Generation IV nuclear energy systems. Economical viability of the most promising reactor

- *Chair of Nuclear Technology - TUM* -

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Madrid, July 19, 2018

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Abstract

Nuclear energy is currently stepping away from the spotlight in the world's energy mix, due to the new tendencies for energy production. This source is inappropriate to fit in the world's energy system as it is, it requires an evolution, and effective answers to the three main challenges of nuclear power: **safety**, **waste management** and **cost effectiveness**. These three problems overshadow the advantages that NPPs provides for the energy transition, the latest initiative to fight back global warming. Some of these advantages are: the low emission derived from this technology, its proven grid suitability, its capacity for base load production (direct substitute of coal plants), and some other, less tangible features, such as nuclear fuel reserves being more widespread than fossil fuels, lack of air pollution, or its high energy density. In this thesis, the need for nuclear energy in the framework of the energy transition is demonstrated, based on the dangerous levels of global warming indicators and the poor performance of the mechanisms to fight it back. The poor performance of current nuclear energy in global energy system, especially in the west, is also covered. As an appropriate response to this situation, and the three main challenges of nuclear energy, this thesis defends innovative Generation IV nuclear energy systems.

Among these Generation IV systems, the VHTR is the one selected for the economic analysis, due to the current feasibility perspective for this reactor. Particularly, the selected design for the case study is the MPBR, a project of the Massachusetts Institute of Technology for this reactor. The most important characteristic of this reactor is the modularity of its elements, which can lead to standardization for manufacturing processes reducing significantly the capital cost of the plant, currently one of the most challenging costs sources of NPPs. The plant is medium size, 120 MWe, but the design is meant to be further developed to smaller sizes while maintaining modularity of the elements, in order to be more flexible against variable energy demand.

The strategy to build the economic model of the plant was a bottom-up approach. The costs were categorized and cost ranges were determined based

on comparative measures. The innovative characteristics of the plant makes the exact determination of these costs unrealistic and, therefore, the cost ranges meant a more robust approach.

Construction and O&M cost are the most challenging cost to determine, due to the innovative characteristics of the plant. These cost are obtained from the economic model as a direct comparison to current NPPs, as it was suggested in studies to determine the cost of nuclear power [1], [2]. As for nuclear fuel, the approach was developed based on the division of cost between material, fabrication, quality assurance and back end to develop an estimation for fuel cycle cost. Th hypothesis taken for this cost source, even in the base case, were not the most optimistic, in order to increase the robustness of the model against a more pessimistic scenario.

From this model, the economic assessment of the plant was tested with the conventional parameters of net present value, payback period and IRR. The longer lifetime of this plant compared to current nuclear favours the profitability criteria of this parameters, so the results were favourable except for the most pessimistic scenario, were these criteria was close to profitable but were not accomplished. However, the levelised cost of electricity obtained was higher than this parameter for current nuclear in the base case and in the pessimistic scenario, a realistic result if the novelty of the technology is taken into account.

The sensibility analysis demonstrated the robustness of this plant against increases in cost factors, and the improvements in the profitability of the plant with the incorporation of by-products sales.

In conclusion, the economic viability of the plant is proven to be achievable under the majority of the considered scenarios. Construction cost remain the most critical factor for the cost effectiveness of this plant. Therefore, the problems associated with construction of NPPs such as delays and construction over-costs need to be prevented to ensure the profitability of new developments of nuclear technology.

Resumen

La energía nuclear pierde actualmente protagonismo en el mix energético global, debido a las nuevas tendencias para la producción de energía. Tal y como es, este recurso no es apropiado para encajar en el sistema energético global, requiere una evolución el desarrollo de respuestas apropiadas a los tres grandes retos a los que se enfrenta: seguridad, gestión de residuos y efectividad económica. Estos problemas ocultan las ventajas que este recurso presenta para la transición energética, una de la últimas iniciativas para mitigar los efectos del calentamiento global. Algunas de estas ventajas son: las bajas emisiones derivadas de esta tecnología, su probada adaptación a la red, la capacidad de producción base (sustituta de las centrales de carbón), y otras, menos tangibles, como la dispersión de reservas de combustible nuclear, la prevención de la contaminación del aire o la alta densidad energética.

En este proyecto, se prueba la necesidad de la energía nuclear el marco de la transición energética, basado en los alarmantes niveles de los indicadores de cambio climático y en la actuación inefectiva de los mecanismos de prevención. El papel secundario de la energía nuclear en el sistema energético global, especialmente en occidente, se cubre también. Este proyecto apuesta como los sistemas de Generación IV como una respuesta a esta situación y a los principales retos de la nuclear actual.

De entre los sistemas de Generación IV, se selecciona el VHTR para su análisis económico, debido a las perspectivas de viabilidad técnica de este reactor. En particular, el diseño seleccionado es el MPBR, un diseño del MIT de este reactor. La característica más importante de este rector es la modularidad, que puede llevar a estandarización de su fabricación y reducir su coste de construcción, actualmente el factor más crítico en plantas nucleares. El diseño es de tamaño medio, 120m MWe pero la motivación de su desarrollo es reducir su tamaño manteniendo la modularidad, para mejorar la flexibilidad frente a la demanda eléctrica.

La estrategia para construir el modelo económico de la planta fue de bottom-up. Los costes se categorizan, y se determinan rangos de valores basados en

medidas comparativas. La característica innovadora de este reactor hace que la determinación exacta de los costes no sea realista. Por este motivo, los rangos de valores se presentan como una alternativa más robusta.
Partiendo de dicho modelo, la valoración económica de la planta se pone a prueba con los parámetros convencionales de rentabilidad: valor actual neto, periodo de retorno y tasa interna de retorno. La extensa vida de la central en comparación con las plantas actuales favorece la satisfacción de los criterios de rentabilidad. Los resultados son favorables exceptuando el escenario más pesimista, donde no se satisfacen, pero llegan a resultados cercanos. En cuanto al coste nivelado de la electricidad, se obtienen valores mayores que los declarados para nuclear en el caso base y en el escenario pesimista, lo que supone un resultado realista teniendo en cuenta la novedad de la tecnología.
El análisis de sensibilidad demuestra la robustez del modelo de esta planta frente a incrementos de costes. También muestra la mejora de rentabilidad de la panta lograda con la incorporación de productos secundarios para la cogeneración.
En conclusión, la viabilidad queda demostrada ante la mayoría de los escenarios considerados. El coste de construcción se mantiene como el factor más crítico para la viabilidad económica. Los problemas asociados con este coste, como retrasos o sobrecostes, deben ser evitados para asegurar la rentabilidad de los nuevos desarrollos de la energía nuclear

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I agree that the work of the Department of Nuclear Technology may be made available to the public.

Munich, April 26th Pablo Bullido Alonso

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List of Acronyms

CCS: Carbon Capture and Storage

IEA: International Energy Agency

HLW: High Level Waste

MLW: Medium Level Waste

LLW: Low Level Waste

NPT: Non proliferation Treaty

NPP: Nuclear power plant

NEA: National Energy Association

DiD: Defence in Depth

SMR: Small Modular Reactor

GIF: Generation IV international forum

PWR: Pressurized water reactor

BWR: Boiling Water reactor

LWR: Light Water Reactor

GFR: Gas Fast Reactor

COT: core outlet Temperature

LFR:Lead Fast Reactor

MSR: Molten salt reactor

SCWR: Supercritical Water Reactor

SFR: Sodium Fast Reactor

VHTR: Very High Temperature Reactor

TRISO: Tristructural isotropic

MPBR: MIT Pebble Bed Reactor

QA: Quality assurance
FCC: Fuel Cycle cost
LCOE: Levelized cost of electricity
WACC: Weighted average cost of capital
IRR: Internal rate of return
NPV: Net Present Value
PBP: Payback Period
O&M: Operation and maintenance

Chapter 1

Introduction

At the moment, our society is facing one of the biggest challenges in history, that is climate change. Scientist are not yet sure of the possible effects of this phenomenon but they agree that we are coming close to the point where its consequences might be irreversible.

But first, an agreement must be reached on whether or not climate change is a problem, and more importantly, whether or not measures can be taken in order to mitigate this effect. To do that, NASA [10] has developed five indicators that reveal indeed that global warming is a real issue.

These indicators are (1) Carbon dioxide concentration on the atmosphere, (2) Global temperature of the earth, (3) the Arctic sea ice minimum, (4) land ice, and (5) the sea level. Later in this thesis, these indices will be studied in order to draw the conclusion that the temperature of the earth is actually increasing, in a phenomenon better known as global warming. Furthermore, the study of these indices will also reveal that the human factor is helping them rise beyond every historical level.

The situation demands urgent solutions, yet, there are a few on the portfolio to fight back global warming. These are focused on problems related with the consumer habits of the modern society. For instance, a proposed solution on the EU is the model of circular economy [11], a concept that seeks to rebuilt capital, ensuring an enhanced flow of goods and services. This means, that seeks to implant a circular flow for goods and services, with the aim of reducing production, waste, energy, and money along the value cycle. This also implies changing the consumer habits of demand of energy. The circular economy requires a decrease in the energy demand from the part of consumers, either in the industry field or the everyday life of our society.

Another solution more focused on the energy problem, is known as energy transition. This means changing the main energy resources, from carbon based fuels, to free emission resources and technologies. These technologies can be categorized in three groups, renewable energy, conventional technologies with carbon dioxide capture and storage, and nuclear energy. The greatness of this solution is that is aims to eliminate all the dependence on fossil fuels, or at least, eliminate all the negative effects of its usage (as in the case of CCS).

At this point is necessary to introduce the concept of energy mix. The energy mix of a region is the way in which a region supplies its energy demand with the available resources. Since electricity cannot be stored, generation and demand must be equal instantaneously. This is an arduous task, and it is contingent on the technologies that supply that energy. Some power plants are more flexible than others, being able to increase or decrease its generation to maintain the equilibrium between supply and demand, other are more reliable, without great flexibility to change but with a continuous production during the year. in addition, there are different kinds of power plant according to the stability they provide to the grid, which is closely monitored.

The concept of the energy mix is important to reach the realization that the utopia of 100% renewable generation is not achievable. The intermitency of these resources makes it impossible to match generation and demand. Besides that, the renewable resources, though widely spread, are still concentrated in areas around the globe, and not every region can rely on them. This problem will be the biggest drawback of renewable energy technologies until the storage of electricity in great quantities is achievable and efficient.

Nevertheless, many renewable technologies could still be criticized because of the stability of the grid, to which they contribute with less inertia than other power plants, making it harder to provide stability in supply. This does not mean that renewable energies do not have a big role to play in the future development of energy systems. There are already developments in smart grids to help the integration of renewables. And the fact that they accounted for almost 20% [12] of energy generation in 2014 proves that they can already be considered a conventional resource in many areas of the planet. Nevertheless, these technologies must maintain its drive, research, and development so that they can be a leading force in the worldwide energy mix.

On this framework, is where nuclear energy has a privileged position. Nuclear technology obtains energy from the fission of atoms. It can be considered a conventional technology, because the first power plants were built during the 1950s, and it continued its development to commercial power plants over the next decade [13]. Nevertheless, nuclear technology has been in continuous development since its birth. The reason for this continuous improvement has been the different challenges that this industry has faced over the years.

When nuclear technology was first developed it was closely related to the weapons industry. It was not until the 1950s that it started to be conceived as a viable energy resource. And even after being established as a reliable source, controversy has always surrounded it. Policies for non-proliferation of nuclear weapons have been promoted, and many countries participate on international institutions that promote safety on power plants. Yet, there is still much to be done on this issue.

Additionally, unfortunate accidents on nuclear power plants helped the bad social conception to create a hostile perception of it. The nuclear industry then responded by increasing the safety measures worldwide in other to prevent further accidents, but the idea of nuclear energy being dangerous was already established. The latest nuclear accident [14] (the future of nuclear energy reconsidered) motivated many countries to either slow down or phase out their nuclear programs. It also led to a rise in the external cost associated with nuclear energy. Incidentally, this current has more followers on the western countries than on eastern ones, where developing economies such as China or India are pushing their nuclear industry and other fields related to it such as the construction industry.

Later in time, another challenge arose. The nuclear waste produced on a power plant contains several elements (such as the minor actinides and the fission products) with high radioactivity and long active periods. Despite of this fact, the nuclear fuel cycle takes these elements into account, and has developed methods for its long-term storage and disposal, with the main objective of eliminating any possible effect to the people or the environment. Nevertheless, the lack of knowledge among the main public created a big response against nuclear energy. There are also several scientific institutions that maintain that the closed fuel cycle is far from being cost effective [15], and, therefore, from being adopted as a method of nuclear waste treatment.

Finally, the third challenge and the most current issue, is related to the economic viability of nuclear power plants. The construction of a plant of these characteristics is extremely capital intensive, which results on these plants having high fixed costs [16]. Even though the variable costs are lower than for other power plants, the current tendency to micro-generation leaves nuclear energy on an uncomfortable position, with the necessity of development of small modular reactors, SMRs, to keep up with this tendency, losing the cost-effectiveness of the economies of scale [14]. On the other hand, in developing countries such as china, where nuclear energy is being pushed, the construction cost of nuclear plants is proving to be more competitive than in other areas. The reason for this, is that the construction industry is extremely experienced, due to activities performed in different fields in the development of the country. As a result, delays and other costs associated with a poor performance during the commission of a nuclear power plant are lower than in other parts of the world, and, therefore, the fixed cost is also lower.

Nuclear technology is currently facing these three main critics: safety, waste management and cost-effectiveness. In fact, R&D in nuclear industry are focused on easing these negative effects and improve its biggest advantages. These are the reliability of supply and the lack of carbon dioxide emissions. Since nuclear power plants are spread around the globe, its integration on the electric grid is already proven feasible, which is an advantage when compared to some renewable technologies. The reliability of supply of this sort of power plants is also attested, since the nuclear generation is commonly used in the energy mix as base load (this is the energy that is demanded continuously throughout a period of time).

Taking all of this into account, it can be affirmed that nuclear energy is to play a major role inside the framework of the energy transition. In the following chapters the different topics mentioned in this introduction will be developed and analysed in depth.

Chapter 2

Energy transition

Energy transition is the concept of reducing the dependency on fossil fuels in the energy sector. It implies *transitioning* from conventional power plants such as coal or natural gas, to a family of resources with low or no CO_2 emissions.

The concept of the energy transition is starting to be applied in many countries around the globe. This countries have push renewable technologies in their energy mix, and are looking at alternatives to substitute fossil fuels. The transition is going slow and is not expected to accelerate, since it is mainly driven by economical decisions. Under such circumstances fossil fuels offer better perspectives that its low-emission competitors. The reason is the liability of newness of many low-emission technologies, that means that these need high investment to represent a viable alternative.

The challenge for energy transition starts in achieving this objective in an environment with such extremely opposing conditions. Energy demand has an increasing trend that is not expected to change. At the same time, world population experiments a similar trend. The recent drop in oil prices has been a setback for new, clean technologies, that are often more expensive than fossil fuel powered plants.

Meanwhile, climate change remains an urgent problem. Even tough relative consensus has been achieved regarding global warming, there are are countries in which it is still a controverted topic. Nevertheless, Carbon emissions grow steadily and carbon dioxide concentration on the atmosphere has reached its maximum historical level. Other indicators of global warming, such as earth and sea ice level or mean global temperature support this conclusion.

The objectives of the energy transition are to be achieved through the development of certain technologies. This means both the improvement of *efficiency* of current technologies, to reduce the consumption of fossil fuels, and the *development of technologies with no emissions* such as renewables and nuclear. Carbon capture and storage is also expected to play a significant role, enabling the usage of fossil fuels without releasing the CO_2 to the atmosphere.

These are the topics that will be analysed in this chapter. Energy transition will be explained, along with the tools that have achieved the most widespread acceptance.

2.1 Facing an increasing demand

Since the 1960s, world population has increased from a little more than 3 Billion to approximately 7.5 (world data bank). This increase in population has caused a similarly high increase in world energy consumption, which has also risen from 1336 kg of oil equivalent per capita in 1960 to almost 2000 kg in 2014. This tendency is not expected to stop, since the population projections indicate a level of almost 10 billion people by 2050, as a result, the energy demand is also expected to increase leading to higher levels of carbon dioxide emissions. This is the main reason the current energy system is unsustainable and why deep changes are needed in the global energy systems [16]. Nuclear energy: status and future limitations

To face this challenge, energy demand must be reduced and supplied by a de-carbonized energy system. In other words, there is a necessity for the increase of energetic efficiency and for the development of technologies with

0 carbon dioxide emissions.

2.1.1 Energy Efficiency

Historically, energy demand has been related to GDP [17], as shown in figure 2.1. This relation however is weakening in both developed and emerging countries, due to the improvements made in the efficiency of the technologies. The tendency for these improvements started around the 1970s in the strongest economies, who started the needed research and development for this technology. Currently, and over the last decade, emerging countries such as China and India have implemented these improvements as well, successfully responding to their internal increase in energy demand.

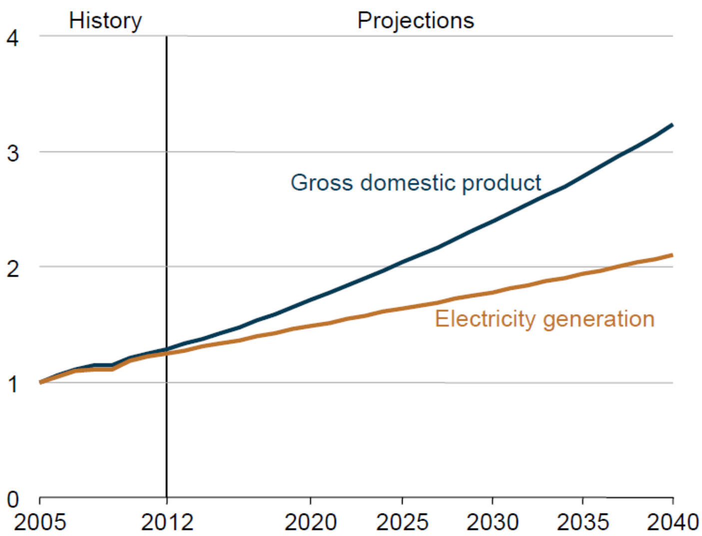

Figure 2.1: Relationship between global GDP and energy. Index, 2005 = 1. Source International energy outlook 2016

A measure of energy efficiency is Global energy intensity. It is calculated as the amount of energy used per unit of gross domestic product. It measures the energy efficiency of a nation's economy because it measures the cost of transforming energy consumption into economic growth. This index has improved [18] decreasing by 1.8% in 2015 in the IEA members, which is still far from the goal of 2.6% to be consistent with the climate change goals, but

is a significant improvement compared to previous years. It has also been heavily influenced by the drop of prices of crude oil. Its evolution can be observed in figure 2.2.
Nevertheless, it proves that the energy systems worldwide are shifting into a more efficient model. IEA members have improved their energy efficiency by 14% between 2000 and 2015, meaning savings of 450 million tons of oil equivalent at the last year of the period. Besides that, the fact that GDP has increased by 2% in IEA members while the primary energy demand has remained flat also indicates more efficient exploitation of resources.

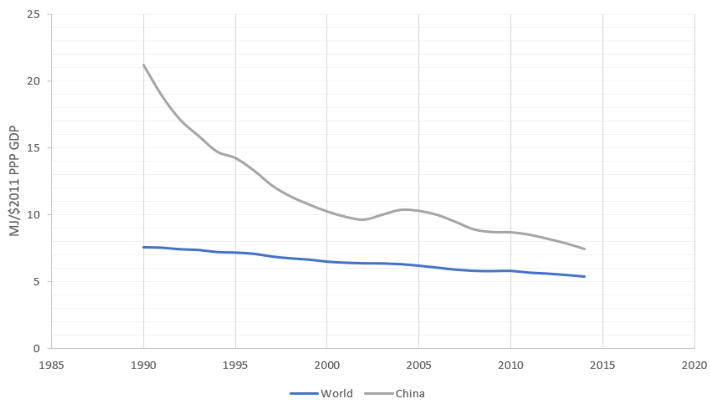

Figure 2.2: Energy intensity Level of primary energy

A noteworthy case is the People's Republic of China, a country that has become a driver in energy efficiency at a very quick rate. In 2015, China has improved its energy intensity by 5.6%, reached the lowest increase in primary energy consumption since 1997, 0.9%, while increasing its GDP by 6.9%. Yet, the energy intensity level of China is still 50% higher that the OECD average, which means that there is still much to do.
The increase in energy efficiency has been made possible by an enforcement of efficiency policies. These have been especially implemented in industrialized countries such as Canada, Germany or USA. Public policies have also helped energy efficiency by protecting the sector from energy declining prices. For instance, the price drop of crude oil was 60%, but the taxes slowed down this drop to the final users to a final price reduction ranging from 38% in

the USA to 16% in Germany. The necessity of these policies comes from the so called **rebound effect** [19]. This effect is the increase of energy demand due to the lower prices associated with more efficient systems.
These efforts have helped to slow down the increase in energy demand. However, energy systems worldwide still have a strong dependency on fossil fuels which leads to high annual CO_2 emissions enhancing the greenhouse effect and, therefore, global warming. The goals of the fight against climate change must not only be focused on improving the efficiency of existing technologies, but also lead to a de-carbonation of energy systems.

2.1.2 Energy Technologies for de-carbonation

In the previous section, the improvement of the efficiency of the existing energy technology has been discussed. this field of development is, though necessary, insufficient to meet the goals proposed by the latest convention on climate change of Paris 2015 [20]. In order to achieve these goals, countries must develop an energy transition to reduce the dependency of fossil fuels and, thus, also reduce human carbon dioxide emissions to the minimum possible level. Figure 2.3 shows the evolution of these emissions.

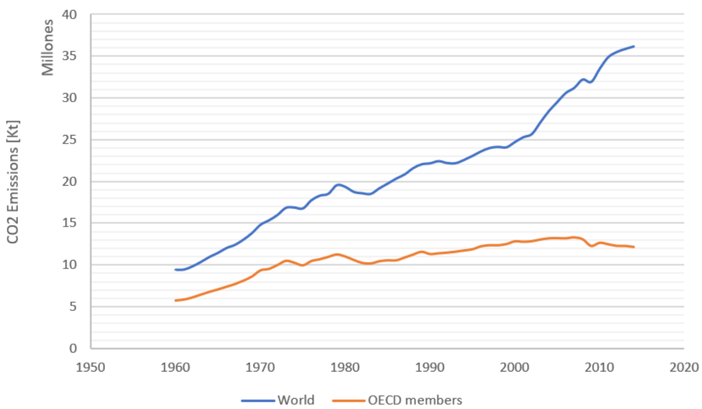

Figure 2.3: CO_2 emissions in Kt

The existing technologies able to fulfil these goals are, as previously mentioned, renewable energies, carbon capture and storage, and nuclear energy.

In this section the development of these technologies will be analysed.

Development of renewable energy technologies

Renewable energy plays the most recognizable role on the energy transition. The growing concern about climate change along with the favourable policies adopted by many countries that sought energy independence were at first the driving factors for its success. Today, on the other hand, most of this development is self-driven, due to the fact that many of these technologies have already established as mainstream energy resources, especially on the power sector. The cost-effectiveness of these technologies is no longer questionable. Proof of this fact is the estimated global energy generation of 19.2% by renewables in 2014 [12], a year in which the price of crude oil dropped 60% and the net investment in power capacity additions for renewables outpaced fossil fuels for the sixth consecutive year.

Even though renewables are closer today to conventional resources than to risky bets, its development is far from coming to a full stop. Research and development programs are ongoing on related fields: improvements of capacity, use of smart grid technologies and progress in hardware and software to support the integration of the technology as well as research in energy storage and commercialization.

The growth of renewables is mainly limited to the power sector. In the heating and cooling sector renewable energy supplies approximately 8% of final heating or cooling, mainly represented by biomass. At the same time renewable only meant an estimated 4% of global fuel for road transport. The lack of policies supporting these two sectors is the main reason for their slow development. In the transport sector, the electrification of mobility is de mayor factor for sustainability while in the heating and cooling sector, the low prices of the fossil fuels constrained the renewables.[21]

In the past years, the installed capacity of renewables has soared with the net investment growing consistently each year. In addition, new renewable power plants have been installed with complementary assets to improve their performance. For example, concentrated solar power plants came on line with incorporated thermal energy storage for the second year in a row [21]. Energy storage is attempting to be de solution for the variability issue with renewables. The possibility of accumulating the excess of energy produced by these power plants during low demand periods to spend it during high demand hours could lead to a zero carbon emission system. Unfortunately, only few renewable technologies are, as for now, storable. Hydro-power and biomass work as functional resources according to this matter, on the other hand, wind and sun power are limited to the availability of the resource. There have been attempts for hybridation of two technologies to mitigate these effects, even with energy storage involved as in the case of the island of *El Hierro* in Spain. This power plant combines an wind power with hydro power with pumped storage. As a result,it is able to maintain certain regularity of supply combining these two renewable resources.

Nevertheless, energy storage technology is still on the earliest stages of its development [22]. Pumped storage is its strongest representative, and the others, such as batteries, are facing different challenges regarding its efficiency, safety or regulatory policies.

