034818	0,045353677	0,0654274816406732	0,0694975448282132	0,0740181422974332	17044044,55	18104307,56	19281936,02	5096125,608	6156388,613	7334017,077
2033	10883709,91	11439048,85	12049926,14	0,040652971	0,04272728	0,045009036	0,0650828413722816	0,0691529045598216	0,0736735020290416	17241625,2	18319858,77	19517447,04	5191699,067	6269932,632	7467520,9
2034	10985717,1	11541056,04	12151933,33	0,040387785	0,042429428	0,044675251	0,0647490559154929	0,0688191191030329	0,0733397165722529	17439086,04	18535290,16	19752838,24	5287152,708	6383356,832	7600904,904
2035	11087724,3	11643063,23	12253940,52	0,040130822	0,042140811	0,044351815	0,0644256203953488	0,0684956835828888	0,0730162810521088	17636432,63	18750607,31	19988115,19	5382492,104	6496666,787	7734174,664
2036	11189731,49	11745070,43	12355947,72	0,039881705	0,041861007	0,044038256	0,0641120607689495	0,0681821239564895	0,0727027214257095	17833670,2	18965815,45	20223283,13	5477722,487	6609867,729	7867335,411
2037	11291738,68	11847077,62	12457954,91	0,03964008	0,041589619	0,043734127	0,0638079315072540	0,0678779946947940	0,0723985921640140	18030803,69	19180919,49	20458346,97	5572848,775	6722964,577	8000392,063
2038	11393745,88	11949084,82	12559962,11	0,039405614	0,041326271	0,043439009	0,0635128134829420	0,0675828766704820	0,0721034741397020	18227837,7	19395924,06	20693311,35	5667875,595	6835961,956	8133349,246
2039	11495753,07	12051092,01	12661969,3	0,039177995	0,041070612	0,043152507	0,0632263120432815	0,0672963752308215	0,0718169727000415	18424776,6	19610833,52	20928180,62	5762807,302	6948864,223	8266211,318
2040	11597760,26	12153099,2	12763976,49	0,038956925	0,040822311	0,04287425	0,0629480552493667	0,0670181184369067	0,0715387159061267	18621624,5	19825651,98	21162958,88	5857648,004	7061675,484	8398982,383
2041	11699767,46	12255106,4	12865983,69	0,038742127	0,040581054	0,042603887	0,0626776922652082	0,0667477554527482	0,0712683529219682	18818385,26	20040383,3	21397650	5952401,571	7174399,611	8531666,314
2042	11801774,65	12357113,59	12967990,88	0,038533337	0,040346545	0,042341087	0,0624148918820053	0,0664849550695453	0,0710055525387653	19015062,54	20255031,14	21632257,65	6047071,66	7287040,259	8664266,767
												NPV=	0,000 €	0,000 €	0,000 €
												IRR=	6,000%	8,000%	10,000%

			Remarks
7109262 scf of NG =	2141779	KWh	https://www.convert-me.com/en/convert/energy/mscfgas/mscfgas-to-kwh.html?u=mscfgas&v=7.109
Terminal Fees	20000	Euros	
Fuel consumption per roundtrip	40	t	Approximate consumption in tons
Fuel Prices	326,4	$/mt	https://shipandbunker.com/prices/emea/medabs/gr-pir-piraeus
Minimum Premium for i1	0,02007380491342	Euros/KWh	Minimum premium on the NG transportation cost in Euros / KWh, in order for the NPV to be equal with zero
Minimum Premium for i2	0,02414386810096	Euros/KWh	
Minimum Premium for i3	0,02866446557018	Euros/KWh	
Capex for Vessels	25284000	Euros	1 US Dollar = 0,8428 Euros
CAPEX for TITAN4 Containers	53096400	Euros	1 US Dollar = 0,8428 Euros
RFR for i1	9335,9499321570	$ / Day	Required Frate Rate for vessel Owner
RFR for i2	10840,3366458738	$ / Day	
RFR for i3	12495,1741022749	$ / Day	
Charter Rate for i1 (1,2 x RFR for i1)	11203,1399185884000	$ / Day	
Charter Rate for i2 (1,2 x RFR for i2)	13008,4039750486000	$ / Day	
Charter Rate for i3 (1,2 x RFR for i3)	14994,2089227299000	$ / Day	