In conclusion, the energy challenge has lead to an enforced development in renewables for the past few decades, especially in the power sector, where some of these resources are already playing an important role. Yet, there is still much to be done in order to achieve a system totally free of CO_2 emissions. The biggest efforts are directed to the challenges of increase in capacity due to the low energy density of some resources (biomass) when compared to fossil fuels, and to the development of an effective storage technology, which enables variable resources (solar power or wind) to provide energy simultaneously with the demand, rather than depending on the availability of the resource. Despite these efforts, the urgency of the main problem, which is climate change, calls for more intimidate actions, as well as for different ways to achieve the zero emission system in order not to rely only on the development of renewables.

Development of Carbon Capture and Storage

Another growing technology for the reduction of carbon dioxide emissions is the carbon capture and storage. This technology has the objective of eliminating the CO_2 emissions produced by the burning of regular fossil fuels in the power sector. In addition, it can also be applied to biomass power plants, which are CO_2 neutral on their own, making them a sink for carbon emissions, bringing closer the objectives described in the Paris agreement. In the following frame a description of the technologies for carbon capture and storage can be found, based on the *Encyclopedia of technology* [23]

Carbon Capture and Storage

Carbon capture and storage, henceforth *CSS*, comprises the series of methods used for the sequestration and storage of carbon emissions applied during different stages of the use of fossil fuels. Several technologies exist regarding either the capture of these emissions or its final disposal.

The motivation for this technology is the belief that coal combustion will still be one of the most important energy resources for a good part of this century, mainly because [24] its cost effectiveness and its acknowledged large reservoirs. Thus, there is a need for a method that enables its usage while mitigating its environmental impact.

Sequestration of the CO_2 there are three mainstream methods: (1) flue gas separation, (2) oxi-fuel combustion, and pre-combustion capture. The first two take part after the combustion of the fuel and the third is applied before.

Flue gas separation is a process of chemical absorption in which carbon dioxide is absorbed in a liquid by the formation of a chemically bounden compound. This compound is later introduced on a regenerator with water vapour. As a result, a concentrated current of CO_2 is obtained. It can be send directly into storage or sold as a raw material to improve the cost-effectiveness of this method.

The second method for carbon emission separation is the *oxi-fuel combustion.* In this method, the combustion reaction takes place with a purified oxygen current. The products of the reaction are then, mainly water an carbon dioxide, which can be easily separated by a condensation process. This method relocates the separation from the emissions of the combustion to the reagents. Therefore, an *air separation unit*, ASU is needed to obtain the purified O_2 current. The main advantage of this method is that it has already been integrated in existing *pulverised coal*, PC power plants.

Finally, the third method for capture [23], is the *pre combustion capture*. This method eliminates all the carbon compounds on the synthesis gas used as fuel, especially in IGCC (integrated gasification in combined cycle) power plants. The *carbon monoxide* present in the fuel gas is separated before the combustion leaving a synthesis gas with high content of hydrogen, which is later conducted to the turbine to produce electricity. the CO obtained before reacts with water to obtain CO_2 and finally capture it. This method offers several advantages, such as the current of CO_2, which is now pressurized, or the possibility of selling hydrogen as a by-product, for instance, for its usage in fuel cells. In addition, this method could be applied in gasification plants, which do not produce electricity, but sell their synthesis gas product to power plants. In this case, hydrogen would be the final product.

Regarding the final storage of the carbon dioxide, there are several alternatives. Yet, these alternatives [23] must account for he fact that the storage could last for long periods of time, and develop ways that minimize its impact to the environment, the risk of accidents, and, obviously, the cost. Besides that, the implementation of this method must be done in a lawful way recognised and reflected in the corresponding regulations.

The methods for storage can be mainly divided on two categories: geological and ocean storage. Geological storage is performed through different systems. CO_2 can be injected into a well after separating it from the process of extraction of gas and oil, which results on acid gas, a mixture of CO_2 and H_2S. Another system for storage is the *enhanced oil recovery*, or EOR, though this system usually only works as temporal storage, since in many EOR projects the CO_2 is released to the atmosphere after the blowing down of the reservoir.

A more efficient method is the storage of CO_2 in un-mineable coal seams. The main benefit of this method is the absorption affinity of CO_2 in the pores of coal, which is higher than this parameter for methane. This makes this system a very suitable way of extracting coal bed methane, a non conventional hydrocarbon, while storing the emission of CO_2.

Deep saline formations are also a viable storing reservoir for CO_2 emissions. These formations are widely spread and have the largest storage volume. Through a mechanism of solubility and mineral trapping, the injected carbon dioxide dissolves in fluids and reacts with minerals forming stable carbonates, thus providing the possibility of being trapped permanently.

The ocean offers the highest potential for CO_2 storage by a wide margin compared to the other alternatives. It is also presented as an acceleration of an existing process, since the mechanism of atmospheric carbon dioxide dissolving into sea water occurs naturally. It is also estimated that the environmental impact of dissolving half the anthropogenic CO_2 emissions would rise the sea water carbon concentration by 2% and acidify the pH by 0.15. In other words, it is estimated that the impact would not be important, yet mistakes have been made before regarding that matter.

Two main methods are currently being considered for injecting CO_2 into sea water. One is based on injecting it at high depth, bellow 3000 meters, at which point CO_2 is denser than water, and it would form a deep lake. The other system injects it at mid-depth, 1500-3000 meters, where droplets of CO_2 would ascend by buoyancy, but be dissolved into water before rising 100 m.

The biggest disclaimer for CO_2 storage is the uncertainty of its effects. Studies have been made regarding the possible relation between geological storage and seismic activity, or the effects of ocean storage on sea life, but non of them offer conclusive statements. In order to implement any of the previously discussed systems, more research should be conducted regarding the system in general and the particular storing site.

The report by the IEA: **20 years of CCS** [25] gives an outlook of the development of CCS since this technology started its development. IAE considers CCS to be the only technology able to achieve negative emissions, and, therefore, considers it to be a crucial element to achieve the ambitious target set by the Paris Accord of *well bellow 2°C*.

This study presents significant milestones achieved in the development of CCS, such as the Sleipner project in Norway, which is the first project with associated CO_2 monitoring along with storage. Another example is the publishing of the **2005 IPCC Special Report on CCS**, which increased the recognition of the future role of CCS for future climate change goals, and the later publishing of yet another study, **IPCC Fifth Assessment Report** in 2014, which continued to emphasize the importance of CCS, even concluding that it was impossible to achieve the equivalent atmospheric concentration of CO_2 to increases in temperature around 2°C, if the availability of CCS was limited.

Projects with CCS are growing both in number and in size, as it can be observed in figure 2.4. In 2016, 15 projects were already operational and 7 more were expected to come on line in the next two years. Besides that, the diversification that this technologies are going through proves that CCS is not only applicable to a clean carbon power technology, but to different power and industrial processes.

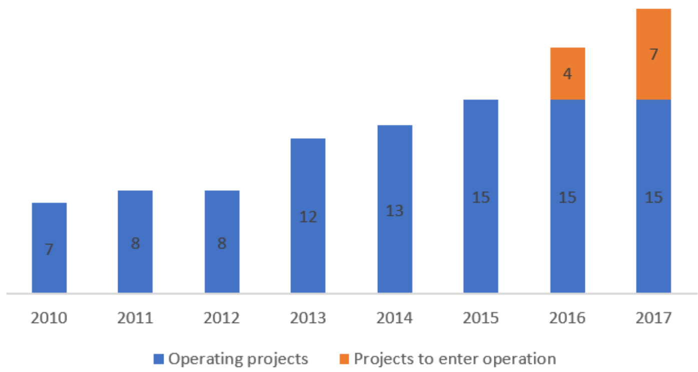

Figure 2.4: Evolution of large-scale CCS projects. Source: The global CCS Institute

After the release of the two reports mentioned above, investment in CCS gained strength, and the most developed countries in the world planned investment figures near USD 30 billion for the development of 20 new projects of large scale. Albeit, the financial support has been lower than initially expected, with only 2,8 billion finally being actually invested. This lack of support came partially motivated by the uncertainty regarding future possible liabilities, such as the distinction between the local impact of a hypothetical CO_2 leakage and the global impact to climate change, which is missing from the current risk management policy.

Energy transition to a de-carbonize system is expensive, and will be even more if CCS is not developed consequently. The cost of not pushing this technology is expected to be even up to USD 3.5 trillion. In addition, CCS is not only important in the power sector, many industrial processes can only be de-carbonized by the application of this technology. It is in fact the only way of developing a sink-hole for carbon emissions when applied to biomass projects.

The conclusions of this study are clear. Development of CCS has offer some significant advantages, but it is far from being on track. A lot of financial support, research and development is still needed in order to achieve the goal of the Paris Agreement. This shows that CCS and renweables are facing remarkable similar problems regarding its current status and its future development. Therefore, the conclusion is the same as in the previous section: the measures needed for the challenge of climate change need to have a more immediate character, even though the development of this two fields must maintain and even increase its thrust.

2.2 Climate Change

Before this section, climate change has been introduced as the underlying problem calling for all the measures explored. Energy transition and all the presented technological advances for it have climate change as a root cause.

However, climate change is by itself a controversial topic. In this section, evidence will be presented in favour of the reality of climate change and some of its possible effects will be accordingly discussed. The objective is to create awareness of this problem and to clarify the foundation in which this project is built on.

2.2.1 Climate Change Indicators

NASA [10] has developed a system in which five indicators act as a tool for diagnosis of the status of climate change. Each of these offers evidence of climate change that the earth is already experimenting. Some of them are underlying proof of the climate change, whereas other are direct plausible effects of it.

Carbon dioxide

Carbon dioxide is a greenhouse effect gas, which appears naturally in the atmosphere, due to processes such as respiration and combustion, or is naturally released in volcano eruptions. Therefore, its levels throughout history are rather variable, oscillating between concentrations of 80 and 300 parts per million, with a cyclic behaviour.

Since the industrial revolution, other sources of carbon dioxide emissions were added, coming basically from the combustion of fossil fuels, both in the power sector and in a wide rage of industrial processes. As a result, the concentration of this gas in the atmosphere as grown steadily breaking the cyclic pattern and reaching the highest registered level of 407 parts per million in 2017, as shown in figure 2.5.

The increase of the concentration of this gas involves an increase in the greenhouse effect, trapping the solar radiation inside the atmosphere and increasing the mean temperature of the earth, thus favouring climate change.

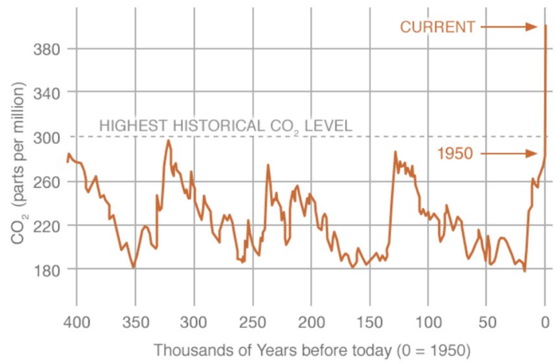

Figure 2.5: Historic levels of CO_2 concentration

Global Temperature

As it was introduced in the previous section, an increase in the greenhouse effect causes an increase in global mean temperature. This means, that the global mean temperature is follows a similar cycle as CO_2 concentration, despite being affected by other factors as well. Accordingly, since the industrial revolution, global mean temperature had a growing behaviour during the last century as shown in the figure 2.6, reaching 0.99°C in 2016, from a value of -0.12°C in 1881. In fact, 16 of the 17 warmest years recorded in the period took place between 2001 and 2016, with the exception of 1998.
Global mean temperature serves as both an indicator of global warming and as a cause for the following indexes, such as sea level or the levels of ice.

Arctic Sea Ice Minimum

The Arctic sea ice reaches its minimum level in the month of September each year. The figure 2.7 shows the minimum area covered by ice since 1979. This data is recorded by satellite and, as a result, the figure 2.7 does not show the occupied area before that year. Even though the historical minimum took place in 2012 the tendency to decrease is clear.

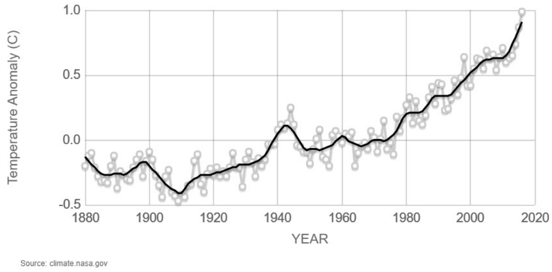

Figure 2.6: Historic levels of Global mean temperature

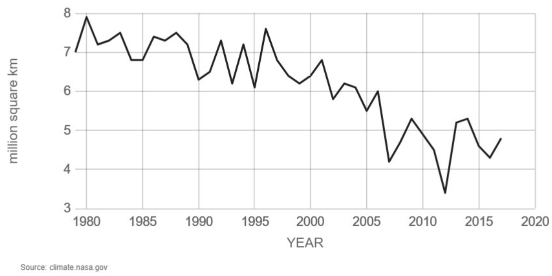

Figure 2.7: Arctic Sea Ice Minimum

Land Ice

The mass of land ice serves also as an indicator of the climate change. The biggest two exponents of ice mass inland are Antarctica and Greenland. Figures 2.8 and 2.9 show the evolution of the ice mass in these two regions. The level has steadily decreased in both cases since 2002, and shows additionally an acceleration on this rate since 2009.

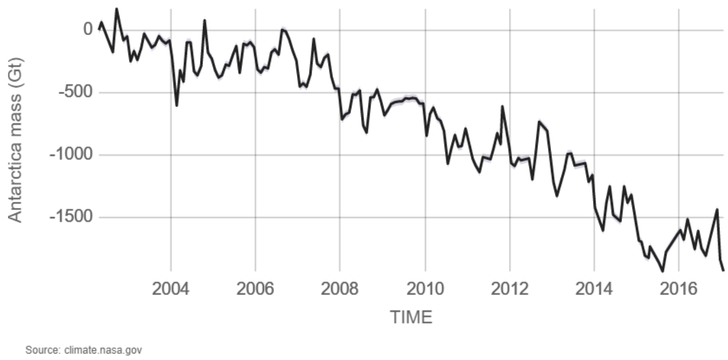

Figure 2.8: Antarctica Mass variation

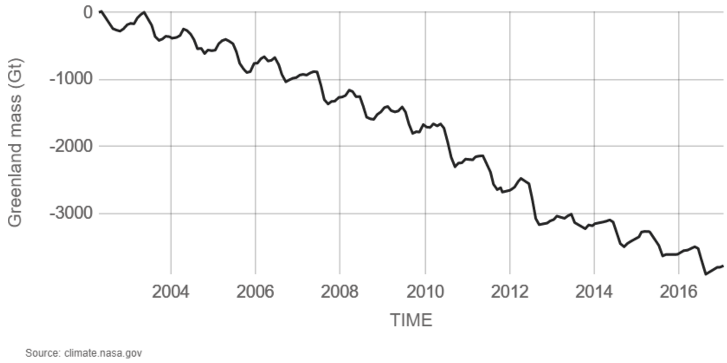

Figure 2.9: Greenland Mass variation

Sea Level

The water mass that is no longer frozen both in sea and land ice is causing the mean sea level to rise. The increase in temperature also contributes to the variation of the sea level due to the expansion of water as it warms. These effects combined have lead to an increase of 84.8 mm in the sea level with a mean rate of change of 3.4 mm per year accounted since 1993.

Figure 2.10 represents the variation of sea level with time. This figure is in concordance with everything until now, proving that climate change is a real and urgent issue, whose effects are already showing.

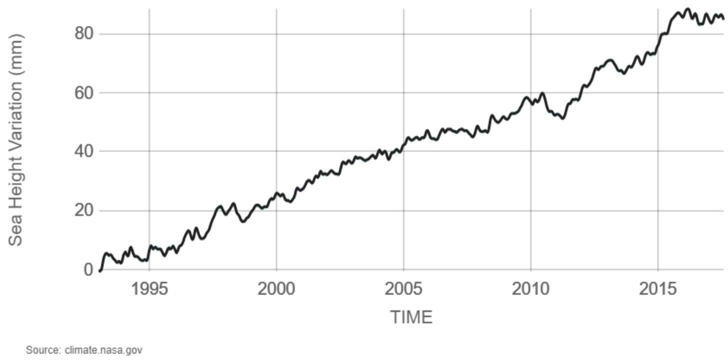

Figure 2.10: Sea Level variation

2.2.2 Climate Change Causes

The indicators on section 2.2.1 were valid proof of the existence of climate change. The did not show, however, that the maximum levels reached were not a result of the cyclic behaviour of climate. In other words, they did not show evidence for the human factor to play an important role in this matter. There is still controversy pointing out the solar radiation activity and fluctuations being the main cause for the current climate change.

Regarding the human factor theory, the main proof is that the carbon emission have soared since the industrial revolution due to the new sources and the elimination of sinks of CO_2 due to deforestation. However, these could be seen as added effects to a variation in solar activity.

As a matter of fact, the recorded data show a slight drop in the energy output of the sun since 1918 [10]. This seems to prove that the sun energy variability is not positively related to climate change. On a long term analysis, the most recent studies [26], [27] show that the solar activity, albeit being possible related, could not be the only cause for the maximum levels registered for the climate change indicators, and that it could only account for 10% of the 20th century global warming.

This conclusion leaves the human factor as the main responsible for the increase in the greenhouse effect and, thus, climate change. This statement might seem as a shaming realization but it also means that measures can be implemented to fight global warming by reducing the emissions and putting all the indicators back on track.

2.2.3 Climate change effects

The effects of climate change are still rather uncertain, although there is consensus about those effects that are already showing. The **Third National Climate Assessment Report** [28] explores some of these effects across the different regions of the U.S.

Several of these consequences have already been discussed as climate change indicators in the section 2.2.1, such as the increase in mean temperature and the ice melting, both inland and in the sea, which is also a direct consequence of the rise of the sea level. However, others have a less direct relationship. For instance, the extreme weather phenomenons became more frequent since the beginning of human-induced climate change. Hurricanes and severe storms have increased both in intensity and frequency, as well as events of flooding and drought, depending on the region. In fact, precipitation patterns are changing all over. The frost-free season is also lengthening steadily since the 1980s. It is still unclear whether this is beneficial for the agriculture or not. Nevertheless, the changes in precipitation patterns are already influencing the exploitation of underground water supply, on which this sector is highly dependant.

The higher concentration of CO_2 in the atmosphere is also accelerating the rate at which this gas is absorbed by sea water, following the natural CO_2 cycle. This effect acidifies water lowering its pH. This acidification is likely to affect the ecosystem, though the level of affection is still rather unclear.

The outcome of climate change regarding global economics is also unclear, though there are experts that point out that "unmitigated warming is expected to reshape the global economy by reducing average global incomes by roughly 23% by 2100 and widening global income inequality, relative to scenarios without climate change" [29].

In short, there is scientific consensus about some of the most direct effects of global warming, and the challenges that will arise if this phenomenon is not mitigated. The more indirect consequences are uncertain, but some of the theories point towards even more challenging problems, such as the change in the patterns of sea current, that is likely to change the climate zones around the globe as well.

Chapter 3

About Nuclear Energy

Chapter ?? discussed the necessity for an energy transition based on the time-pressing issue of global warming. However, the solutions explored in that chapter did not include nuclear energy. This controversial power source offer a viable solution due to the fact that there are no emissions produced during its power cycle. Nuclear energy is a source of debate due to some characteristics that have been detrimental to its image in front of public opinion. Nuclear weapons proliferation, nuclear waste management, power plant safety and economics are the main four challenges that nuclear energy has to face.

Nevertheless, nuclear power is proven to be a reliable energy source with zero emission during the power cycle, whose integration in the power grid is already developed and functional, in contrast with some renewables. This advantages may gain additional importance given the urgency of the matter, even overweighting some of the challenges. Despite of this fact, nuclear power can overcome these challenges by improving its sustainability, safety and cost-effectiveness, while being a clean energy source regarding emissions of greenhouse-effect gases. This is the objective of generation IV and the target for nuclear power in the foreseeable future.

3.1 Current status of Nuclear Energy

The role of nuclear energy in current energy systems worldwide has become less important over the last decade. With the exception of some countries such as China, India or Pakistan that have accelerated its nuclear program, the vast majority of the countries are either slowing down its nuclear development, or implementing measures to completely bring it to a full phase out.

The current status of nuclear energy is published in documents such as **The World Nuclear Industry Status Report** [30] annually. These reports offer an exhaustive analysis of the present role of nuclear an the tendencies for its development.

Regarding nuclear programs and reactors, China is the leading force accounting for five out of the ten reactors that started on 2016. On the same year, two reactors were shut down in Russia and in the U.S.

The number of operating rectors in 2016 is 403 distributed along 31 countries, this number is lower than the maximum achieved in 2002 of 438. Total capacity increased by almost 1% reaching 351 GW, a level also below the peak of 368 GW achieved in 2008. Electricity generation also increased in 2016 compared to 2015, reaching 2476 TWh, but is consistently below the generation peak of 2006. In this area, China played a mayor role, developing its nuclear program and reaching 36.6 TWh of nuclear generation.

Nuclear electricity generation is driven by five big players. These are, by rank, the U.S., France, China, Russia and South Korea. They accounted for 70 % of nuclear electricity generation in 2016. This helped nuclear share on the energy mix to remain stable on an 10.5% level.

The average age of operating nuclear reactors has risen, and in 2017 reached 29.3 years. 234 reactors have been operational for 31 years and more. Out of these 234, 64 have operated for longer than 60 years. This is due to the policies of lifetime extensions, mainly implemented in western countries, and in countries with past experience in nuclear energy. These policies are, however, regulated differently in each country. In the U.S. for instance, the majority of the reactors received license extensions for up to a total lifetime of 60 years, whereas in France, only 10 year extensions are granted after passing an in-depth safety assessment.

The lifetime projections of worldwide reactors are not optimistic. In the decade of 2020, 194 reactors would have to be replaced if all presently operating units were shut down at the end of a 40 year lifetime (with the exception of those that are beyond the 40 year mark), even if all the reactors under construction were completed. The license extensions do not offer a brighter perspective, being only able to delay the problem.

The nuclear construction sector is also facing some challenges. Many of the projects under construction are facing delays or have even come to a full shut down for several reasons. An example for this the Angra-3 in Brazil, which was halted due to corruptions charges against the senior management. Construction time has an average of 10.1 years in the last decade, with an extremely wide rank from 4 to 43 years. Prototype reactors such as the *Prototype fast breeder reactor* are reaching construction times of more than a decade, with two of them reaching it in 2017.

The finances of nuclear industry are suffering the effects of the loss of interest in new-built power plants. The bankruptcy of the giant Toshiba-Westinghouse was due to dramatic cost overruns, delays and technical problems. The nuclear french company AREVA also went technically bankrupt after cumulative losses over a six year period. The European commission has developed a rescue strategy for this company, which was approved in August 2017, but since the company is struggling with a quality-control scandal, a dozen reactors have been already shut down in France.

The *Small Modular Reactors*, SMR programs are also victims of this loss in interest in new-built nuclear. These reactors were the bet to solve issues of large nuclear plants regarding capacity and capital intensity. One SMR is scheduled to start-up in China in 2018, yet, some other promising designs have failed to find buyers, such as the SMART in South Korea and m Power in the United States.

At the same time that interest in nuclear industry is slowly fading, the efforts to push renewables have increased. After the record investment in 2015, investment in renewables dropped by 23% in 2016, due to the improvement in cost-effectiveness in several technologies. Even in China, the leader in nuclear capacity installation in the past decade, renewables have outpaced nuclear reaching capacity of 150 GW of wind power and 78 GW solar, compared to the 32 GW of total nuclear capacity.

In conclusion, the present of nuclear energy does not offer an optimistic perspective in terms of development. The mainstream tendency is to maintain the existing plants and extending their lifetime to take advantage of the low emission characteristic of the technology. There are exception to this view, such as China and India which are developing its nuclear program, or Germany, which is decommissioning its nuclear power plants to achieve a zero-nuclear energy mix. Yet, the role that nuclear energy is to play in the energy transition is subject to controversy, and other means to achieve this clean energy system are currently outpacing nuclear industry.

3.2 Challenges of Nuclear Energy

As it has been discussed in section 3.1, nuclear industry is slowly losing its former thrust and lack of confidence caused it to be in a delicate situation. On this section the reasons that lead nuclear power to this situation will be explored and analysed.

Since the firsts commercial power plants started up in the 1950s, nuclear power has been in de middle of controversy, mainly due to three topics: nuclear safety, waste disposal, and nuclear power cost effectiveness. This three challenges arose in chronological order, and they are yet to be addressed according to public opinion.

Nuclear safety was the first challenge that nuclear industry had to face. The reason was the relation between nuclear power plants and nuclear weapon proliferation. Yet, related to this topic, the safety in nuclear power plants is also part of the issue, due to accidents that occurred all over the world. Three of these accidents were especially unsettling for the public opinion and for the nuclear sector: the partial core meltdown on *Three Mile Island*, the *Chernobyl* disaster, and the *Fukushima Daiichi* accident. This last accident happened in 2011 and it played a mayor role in the decision of slowing down or phasing out nuclear programs all over. It is also the reason of the recent confidence loss in nuclear power and is the prove of the prevailing character of this challenge.

Nuclear waste disposal was the second great challenge to appear, with public concern arising about the addressing of radioactive waste that nuclear power plants produce. Minor actinides and fission products are some of the waste produced in a regular nuclear fission power plant, and they are classified as long life high radioactivity waste, or *high level waste*, HLW. There are other sorts of radioactive waste, classified depending on their life period and radioactivity level, *intermediate level waste*, ILW and *low level waste*, LLW. Intermediate and low level waste do not require long periods of storage, while HLW require disposal and storage during periods of 1000 years and more in order to radioactivity to decay and reach natural levels. The uncertainty about those long periods and fear of hypothetical leakage are the reasons for public concern.

The third challenge is the most recent, and it has to do the the economics of nuclear power. Nuclear power plants and all the power plants that are capital intensive are in jeopardy because of the tendency to micro-generation and distributed-generation. This two concepts are associated with more efficient and sustainable generation systems in which the by-products of power plants can be used (for example the residual waste on an district heating network). Nuclear plants reach cost effectiveness due to economies of scale, that is, the capacity, and therefore size, of the plant has to be big enough to reduce the cost of the unit energy. With micro-generation, the bet is to build small modular power plants with low fixed cost, that are able not only to produce electricity but also offer useful by-products. Nuclear energy has

the advantage of having low variable cost for nuclear fuel, but the drop of cost of fossil fuels is also detrimental for this sector. In addition, the development of renewable energy technologies improves their cost structure and their efficiency leaving nuclear further behind in economic terms.
In the following subsections, the three mentioned challenges will be discussed along with the measures that have been and are being taken to address them by the nuclear sector.

3.2.1 Nuclear Safety

Nuclear safety involves to tiers. On the one hand is about non-proliferation of nuclear weapons, on the other, involves safety during the life cycle of a nuclear power plant.
Regarding the proliferation of nuclear weapons, the regulation for disarmament reached a significant milestone in 1968 with the conclusion of the negotiation of the *Treaty on the Non-Proliferation of Nuclear Weapons* also known as NPT [31], [32]. The objective of this treaty is to prevent the spread of nuclear weapons and to promote the cooperation in the peaceful uses of nuclear energy. The NPT entered into force in 1970 and in 1995 was extended indefinitely. The five nuclear weapon states and 186 more countries have joined the treaty, recognising that the possession of nuclear weapons is more of a threat than a positive measure for national security. Even though NPT is not the only measure for non proliferation, it is the most widespread and the one that has achieved the most significant success, as it was proven in the cases of Iraq, Iran and North Korea.
These countries used non declared facilities and research reactors to produce weapon-grade fissile material (enriched uranium and plutonium). Since the existence of these facilities was undeclared to the IAEA, no safeguards arrangements were placed. Iraq and Iran did not declare the facilities despite being parties of the NPT. As for North Korea, the safeguard agreement had not concluded its negotiation when the developing of weapon-grade plutonium took place. These cases shed light over the weaknesses of the NPT,

especially regarding non declared facilities and indigenous sources of Uranium. However, these activities were detected in Iran and North Korea and were controlled by international diplomacy. The case of Iraq developed differently due to the military conflict.In order to address these weaknesses an additional protocol was developed in 1997, which is mean to help strengthen IAEA position to detect undeclared activities.

The NPT has, therefore, proven its effectiveness. Yet, there is still room for improvement. Safeguard agreements in nuclear facilities in a similar way to auditors. Its main objective is to build confidence on nuclear programs worldwide. The article VIII of the Treaty includes periodic revisions of the operation every five years, in line with a philosophy of continuous improvement.

Aside from the policies for non-proliferation, scientific research has been conducted to reveal the relationship between the developing of civilian nuclear programs i.e. energy sector, and proliferation of nuclear weapons. *Examining relationship between nuclear proliferation and civilian nuclear power development* [33] is one of these studies. Its conclusions are that even though the initial motivation to develop a nuclear program might be dual purpose (both energy and weapon proliferation), the role of non-proliferation is extremely important for the ultimate success of civilian nuclear power. There are other factors that were found to be important, such as a mature level of democracy or strong economical capability.

Safety in nuclear power plants, or NPPs, involves the safety measures to avoid accidents. It also includes the measures that must be taken in case of an accident to minimize its effects as much as possible, and the safe construction and decommissioning of the power plant that means risk reduction during this stages. In short, safety in nuclear facilities is meant to include every possible aspect of construction, operation and decommissioning.

By far, the biggest concern in NPPs is reducing the risk of accidents, and the effects of these, to the minimum. After major nuclear disasters such as the accident in the Chernobyl reactor, or other accidents which less severe, though still harmful consequences, e.g. Three Mile Island or Fukushima-Daiichi, the public image of nuclear safety has been at jeopardy. The third mentioned event is the most recent and has, thus, the most relevant consequences. The Fukushima-Daiichi was followed by the acceleration of the nuclear crisis, with many countries taking measures to slow down nuclear programs and the nuclear industry suffering serious drawbacks due to confidence loss.

The response of the nuclear sector to this confidence loss was to strengthen the safety measures and to correct possible mistakes. In order to do so the Nuclear Energy Agency, NEA, used its long established mechanisms to enhance global nuclear safety. Many of the key messages and lessons obtained from the last significant nuclear accident in the Fukushima-Daiichi NPP are contained in the report **The Fukushima Daichii Nuclear Power Plant Accident**, published by the NEA in 2013 [34].

As a consequence of the accident, the NEA demanded that all country members carried out stress tests in al the NPPs, which are comprehensive safety reviews, before continuing its operation. These tests were designed to evaluate the capability of the NPPs to cope with unexpected conditions similar to those experienced in the Fukushima-Daiichi accident. As a result, the adequacy of design based assumptions was evaluated, and conclusions were drawn about beyond-design-basis events.

The current safety systems in all NEA countries were revised and some upgrades are being undertaken to improve the response of each power plant against natural events that may block access to the power grid or prevent systems such as the residual heat removal from coming on line. This extends to events that may affect more than one reactor at the same time, also known as multi-unit events.

The concept of Defence-in-Depth was concluded to remain valid after the accident. However, its application needs to be enhanced to develop robust reactors against malfunction of safety systems in events such as natural disasters.

Defence-in-Depth

Defence-in-depth or DiD [35] is a method of reasoning used for the examination of an installation. It is based on the assumption that, even though the measures developed to deal with accidents are such that they aim to prevent their occurrence, these accidents do happen and their consequences must be restricted to levels considered acceptable.

In nuclear industry, DiD consists in several actions, procedures and pieces of equipment, classified in levels aiming to prevent degradation in one level to lead to the next one, and to mitigate the consequences of a failure in the previous level. In addition, mitigation efficiency is subordinate to prevention of failure.

Accountability was a topic also thoroughly discussed after the accident. The key message published on the report was that "Nuclear safety professional have a responsibility to hold each other accountable to effectively implement nuclear safety practices and concepts". The primary safety responsibility belongs to the operators of NPP, but public authorities need to provide safety regarding nuclear power. Thus, the conclusion is that safety systems are to be validated internationally, with organisation such as NEA ensuring its fulfilment.

In conclusion, nuclear safety is an iterative process, in which development is being conducted both in non-proliferation programs and in the safe operation of NPPs. As an iterative process, the occurrence of failures in these fields cannot be considered impossible, but rather unavoidable. Prevention of this failures and mitigation of the consequences that these may have in society are the mayor topics in which upgrades and improvements are being undertaken.

3.2.2 Nuclear Waste Disposal

Nuclear fuel follows a series of processes, from fuel fabrication to final disposal, that as a whole are known as the nuclear fuel cycle. The report **Nuclear Energy Today** [36] explains the different stages of this process of this process. The cycle is divided in two sections. The front-end section includes the processes from the mining of the uranium ore till the burn up of the fuel in the reactor, back-end comprises the processes that handle spent nuclear fuel, SNF.

After being burned up in the reactor, SNF emits very high levels of radioactivity due to the minor actinides and fission product it contains. For this reason, it has to be stored in pools in the NPP. The water in the pools serves a dual purpose, it is both a shield for radiation, and it functions as a coolant. This process is named interim storage, and it last until the residual heat of the SNF has remitted to a level at which the material is safe to handle, the typical period of interim storage is five to ten years.

Once the spent fuel has reached a much lower temperature, it is ready for the following step of the cycle. this can be either long-term storage or reprocessing.

Long-term storage is done in either wet or dry conditions, where either water or natural air convection act as coolant mechanisms respectively. It requires close monitoring to avoid any possible leaks. After long-term storage, nuclear waste is finally conducted to final disposal.

Reprocessing is a stage in which the recyclable material contained in the SNF is recovered in order to be used again in a reactor. This material can make up to 96% of the mass of the SNF, consisting in uranium and plutonium generated in the reactor. Thus, reprocessing reduces the mass of nuclear waste, and the needs of new fuel. The recycled fissile material is used for the manufacturing of mixed oxide fuel, MOX, with recovered plutonium, or for enriched recycled uranium, ERU, in the case of recycled uranium. The latter is more challenging due to the fact that recycled uranium is more radioactive that natural uranium, and requires dedicated enrichment processes for that reason. Currently, recycled uranium is being stored for future use.

There is little scientific consensus about the necessity for reprocessing. Studies such as **The Future of Nuclear Fuel Cycle** [15] defend that the perspective of waste management is not sufficient to set the balance in favour of this technology. There are other disadvantages drawn from its apply, such as the increase of cost and safety issues. Besides that, uranium reserves do not sustain the need of reprocessing either, since they are considered to be abundant.

Therefore, reprocessing is not a stage of the cycle that is applied to all SNF. The majority of this waste is not reprocessed and is send directly from interim storage to final disposal.

The front-end section of the cycle does not generate radioactive nuclear waste, and therefore generates little public concern. On the other hand, once the fuel is burned in the reactor and the back-end section begins, the managing of the nuclear waste is more problematic due to the radioactivity of the material.

Nevertheless, the concept of nuclear waste involves more than the SNF. Nuclear waste is generated in hospitals, industrial processes and in the decommission of nuclear facilities. In order to address the different characteristic of different types of nuclear waste, it is classified in HLW, LLW, and LLW, as it was introduced earlier on section 3.2.

HLW is mainly produced in the reactor as SNF, but some of this category also has an origin on the reprocessing of SNF to recycle unused nuclear fuel. HLW generates heat and is highly radioactive, thus it requires both shielding and cooling.

ILW has its origin on industrial processes and also in reprocessing facilities. The heat generated by this waste is negligible but it requires shielding due to the amount of radiation it emits.

LLW is the category in which waste with very low radioactivity levels and very short life are included. Items that have been involved in handling low activity, short-lived radioactive material are considered LLW. In addition LLW is generated during the decommissioning of NPPs. The handling of LLW is not problematic because the amounts of heat and radiation it emits are negligible.

The final disposal of nuclear waste, particularly of the HLW, is the most controversial matter. Even though this category represents the smallest amount of nuclear waste, in terms of size, it accounts for most of the radioactivity. There is, on this account, public concern about its management, which requires for it to be isolated to avoid any harmful consequences, and close monitoring for very long periods of time.

Management of nuclear waste is a national responsibility, yet, international cooperation has led to the development of a set of principles that guide this matter. In this regard, the IAEA redacted the *Principles of Radioactive Waste Management*, which are thoroughly explained in the report **Nuclear Energy Today** [36], published by the NEA.

The principles of radioactive waste management serve as guidelines that push countries to respect safety along the process, avoiding any harmful consequences to this or future generations. They ensure that waste management takes place within a transparent and lawful framework. In addition, they force the nuclear sector to minimize waste production as much as possible, regardless of the effort that this may mean.

These principles can be translated into practical steps that nuclear industry needs to implement to develop effective waste management techniques. These are: *Minimization*, *conditioning and packaging*, *interim storage* and *final disposal*.

Minimization of the amount of generated radioactive waste is the first step for effective waste management. This is made possible in modern NPPs via good practice. *Conditioning and packaging* is crucial for both transport and storage, in order to prevent good isolation of radioactive material, even in case of contingency such as natural phenomena. *Interim storage*, as it was previously explained, is meant to reduce heat generation and radio-toxicity in nuclear waste until it is safe to handle.

Final disposal is the final step in waste management. It refers to a storage of waste without intention of retrieval, in contrast to interim storage. Regarding LLW and ILW, there are operating facilities in several countries, of which several have been already sealed. Safety measures have been applied to ensure the isolation of those facilities, even from water. As for HLW, or long lived LLW, the solutions are still under consideration, and no repository for these

is operational.
The most accepted solution is *Geological disposal*. Yet, this solution has no prototype facility as for now. The problem is the insufficient knowledge of geological conditions over such long periods of time to ensure that no significant radioactivity returns to the surface.
Therefore, the challenge of waste management is ultimately unsolved. There is no consensus about the final step in waste disposal that will ensure not to be a burden for future generations. Even though deep geological disposal is regarded as a viable solution, it has failed to achieve public acceptance as for now.

3.2.3 Nuclear Economics

The third main challenge that nuclear sector is facing is the loss of economic competitiveness compared to other players in the energy mix. In this Thesis, this has been previously discussed in subsection 2.1.2, by exploring the development being pushed both in renewable energy technologies and CCS, in contrast to the fading interest in nuclear technology exposed in section 3.1.
Nuclear economics are a challenge due to the trend in the sector of having very high fixed cost and long construction times, often lengthen by excessive delays, challenges that are explored in *Economics of nuclear and renewables*, an article published by energy policy in 2016, [37]. In addition, the uncertainty in policies regarding NPPs leads to loss of confidence from investors, increasing the interest rates. The cost of operating a nuclear plant does not represent a great challenge, due to the low prices of nuclear fuel compared to fossil fuels. This are the three main factors used in assessing the economical viability of an energy project: *construction costs*, the *operating costs* and the *discount rates*, or cost of capital. These three factors need to be considered against the price of the electricity generated, a other by-products in the case of co-generation. As a result, whereas renewables have achieved general consensus and are growing in capacity and effectiveness, nuclear power loses relevance in the global energy mix.

The cost in an nuclear power plant is driven by the *construction costs* rather that the operating cost. Natural gas power plants represent the opposite side of the spectrum, coal plants lie in between the previous two. The cost structure of NPPs is the reason why the are used as base-load in most energy mixes, so that the operating hours are maximized. The most prominent competing technology for base-load are coal plants, and because the lack of development of CCS and the application of carbon tax is limited, their cost is, as for today, lower than NPPs. Two main conclusion are thus drawn from the Construction cost a a nuclear plant. The first one is that despite being the most important source of cost in an NPP, construction processes are usually surrounded by lots of mistakes, which lead to delays and other avoidable missteps. The second one is that due to the fading interest in new-built nuclear, this is a trend that is not expected to change.

Even though this environment if often regarded as a global trend, it is important to distinguish between countries that have centrally-planned economies, represented mostly by China as far as nuclear industry is concern, and those with more privatised and liberalised economies, a more prominent profile for western countries. Investors in privatized energy systems condition their decision of financing nuclear to the existence of government assistance to reduce the risk. Yet, regulatory polices, and therefore, subsidies, have proven to be inconsistent with time in these economies. This means an increased difficulty to finance the project, in other words, an increase in the *cost of capital*. The study **The future of nuclear energy** sets the weighted average cost of capital of an NPP at 11.5% and at 10% in the revision in 2009 [38], [39], six years after the original report. This value is in both cases a much higher value that a regular coal plant or combined cycle gas powered plants.

On the contrary, in centrally-planned economies, the cost of new-built nuclear is lower, or at least appears to be. *Cost of capital* is harder to calculate in such economies where it can be diluted across the whole energy system. Besides that, regulatory policies represent less of a threat in these regions, because government implanted measures tend to be more consistent and durable. As a result, most of the new-built nuclear is concentrated in such countries, e.g China. The construction know-how is also being refined in this economies, leading to reduction of construction times and delays, thus improving the general financial performance of the nuclear sector.

The *operating cost* of an NPP do not represent a problem when compared to other factors. The uranium reserves are abundant and prices of nuclear fuel are not expected to increase significantly. This is also a reason for the detractors of nuclear waste reprocessing. Implementing this stage means an increase in operating costs, as well as additional HLW produced during the process (also harder to manage, since is in liquid stage), so it is not economically beneficial as for today.

SMRs are an alternative to conventional power plants, that aim to improve their economic performance. SMRs intend to rely less on economies of scale that conventional reactors, due to the size reduction. Additionally, they are supposedly safer, and therefore require less elements in their safety systems. They offer the advantage of increasing the capacity of a given plant by adding new reactor modules, as more energy is demanded, and thus dividing the investment in smaller packages, diversifying risk. They also have possible application in micro-generation, in line with the current trend. Nevertheless, the one-of-a-kind nature of these reactors might increase their initial cost and, since currently there are no SMRs in operation all the advantages remain theoretical, and their actual cost unknown. The present, fading interest in nuclear leave this new alternative in a weak position.

In conclusion, two out of the three cost factors of nuclear projects need to be improved, *cost of capital* and *construction costs*. In order to do so, regulatory policies, often related to public perception of nuclear safety, need to become more consistent and nuclear sector need to regain the trust in possible investors. The construction nuclear sector needs also to improve their performance, and would possibly benefit from standardized designs that enables it to gain valid experience, and, therefore, to eliminate delays and to correctly estimate construction cost beforehand (eliminating cost over-runs).

SMRs raised as a promising alternative but their position is uncertain, due to their elevated need of development in an environment with fading trust in nuclear energy.

3.3 The new role of Nuclear Energy

The conclusion that can be drawn from the previous analysis is that nuclear needs to develop systems to address these challenges in order to have a significant role in the energy transition.

Nuclear technology must achieve safer and more cost-effective conditions, and a sustainable waste management must be integrated in the nuclear sector. Such development is likely to require lots of effort and resources, but it is sustained on the fact that climate change, as it has been previously explained, is a real and urgent problem. All possible actors in the energy transition (renewables, improvement of efficiency in fossil fuel technologies, CCS and nuclear) need to be pushed to reduce the dependency on fossil fuels. On this framework, the benefits of a modern nuclear technology, that is able to successfully address all challenges, are unique and have unparalleled value.

This idea is the one behind the developments of generation III, III+, and IV reactors. These new designs are focused on finding solutions for the current problems of NPPs. Generation III and III+ had as a main objective the challenge of nuclear safety, being essentially generation II reactors with state-of-the-art improvements when these designs were created. In Addition, waste management is also improved by the optimization nuclear fuel cycle and fuel reprocessing is more integrated than in former generation II.

Generation IV reactors are designed to be the real game changer for nuclear technology, with state-of-the-art systems for nuclear safety and integrated safeguards to ensure non-proliferation. Burn-up of fission products is also integrated in fuel cycle, to shorten the life of nuclear waste as well as the quantity and level of radio-toxicity. Regarding cost effectiveness, generation VI NPPs will account the generated by-products, such as hydrogen or high temperature heat from co-generation, apart from the electricity generated with an expected very high level of efficiency.

The market price of energy is also expected to increase due to carbon emission tax applied to conventional fossil fuel plants, which currently set this parameter, even though it is also expected to be affected by the expansion of renewables, meaning a probable decrease. Therefore, the cost of electricity in generation IV NPPs needs to achieve values similar to conventional coal plants after the carbon tax, so that these plants can have a significant role in an energy system after the energy transition.

SMRs are also present promising advances in generation IV. Some of the new designs are suitable for smaller NPPs in line with the tendency to micro-generation. The by-products became especially important in this scenario, where co-generation can be integrated as a district heating. As it was explained in subsection 3.2.3, SMRs are less capital intensive than regular sized power plants, and they do not rely as much in economies of scale, thus improving the performance of generation IV financially.

The new role of nuclear energy is, thus, to be achieved by the modernization of the technology. This modernization takes form in development of Generation IV. The challenges of nuclear safety and nuclear waste management are addressed in this new designs, yet, the economical viability of Generation IV is still unclear because of the uncertainty of the surrounding factors, such as the prices in fossil fuels, the expansion of renewables, their efficient integration in the electrical grid, or development in storage technology. Factors that will, presumably, shape the energy market in the future.

Due to the one-of-a-kind nature of these new developments, the process is expected to be costly. This is the reason why the nuclear alternative for the energy transition has not drawn as much attention as others, like renewables or CCS. Nonetheless, this does not mean that this alternative should be disregarded. Nuclear can bring factors to the table that other resources cant, like the reliability of supply, which makes it suitable as base-load, the widespread distribution of its resources, unlike fossil fuels, or its proven integration on

the electrical grid.
In conclusion, the role that nuclear energy is meant to play in the framework of the energy transition has great importance. This is due to the intrinsic benefits of nuclear energy, especially if it is modernized to successfully solve the problems that represent the biggest drawbacks of the technology. Generation IV reactors offer promising perspectives for the addressing of these challenges, but their economical viability in the uncertain environment of energy finances is still unclear. Nevertheless, the advantages of generation IV are unique and may turn balance in favour of it, is they can be translated into economical return.

Chapter 4

Nuclear Technology. Current status and future perspective

Chapter **??** explained the current status of nuclear energy, the challenges it faces, and its needs of development for the energy transition. This chapter will focus on nuclear technology itself, both technologies that are available today, and those that are expected to be available in the near future. Generation IV will be thoroughly explored, since its analysis is the main objective of this thesis.

In order to achieve a better understanding of generation IV, previous generations of NPPs will also be discussed in this chapter. The benefits of generation IV will be explained in perspective to the current technology, comparing how previous generations are failing to address challenges and how generation IV plans to overcome them.

Some insight will be also needed to better understand nuclear technology. For this reason, The physics of current nuclear reactors will be briefly explained. Especially focusing on the parts that are planned to change more drastically, introducing the concept of fast breeder reactors, and other new developments in nuclear technology that will be integrated in generation IV.

Generation IV will be detailed in definition and objectives, and so will be the six final designs purposed by the *Generation IV International Forum*,

GIF. This forum set the technology roadmap for Generation VI and divided different tasks to the affiliated countries, which have grown in number since its foundation in 2001.
The final objective of the chapter objective will be to select one design for the economical analysis. The design will be selected according to several factors. Some of them will be the validity of the needed assumptions, its technical viability with current technology and the measure in which it fulfils the objectives of generation IV.

4.1 Nuclear Technology today. Generation II, III and III+

In this section, we will revise basic concepts of current nuclear energy. It will also serve as a review of current technologies, from early developments of nuclear energy, to more modern technologies, still operating today.
The development of nuclear power in the civilian world started in the decade of 1950. At that time, nuclear generation was still closely related to nuclear weapons, and the development of this technology was seen as a geopolitical matter, especially in the context of the cold war. The advantages of nuclear power arose quickly, with the realization that it was a reliable source of energy. In the military sector, the autonomy of nuclear power submarines had been a competitive advantage since WWII, and that promoted the early developments of other nuclear powered transports, such as ships and even aerospace. Safety concerns slowed down these prototypes, eventually limited tu submarines and ships, were the autonomy of nuclear power represented a great competitive advantage.
The context of nuclear energy was vary optimistic at first, with the United states and the Soviet union as the most important developers. Later in time, the previously mentioned challenges of nuclear energy arose, leading to the current situation, not nearly as optimistic in the western world, with China being the most prominent nuclear developer. The current reactors, that are

being built in China for instance, are very different from those that were built in the earlier stages of this sector.

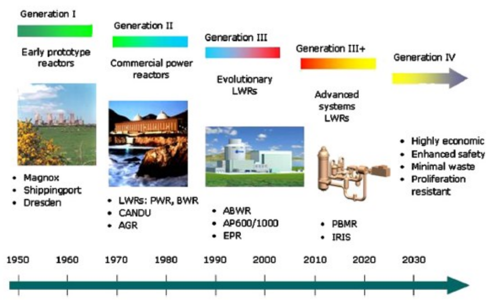

Figure 4.1: Evolution of Nuclear reactors

Nuclear reactors are commonly classified in generations. The early prototypes for nuclear power are known as generation I reactors. The following reactors, better suited for commercialization, were named generation II. Generations III and III+ are the most recent developments, still not fully extended, that improve especially safety features of the NPPs. These new developments also aim to improve the cost effectiveness of the NPP and the fuel cycle. Yet, since their outreach is still limited, their performance on these topic is unclear.

Each generation has meant improvement with respect to the previous one. Generation II corrected the most visible flaws of generation I, such as grid appropriateness and commercialization. After that, the following generation were developed with the objective of meeting the energy market demands an regulatory policies. For this reason, the innovations in these sector have had a predominantly incremental character. The change between generation II and III is considered more drastic, due to the incorporation of highly innovative measures, such as passive security systems. Generation IV is planned to follow a different roadmap. The main objectives of these generation are

not only a limited response of previous reactors, but a drastic change in the extended conception of nuclear energy. Therefore, generation IV is not limited to delay current problems (as it has been the previous strategy in, for example, waste management), but defines proper solutions to finally solve them.
In the following subsections, the topics that have been introduced here will be discussed more thoroughly. In addition, there will be an explanation of nuclear physics in order to help understand the innovations developed from one generation to the next one.

4.1.1 Physics of nuclear energy

The objective of a nuclear reactor is to obtain energy from the radiation released by a controlled chain reaction contained within the reactor core. This means that ultimately, there is a necessity to induce fission reactions. To explain the meaning of a fission reaction we need to go back to nuclear reactions.
Nuclear reactions are defined as the process in which two nuclei, or one nucleus and a subatomic particle, interact to form products that are different from the reactants. It is a similar definition to a chemical reaction, but takes place at a nuclear level. At this level, energy and mass are equivalent, therefore, a change in mass means a change in energy, as described by Einstein in the theory of relativity.
Nuclear reactions affect many subatomic particles and nuclei. Albeit, in a nuclear reactor, the most important particle are neutrons. Due to their lack of charge, neutrons can go through the electron cloud without electrostatic interactions (Culomb's forces) and interact directly with it. Therefore, neutrons are able to induce fissions.
Neutrons can react in different ways with nuclei, and not all of them induce fission in the nuclear fuel. It depends on several factors, such as the nucleus itself, or the energy of both nucleus and neutron, for example. The reactions involving neutrons are divided in two main groups: *neutron absorption* and

neutron scattering.

Neutron Scattering is a nuclear reaction in which a neutron collides with a nuclei and either the same neutron or other neutron from the nucleus is emitted. If the nucleus is left in the ground state, that is, its energy does not change, the reaction is named *elastic scattering*. Otherwise, if the nucleus is left exited and the emitted neutron has lower energy, it is a case of inelastic scattering.

Neutron absorption happens when a neutron is completely absorbed by the nucleus, and, as a result, a compound nucleus is formed. The nucleus is in an exited state and it can decay in several ways, which do not depend on the way that the compound nucleus was formed. The nucleus can emit radiation to lose energy and reach a more stable state. That energy can be liberated by emitting particles like α particles or protons, or by radiation such as γ radiation (photons), this last case is known as radiative capture. Another mechanism of liberating that energy is through a fission reaction. In a fission reaction, an exited nucleus splits into fission products. Neutrons are also emitted as a product of this reaction. These neutrons can be prompt neutrons if they are emitted as products of the reaction, or delayed neutrons if they are generated by the radioactive decay of fission products, which are usually very radioactive. Thus, if a fission reaction generated neutrons, these can generate other fissions. If this phenomenon is sustained in a stable way, it can generate huge amounts of energy. This concept is know as the chain reaction.

The probability of a neutron interacting with a nucleus, either being absorbed or scattered, is a function of the energy of the neutron. The magnitude that measures this probability is the cross section and is measured in barns, a unit of area. Technically, the cross section is an effective area that quantifies the likelihood of a certain interaction between an incident object an a target object [3].The total cross section is the cross section for all the possible interactions. It is the sum of all the partial cross sections of each interaction (elastic and inelastic scattering, absorption, radiative capture, fission etc).

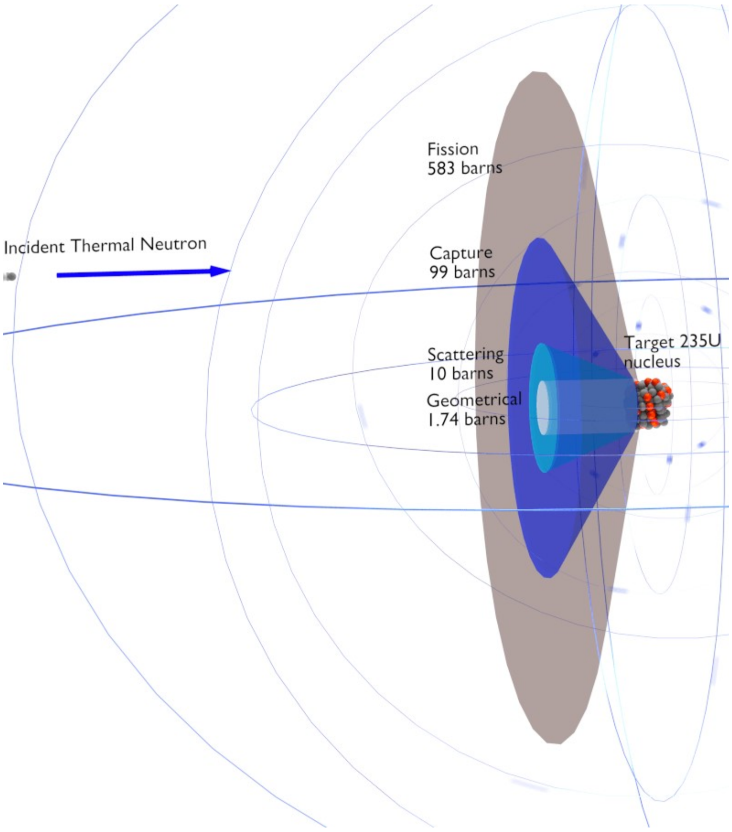

Figure 4.2: graphic representation of cross section. Source: www.nuclear-power.net/neutron-cross-section/ [3]

In a nuclear reactor, the most important interactions, and, therefore, cross sections, are radiative capture and fission. The first one reduces the number of neutrons available for fission and the second one increases it.

Regarding the nuclear fuel, it is mainly made of two different isotopes. These are U-235 and U-238. U-235 is considered fissile material, since a low energy (thermal) neutron can induce fission in a nucleus of this isotope, this means, that it has high cross section for fission for neutrons on the thermal region, shown in 4.3. U-238 is both fissionable and fertile material. Fissionable means that the fission cross section for fast neutrons is considerable, and thus, fast neutron can induce fission in its nuclei, as it can be seen in 4.4. Fertile means that this isotope can transform into fissile material through radiative capture. In the case of U-238, it can transform into Pu-239 by absorbing a neutron, which is a fissile material.

On the regular operation of a nuclear reactor, the fast neutrons generated on a fission reaction can be absorbed by the fuel (by U-238 isotopes) or by the shielding of the reactor core (leakage). The rest need to be slowed down to the thermal region so that they can induce fissions in the nuclei of the fissile material, U-235. This slowing down of the fast neutrons is made in the moderator, whose nuclei have higher probability (cross section) of inelastic scattering of the neutrons. Water is the most commonly used moderator, even though they are other alternatives. As a result, the chain reaction can be sustained.

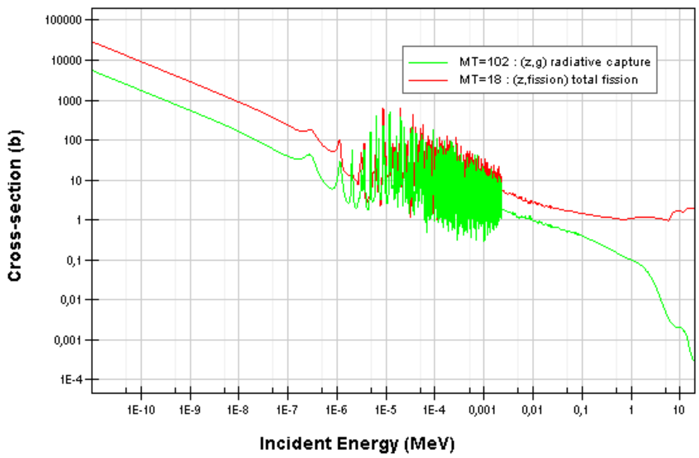

Figure 4.3: U-235 fission and capture cross sections. Source: www.nuclear-power.net/neutron-cross-section/ [3]

The rest of the process is similar to other technologies. Heat generated on the reactor core is transferred to a steam cycle, were it is transformed into electricity. The heat transfer on the reactor core is made through a fluid named coolant, which can also be water, in which case it might share the function of moderator and coolant. This is the case for the vast majority of

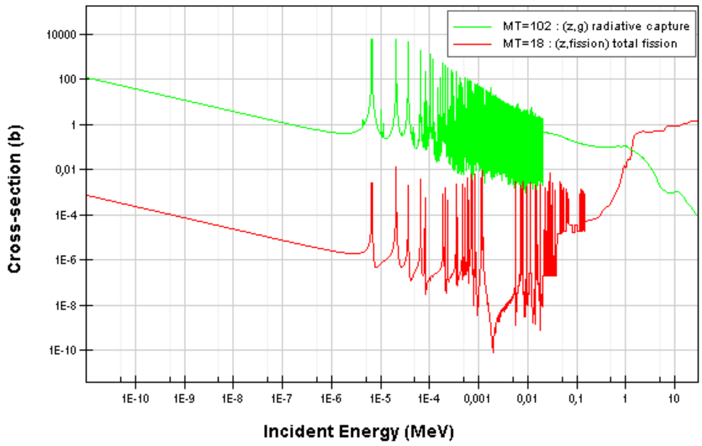

Figure 4.4: U-238 fission and capture cross sections. Source: www.nuclear-power.net/neutron-cross-section/ [3]

reactors that are operational today. These reactors are known as thermal, because the energy of the neutrons that induce fissions is low, and they made use of moderators. Fast reactors made use of fast neutrons to induce fissions, and they do not use moderator. In these reactors, coolant fluids need to have good heat transfer properties, but low cross sections for inelastic scattering, so they do not reduce the energy of fast neutrons generated in fission reactions. They have other advantages, that will be introduced later, since these reactors are mostly present in generation IV.
These are the basic concepts needed to understand nuclear power plants. In the following sections, several designs of different generations will be described. This short introduction to nuclear physics will help understand how these designs have different requirements regarding the grade of enrichment of the fuel, the moderator fluid etc.

4.1.2 Generation II

The first designs of NPPs for commercialized power generation were referred as generation II reactors. These designs, with some slight improvements, make up the majority of reactors operational today. Generation II reactors differ on nuclear fuel needed, whether it is enriched or not, and the coolant and moderator fluids. They also can have direct or indirect cycle. This mean that the coolant transfers energy to the steam cycle directly (going trough the turbine) of indirectly trough a heat exchanger named heat generator.

The main companies that built these reactors were western companies, even though they were very prominent nuclear countries in Asia, particularly South Korea and the former USSR. In the Soviet Union the construction of NPPs was a state matter. Since generation II was mostly developed during the cold war, the knowledge regarding nuclear technology was very strategical, therefore, at the early stages it was rarely shared. That is the reason that made each country tu push their own design, and it was not until later in time were the Pressurised Water Reactor, PWR, and the Boiling Water Reactor, BWR, commonly referred as Light Water Reactors, LWR, set themselves ahead and became the most common reactors. Both of these designs were born in the United States, and both require enriched uranium (higher mass percentage of fissile material U-235). The technology of enrichment was very crucial at that time because it enable the production of nuclear weapons. Another generation II design, the Canada Deuterium Uranium, or CANDU, eliminated the need of enrichment trough the use of heavy water as moderator and coolant.

The Soviet Union had their own designs with significant differences to those in the western world. For example, the *reaktor bolshoy moshchnosty kanalny*, high-power channel reactor, or RBMK, which uses graphite as moderator. This design, though unusual, gained importance in the Soviet Union nuclear program. The catastrophe of Chernobyl stopped drastically its progression for obvious safety reasons. Those RBMK reactors still operational had to undergo drastic changes in their design to ensure that an accident will not happen again.

At the early stages of nuclear power, the countries that lead that development gained the experience and the know-how that help them maintain that leadership position until today. The environment has changed, with some countries like Germany stepping out of the race, and some historic nuclear

powers planning on doing the same, such as South Korean or France. Similarly, countries like China and India have developed their nuclear programs to inherit that leadership positions soon.
Generation II reactors evolved from early generation I prototypes. They are more suitable for energy generation and improved the cost-effectiveness of these first designs. These economic viability is know more uncertain due to the over-costs and delays during construction, as well as the new regulatory policies. As for safety, most of the systems in generation II NPPs are passive, which was one of the most important fields of improvement for following generations. Waste management in generation II can be either open or closed cycle with reprocessing, even though the latter was developed once generation II was settled.
LWR made up the vast majority of operational reactors today, exactly 82% [3] of the installed nuclear capacity belongs to these technologies. The lifetime of a generation II reactor is typically 40 years but lifetime extensions, as previously mentioned, have lengthened the operational period of many of these NPPs. This has occurred especially in the western world, where the reactor fleet is significantly older than in emerging nuclear powers.
For this reason, it can be observed that generation II is far from being outdated. LWR not only mean the most prolific technology in nuclear sector, but also the preferred technology in reactors under construction. The original design has undergone some changes that are the response for safety and economic concerns, installing passive safety systems and optimizing the process to improve efficiency. Emerging nuclear powers even developed their on designs based on these LWRs. Precisely these incremental changes and optimization processes in generation II reactors make up the new set of systems that we renamed generation III.

4.1.3 Generation III and III+

Generation III and III+ were developed as a response to the main topics of concern arose by generation II. The main topic was nuclear safety, based on the accident of three mile island and Chernobyl (even later in time the accident of Fukushima-Daiichi). Following safety concern, other challenges began to appear, such as waste management and the economics of nuclear power. To these challenges, generation III and III+ have supposed a incremental improvement.

The new reactors designs are deeply based on generation II reactors, but incorporate recent improvements. The lack of standardization in generation II reactors is corrected with these new systems. Fuel burn-up is optimized to both improve the economic efficiency of the plant and reduce the amount of generated waste. The steam cycle is revised to increase the thermal efficiency and reduce fuel consumption. The lifetime of the plants is lengthen to from 40 to 60 years. Modularized construction is made possible due to the standardization. Finally, safety systems become passive, eliminating the need of automation or human intervention, and making them more robust. Passive safety systems are no longer require an external source of energy but rather work based on principles like gravity and natural convection.

Generation III and III+ have had limited reach. Even though some reactors are operational, their presence in the total installed nuclear capacity is still scarce. Generation III and III+ reactors have theoretically improved nuclear safety performance, yet, public acceptance of nuclear is still limited, and there are doubts regarding the suitability of these new reactors for the existing electric grid. Construction of these new systems is also a controverted topic. Since the construction of generation II systems accumulate so many over-costs and delays, it is widely assumed that these systems will have poor performance in that matter, especially at the beginning of their learning curve.

Albeit, the economic performance of generation III is also theoretically improved in the operational stage, due to the increased efficiency. Even regarding construction, modularization and standardization are supposed to accelerate the progress along the learning curve reducing over-costs and delays quickly.

All of these improvements make generation III and especially III+, an important milestone in the progress of nuclear energy. Nevertheless, their biggest innovation, which is passive safety systems, though promising, remain mostly untested. Their performance on the other main challenges of economics and waste management is theoretically better than generation II, but their measures mean more of a delay in these problems, rather than a definitive solution. Generation IV is poses as the set of innovations that will mean the ultimate response to these persistent questions.

4.2 The Future of Nuclear Technology. Generation IV

Generation IV is the most recent nuclear generation and is composed by the set of systems purposed by the **Generation IV International Forum**, or *GIF*. This systems are considered revolutionary, since they are based on radically different system from previous generations.
Some of these systems were studied and ruled out in the past due to the young state of the technology, that lack the tool and experience to make them possible. Now, due to the advance in the technology, the study of these systems is being resumed.
The envisage for the radical innovations in this generation is that they will affect every aspect of nuclear power. The neutron spectrum changes in the majority of the designs from thermal to neutral, which enables a better fuel burn-up and breeding of fissionable material from fertile isotopes such as U-238. Fast neutrons also offer the possibility of the burn of radioactive waste, reducing drastically their lifetime. Meanwhile, reprocessing of nuclear waste is also a favoured technique in this systems. Economically, both the better burn-up of nuclear fuel and the change of co-generation improves the reactor overall performance. Finally, as for safety, generation IV incorporates and improves the passive systems of generations III and III+, as well as some new systems for safety and protection against nuclear weapon proliferation.

Generation IV systems are planed to star commercialization beyond 2050. That means that there is still time to find solutions to the problems that this new technology involves. There is still plenty of research needed for the assessing the viability, and for the development of these systems.
The following sections will discuss generation IV in detail. We will review its objectives and the countries that are committed with its development, that is, the countries that took part in the *GIF*, an those that have joined later. Finally, we will present the six final designs selected and analyse them in order to select one technology to base the economical model on.

4.2.1 Generation IV. Objectives

The objectives set the roadmap that the development of this generation has to follow. These are meant as as a response to the challenges that current nuclear industry is facing. Therefore, these statements are related to sustainability, safety, non proliferation of nuclear weapons and economics. The following table 4.1 displays the goals of generation IV as described by the *GIF*.

4.2.2 Generation IV international Forum. *GIF*

The GIF is self defined as: "A co-operative international endeavour which was set up to carry out the research and development needed to establish the feasibility and performance capabilities of the next generation nuclear energy systems" [40].
Its founding charter was originally signed by Argentina, Brazil, Canada, France, Japan, Republic of Korea, South Africa, the United Kingdom and the United States, in 2001. Several countries have joined since, and currently 13 countries and the Euroatom are the members of this initiative.
The purpose of the GIF and the vision for generation IV are redacted on its founding charter [41]. This cooperative intends to develop one or more systems that, while respecting all regulations can be constructed and operated,

Sustainability-1	Generation IV nuclear energy systems will provide sustainable energy generation that meets clean air objectives and provides long-term availability of systems and effective fuel utilisation for worldwide energy production.
Sustainability-2	Generation IV nuclear energy systems will minimise and manage their nuclear waste and notably reduce the long-term stewardship burden, thereby improving protection for the public health and the environment.
Economics-1	Generation IV nuclear energy systems will have a clear life-cycle cost advantage over other energy sources.
Economics-2	Generation IV nuclear energy systems will have a level of financial risk comparable to other energy projects.
Safety and Reliability-1	Generation IV nuclear energy systems operations will excel in safety and reliability.
Safety and Reliability-2	Generation IV nuclear energy systems will have a very low likelihood and degree of reactor core damage.
Safety and Reliability-3	Generation IV nuclear energy systems will eliminate the need for off-site emergency response.
Proliferation Resistance and Physical Protection	Generation IV nuclear energy systems will increase the assurance that they are very unattractive and the least desirable route for diversion or theft of weapons-usable materials, and provide increased physical protection against acts of terrorism.

Table 4.1: Goals of Generation IV

thus generating a reliable supply of energy, competitively priced, while successfully addressing nuclear safety, waste, proliferation and public acceptance concerns.
The founding charter of the GIF also states the main functions that this cooperative intends to conduct. The way of accomplishing this mission is, apart from the labour of the GIF, to be able to collaborate with all sectors of international research community. The functions of the GIF, as stated on its founding charter are the following.

1. Identify potential areas of multilateral collaborations on generation IV nuclear energy systems
2. Foster collaborative R& D projects
3. Establish guidelines for the collaborations and reporting of their results
4. Regularly review the progress and make recommendations on the direction of collaborative R& D projects
5. Establish and regularly review an inventory of the potential areas of needed research
6. Conduct such other activities to advance achievement of the GIF's objective as the Members may jointly determine

The membership of the GIF is achievable for every country, as long as all the members approve. These members have the obligation to show active participation in collaborative projects, particularly, they are expected to participate in at leas one significant collaborative project.

4.2.3 Generation IV Reactors

In this chapter we will present the 6 final designs selected by the GIF form over the 130 alternatives. The selection of these designs was motivated by the scope to which each system provide new solutions to the topic of safety, efficiency, sustainability, economic competence, and non proliferation. In addition, these reactors were selected based on their feasibility and viability.

The most radical innovation in generation IV reactors is the introduction of fast reactors. This means, reactors in which the neutron flux is in the fast spectrum. In section 4.1.1, we explained how the vast majority of operational reactors today work with a neutron spectrum in the thermal region, and how this neutrons were a product from fission reactions whose energy needed to be reduced to reach the thermal region. Once they reached that energy level, they were able to induce fission in fissile isotopes and thus sustain the chain reaction.

In fast reactors, the fast neutrons are not moderated, and fissions are induced in fissionable elements. In addition, fast neutrons have the advantage of producing fissionable elements from fertile material (U-238, Th- 232). In this way, they allow to increase the fuel burn-up from approximately 5% to levels between 70% to 90%, as well as the use of thorium as fuel, whose reserves are more abundant than for uranium.

The use of fast neutrons have another critical advantage, the burn-up of radioactive waste. This means that fission products are in turn fissioned inside the core, reducing the lifetime of these radioactive elements. Fast reactors, thus, incorporate the principle of sustainability, as a more advanced way of reprocessing.

These fast reactor involve, albeit, some challenge. The lack of a moderator fluid affects the selection of the coolant as well. The new coolant fluids need to have good heat transfer properties and small cross-sections for inelastic scattering. For these reason, the coolant in these systems needs to have a heavy nucleus, and also be in a physical state that is beneficial for heat transfer. Some of the alternatives are liquid salts or metals. The fusion temperature of these materials is high, a fact that means challenge in the selection of constructive materials.

Nevertheless, there are still designs in generation IV that work in the thermal spectrum, or hybrid technologies, that are able to work with fast, thermal, or epithermal neutrons. The innovation of these systems comes mainly from the increase in temperature, which leads to unprecedented efficiency levels. It also makes these systems suitable for co-generation, due to the high temperature heat generation, which can be used in district heating, industry, of for hydrogen generation.

High temperature reactors involve a similar challenge to fast reactors. The constructive materials need to be able to withstand the temperature. Fuel also requires research to avoid the fusion of the core.

In conclusion, these new systems face the problem of inexperience with the technology. New materials are demanded for the development of the technology, both for constructive (turbines, reactor vessel, etc.) and functional elements (fuel, coolant, moderator if needed). The current status of these systems is still immature, lots of research is still needed. Even though the technical viability of some of the designs has already been proven, performance analysis are still ongoing even for the most advance designs and demonstration is not expected to begin in any case before 2023.

For the description and analysis of the 6 reactors the information is based on the publications of **Technology Roadmap Update for Generation IV Nuclear Energy Systems** and **Generation IV nuclear reactors: Current status and future prospects** [42] [6].

Gas-cooled Fast Reactor. GFR

The gas cooled fast reactor is a system that aims to combine the advantages of fast reactors with those of the hight temperature reactors. In fact, the core outlet temperature, COT, is expected to have the highest value of al systems, around 850 °C. Unfortunately, combining the advantages means that it also involves the disadvantages of the inexperience with fast neutron spectrum and the challenge that high temperature entails for all materials.

GFR was initially meant to be coupled with a direct Bryton cycle with helium as a work fluid. This first attempt was designed to have 600 MWth, but there was economic concerns due to the loss of economy of scale and high quality fuel requirements to achieve the break-even condition in the breeder. This early concept is still considered as a SMR which does not require to fulfil that condition, but main research diverted into a new model of 2400 MWth. This second concept corrects the disadvantages of the previous one. It has different structure apart from size, since the reactor is indirectly coupled with a helium-hydrogen closed Brayton cycle, which can be in turn coupled with a Rankine cycle through a heat recovery boiler. The waste heat obtained from the combined cycle has a lower temperature that if it was obtained from the Brayton cycle, which is detrimental for its use in co-generation, but if achieves a higher efficiency. Nevertheless, the efficiency achieved with the direct cycle in the first concept, GFR-600, is higher [42], [6].

The advantages of choosing helium as a work fluid are that it is chemically inert and that it has low neutron moderation [42]. For this reason it prevents corrosion and allows the neutron flux to be in the fast spectrum. However, regarding safety, the use of this coolant has some drawbacks too. Due to its low chemical inertia forced circulation is needed, and therefore it requires other solutions to implement passive safety systems. Helium has also low specific heat and therefore poor heat transfer properties. For this reason, the system require elevated mass flux to regulate the temperature core, and helium requires pressurization in turn[6]. The same way as all fast reactors, the lack of moderator means that the reactor pressure vessel, RPV, receives high dosage of fast neutron radiation, which again arise the need of more radioactive resistant materials.

The following table 4.2 show a summary of the exiting concept for GFR systems.

The nuclear fuel entails another challenge. It has to be able to withstand the high temperatures without reaching fusion state. To achieve this, the first attempts are designed to have a carbon layer to control the temperature eof the uranium core. Lots of research is still needed regarding this topic. Yet, the development of other generation VI high temperature reactors will be useful for the GFR [6].

	GFR-600	GFR-2400
Thermal/Electrical power	600/288	2400/1120
Core pressure [MPa]	7	7
COT [°C]	850	850
Thermodynamic cycle	Direct Brayton cycle	Indirect Brayton cycle
Working Fluid	He	He/Ni
Net electrical efficiency [%]	48	45

Table 4.2: Summary of GFR projects. Source Energy Policy, Generation IV nuclear reactors: Current status and future prospects, [6]

This design is considered one of the most innovative concepts of generation IV due to the combination of a fast breeder reactor and a high temperature reactor. In fact, the GFR concept is still on the early stage of it development. The viability of this system is not yet assessed. This first stage is expected to be completed by the first years of the decade of 2020s.In addition, The construction of the first demonstrative reactor, ALLEGRO demonstrator, has already been planned [42].

Lead-cooled Fast Reactor. LFR

The LFR is a fast reactor that uses either lead or lead-bismuth eutectic, LBE, as a coolant. It is a reactor suitable for electricity generation and for actinide burning. The concepts for this reactor are very different in size including concepts of SMRs.

Lead is cheaper, less corrosive, and more abundant than LBE, but its melting point is higher, 327°C compared to 127°C of LBE. Therefore, lead has higher risk of solidification during transitory conditions. Yet, LBE has the disadvantage of producing Po-210, a highly toxic radioactive isotope, that requires complex treatment.

The main advantages of this reactor are related to the innovative use of molten metal as a coolant. The thermo-fluid-dynamic properties favour the natural convection, providing a passive safety system. The high density of the material also means a high thermal inertia and contributes to fuel dispersion instead of compaction in case of the destruction of the core. Besides that, both alternatives of coolant are inert with air and water and have high boiling points, with reduces the risk of core voiding and enables the thermodynamic cycle to have high maximum temperature increasing its efficiency. Regarding nuclear properties, lead acts as a gamma ray shield and traps volatile fission products such as caesium. Additionally, its low neutron moderation allows more space between fuel pins reducing the risk of blockage and lowering the core pressure drop.

Nevertheless, this system involves some important challenges too. The root of these challenges is, similarly, the use of molten metal as coolant. The movement of the coolant causes erosion of the constructive materials. Besides that, at low temperatures, the precipitation of the coolant increases corrosion, and at high temperatures, it dilutes, leading to the same consequence. To avoid the corrosion, a protective layer is created by the induction of oxygen. This protects the exposed steel from the coolant. The devices of flow control need to be rethink as well, due to high temperatures and high densities of the coolant. Monitoring and inspection of the core is more challenging due to the opacity of lead, as well as fuel handling. Finally, lead needs an appropriate disposal process due to its toxicity and environmental issues.

Many different concepts are being developed based on LFR, But the main three designs are summarized in the following table 4.3. This are the European Lead-cooled System, ELSY, the Small Secure Transportable Autonomous Reactor, SSTAR, and the SVBR, in English, Lead-Bismuth Fast reactor.

The Russian submarine program used Pb-bi reactors successfully. However, the current concept is bigger, and is designed to work at higher capacity factors. The former Pb-Bi reactors worked in the epithermal spectrum rather that fast, and had also lower working temperatures than generation IV LFR. As a result, the existing experience cannot be easily applied.

The development of LFRs has already started. Currently, the project is in the viability assessing process. Demonstrative reactors are expected to start

	ELSY	SSTAR	SVBR
Thermal electrical power [MW]	1400/1600	45/19.8 (SMR)	280/75(SMR)
Coolant	Pb	Pb	LBE
Convection	Forced	Natural	Forced
Fuel	MOX	Nitride Fuel	MOX, Nitride fuel
Thermodynamic cycle	Rankine	Brayton	Rankine

Table 4.3: Summary of LFR projects. Source Energy Policy, Generation IV nuclear reactors: Current status and future prospects, [6]

construction in the decade of 2020s.

Molten Salt Reactor. MSR

MSR is a reactor that can work either with a fast neutron spectrum or thermal using graphite as a moderator. Its most characteristic feature is the that fuel is liquid, since it is dispersed in the coolant.

This system provides several noticeable advantages. The fuel in these reactors does not require fabrication, and it can be reloaded on-line. As a consequence, the fuel cost are reduced, and the NPP reaches more active hours per year. The composition of the fuel is homogeneous, this mean that no hot spots are formed by the addition of fissile material and the fuel cycle has great flexibility, even achieving breeding conditions working in the thermal spectrum. The high melting point of this salts is the reason for the high working temperature of this systems, increasing the efficiency. Besides that, the high specific heat of these salts make them suitable coolants and eliminate the necessity of pressurization of the reactor vessel.

However, this system entail some drawbacks as well. First, the highly corrosive character of molten salts, which is strengthen by oxidative fission products. This affects all constructive materials and elements such as pumps that are in contact the coolant. Another problem is the process of lanthanides, noble gasses and noble metals. Lanthanides and actinides are removed offline, due to the duration of the reprocessing, whereas noble gasses and metals are removed on-line through the injection of helium. The properties if the coolant are not fully understood, and, therefore, its composition must be optimised and the chemistry and thermo-fluid-dynamic must be researched further.

There are two main concept of MFR, the Molten Salt Fast Reactor MSFR, and the Pebble Bed advanced high temperature reactor ,PB-AHTR. The first design is a good example of the characteristics exposed above, being a fast reactor that uses a mixture of fluorides of thorium and uranium dispersed in a lithium fluoride molten salt. The second one, however, is a thermal reactor that uses graphite as moderator and uses solid fuel, and is therefore in the middle of the category of MSR and the very high temperature reactor, VHTR, a different generation IV reactor that will be discussed later.

The summary of these alternatives can be found in the following table 4.4.

	MSFR	**PB-AHTR**
Thermal electrical power [MW]	3000/1300	900/410
Spectrum	Fast	Thermal
Moderator	-	Graphite
Fuel	liquid $UF_4 - ThF_4$	Solid TRISO Pebble
Primary molten Salt	^7LiF	$^7LiF - BeF_2$
Thermodynamic cycle	Multiple reheat helium Brayton Cycle	Multiple reheat helium Brayton Cycle
Net electrical efficiency [%]	45-55	46

Table 4.4: Summary of MFR projects. Source Energy Policy, Generation IV nuclear reactors: Current status and future prospects, [6]

The development of MFRs has been slower than in previously explained generation IV systems. In this case, the viability assessment is not expected to conclude before 2025, when the performance analysis is scheduled to start.

Supercritical Water cooled Reactor. SCWR

This reactor is considered the evolution of the Generation III BWR. It can work either on the fast or the thermal spectrum. It improves the efficiency of the BWR by 10% with respect to generation III reactors and simplifies the layout since the coolant is in a single phase. The main problem is presents is the corrosiveness of supercritical water. This system is very promising because it combines the experience gained from operating BWR nuclear power plants and the knowledge from the operation of fossil fuel plants that use supercritical water as work fluid.

SCWR posses some features that mean unique advantages. Some of them have already been mentioned, such as the increase in efficiency (up to levels of 44%) and the simplicity of the NPP (eliminating coolant pumps in the reactor). In addition, Compared to BWR, steam separators and dryers can be omitted since the coolant is superheated in the core up to a single phase. This fluid has very high enthalpy at the outlet of the core, which allows the turbine system to have a significant reduced size, meaning equally significantly lower capital costs. Due to the nature of the coolant, the containment can be smaller than in current water cooled reactors, which also has a beneficial impact in costs.

Despite all these promising features, this system is also facing some challenges. The cladding of the fuel, for instance, need to be able to withstand higher temperatures, this means that it requires different materials that may affect the fuel burn-up and the peak cladding temperature. It is very important to avoid conditions that lead to fuel cladding overheat, such as overpassing the design limit of coolant mass flux or heat flux. These systems might also require multiple heat-up steps plus coolant mixing to overcome the formation of hot spots due to the larger enthalpy rise of the coolant. Yet, this might add complexity to the layout. Supercritical water entails problems with water radiolysis and corrosion due to its chemical properties. Safety strategy is fundamentally different to BWR since it need to control the coolant mass flow rather than its inventory due to the absence of recircula-

tion inside the reactor. Finally, when working in the fast neutron spectrum, the requirement of a negative reactivity coefficient (for stability purposes) means that the breeding gain is limited to negative values.
The following table shows the characteristics of some of the concepts or SCWR. These designs are the High pressure light water reactor, super LWR, Super-fast LWR, and the CANDU- SCWR.

	HPLWR	**Super LWR**	**Super-Fast LWR**	**CANDU-SCWR**
Thermal electrical power [MW]	2300/1000	2300/1000	2358/1000	2550/1220
Spectrum	Thermal	Thermal	Fast	Thermal
Fuel	UO_2	UO_2	MOX	UO_2/Th
Moderator	Light Water	Light Water	Light Water	Heavy Water
Reactor layout	RPV	RPV	RPV	Pressure tubes
Outlet Core Temperature [°C]	500	500	500	625
Core pressure [MPa]	25	25	25	25
Net electrical efficiency [%]	43.5	43.8	43.8	48

Table 4.5: Summary of SCWR projects. Source Energy Policy, Generation IV nuclear reactors: Current status and future prospects, [6]

Similarly to previously exposed generation IV systems, SCWR has already finished the viability assessment, and the performance analysis is ongoing. The demonstration phase is expected to begin by 2025.

Sodium-cooled Fast Reactor. SFR

SFR is a fast reactor that uses liquid sodium as coolant. Since it is a fast reactor it does not require moderator. This reactor is highly versatile and it can function as a breeder (generating more fissile material that what it consumes), as a burner (transmutation of fission products), or as a converter, with a near one breeder ratio, which reduced drastically the frequency of refilling.

Sodium has good properties as a coolant. It has high specific heat at low pressures, so it eliminates the necessity of pressurization of the reactor vessel. It has a low melting point, 98°C and is less corrosive than other liquid metal alternatives such as lead. However, its boiling point, 833°C, limits the core outlet temperature, an, thus, the efficiency of the power cycle. It is also highly reactive to air and water. For this reason, the primary circuit need to be hermetically sealed. The safety goal of generation IV is fulfilled by the installation of an intermediate circuit with non-radioactive sodium between the primary circuit and the power cycle, this helps to reduce the damage in case of contingency.

Although this systems is the most experimented among the fat reactors, the economy poses a challenge. The complexity of the system due to the three different circuits increases the capital cost making it hard to be competitive against other base load technologies such as coal, especially if no emission taxes are applied.

To achieve the sustainability goal of the GIF, this fast reactor requires reprocessing to close the fuel cycle. The most advanced options for reprocessing are: advanced aqueous process, and pyro-metallurgical process. The first alternative consist on separation processes based on solvent extraction technology. Pyro-metallurgical process is the electro-refining of metal fuels in high temperature chloride salts [43].

For the design of the reactor, there are two alternative as well, and a third new concept that works as a hybrid of the others. The alternatives are: loop configuration and pool configuration. They differ on the way that the coolant circulates through the core, and each has some advantages and disadvantages. For example, in the loop layout the risk of leakage is higher, since there are pipelines carrying coolant outside the core, while in the pool

configuration the reactor pressure vessel confines all the radioactive sodium. Loop configuration is smaller and cheaper, but the maintenance of pool configuration is easier. Thermal inertia is higher in pool configuration, which makes transitions slower, even in the case of an accident, thus, this layout is the more experimented [44].
There are several design concepts for SFR. They all face the biggest challenge of economy, due to the complexity of the systems. Nevertheless, they are a good example of the fulfilment of the goals for Generation IV. Regarding non-proliferation, some of these designs use reprocessed fuel with transuranic elements, TRU-MOx, which avoids the use of breed fuel for nuclear weapons fabrication.
The summary of the exiting projects is shown below on table 4.6.

	JSFR	**KLAIMER**	**SMFR**
Thermal electrical power [MW]	3570/1500	1523/600	125/50
Fuel	TRU-MOX	U-TRU-10%Zr	U-TRU-10%Zr
Fuel Cycle	Aqueous	Pyro-metallurgical	Pyro-metallurgical
Breeder Ratio	1.03-1.2	1.0	1.005
RPV Layout	Loop	Pool	Pool
Outlet Core Temperature	550	545	510
Thermodynamic cycle	Rankine	Rankine	Brayton
Working fluid	Steam	Steam	Supercritical CO_2
Net electrical efficiency [%]	42	39.4	38

Table 4.6: Summary of SFR projects. Source Energy Policy, Generation IV nuclear reactors: Current status and future prospects, [6]

The development of the SFR has completed the viability assessment and the performance analysis is ongoing. Demonstration phase is expected to begin in 2022.

Very high temperature Reactor. VHTR

The VHTR is the natural evolution of the current High temperature gas reactors, HTGR. It is a thermal reactor cooled by helium (similar to the GFR), and moderated by graphite. The biggest advantage of this reactor is the high temperature, which increases the efficiency of the cycle and allows for the production of high temperature heat, which can later be used for industrial purposes, district heating, or hydrogen production by the coupling of a hydrogen production plant.

Helium is an inert gas both radiologically and chemically. This makes it a suitable choice as coolant. It has other drawbacks, as explained in the GFR section, such as low density or low chemical inertia.

There are currently two configurations for the fuel assembly of this reactor, the pebble bed and the prismatic block. The pebble bed configuration has less power density and, thus, higher construction cost. Yet, it increases the life of the reactor due to better neutron stability. Pebble bed layout mean other source of cost reducing, since its operating temperature is lower, the requirements for the materials are less demanding and conventional steel can be used. It also allows for on-line refuelling meaning a higher capacity factor. The prismatic block, however, has the advantage of producing less dust, that damages the rest of the equipment (heat exchanger, pipelines, etc.).

The power converting unit in the VHTR is designed to be a direct helium Brayton cycle. There is another alternative for placing an indirect Rankine cycle with a steam generator at the lower end of the outlet temperature range. For VHTR, by-products have a similar importance to power generation. For this reason, the heat for the production of these products is obtained from the coupling of a heat exchanger to the reactor core, in an indirect cycle. There are multiple possible applications for this heat such as refineries, petrochemical industry, metallurgy or hydrogen production. This last alternative is the most promising, and the one that requires more assessment and development. Some purposed methods for hydrogen production are thermochemical processes, thermochemical and electrolysis, high temperature steam electrolysis, or the steam reformer technology from heat, water and natural gas.

Out of the six reactors purposed by the GIF, the VHTR is the one that has developed further. This reactor is an evolution of HTRs. Even though this design was not widespread, there are some examples of NPPs that made use of this technology, such as the Dragon reactor in England and the THTR-300 in Germany. These projects allowed to gain experience with gas cooled reactors and higher operating temperatures than conventional NPPs. The development of new nuclear fuel assemblies that were able to contain fission products and withstand such high temperatures was initiated in these projects, even though the improvement in this fuel is still a matter of research.

This is the case of TRISO fuel, one of the challenges of VHTR. TRISO fuel is the name for micro fuel particles made of a kernel of UOx coated by four layers of different material designed to achieve high temperature resistance and fission products containment. These layers are, from bottom to top: Porous buffer carbon layer, dense pyrolytic carbon layer, ceramic carbon silicate layer, and the second pyrolytic carbon layer [45].

The incorporation of this fuel, both in pebble bed and in prismatic block, has mean an improvement of security for the VHTR. Safety is the goal of Generation IV that this reactor fulfils better. The improvement of efficiency and by-products production improve the economic performance of this reactor too. Nevertheless, the VHTR has an open fuel cycle, which means that it would benefit from the development of other reactors that can work as nuclear waste burners for transmutation.

The different concepts of VHTR differ in the fuel configuration or the power cycle. They also have different by-products associated. They are all small reactors, designed to be incorporated to industrial complexes to supply electricity and heat demands. There are some examples of reactors in operation. In Japan, the High temperature engineering test reactor, HTTR, which has a similar design to the GT-MHR (gas turbine - modular helium reactor), but with a smaller size since it is a demonstration project, has been operational since 1999. It has served the purpose of gaining experience with the new fuel and the materials requires, as well as the radiated graphite management.

The rest of the existing concepts are summarized in table 4.8. High Temperature Gas-Cooled Reactor Pebble bed Module, HTR-PM, Next Generation Nuclear Plant, NGNP, the already mentioned GT-MHR and the Gas trubine high Temperature Reactor 300, GTHTR300C.

Reactor	**HTR-PM**	**NGNP**	**GT-MHR**	**GTHTR-300C**
Thermal/Electrical power [MW]	2 x 250/210	600/240	600/286	600/240
Core Layout	Pebble Bed	Prismatic Block/Pebble Bed	Prismatic Block	Prismatic Block
Fuel	TRISO	TRISO	TRISO	TRISO
Outlet Core Temperature [°C]	750	750	850	850
Outlet Core Pressure [MPa]	7	-	7	7
Thermodynamic cycle	Rankine	Rankine	Brayton	Brayton
Net electrical efficiency [%]	42	40	48	46
By-Products	-	Industrial co-generative application	Production of hydrogen and desalinated water	Production of Hydrogen

Table 4.7: Summary of VHTR projects. Source Energy Policy, Generation IV nuclear reactors: Current status and future prospects, [6]

Even though the development of this technology is in a very advanced stage, there are still challenging problems, especially regarding constructive elements, management of nuclear waste (radiated graphite), and by-product generation.

4.2.4 Conclusion of Generation IV

After the overview of all the systems of generation IV, conclusion can be drawn about performance and technical feasibility of these systems. The following table shows a qualitative evaluation of the performance of each system on the goals of generation IV. The table also shows the current technical feasibility of the systems.
On the field of current technical feasibility, the best performance is achieved by the VHTR and the SFR. For this reason, and in order to obtain the most realistic estimations in the economical analysis, the reactor that is going to be selected is the VHTR. Besides the technical feasibility, the VHTR performs significantly good at some goals, such as the electrical efficiency or the generation of high temperature heat. The thermal spectrum of this reactor limits its performance in the sustainability goal, both in the creation of fissile material and in the transmutation of nuclear waste. Therefore, the development of this system would benefit greatly from the parallel development of a fast reactor that can work as a burner reactor.
Nevertheless the experience obtained from the operating HTRs, as well as some demonstrative prototype VHTR plants, allows for educated guesses regarding the economic assessment of a full size NPP. The mayor challenge in assessing this system is the lack of information regarding the sources of cost: construction, fuel, operation and maintenance, and decommissioning. In the case of the VHTR, the generation of by-products means an additional challenge, due to the uncertainty about the economic valuation of these by-products.

	VHTR	GFR	SFR	LFR	SCWR	MSR
Efficient Electricity Genration	Very High	High	High	High	High	High
Flexibility: Availability of high-temperature process heat	Very High	High	Low	Low	Low	Low
Sustainability: Creation of fissile material	Medium/ Low	High	High	High	Low	Medium/ Low
Sustainability: transmutation of waste	Medium	Very High	Very High	Very High	Low	High
Potential for passive safety	High	Very Low	Medium/ Low	Medium	Very Low	Medium
Current technical feasibility	High	Medium/ Low	High	Medium	Medium/ Low	Low

Table 4.8: Grading of generation IV projects

Chapter 5

Economic Model of the VHTR

The conclusion of the last chapter wast to select the reactor type VHTR as the one to develop the economic model. After selecting this reactor, it is necessary to determine the characteristics of the hypothetical NPP that is powered by this technology. VHTR is a reactor focused on modularity, as it was explained in the previous chapter. Therefore, the plant will be medium size and several small modules will constitute the power converting unit.

After establishing the characteristics of the power plant, the next objective will be to create the economic model. This model will be constructed based mainly on two principles. Bottom-up cost building and similarity. The main sources of costs will be divided and each part will be analysed separately. When no reliable data is available, the cost of that part will be determined based on a similar process of which there is enough information. This will be especially relevant in the determination of capital costs, due to the novelty of this reactor.

The economic model aims to determine a set of values based on which the economical viability of the project will be attested. After that, the indicators of the viability will be commonly used parameters: net present value, internal rate of return and the payback period. The levelized cost of electricity will also be calculated and compared to exiting technologies.

The values obtained from the economic model are the inputs to perform an sensitivity analysis for this reactor. The viability will be tested based on changes of this parameters, in order to determine which of these are more critical in this plant. Therefore, conclusions can be drawn about the need of research and optimisation of different fields, such as fuel material cost or the construction process.

In this chapter, many assumptions will be needed due to the uncertainty regarding many parameters. The validity of this thesis is dependant on these hypothesis and these will be therefore based on available articles and reports regarding nuclear energy. Nevertheless, these assumptions will also be subjected to the later sensitivity analysis to increase the robustness of the conclusions.

5.1 Nominal characteristics

The model of the NPP will be based on the existing prototype projects of VHTRs. Two of these projects are especially well documented, the HTR-10 in China and the MPBR design by the MIT, which shares many characteristic with the cancelled project PBMR in South Africa. This last example had extremely high over-costs and construction delays, that eventually lead to its cancellation. Yet, both reactors take advantage of the modularity and standardization of the reactor, and other beneficial characteristics such as the high capacity factor and electrical efficiency. Therefore the economical analysis will be based on the case of MIT's MPBR, widely documented in the article **MIT Pebble Bed Reactor Project**, by A.C.Kadak [4].

The plant model will then have some of this benefits. The fuel burn-up is high and the systems allows for on-line refueling, which increases drastically the capacity factor. Nevertheless, for the base case of the analysis, the capacity factor will be set to 85%, which is a standard value for NPPs.

The plant is made of modular components made up a power unit consisting in pressure vessel, heat exchangers and power converting cycle. Altogether they make up a modular power unit with a total electrical capacity of 120 MW.

The economical analysis will be performed for one of these units, due to the assumable reduction cost motivated by the learning curve in this modularity, the conclusions obtained will be applicable to bigger plants.

The MPBR makes use of an intermediate helium heat exchanger to connect the primary and secondary loops. The reason for this heat exchanger are the safety achieved by isolating the radiated helium and the flexibility added to the secondary loop, especially for future development in by-products generation.

The modularity of this plant allows for all components to be transported by train our truck, exept for the pressure vessel. This components have de form os "space frames", and they are meant to be assembled at the plant, reducing significantly the construction costs[4].

There is, as a result, constraints in the size of the space frames, in order for them to be transportable by cheap means. The final design accounts for 27 modules. The resulting plant has a dimension of 70 x 80 ft. Its power density, given that the nominal capacity is 120 MWe, is comparable to conventional technologies such as gas turbine systems.

The net electrical efficiency will be between 45% and 48%, close to the VHTR target of 50% efficiency. The gap is due to the uncertainty of the efficiency of the intermediate heat exchanger, which depend on the co-generation applications of the facility.

The power converting unit of this plant is an indirect helium Brayton cycle. An schematic layout of the facility is showed on figure 5.1.

In addition, figure 5.2 shows the space frame modules that made up the power unit of the facility.

Finally, the nominal specifications of the plant are summarized on table 5.1. The rest of the data needed for the development of the model will be introduced in the following sections, specifically in the corresponding cost analysis to which it concerns.

Power	250 MWth - 120 MWe
Target thermal efficiency	45%
Core height	10 m
Core Diameter	3.5 m
Pressure Vessel Hight	16 m
Pressure Vessel Radius	5.6 m
Number of Fuel Pebbles	360,000
Microspheres per pebble	11,000
Expected fuel burnup	90,000 MWd/MBTU
Fuel	UO_2 TRISO Pebble
fuel Pebble diameter	60 mm
Fuel Pebble enrichment	8%
Uranium mass per pebble	8 g
Coolant	Helium
Helium Mass Flow rate	120 kg/s
Helium entry/exist temperature	520°/900°
Helium pressure	80 bar
Mean Power Density	3.54 MW/m^3
Number of control rods	6

Table 5.1: Nominal characteristics of the MPBR. Source: **MIT Pebble Bed Reactor Project**, by A.C.Kadak [4]

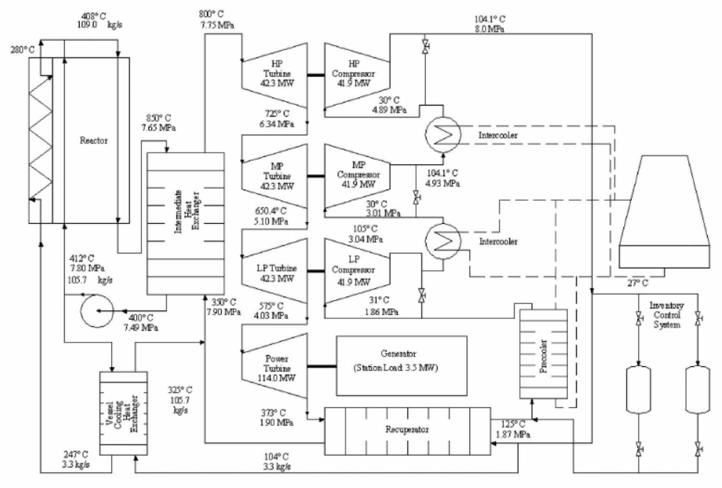

Figure 5.1: layout of the MIT Pebble Bed reactor. Source MIT Pebble Bed Reactor Project [4]

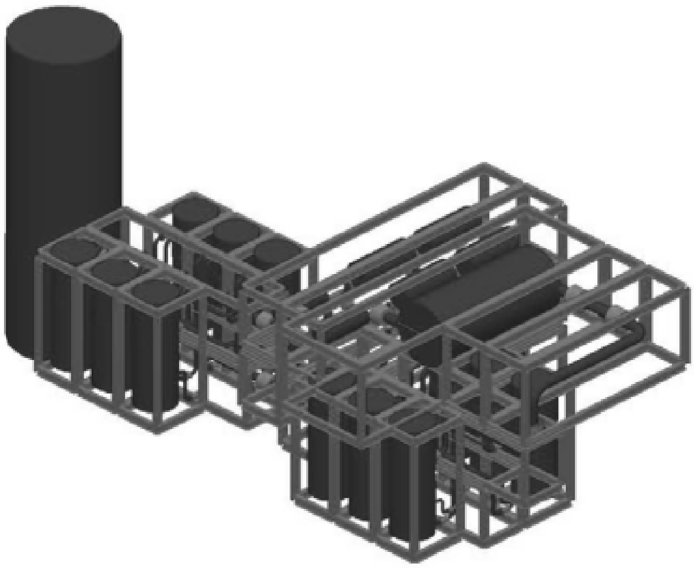

Figure 5.2: Modules of the power unit in the MPBR. Source MIT Pebble Bed Reactor Project [4]

5.2 Fuel cycle cost

Fuel cycle cost represents one of the most challenging cost analysis of this reactor. TRISO pebbles are not currently an extent form of nuclear fuel and, therefore, there are not many sources of commercial costs of this material.
TRISO particles have already been introduced, There are composed of a kernel of nuclear fuels with four layers of coating meant to retain the fission products inside the particle and withstand the high temperatures of the reactors in which they are expected to be used. A TRISO Fuel Pebble is a sphere of composite material, with TRISO Particles embedded inside a graphite matrix, which serves the purpose of moderator as well as intermediate coolant between the particles and the helium on the reactor. Graphite is flammable material, and thus adds a challenge to the nuclear reactor to be isolated from external oxygen to avoid combustion.

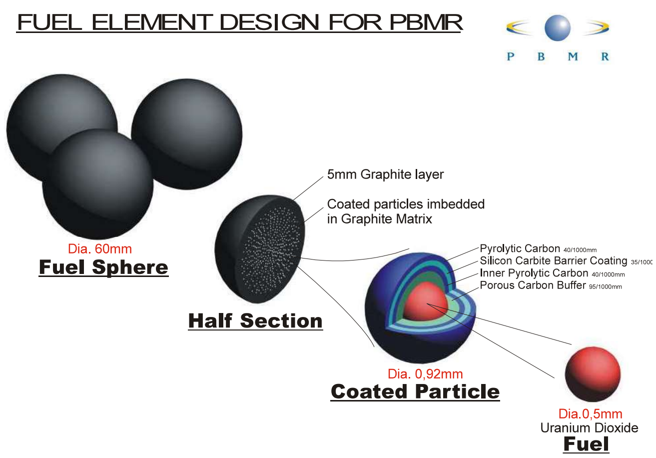

Figure 5.3: TRISO Fuel Pebble Diagram. Source MIT Pebble Bed Reactor Project [5]

For the cost analysis of the fuel, we will assess separately all the process of a open fuel cycle. If reprocessing is included in the future, it will meant an additional source of cost. Yet, as the development of the VHTR is expected to be parallel to the development of fast reactors designs, this cost could be

reduced due to the application of waste burners of fast reactors.
The different steps analysed of the fuel cycle will be: enrichment, material cost, manufacturing costs, quality assurance costs and back-end costs. For these calculations, the process was based on the fuel cycle cost analysis performed by *C. W. Kingsbury* on his thesis **Fuel Cycle Cost and Fabrication Model for Fluoride-Salt High Temperature Reactor (FHR) Plank Fuel Design Optimization** [8]. The fuel assembly of the reactor analysed on this thesis is different from the fuel pebble, albeit, there are some useful conclusions that can be drawn from it. The model used can be seen in figure5.4.

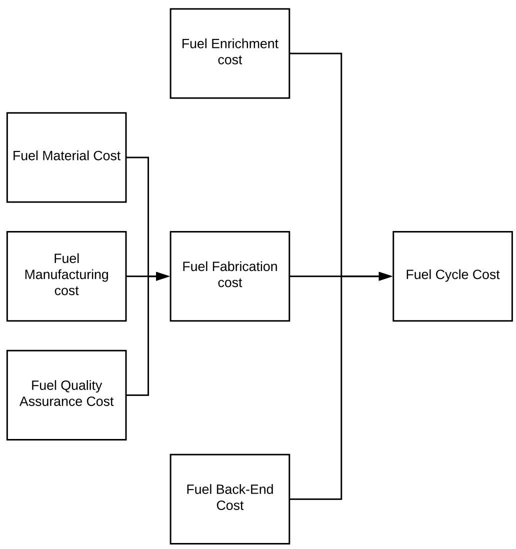

Figure 5.4: FCC Model

5.2.1 Fuel enrichment cost

The fuel enrichment cost cover all the costs sources from uranium mining to the final manufacturing of the material inside the kernels of the TRISO particle. To calculate this cost, we will use the equations corresponding to the chemical process [8]. This equations need the inputs of unitary prices of mining, conversion and enrichment, as well as the mass fraction of enrichment

in the flows of feed, waste and product.
The fractions of the mass flows are determined by both the nominal characteristics of the plant (8% of enrichment in the product) and the common valued of the process (0.71% in the feed flow and 0.20% in the waste flow). These mass fractions will be denoted as x_i, where the sub-index i indicates the corresponding mass flow.
The mass flows will be denoted as F, P, and W, meaning feed, product and waste flow respectively. The separation potential, $V(X_i)$ is a function needed in the SWU factor equation, S, which calculates the SWUs needed per KgU enriched. This serves as an input for the last equation that calculates the price of enrichment, in which the losses of conversion and fabrication, l_c and l_f are set to 0 since they are considered neglectable [8].

$$F = P + W \tag{5.1}$$

$$x_f F = x_p P + x_w W \tag{5.2}$$

$$\frac{F}{P} = \frac{x_p - X_w}{x_f - X_w} \tag{5.3}$$

$$\frac{W}{P} = \frac{F}{P} - 1 \tag{5.4}$$

$$V(x_i) = (2 \cdot x_i - 1) \cdot ln\frac{x_i}{1 - x_i} \tag{5.5}$$

$$S = V(x_p) + \frac{W}{P} \cdot V(x_w) - \frac{F}{P} \cdot V(xf) \tag{5.6}$$

$$\dot{P}_{enr.U} = [\frac{\dot{P}_{ore}}{(1 - l_c)(1 - l_f)} + \frac{\dot{P}_{conv}}{1 - lf}] \cdot \frac{F}{P} + \frac{\dot{P}_{SWU}}{1 - l_f} \cdot S \tag{5.7}$$

The other inputs needed for these equations are the prices of uranium ore, conversion and enrichment. These values are presented in the following table

5.2 [7]

$\dot{P}_{ore}$ **[$/ KgU]**	48.4
$\dot{P}_{conver}$ **[$/ KgU]**	6
$\dot{P}_{SWU}$ **[$/ SWU]**	37

Table 5.2: Uranium Prices. Source UxC [7]

Finally, by introducing all the inputs the cost of the enriched uranium can be calculated. It is show in table.

$\dot{P}$ **[$/ KgU]**	1424.4

Table 5.3: Cost of enriched uranium

5.2.2 Fuel material cost

The next part of fuel cost corresponds to the cost of materials. These materials are the graphite matrix and the TRISO particles. Following the bottom-up cost building strategy, these will be studied separately.
TRISO material cost, when isolated from conversion and coating material costs has an aproximate value od 1,000 $/KgU. This conclusion is achieved from subtracting the enrichment costs from the bold figure of approximately 6,000 $/KgU of enrichment conversion and coating materials [8].

$\dot{P}$ **[$/ KgU]**	1,000

Table 5.4: TRISO Material cost

On the other hand, the graphite matrix material cost requires some calculation. The first step si to calculate the volume of graphite needed per pebble. To calculate that, we need to subtract the volume of a TRISO particle times the number of particles per pebble from the total volume of the sphere.

$$V_{graphite} = V_{pebble} - N \cdot V_{microsphere} \tag{5.8}$$

Where N is the number of micro-spheres per pebble. The result of this equation is:

$$V_{graphite} = 109541.9 \quad mm^3$$

The graphite matrix is in turn a composite, made up of different kinds of graphites. Their prices and mass fractions are showed in the following table.

	Mass fraction [%]	**Price [$/Kg]**
Natural Graphite	64	75
Synthetic Graphite	16	65
Resines	2	19,5

Table 5.5: Graphite matrix material cost. Source **Fuel Cycle Cost and Fabrication Model for Fluoride-Salt High Temperature Reactor (FHR) Plank Fuel Design Optimization** [8]

From this data a weighted average graphite material price can be calculated, which combined with the graphite density and the mass of uranium per pebble can be finally converted into units of $/KgU.

$\dot{P}$ **[$/ KgU]**	1,550.12

Table 5.6: Graphite Material cost

Finally, by adding the to material costs values the total material cost is obtained.

$\dot{P}_{TRISO}$ **[$/ KgU]**	1,000
$\dot{P}_{Graphite}$ **[$/ KgU]**	1,550,12
$\dot{P}_{material}$ **[$/ KgU]**	2,550,12

Table 5.7: Fuel Material cost

5.2.3 Fuel manufacturing costs

After calculating the costs of enrichment and materials, the next step is to calculate the cost of fuel manufacturing. This is similarly divided into the manufacturing cost of TRISO and the manufacturing cost of a fuel pebble.

The TRISO manufacturing process have been studied since the first gas coled reactors were operational. Sutdies in the 1960's stated a cost of 0.2 $/particle, yet, more recesnt studies defend a drastic cost reduction reaching values of 0.00001 $/particle [8]. Since the gap between these values is so wide, two intermediate values will be added for sensitivity analysis purposes. From the manufacturing cost of one particle we can obtain the cost manufacturing cost of TRISO in a pebble, which, combined to the uranium mass per pebble leads us to the value in terms of $/KgU.

$/particle	**$/pebble**	**$/kgU**
0.00001	0,11	15,71
0,001	11	1,571,43
0,01	110	15,714,29
0,2	2200	314,285.71

Table 5.8: TRISO Manufacturing Cost. Source **Fuel Cycle Cost and Fabrication Model for Fluoride-Salt High Temperature Reactor (FHR) Plank Fuel Design Optimization** [8]

The manufacturing cost of the Pebble will be calculated based on the similarity of the plank fuel assembly studied on the thesis **Fuel Cycle Cost and Fabrication Model for Fluoride-Salt High Temperature Reactor (FHR) Plank Fuel Design Optimization** [8]. This assembly is a composite material with a different shape than the fuel pebble, yet sharing the same materials. Therefore, we take the first assumption by applying similarity laws between the fuel pebble and the plank.

The results of the pebble manufacturing cost are a function of the packing fraction, which in the pebble is approximately 60% [5]. For the fuel plank, the cost has only been calculated up to 50% packing fraction. For this reason, an extrapolation is needed.

The pebble cost will be determined by multiplying the TRISO manufacturing cost by a factor previously determined by the data of the fuel plank, denoted as α. This factor takes into account the capital cost and operation and maintenance cost of a fuel manufacturing plant. The exact determination

of the manufacturing plant requires the analysis of a similar plant which is subject of a different analysis. Nevertheless, given the similarity between the fuel assemblies this approximation is reasonable.
The equation to determine the pebble cost is, consequently, the following:

$$\dot{P_{manu,matrix}} = \alpha \cdot \dot{P_{manu,TRISO}} \tag{5.9}$$

An the expression to calculate the pebble manufacturing cost is:

$$\dot{P_{manu,pebble}} = (1 + \alpha) \cdot \dot{P_{manu,TRISO}} \tag{5.10}$$

Accordingly, the first step is to calculate the α multiplying factor for different packing fraction on the fuel plank assembly. This will be later extrapolated and applied to the fuel pebble.

Packing fraction	**TRISO manufac-turing cost**	**Total cost**	α
10	2,518.6	3,335.3	0.32
20	2,518.6	3,033.1	0.20
30	2,518.6	2,911.2	0.15
40	2,518.6	2,842.7	0.12
50	2,518.6	2.797.9	0,11

Table 5.9: Calculation of α multiplying factor on fuel plank assemblies. Source **Fuel Cycle Cost and Fabrication Model for Fluoride-Salt High Temperature Reactor (FHR) Plank Fuel Design Optimization** [8]

The next table shows the multiplying factors for the different packing fractions, and the extrapolated value of the factor corresponding to a packing fraction of 60%. The fourth column shows the calculated error between the values calculated through the extrapolating function (polynomial function of third degree)and the empirical values.
Figure 5.5 shows the graphic representation of the calculation performed on table 5.10. The formula of the extrapolating function is also included.

Packing fraction	α empirical	α calculated	Error [%]
10	0.32	0,32	0.17%
20	0.20	0.20	1.08%
30	0.15	0.15	2.13%
40	0.12	0.13	1.70%
50	0.11	0.11	0.52%
60	-	0.05	-

Table 5.10: Extrapolation of α multiplying factor based on empirical values

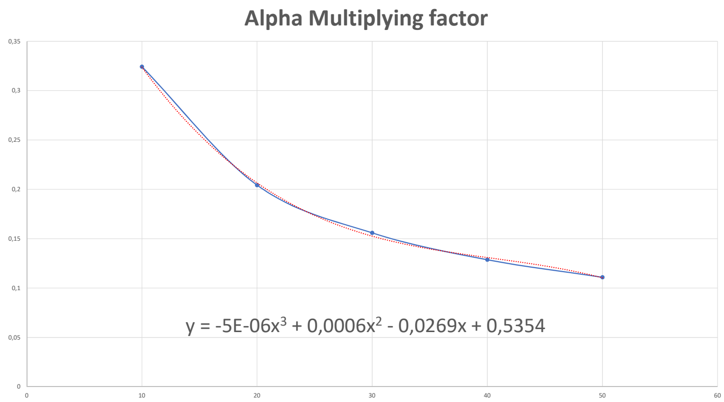

Figure 5.5: Extrapolation of α multiplying factor based on empirical values

Finally, with the value of the multiplying factor, we can obtain the prices of manufacturing for the different values of TRISO manufacturing price. This values are represented on table 5.11.

$\dot{P}_{manu,TRISO}$ **\$/particle**	$\dot{P}_{manu,TRISO}$ **\$/KgU**	$\dot{P}_{manu,matrix}$ **\$/KgU**	$\dot{P}_{manu}$ **\$/KgU**
0.00001	15,71	0.94	16.65
0,001	1,571,43	93,96	1,665.39
0,01	15,714,29	939.57	16,653.85
0,2	314,285.71	18,791.33	333,077.05

Table 5.11: Manufacturing Cost.

5.2.4 Fuel Quality assurance costs. QA

In a similar way to how the matrix manufacturing costs have been calculated, quality assurance cost will be estimated as a percentage of the rest of the fabrication costs. These fabrication cost are materials and manufacturing cost. The percentage that QA represents of the sum of material and manufacturing cost is uncertain. Commonly, in new nuclear reactor applications this percentage can be as high as 30% [8], due to defects in the coating of the TRISO particles or other possible defects occurring during fabrication.

This value might be however reduced due to the closely monitoring of the fabrication process associated with this new fuel assembly. The variance in this value will be later studied in the sensitivity analysis. In this subsection the QA cost will be calculated for a range of values from 10% (optimistic scenario) to 30%, regarded as the most realistic value.

The following equation shows the calculation of the QA cost.

$$\dot{P_{QA}} = x_{QA} \cdot \frac{\dot{P_{mat}} + \dot{P_{manu}}}{1 - x_{QA}} \tag{5.11}$$

From that the expression for total fabrication cost can be deduced.

$$\dot{P_{fab}} = \dot{P_{mat}} + \dot{P_{manu}} + \dot{P_{QA}} = \frac{\dot{P_{mat}} + \dot{P_{manu}}}{1 - x_{QA}} \tag{5.12}$$

As a result, table 5.12 shows the resulting quality assurance costs for the different TRISO manufacturing prices and percentage of QA.

$\dot{P}_{manu,TRISO} - QApercentage$	10%	20%	30%
0.00001	285.20	641,70	1,100,05
0,001	468,39	1,053.88	1,806.65
0,01	2,133.78	4,801.00	8,230.28
0,2	37,291.91	83,906.79	143,840.22

Table 5.12: Quality Assurance Cost.

5.2.5 Fuel Back-end cost

The back-end cost corresponds to the back-end process of spent fuel removal, disposal and storage. Further development of this thesis might include a closed fuel cycle with reprocessing, yet, in our analysis we will not considered this possibility in depth given the limited relevance of this technology.
The back-end cost is estimated by the *NEA* in its report **Projected cost of Generating Electricity**. The estimated value is 2.33 $/MWh [46], which need to be converted to the working unit of $/KgU through the values of capacity factor and fuel burn-up. Table 5.13 shows the final values.

$/MWh	**$/KWe**	**mills/KgU**
2.33	17.35	2.42

Table 5.13: back-end Cost.

5.2.6 Fuel cycle cost. Conclusion

The final objective of this section was to determine a value or set of values based on plausible assumptions and, when available, reliable data, for the fuel cycle cost of the plant. Due to the with of some of the data (mainly TRISO manufacturing cost and QA cost), the final set of values has a broad range from the lowest to the highest cost. This means that the sensitivity analysis will have to take many cases of the fuel cost into account.
Tables 5.14 and 5.15 show the final values for the FFC cost for the different values of TRISO manufacturing cost and QA cost. The units of table are in the previously calculated $/kgU and on table have been converted to $/MWhe through the nominal burn-up, efficiency and capacity factor values. The Report **Projected cost of Generating Electricity**, estimates a value of approximately 10 $/MWhe for the fuel cycle cost of regular current nuclear applications [46]. Aside from the bottom row of table 5.15, the values have the same order of magnitude as this estimation. The high values contained in this row are explained by the highest TRISO manufacturing cost, which

TRISO man. price	QA 10%	QA 20%	QA 30%
0.00001	4,276.4	4,616.3	5,074,6
0,001	4,459.6	5,028.5	5,781.2
0,01	6,125.0	8,775.6	12,204.8
0,2	41,283.1	87,881.4	147,814.8

Table 5.14: FCC cost in $/KgU.

TRISO man. price	QA 10%	QA 20%	QA 30%
0.00001	4.12	4.45	4.89
0,001	4.30	4.85	5.57
0,01	5.90	8.46	11.77
0,2	39.81	84.76	142.56

Table 5.15: FCC cost in $/MWhe.

corresponds to a 1960's estimation. Therefore,the upper values have a more realistic character.

The conclusion is, as a result, that in equal conditions for the rest of the costs sources (capital cost, O&M, decommissioning) the planned nuclear facility will be in most cases, at least as cost-effective as a regular nuclear plant, having in several cases as well, a lower fuel cost, mainly due to the high burnup value of the reactor.

The weight of each cost component in the FCC cost is shown in figures 5.6 and 5.7 for the cases of 10% QA and 30% QA respectably. These figures show how QA represents an important percentage of the cost regardless of the case of TRISO manufacturing cost. Besides that, they indicate the importance gained by manufacturing costs as the price per TRISO particle increases. On the other hand, the back-end cost component represents a negligible percentage of the FCC.

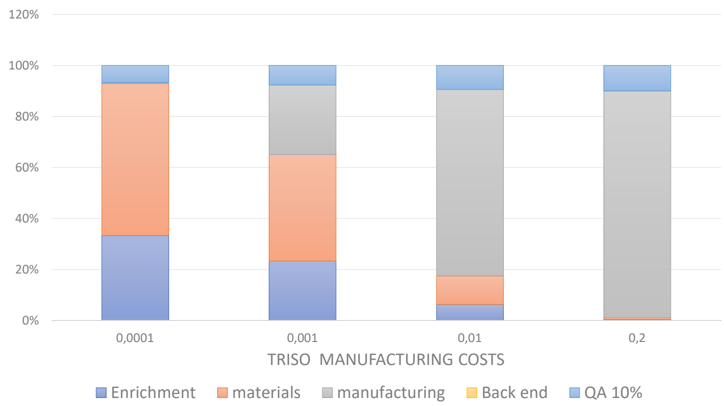

Figure 5.6: FCC cost components. QA 10%

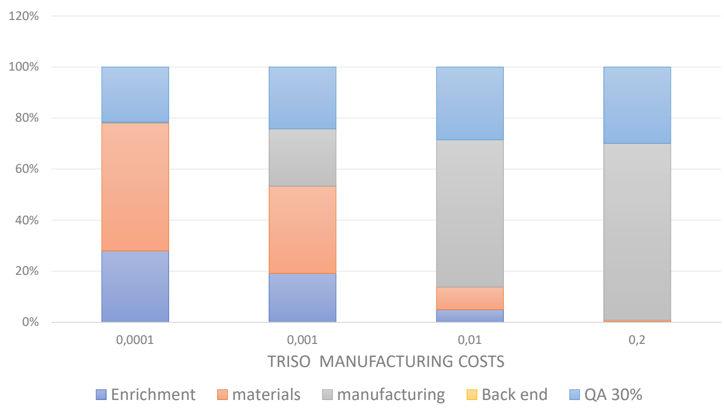

Figure 5.7: FCC cost components. QA 30%

5.3 Operation and Maintenance cost

The operation and maintenance cost means the expenditure of operating the facility and of the maintenance service. This cost has commonly a more important weight in nuclear industry than in other electricity generating technologies. Safety measures are included in this field and, therefore, the requirements are strict in nuclear facilities. Generation IV power plants incorporated, as it was discussed, passive safety features, which lead to reduction of this costs. In the case of the Pebble Bed Reactor, on-line refueling is a feasible feature which may also reduce this cost.

For the estimation of this parameter, this study is based on less optimistic assumptions. The O&M cost of the PBR will be regarded by the estimation of the **GIF Symposium Proceedings**, which establish the value between 50 and 100 $/KWe, on 2009 $ [1]. As an additional value, the O&M cost of advanced nuclear facilities will also be included in the economic model, obtained from the report **Capital Cost Estimates for Utility Scale Electricity Generating Plants**, by the U.S Energy Information administration [9].

The values obtained from these sources need to be restated by the inflation rate when necessary. Monetary values from years previous to 2016 will be increased based on a 3% rate establish for all project costs (from the report **The future of nuclear power** by the MIT [38]).

Table 5.16 show the final obtained values from the **GIF Symposium Proceedings**, restated by inflation and converted into mills/KWhe.

2009 EUR/KWe	2016 EUR/KWe	2016 $/KWe	$/KWhe	mills/KWhe
50	57.96	72.45	0.0097	9.73
60	69.56	86.95	0.0117	11.68
70	81.15	101.44	0.0136	13.62
80	92.74	115.93	0.0156	15.57
90	104.33	130.42	0.0175	17.52
100	115.93	144.91	0.0195	19.46

Table 5.16: O&M Cost estimation for VHTR. Source:GIF Symposium Proceedings [1]

The additional value calculated is based on the data obtained from the EIA report [9]. This Document provides two values for O&M, since it is divided in fixed cost (base on the capacity installed), and variable cost, (dependent on operation). In order to be able to compare it with the other values, we calculated the total annual O&M cost and divided it by the generation to get a variable O&M cost parameter. In this case, no restating is necessary since the values are already in 2016 $.

Fixed cost $/KW	**Variable cost $/MWh**
100.28	2.3

Table 5.17: O&M Cost of Advanced nuclear. Source:**Capital Cost Estimates for Utility Scale Electricity Generating Plants**,[9]

From these values we proceed with the calculation:

$$\dot{P_{O\&M}} = \frac{(100.28 \cdot Capacity[KW] + 2.3 \cdot Annual \quad Generation[KWhe])}{Annual \quad Generation[KWhe]}$$

$$\dot{P_{O\&M}} = 15.77 \quad mills/KWhe$$

Accordingly, the resulting cost has the same order of magnitude than the values obtained in table 5.16. These values are, as expected, higher than this parameter in other technologies. For instance, the O&M cost for a regular gas plant has an approximate value of 5 mills/KWhe.
The conclusion drawn form this section is the same that was achieved after the FCC analysis. The similarity between the obtained values for this new reactor and current nuclear facilities leads to the fact that the viability of these new Technology is not strongly dependant on the operation and maintenance costs.

5.4 Capital cost

For the capital cost, We will base the cost analysis on the data provided by the studies published by the MIT on the MPBR. Additionally, bibliography regarding the Chinese project HTR-10 will also be consulted to increase the robustness of the model.
The capital cost of the facility is presented often in energy projects as a parameter dependant on the plant's capacity. The two previously mentioned

NPPs will provide specific values of capital cost, which will then be divided by the plant's capacity to obtain the normalized capital cost.
The article **Economic potential of modular reactor nuclear power plants based on the Chinese HTR-PM project**, analyses the potential economical viability of these reactor, and estimates the capital cost between 90 and 120% of a current PWR [2]. Therefore, the capital cost estimation from this source will be regarded as the cost of an advanced nuclear facility (current designs for PWRs) corrected by the mentioned factors. During the sensitivity analysis the different values for capital cost obtained in this section will be applied to verify the capital cost limitations in the facility.
Table 5.18 shows the capital cost analysis for the MPBR by the MIT.
The unit capital cost is obtained by dividing the capital cost by the plant capacity of 1100 MWe. This value needs to be then restated by inflation.

$$Unit \quad capital \quad cost \quad [2016's \quad \$/KWe] = 4,243.9$$

On the other hand, Table 5.19 shows the capital cost analysis for an advanced nuclear facility with a capacity of 2,334 MW.
As a result, Table 5.20 shows a summary of the capital cost values and the overnight cost values obtained from the estimate of the MPBR to the variations (ranging from 90 to 120%) on the final value on the advanced nuclear facility.

5.5 Cost of decommissioning

The cost of decommissioning of a energy facility responds to the necessity of dismantling the plant after its life has ended. In nuclear industry this cost are higher than in other energy applications due to the contamination that some of the constructive material suffer during operation for being in contact with radioactive material.
For pebble bed VHTR, the cladding of the TRISO nuclear fuel drastically reduces this contamination, which also helps reduce the decommissioning

	Millions of 1992's $
LAND & LAND RIGHTS	2.50
STRUCTURES & IMPROVEMENTS	192.0
REACTOR PLANT EQUIPMENT	628.0
TURBINE PLANT EQUIPMENT	316.0
ELECTRIC PLANT EQUIPMENT	64.0
MISCELLANEOUS PLANT EQUIPMENT	48.0
HEAT REJECTION SYSTEM	25.0
TOTAL DIRECT COST	1,275.50
CONSTRUCTION SERVICE	111.0
HOME OFFICE ENGR. & SERVICE	63.0
FIELD OFFICE SUPV. & SERVICE	54.0
OWNER'S COST	147.0
TOTAL INDIRECT COST	375.0
TOTAL BASE CONSTRUCTION COST	1,650.0
CONTINGENCY	396.0
TOTAL OVERNIGHT COST	2,046.5
AFUDC	250.0
TOTAL CAPITAL COST	2,296.5
UNIT CAPITAL COST [$/KWe	1,860.0

Table 5.18: Capital Cost estimate for the MPBR. Source: Modular Pebble Bed Reactor High Temperature Gas Reactor [5]

	2006's m$
CIVIL STRUCTURAL MATERIAL AND INSTALLATION	1,927,067
MECHANICAL EQUIPMENT SUPPLY AND INSTALLATION	3,782,925
ELECTRICAL / I&C SUPPLY AND INSTALLATION	700,954
PROJECT INDIRECTS	3,029,122
EPC COSTS BEFORE CONTINGENCY AND FEE	9,440,067
FEE & CONTINGENCY	1,446,413
TOTAL PROJECT EPC	10,886,479
OWNER'S COSTS	2,395,025
TOTAL PROJECT COST	13,281,504
TOTAL PROJECT EPC [$/KW]	4,873
OWNER'S COST 22% [$/KW]	1,072
TOTAL PROJECT COTS [$/KW]	5,945

Table 5.19: Capital Cost estimate for the AN facility. Source: **Capital Cost Estimates for Utility Scale Electricity Generating Plants** [9]

	Unit capital cost [%/KW]	Unit capital cost [%/KW]
MPBR	4,243	1,860
Advanced nuclear	5,121 5,690 6,259 6,828	4,385 4,873 5,360 5,847

Table 5.20: Unit capital an overnight cost estimates for the MPBR

cost. The modularity of the plant also helps reducing the cos of dismantling the facility for obvious reasons.
Nevertheless, in this analysis, we will not take these reductions into further consideration since they are already present in the reduction in capital costs. Additionally, analysing a less optimistic cost scenario ensures the viability of other scenarios where these reductions are indeed present.
To asses the cost of decommissioning, we will base the cost calculation on the estimation published on **Projected cost of Generating Electricity**. The estimated value is 15% of the facility overnight cost for nuclear plants [46]. To increase the robustness of the model and in order to obtain ore values for the sensitivity analysis we will also calculate the decommissioning costs in a rage from the estimated 15% to 30 % of the overnight costs.
Table 5.21 is based on table 5.20 and serves as a summary of the final values obtained for unit decommissioning costs

	Decom. Costs 15% [%/KW]	Decom. Costs 20% [%/KW]	Decom. Costs 30% [%/KW]
MPBR	637	849	1,273
Advanced nuclear	768	1,024	1,536
	854	1,138	1,707
	939	1,252	1,878
	1,024	1,366	2,049

Table 5.21: Unit decommissioning cost estimates for the MPBR

5.6 Price of electricity

Sales of electricity mean the sole source of income of most electricity generation projects. In the case of co-generation, the sales of by-products such as heat or hydrogen may lead to additional revenues.
The pebble bed modular reactor is design to be able to generate heat in addition to electricity. Nevertheless, the sale of this heat must be ensured beforehand by addressing an existing heat demand. These kind of facility is

meant to supply the heat demand of an industrial park while feeding most of the electricity needed.
In our case, we are not going to incorporate additional by-product sales until the sensitivity analysis, where scenarios with heat demand will be studied. For the base case, since the sale of by-products will only mean and improved economical performance of the facility, this possibility is not yet considered.
The study by the MIT, **The future of nuclear power** [38], sets the price of electricity in 84 2007's $/MWh. This value, when restated by inflation, becomes 109,6 $/MWh.
The Energy information administration, EIA, publish in the report **Electric power monthly** another value for the electricity selling price of 101 $/MWh. The two values have the same order of magnitude and come from reliable sources.
For the base case analysis, a mean value between the two will be set as the electricity selling price. In the assessment of other scenarios, we will use the originals and some variations around them.

5.7 Conclusions of the economic model

The economic model has successfully determined a rank of values for all sources of cost and revenue. The study of these values in absolute terms leads to the fact that this facility may achieve profitability under similar conditions of current nuclear, since most of the cost parameters have the same order of magnitude as current nuclear plants.
The incorporation of by-product sales, whose production is embodied on the plant's design, may even increase the cost-effectiveness of the plant. Other presumable cost reductions are also likely to help this objective, such as the capital cost reduction due to modularity.
Regarding this last example, the learning curve is expected to mean a reduction in capital costs with the increase in number of modules installed. Bigger plants will lead to reduced cost, and therefore, higher profitability. This ef-

fect is limited to the tendency to micro-generation, and the availability for this plant to be installed in co-generation suitable sites, such as industrial parks.

Chapter 6

Economic Analysis

In the previous chapter we have constructed an economic model to obtain a rank of values of both cost and income sources of the nuclear facility. In this one, we will calculate the most important value indexes to determine the viability of the project.
These value indexes are the net present value, the internal rate of return and the payback period. Besides that, the levelized cost of electricity will also be calculated as a comparison value to other technologies.
Due to the with of the rank of the values obtained in the previous chapter, the necessity arose to create several scenarios, depending on how pessimistic or optimistic the estimations are. For the base case, we will use the average values obtained in the economic model.

6.1 Methodology

The methodology in this section consists, firstly, in calculating the free cash flow, FCF, and then operating with it to calculate the value indexes mentioned at the introduction.
FCF is the cash available after addressing both operative and investing necessities. This parameter does not take debt into account, thus neglecting the financing necessities. In our analysis, we will include cash flow from fi-

nancing in some scenarios to test the effect of debt payments and interest on the project's cost effectiveness.
The sum of the free cash flows through the project's life taking into account the time value of money is what we called *net present value*, NVP. This parameter indicates the profitability of the project. It provides a the value of the project's cash flows at the present day. As a general criterion, if the value is positive, the project is considered profitable.

$$NPV = \sum_{i=0}^{N} \frac{FCF_i}{(1+r)^i} \tag{6.1}$$

Where:

- NPV = Net present value
- N = Total life of the project
- FCF_i = Free Cash Flow at year i
- r = Discount rate

The typical profile of this cash flows begins with negative values at the early life of the project, corresponding with construction, and then positive values due to the revenues being higher than the expenses. The time at which the cumulative cash flow becomes positive is the *payback period*. It gives a general idea of how long it takes the project to pay the initial investment and start generating revenues. This parameter takes, similarly to the NPV, the time value of money into account. The profitability criterion of this parameter is, generally, whether it is lower than half of the project's life.
Internal rate of return, IRR, is a value indicator related to the NPV. It refers to the value of the discount rate at which the NPV becomes zero. Therefore, it means the limit for the cost of capital at which the project is still profitable. IRR will be higher than the discount rate in a project with a positive NPV, a profitable project. If the NPV has been calculated beforehand, the IRR does not offer additional information on the project's profitability, but gives

a security margin between the real discount rate and the limit value at which we should drop the project. The criterion to evaluate this parameter, is thus whether it is higher than the weighted average cost of capital, and the difference between these values should also be considered, to evaluate the security margin. The calculation of the IRR is performed by solving the NPV equation for r when NPV equals zero.

$$0 = \sum_{i=0}^{N} \frac{FCF_i}{(1 + IRR)^i} \tag{6.2}$$

The levelized cost of electricity, LCOE, is an average value of the cost of generating power, that takes into account all the sources of cost throughout the total project's lifetime. It is the sum of all the cost sources of the project divided by the total electric generation. In the LCOE, the relative weight of the different cost sources can also be evaluated, to check the importance of each of them in the total cost.

$$LCOE = \frac{\sum_{i=0}^{N}[(INV_i + F_i + OM_i + DEC_i)/(1 + r)^i]}{\sum_{i=0}^{N}[E_i/(1 + r)^i]} \tag{6.3}$$

Where:

- INV_i = Capital cost at year i
- F_i = Fuel cost at year i
- OM_i = operation and maintenance cost at year i
- DEC_i = Decommissioning cost at year i
- E_i = Energy generated at year i
- r = rate of discount

6.2 Base case

The base case of the analysis uses as inputs the average of the values obtained in the economic model. The detail of the calculations can bee seen in annex C. On this section, we will merely show the input and output values of the analysis, and draw conclusions about these results.
In addition to the values obtained in the economic model, for the calculations in the analysis, we need to set a discount rate and escalations rates for fuel and O&M costs. The discount rate will be set at 10%, which is a common value for nuclear facilities [46]. The escalation rates for fuel and O&M are obtained from **The future of Nuclear power**, and are set at 0.5% and 1% respectively [38]. In addition, a tax rate is applied of 37%, similar the the tax rate in the USA [38]
The lifetime of the facility is planed for 60 years, as stated by the GIF [42]. This lifetime reaching the planned lifetime of current advanced nuclear plants and the lifetime of generation II reactors after lifetime extensions. Accordingly, an extended lifetime might be expected for Generation IV. This assumption is, however, not considered.
Apart from that, all calculations are made for real dollars, and therefore a constant inflation rate of 3% is considered.
The input values for the base case are the following:

Fuel [$/MWh]	6.04
O&M [$/MWh]	14.99
Capital [$/MW]	5,587,634
Decommissioning [$/MW]	1,252,898
Electricity selling price [$/MWh]	105,30
WACC [%]	10

Table 6.1: Base case inputs

With these values, and proceeding with the methodology explained previously, we can obtain the value indexes shown in table 6.2.

NPV	142,310,008
IRR [%]	11.52
Payback period [years]	25.7

Table 6.2: Base case Value indexes

The three indexes fulfil their respective profitability criteria, even though there is not a very high security margin, revealed by the low IRR.
The LCOE results are shown in table 6.3. The results are shown both in $/MWh units and in relative terms to the total. The most important finding is that the construction remains the most critical issue of this facility, as it happened in previous generations of reactors, and in spite of the reductions due to modularity (even though the average capital cost used includes values higher than current estimates).

LCOE	Construction	79.81	73.9%
	Decommissioning	0.31	0.29%
	Fuel	7.69	7.12%
	O&M	20.12	18.64%
	Total	**107.93**	**100%**

Table 6.3: Levelized cost of Electricity

The second finding is the negligible importance of decommissioning cost, due to the reduction in value it suffers from being at the end of the plants lifetime. Even though in absolute terms the cost of decommissioning is very high, once it is restated by the discount rate in shrinks to less than 2% of the NPV.
Yet, the most important finding for the base case is that the project is profitable in spite of all the detrimental assumptions that have been taken into account, such as using outdated values for the fuel cost, pessimistic estimates for the rest of the costs sources, and a lower electricity selling price than in some estimations.
Regarding the total LCOE, the calculation give a positive prospect for this technology, since the value is close to current values for this parameter. Nevertheless, it is still higher than the value achieved for some emerging nuclear

countries, such as China [46].

6.2.1 Base case with debt financing

The analysis of the base case assumed the rigorous definition of FCF, and therefore did not include debt financing. When the cost of debt is included the analysis, the value indexes experience a drop bringing the close to the profitability criteria, and in some cases exceeding the profitability boundaries.

The incorporation of debt to the base case has been made assuming a 50% debt financing of the initial investment, with a due payment of 30 years, of half of the project's lifetime. The interest rate is a fixed value of 8% [38]. When the cash flow from financing is subtracted from the free cash flows, the value indexes achieve the values shown in Table 6.4.

NPV	18,928,178
IRR [%]	10.19
Payback period [years]	47,76

Table 6.4: Base case Value indexes

As a result, the NPV remains positive, indicating a profitable project. Yet, the IRR shows the little margin with respect to the discount rate, or the weighted average cost of capital. The payback period rises beyond the limit of 30 years due to the influence of debt payments.

There are some measures that can be taken to limit the influence of debt. The most effective would be to extend the due date to reduce the value of the payments at the present date. This would lead to a similar effect to the conclusion drawn from the decommissioning cost. The later a payment is due, the smaller its present value would be when discounted by the WACC.

LCOE is not affected by debt financing, and thus, the conclusions drawn from its calculations are the same as in the previous analysis.

6.3 Sensitivity Analysis

After The analysis of the base case, the sensitivity analysis intended to verify how robust the economical viability of the plant is regarding changes in the input parameters. This part of the thesis aims to answer the questions about what could happen if the prices of uranium rose, or the labour cost of O&M suffer an increase.

The first approach to do this analysis will consist on building up scenarios with extreme conditions regarding the input. Each case will have either very pessimistic or optimistic conditions.

Secondly, we will test the economical performance of the plant subject to variations in input parameter individually. Since the most critical parameter has proven to be capital cost, this will be the subject of the first analysis. In addition, even though the fuel cost was not as critical, will also be attested, since the uranium market is more volatile than O&M.

After that, we will incorporate possible sales of by-products, due to the nature of the technology, which is indeed designed for co-generation. The sensitivity regarding debt financing will lead the last test, since its effects have been proven significant in the base case.

6.3.1 Scenario analysis

The build up of the scenario analysis will be made according to the extreme values for the parameters obtained in the economic model. Many of these values are not fairly realistic since they are base in bold assumptions. Nevertheless, these scenarios are meant to give a general idea about the robustness of the viability of the plant, and these assumptions fit that purpose.

Pessimistic Scenario

The values of the pessimistic scenario are the most unfavourable of the sets obtained in the economic model. This means, that for the sources of cost

these values will be the highest and for the income sources (electricity selling price) will be the lowest.
Table 6.5 show the inputs used in this scenario.

Fuel [$/MWh]	11.7
O&M [$/MWh]	19.4
Capital [$/MW]	6,828,536
Decommissioning [$/MW]	1,365,707
Electricity selling price [$/MWh]	101.0
WACC [%]	10

Table 6.5: Pessimistic scenario inputs

With these inputs, the value indexes and the LCOE values obtained are shown in tables 6.6 and 6.7 respectively.

NPV	-51,185,433
IRR [%]	9.54
Payback period [years]	43.6

Table 6.6: Pessimistic scenario Value indexes

LCOE	Construction	97.53	70.17%
	Decommissioning	0.34	0.25%
	Fuel	14.99	10.79%
	O&M	26.13	18.80%
	Total	**139.00**	**100%**

Table 6.7: Levelized cost of Electricity for the pessimistic scenario

The results in this case show that the inputs are too unfavourable for the indexes to meet profitability criteria. The percentage of the LCOE that construction cost represent has not change significantly but the importance of both fuel and O&M has increased with respect to the base case. If the situation develops in an increase of these costs (uranium market instability

or introduction of more strict regulatory framework), the profitability of the plant would be at risk.
Furthermore, if we introduce debt financing in these conditions, the indexes suffer an even more significant drop. The conditions of the debt are the same as those applied in the base case: 30 years due, 50% of the initial investment and 8% of interest rate. The results can be seen in table 6.8.

NPV	-201,967,907
IRR [%]	8.31
Payback period [years]	-

Table 6.8: Pessimistic scenario Value indexes with debt financing.

As it was advanced, the profitability of the project cannot be ensured under such unfavourable conditions. The payback period is not calculated because the cumulative discounted cash flow does not achieve a positive value throughout the project's lifetime.

Optimistic Scenario

The optimistic scenario is built similarly to the previous one, only with completely opposite conditions. The results expected from this case would indicate extreme profitability of the plant. The summary of the inputs is shown in table 6.9.

Fuel [$/MWh]	4.12
O&M [$/MWh]	9.73
Capital [$/MW]	4,243,919
Decommissioning [$/MW]	1,138,089
Electricity selling price [$/MWh]	109.6
WACC [%]	10

Table 6.9: Optimistic scenario inputs

The results meet the profitability expectations as shown in tables 6.10 and 6.11.

NPV	336,481,399
IRR [%]	14.59
Payback period [years]	14.45

Table 6.10: Optimistic scenario Value indexes

LCOE	Construction	60.61	76.5%
	Decommissioning	0.29	0.3%
	Fuel	5.25	6.6%
	O&M	13.06	16.5%
	Total	**79.22**	**100%**

Table 6.11: Levelized cost of Electricity for the optimistic scenario

In the optimistic scenario, even the analysis of debt financing does not reduce significantly the profitability of the project. Table 6.12 shows how the indexes still meet the criteria with significant margin after applying the debt conditions.

NPV	242,770,443
IRR [%]	13.1
Payback period [years]	18.46

Table 6.12: Optimistic scenario Value indexes with debt financing

The conclusion that can be drawn from the optimistic scenario, as well as from the scenario analysis in general, is that the profitability of the plant is not extremely sensitive to changes in the inputs. The reason from this, is that except from the pessimistic scenario with debt financing, the indexes either meet or are very close to meet the criteria.

Albeit, since the changes have been applied to the all the inputs, the critical sensitivity of the project to changes in specific parameters has not been attested. The following sections will address this question.

6.3.2 Capital cost

The capital cost seems to be the most critical factor regarding the profitability of the project. For this reason, in this section, we will analyse the behaviour of the value indexes when the capital cost changes. The final objective is to obtain a limit value at which the project is no longer cost-effective. This value may serve as a signal of when the project should be dropped.
In this analysis we will introduce the rank of values of capital cost while maintaining constant the rest of the parameters. After that we will calculate the limit at which the value index stop meeting the value criteria. This method will be performed for both no debt and debt financing scenarios.

	Capital Cost	NPV	IRR	PBP
Optimistic estimate	4,243,920	280,188,703	13.7%	16.4
Base case	5,587,635	142,310,008	11.5%	25.7
Pessimistic Estimate	6,828,537	14,980,935	10.1%	49,5
Limit	6,974,500	-	10%	60

Table 6.13: Sensitivity analysis for Capital cost without debt financing

	Capital Cost	NPV	IRR	PBP
Optimistic estimate	4,243,920	186,477.747	12.3%	21.60
Base case	5,587,635	18,928,178	10.19%	47.7
Pessimistic Estimate	6,828,537	-135,801,538	8.8%	-
Limit	5,739,430	-	10%	60

Table 6.14: Sensitivity analysis for Capital cost with debt financing

Tables 6.13 and 6.14 show the sensitivity analysis and the limit value for capital cost for both cases (no debt and debt financing), and figure 6.1 show the graphical representation of these values. In the case of no debt financing,

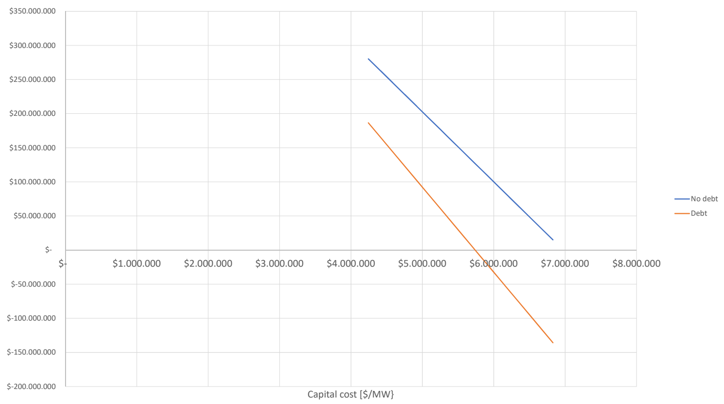

Figure 6.1: Net present value with respect to Capital costs

the limit obtained is higher than the most pessimistic estimation. As for the other case, it is between the base case and the pessimistic estimation.
If we are not considering debt, this result indicates that the project's profitability is safe with respect to increments on the capital cost. On a more realistic perspective, when the analysis takes debt into account, the profitability is at risk if the capital cost increases slightly from the base case. The effect of debt can be, however, mitigated by extending the debt period, by decreasing the value of the debt cash flows are discounted by the WACC.

6.3.3 Fuel cost

For the sensitivity analysis regarding fuel cost, we will follow a similar procedure to the previous test. We will assign the extreme values of fuel cost to the base case and from there we will perform the calculation of the limit value. The analysis will be carried out similarly for the two cases of no debt and debt financing.
Tables 6.15 and 6.16 show the results obtained when changing the fuel cost estimates for both cases with debt and without debt financing. The change in the indexes due to changes in fuel cost exists, yet it has less effect than

	Fuel Cost	NPV	IRR	PBP
Optimistic estimate	4.1	148,647,002	11.6%	25.1
Base case	6.0	142,310,008	11.5%	25.7
Pessimistic Estimate	11.8	123,469,388	11.3%	21.5
Limit	50	-	10%	60

Table 6.15: Sensitivity analysis for Fuel cost without debt financing

	Fuel Cost	NPV	IRR	PBP
Optimistic estimate	4.1	25,265,172	10.2%	45,4
Base case	6.0	18,928,178	10.19%	47.7
Pessimistic Estimate	11.8	87,557	10%	58,6
Limit	11.83	-	10%	60

Table 6.16: Sensitivity analysis for Fuel cost with debt financing

the changes produced by changes in capital costs.
This effect cab be observed on the rather flat slope of the curves shown in figure **??**. This slope indicated that the system is less sensible to changes in fuel cost than it was to changes in capital cost.
The pessimistic estimate for fuel cost in the case with debt financing is very close to the limit value that endangers the profitability of the project. The conclusion is that the uranium market needs to be closely watched in case of financing the project with debt, since it may not be cost-effective should drastic increases in fuel cost appear.

6.3.4 By-products Sales

In previous analysis, costs have been altered to check the sensitivity of the results to these changes. In these case the income source will be subject to change, particularly, the analysis will include revenues due to the sales of by-products.

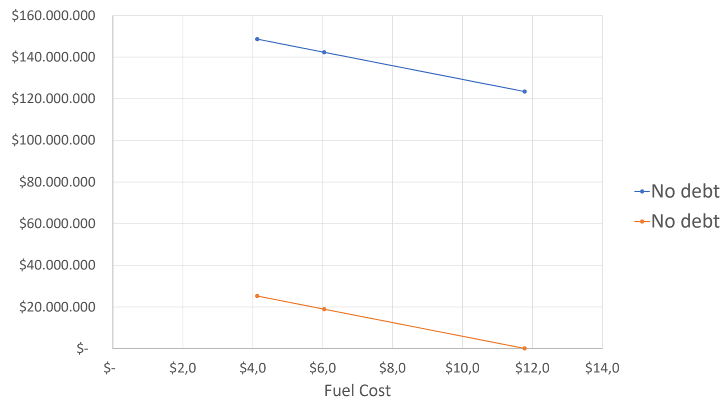

Figure 6.2: Net present value with respect to Capital costs

In a co-generation plant, de dimension criteria is often de by-product demand to maximize the cost-effectiveness of this facility. For instance, if a plant is used for combined-heat-and-power, the principle will be to supply as much of the heat demand as possible, and cover the corresponding part of electric demand. In our case, since the conditions of the plant are unknown, we will have estimation for the by-product sales as a percentage of the electricity sales. Three cases will be tested, 10, 20 and 30% of the electricity sales.
The sales of by-product are promising for the profitability of the plant, since the can only meant additional revenue, and therefore improve the cost-effectiveness. The objective of this analysis is to draw conclusions about the specific effects of this improvement.

By-Prod Sales	**10%**	**20%**	**30%**
Optimistic scenario	418,518,103	500,554,807	58,2591,511
Base case	221,127,792	299,945,576	378,763,360
Pessimistic scenario	24413430	100,012,293	175,611,157

Table 6.17: NPV for the different scenarios including sales of by-products as a percentage of electricity sales

Tables 6.17, 6.18 and 6.19 show the results obtained for NPV, IRR and

By-Prod Sales	10%	20%	30%
Optimistic scenario	15.7%	16.7%	17.7%
Base case	12.3%	13.1%	13.9%
Pessimistic scenario	10.2%	10.9%	11.5%

Table 6.18: IRR for the different scenarios including sales of by-products as a percentage of electricity sales

By-Prod Sales	10%	20%	30%
Optimistic scenario	12.6	11.3	10.2
Base case	21.1	18.1	15.9
Pessimistic scenario	46.1	31.8	28.8

Table 6.19: Payback period for the different scenarios including sales of by-products as a percentage of electricity sales

payback period. The most important conclusion if that even for the most pessimistic scenario, an additional 10% of by-products sales meant to meet the profitability criteria. If this facility is constructed in a site with high heat demand, this will increase ensure the profitability even under the less favourable conditions.

If debt financing is included, the value indexes do not achieve such high values. Albeit, the cost-effectiveness of the plant is similarly strengthened, as it can be seen in tables 6.20 to 6.22.

By-Prod Sales	10%	20%	30%
Optimistic scenario	324,807,147	406,843,851	488,880,555
Base case	97,745,962	176,563,746	255,381,530
Pessimistic scenario	-126,369,043	-50,770,180	24,828,684

Table 6.20: NPV for the different scenarios including sales of by-products as a percentage of electricity sales (with debt financing)

By-Prod Sales	10%	20%	30%
Optimistic scenario	14.2%	15.2%	16.2%
Base case	11.0%	11.7%	12.5%
Pessimistic scenario	9.0%	9.6%	10.2%

Table 6.21: IRR for the different scenarios including sales of by-products as a percentage of electricity sales (with debt financing)

By-Prod Sales	10%	20%	30%
Optimistic scenario	15.62	13.62	12.14
Base case	31.61	25.03	20.90
Pessimistic scenario	-	-	47,5

Table 6.22: Payback period for the different scenarios including sales of by-products as a percentage of electricity sales (with debt financing)

If debt financing is included, the project only achieves profitable conditions when by-products sales represent more than 20% of the electricity sales. This condition can only be achieved if the plant site is selected based on the principle of maximizing by-product sales. An industrial park with high demand of heat or the installation of a modular plant feeding the heat demand of district heating might be good candidates. Nevertheless, The most meaningful conclusion of this analysis is the great improvement that by-products sales lead to. It is critical for the facility to take advantage of its suitability for co-generation applications so that it can achieve profitability conditions even under unfavourable circumstances.

6.3.5 Debt Financing Sensitivity

It has been previously mentioned, that pushing the debt term back in time is a mechanism to reduce its effect on net present value and the rest of the value indexes. There are two main reasons for this, the debt payment is reduced yearly, and the present value of these payments decreases the later these payments are due. The interest that has to be paid experiences the same changes.

For these reasons, this analysis will change the debt term conditions for each scenario, from the original 30 years, to 40 and 45. If the resulting indicators meet the criteria, restructuring debt could be an option to fight unfavourable conditions regarding other sources or costs, or drops in sales.

The results for the several indexes are shown in tables 6.23 to 6.25 .

Debt Term	**30**	**40**	**45**
Optimistic scenario	324,2770,443	263,399,782	27,0909,558
Base case	18,928,178	46,089,202	55,976,732
Pessimistic scenario	-201,967,907	-168,774,962	-156,691,608

Table 6.23: NPV for the different scenarios with changes in debt term

Debt Term	**30**	**40**	**45**
Optimistic scenario	13.1%	13.5%	13.6%
Base case	10.2%	10.5%	10.6%
Pessimistic scenario	8.3%	8.6%	8.6%

Table 6.24: IRR for the different scenarios with changes in debt term

Debt Term	**10%**	**20%**	**30%**
Optimistic scenario	18.5	17.3	16.9
Base case	47.8	39.4	36.9
Pessimistic scenario	-	-	-

Table 6.25: for the different scenarios with changes in debt term

Graphically, the changes in NPV due to restructuration of debt are shown on figure 6.3.

Debt restructuring does not suffice to save the profitability of the project if the most unfavourable circumstances take place. This mechanism might be used in limit cases, or to improve the profitability if desired, yet, the project is not as sensible to changes in debt term as anticipated.

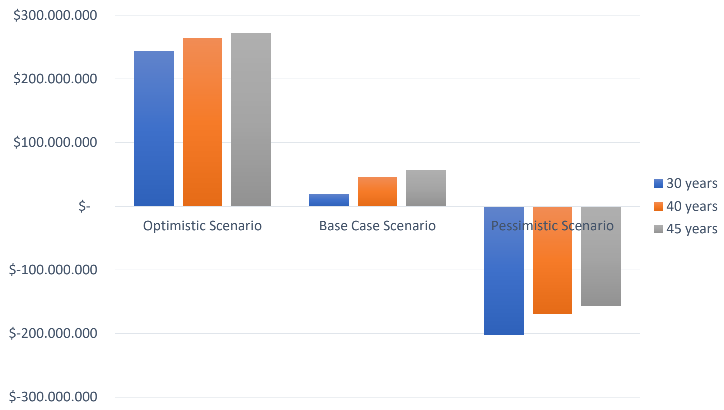

Figure 6.3: Net present value for the different debt structures

6.4 Conclusions of the economic analysis

The project has resulted profitable in most of the cases studied. Even the pessimistic scenario, which was built under the most unfavourable conditions, can achieve profitability by reductions in capital cost or by the sale of by-products.

Debt financing is a delicate problem, leading to un-profitability if the costs conditions are strict. The restructuring of this debt helps to improve the results, but it cannot alone ensure the success of the project.

The sales of by-products has proven to be a critical factor, drastically improving the project's economic performance. The plant site must thus be selected in an environment where the by-product demand is at lest the maximum possible supply. This conditions will ensure the project's success in almost every scenario imaginable.

Capital cost remain the most critical cost source in this new technology, which otherwise has lower cost values than current nuclear. The modularity of the plant is likely to reduce this cost if more than one module is installed. The optimal number of modules will, however, not be determined by the cost reduction, but by the existing demand of by-products, since this parameter

leads to drastic increases in profitability.
In conclusion, it is safe to assume that this plant achieves profitability under most conditions, and an effort should be made to push its development.Reductions in costs are expected to appear with the learning curve, should this system become conventional. As a first approach to generation IV nuclear systems, the MPBR has some of the biggest advantages, and more importantly, its development will help even more advanced systems with other benefits, such as the burner reactors.

Chapter 7

Conclusions

The first part of the project meant to justify the necessity for nuclear energy in the framework of energy transition. Climate change was presented as the main reason for the necessity of this energy transition into de-carbonized technologies. The urgency of the matter is pushing for the development of well understood de-carbonized energy systems, such as renewables or nuclear. Nevertheless, nuclear industry is facing some challenges that have led many regions of the world to adopt a position of maintaining their NPP fleet, authorising lifetime extensions, rather than developing the technology or building new facilities.

This position is particularly prominent in the west, where some countries such as Germany have a complete phase-out planed for nuclear technology. South Korea, which has always been considered a nuclear power, has imitated this measure. Japan is also suffering the consequences of the recent Fukishima-Daiichi accident, and is strengthening its regulatory nuclear framework. Other nuclear powers such as USA, Canada, Russia or France, have an unclear position, exporting nuclear technology and with some local projects under construction, but also implanting the cautious position of not betting high stakes on nuclear.

The Generation IV nuclear systems are designed to be an adequate response to the challenges of nuclear, regarding cost, safety and waste management.

They also embodied some of the tendencies that make renewables such an attractive option: modularity, less capital intensive projects than current nuclear, and possibility of co-generation.

The development of generation IV nuclear systems is slow, yet there are some small, mainly demonstrative projects operational. The most promising design is the VHTR, due to the availability of the technology.

The economic model of the MPBR, a model of VHTR, pointed to the conclusion that the plant would have similar economic performance of current nuclear, while presenting the advantage of not depending on economies of scale. The modularity of the plant also pointed to reductions in capital cost, which seem to be the most critical factor, due to the learning curve from installing several modules. The suitability for co-generation of the facility also predicted an enhanced economic performance.

These predictions, have been confirmed by the economic analysis, although some other problems have aroused. The biggest problem has its roots in the financing of the plant. The inclusion of debt financing had a significantly negative effect on all cases studied, even making some of them unable to meet profitability criteria. The measure to push back the debt term improves the value indexes in those cases, but does not suffice to revert the situation.

In conclusion, global warming is the underlying cause for the necessity for nuclear energy. This is the main failure of current energy transition, which lacks a de-carbonized energy source that has the characteristics of nuclear. The unclear position regarding nuclear in most countries can be changed through the development of Generation IV energy systems. These new Reactors offer viable solution for nuclear safety and waste management, and, as it was proven in the economical analysis, offer beneficial economic perspectives.

Further developments of this thesis should develop a similar methodology for the rest of the generation IV designs. This task will face the problem of the uncertain estimates for most factors since the availability of the technology is lower for the rest of the designs.

Assessing the economic viability of the rest of the reactors will help decide investors to push the development of the most promising designs. Furthermore, due to the fact that most challenges are shared by more than one rector (for example corrosion of constructive materials), the developing of one technology will be a milestone for the rest of the reactors.

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Appendix A Base case

I. No Debt Considered

Imputs

Fuel $/MWh	$	6
O&M $/Mwh	$	15
Capital $/Mwh	$	5.587.635
Decomissioning $/Mwh	$	1.251.898
Electicity price $/Mwh	$	105
WACC %		10%
Byprod percentage %		0%

Outputs

RESULTS			
Net Present Value		$	142.310.008
IRR			12%
Payback period	**disccounted**	$	25,69
	Aprox	$	10,63
LCOE	**construction**	$	79,81
	decomissioning	$	0,31
	fuel	$	7,69
	O&M	$	20,12
	TOTAL	$	107,93

Cost Calculation

	COSTS													
	Construction profile				Decomissioning				Fuel			O&M		
Year	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Profile	Cost [$/MW]	Cost [$]	Discco	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]
$ -	60%	$ 5.587.635	$ 402.309.690	$ 402.309.690	0%	$ 1.251.898	$ -	$ -	$ 6	$ 5.395.096	$ 5.395.096	$ 15	$ 13.390.788	$ 13.390.788
$ 1	40%	$ 5.587.635	$ 268.206.460	$ 243.824.055	0%	$ 1.289.455	$ -	$ -	$ 6	$ 5.422.072	$ 4.929.156	$ 15	$ 13.524.695	$ 12.295.178
$ 2	0%	$ 5.587.635	$ -	$ -	0%	$ 1.328.139	$ -	$ -	$ 6	$ 5.449.182	$ 4.503.456	$ 15	$ 13.659.942	$ 11.289.209
$ 3	0%	$ 5.587.635	$ -	$ -	0%	$ 1.367.983	$ -	$ -	$ 6	$ 5.476.428	$ 4.114.521	$ 15	$ 13.796.542	$ 10.365.546
$ 4	0%	$ 5.587.635	$ -	$ -	0%	$ 1.409.023	$ -	$ -	$ 6	$ 5.503.810	$ 3.759.176	$ 16	$ 13.934.507	$ 9.517.456
$ 5	0%	$ 5.587.635	$ -	$ -	0%	$ 1.451.293	$ -	$ -	$ 6	$ 5.531.329	$ 3.434.520	$ 16	$ 14.073.852	$ 8.738.755
$ 6	0%	$ 5.587.635	$ -	$ -	0%	$ 1.494.832	$ -	$ -	$ 6	$ 5.558.986	$ 3.137.903	$ 16	$ 14.214.591	$ 8.023.766
$ 7	0%	$ 5.587.635	$ -	$ -	0%	$ 1.539.677	$ -	$ -	$ 6	$ 5.586.781	$ 2.866.902	$ 16	$ 14.356.737	$ 7.367.276
$ 8	0%	$ 5.587.635	$ -	$ -	0%	$ 1.585.867	$ -	$ -	$ 6	$ 5.614.715	$ 2.619.306	$ 16	$ 14.500.304	$ 6.764.499
$ 9	0%	$ 5.587.635	$ -	$ -	0%	$ 1.633.443	$ -	$ -	$ 6	$ 5.642.788	$ 2.393.093	$ 16	$ 14.645.307	$ 6.211.040
$ 10	0%	$ 5.587.635	$ -	$ -	0%	$ 1.682.447	$ -	$ -	$ 6	$ 5.671.002	$ 2.186.417	$ 17	$ 14.791.760	$ 5.702.864
$ 11	0%	$ 5.587.635	$ -	$ -	0%	$ 1.732.920	$ -	$ -	$ 6	$ 5.699.357	$ 1.997.590	$ 17	$ 14.939.678	$ 5.236.266
$ 12	0%	$ 5.587.635	$ -	$ -	0%	$ 1.784.908	$ -	$ -	$ 6	$ 5.727.854	$ 1.825.071	$ 17	$ 15.089.075	$ 4.807.844
$ 13	0%	$ 5.587.635	$ -	$ -	0%	$ 1.838.455	$ -	$ -	$ 6	$ 5.756.493	$ 1.667.451	$ 17	$ 15.239.965	$ 4.414.475
$ 14	0%	$ 5.587.635	$ -	$ -	0%	$ 1.893.609	$ -	$ -	$ 6	$ 5.785.276	$ 1.523.444	$ 17	$ 15.392.365	$ 4.053.291
$ 15	0%	$ 5.587.635	$ -	$ -	0%	$ 1.950.417	$ -	$ -	$ 7	$ 5.814.202	$ 1.391.874	$ 17	$ 15.546.289	$ 3.721.658
$ 16	0%	$ 5.587.635	$ -	$ -	0%	$ 2.008.929	$ -	$ -	$ 7	$ 5.843.273	$ 1.271.666	$ 18	$ 15.701.752	$ 3.417.159
$ 17	0%	$ 5.587.635	$ -	$ -	0%	$ 2.069.197	$ -	$ -	$ 7	$ 5.872.489	$ 1.161.841	$ 18	$ 15.858.769	$ 3.137.573
$ 18	0%	$ 5.587.635	$ -	$ -	0%	$ 2.131.273	$ -	$ -	$ 7	$ 5.901.852	$ 1.061.500	$ 18	$ 16.017.357	$ 2.880.862
$ 19	0%	$ 5.587.635	$ -	$ -	0%	$ 2.195.211	$ -	$ -	$ 7	$ 5.931.361	$ 969.825	$ 18	$ 16.177.530	$ 2.645.155
$ 20	0%	$ 5.587.635	$ -	$ -	0%	$ 2.261.068	$ -	$ -	$ 7	$ 5.961.018	$ 886.067	$ 18	$ 16.339.306	$ 2.428.734
$ 21	0%	$ 5.587.635	$ -	$ -	0%	$ 2.328.900	$ -	$ -	$ 7	$ 5.990.823	$ 809.543	$ 18	$ 16.502.699	$ 2.230.019
$ 22	0%	$ 5.587.635	$ -	$ -	0%	$ 2.398.767	$ -	$ -	$ 7	$ 6.020.777	$ 739.628	$ 19	$ 16.667.726	$ 2.047.563
$ 23	0%	$ 5.587.635	$ -	$ -	0%	$ 2.470.730	$ -	$ -	$ 7	$ 6.050.881	$ 675.751	$ 19	$ 16.834.403	$ 1.880.035
$ 24	0%	$ 5.587.635	$ -	$ -	0%	$ 2.544.852	$ -	$ -	$ 7	$ 6.081.135	$ 617.391	$ 19	$ 17.002.747	$ 1.726.214
$ 25	0%	$ 5.587.635	$ -	$ -	0%	$ 2.621.197	$ -	$ -	$ 7	$ 6.111.541	$ 564.071	$ 19	$ 17.172.774	$ 1.584.978
$ 26	0%	$ 5.587.635	$ -	$ -	0%	$ 2.699.833	$ -	$ -	$ 7	$ 6.142.099	$ 515.356	$ 19	$ 17.344.502	$ 1.455.298
$ 27	0%	$ 5.587.635	$ -	$ -	0%	$ 2.780.828	$ -	$ -	$ 7	$ 6.172.809	$ 470.848	$ 20	$ 17.517.947	$ 1.336.228
$ 28	0%	$ 5.587.635	$ -	$ -	0%	$ 2.864.253	$ -	$ -	$ 7	$ 6.203.673	$ 430.183	$ 20	$ 17.693.127	$ 1.226.901
$ 29	0%	$ 5.587.635	$ -	$ -	0%	$ 2.950.181	$ -	$ -	$ 7	$ 6.234.692	$ 393.031	$ 20	$ 17.870.058	$ 1.126.518
$ 30	0%	$ 5.587.635	$ -	$ -	0%	$ 3.038.686	$ -	$ -	$ 7	$ 6.265.865	$ 359.088	$ 20	$ 18.048.758	$ 1.034.348
$ 31	0%	$ 5.587.635	$ -	$ -	0%	$ 3.129.847	$ -	$ -	$ 7	$ 6.297.195	$ 328.076	$ 20	$ 18.229.246	$ 949.720
$ 32	0%	$ 5.587.635	$ -	$ -	0%	$ 3.223.742	$ -	$ -	$ 7	$ 6.328.681	$ 299.742	$ 21	$ 18.411.539	$ 872.015
$ 33	0%	$ 5.587.635	$ -	$ -	0%	$ 3.320.454	$ -	$ -	$ 7	$ 6.360.324	$ 273.855	$ 21	$ 18.595.654	$ 800.669
$ 34	0%	$ 5.587.635	$ -	$ -	0%	$ 3.420.068	$ -	$ -	$ 7	$ 6.392.126	$ 250.204	$ 21	$ 18.781.610	$ 735.159
$ 35	0%	$ 5.587.635	$ -	$ -	0%	$ 3.522.670	$ -	$ -	$ 7	$ 6.424.086	$ 228.595	$ 21	$ 18.969.427	$ 675.010
$ 36	0%	$ 5.587.635	$ -	$ -	0%	$ 3.628.350	$ -	$ -	$ 7	$ 6.456.207	$ 208.853	$ 21	$ 19.159.121	$ 619.782
$ 37	0%	$ 5.587.635	$ -	$ -	0%	$ 3.737.201	$ -	$ -	$ 7	$ 6.488.488	$ 190.816	$ 22	$ 19.350.712	$ 569.073
$ 38	0%	$ 5.587.635	$ -	$ -	0%	$ 3.849.317	$ -	$ -	$ 7	$ 6.520.930	$ 174.336	$ 22	$ 19.544.219	$ 522.512
$ 39	0%	$ 5.587.635	$ -	$ -	0%	$ 3.964.796	$ -	$ -	$ 7	$ 6.553.535	$ 159.280	$ 22	$ 19.739.661	$ 479.761
$ 40	0%	$ 5.587.635	$ -	$ -	0%	$ 4.083.740	$ -	$ -	$ 7	$ 6.586.302	$ 145.524	$ 22	$ 19.937.058	$ 440.508
$ 41	0%	$ 5.587.635	$ -	$ -	0%	$ 4.206.252	$ -	$ -	$ 7	$ 6.619.234	$ 132.956	$ 23	$ 20.136.429	$ 404.466
$ 42	0%	$ 5.587.635	$ -	$ -	0%	$ 4.332.440	$ -	$ -	$ 7	$ 6.652.330	$ 121.473	$ 23	$ 20.337.793	$ 371.374
$ 43	0%	$ 5.587.635	$ -	$ -	0%	$ 4.462.413	$ -	$ -	$ 7	$ 6.685.592	$ 110.982	$ 23	$ 20.541.171	$ 340.988
$ 44	0%	$ 5.587.635	$ -	$ -	0%	$ 4.596.285	$ -	$ -	$ 8	$ 6.719.020	$ 101.398	$ 23	$ 20.746.582	$ 313.089
$ 45	0%	$ 5.587.635	$ -	$ -	0%	$ 4.734.174	$ -	$ -	$ 8	$ 6.752.615	$ 92.641	$ 23	$ 20.954.048	$ 287.473
$ 46	0%	$ 5.587.635	$ -	$ -	0%	$ 4.876.199	$ -	$ -	$ 8	$ 6.786.378	$ 84.640	$ 24	$ 21.163.589	$ 263.953
$ 47	0%	$ 5.587.635	$ -	$ -	0%	$ 5.022.485	$ -	$ -	$ 8	$ 6.820.310	$ 77.330	$ 24	$ 21.375.225	$ 242.356
$ 48	0%	$ 5.587.635	$ -	$ -	0%	$ 5.173.160	$ -	$ -	$ 8	$ 6.854.411	$ 70.651	$ 24	$ 21.588.977	$ 222.527
$ 49	0%	$ 5.587.635	$ -	$ -	0%	$ 5.328.354	$ -	$ -	$ 8	$ 6.888.683	$ 64.550	$ 24	$ 21.804.867	$ 204.320
$ 50	0%	$ 5.587.635	$ -	$ -	0%	$ 5.488.205	$ -	$ -	$ 8	$ 6.923.127	$ 58.975	$ 25	$ 22.022.915	$ 187.603
$ 51	0%	$ 5.587.635	$ -	$ -	0%	$ 5.652.851	$ -	$ -	$ 8	$ 6.957.742	$ 53.882	$ 25	$ 22.243.144	$ 172.254
$ 52	0%	$ 5.587.635	$ -	$ -	0%	$ 5.822.437	$ -	$ -	$ 8	$ 6.992.531	$ 49.228	$ 25	$ 22.465.576	$ 158.160
$ 53	0%	$ 5.587.635	$ -	$ -	0%	$ 5.997.110	$ -	$ -	$ 8	$ 7.027.494	$ 44.977	$ 25	$ 22.690.232	$ 145.220
$ 54	0%	$ 5.587.635	$ -	$ -	0%	$ 6.177.023	$ -	$ -	$ 8	$ 7.062.631	$ 41.092	$ 26	$ 22.917.134	$ 133.338
$ 55	0%	$ 5.587.635	$ -	$ -	0%	$ 6.362.334	$ -	$ -	$ 8	$ 7.097.944	$ 37.544	$ 26	$ 23.146.305	$ 122.429
$ 56	0%	$ 5.587.635	$ -	$ -	0%	$ 6.553.204	$ -	$ -	$ 8	$ 7.133.434	$ 34.301	$ 26	$ 23.377.768	$ 112.412
$ 57	0%	$ 5.587.635	$ -	$ -	0%	$ 6.749.800	$ -	$ -	$ 8	$ 7.169.101	$ 31.339	$ 26	$ 23.611.546	$ 103.215
$ 58	0%	$ 5.587.635	$ -	$ -	0%	$ 6.952.294	$ -	$ -	$ 8	$ 7.204.947	$ 28.632	$ 27	$ 23.847.662	$ 94.770
$ 59	0%	$ 5.587.635	$ -	$ -	0%	$ 7.160.863	$ -	$ -	$ 8	$ 7.240.972	$ 26.159	$ 27	$ 24.086.138	$ 87.016
$ 60	0%	$ 5.587.635	$ -	$ -	0%	$ 7.375.689	$ -	$ -	$ 8	$ 7.277.176	$ 23.900	$ 27	$ 24.327.000	$ 79.896
$ 61	0%	$ 5.587.635	$ -	$ -	0%	$ 7.596.959	$ -	$ -	$ 8	$ 7.313.562	$ 21.836	$ 27	$ 24.570.270	$ 73.359
$ 62	0%	$ 5.587.635	$ -	$ -	100%	$ 7.824.868	#######	#####	$ 8	$ 7.350.130	$ 19.950	$ 28	$ 24.815.972	$ 67.357
			$ 670.516.150	$ 646.133.745			#######	#####		$ 398.356.899	$ 62.258.483		$ 1.167.334.440	$ 162.909.282

Revenue Calculation

REVENUES						
Electicity				by-products		
Generation [MWh]	Discounted Generation	Price [$/MWh]	Sales [$]	Generation [MWh]	Price [$/MWh]	Sales [$]
$ -	$ -	$ 105	$ -			$ -
$ -	$ -	$ 108	$ -			$ -
$ 893.520	$ 738.446	$ 112	$ 99.818.043			$ -
$ 893.520	$ 671.315	$ 115	$ 102.812.585			$ -
$ 893.520	$ 610.286	$ 119	$ 105.896.962			$ -
$ 893.520	$ 554.806	$ 122	$ 109.073.871			$ -
$ 893.520	$ 504.369	$ 126	$ 112.346.087			$ -
$ 893.520	$ 458.517	$ 130	$ 115.716.470			$ -
$ 893.520	$ 416.834	$ 133	$ 119.187.964			$ -
$ 893.520	$ 378.940	$ 137	$ 122.763.603			$ -
$ 893.520	$ 344.491	$ 142	$ 126.446.511			$ -
$ 893.520	$ 313.173	$ 146	$ 130.239.906			$ -
$ 893.520	$ 284.703	$ 150	$ 134.147.103			$ -
$ 893.520	$ 258.821	$ 155	$ 138.171.516			$ -
$ 893.520	$ 235.292	$ 159	$ 142.316.662			$ -
$ 893.520	$ 213.902	$ 164	$ 146.586.162			$ -
$ 893.520	$ 194.456	$ 169	$ 150.983.747			$ -
$ 893.520	$ 176.778	$ 174	$ 155.513.259			$ -
$ 893.520	$ 160.707	$ 179	$ 160.178.657			$ -
$ 893.520	$ 146.098	$ 185	$ 164.984.017			$ -
$ 893.520	$ 132.816	$ 190	$ 169.933.537			$ -
$ 893.520	$ 120.742	$ 196	$ 175.031.543			$ -
$ 893.520	$ 109.765	$ 202	$ 180.282.489			$ -
$ 893.520	$ 99.787	$ 208	$ 185.690.964			$ -
$ 893.520	$ 90.715	$ 214	$ 191.261.693			$ -
$ 893.520	$ 82.468	$ 220	$ 196.999.544			$ -
$ 893.520	$ 74.971	$ 227	$ 202.909.530			$ -
$ 893.520	$ 68.156	$ 234	$ 208.996.816			$ -
$ 893.520	$ 61.960	$ 241	$ 215.266.721			$ -
$ 893.520	$ 56.327	$ 248	$ 221.724.722			$ -
$ 893.520	$ 51.206	$ 256	$ 228.376.464			$ -
$ 893.520	$ 46.551	$ 263	$ 235.227.758			$ -
$ 893.520	$ 42.319	$ 271	$ 242.284.590			$ -
$ 893.520	$ 38.472	$ 279	$ 249.553.128			$ -
$ 893.520	$ 34.975	$ 288	$ 257.039.722			$ -
$ 893.520	$ 31.795	$ 296	$ 264.750.914			$ -
$ 893.520	$ 28.905	$ 305	$ 272.693.441			$ -
$ 893.520	$ 26.277	$ 314	$ 280.874.244			$ -
$ 893.520	$ 23.888	$ 324	$ 289.300.472			$ -
$ 893.520	$ 21.716	$ 333	$ 297.979.486			$ -
$ 893.520	$ 19.742	$ 343	$ 306.918.870			$ -
$ 893.520	$ 17.948	$ 354	$ 316.126.436			$ -
$ 893.520	$ 16.316	$ 364	$ 325.610.230			$ -
$ 893.520	$ 14.833	$ 375	$ 335.378.536			$ -
$ 893.520	$ 13.484	$ 387	$ 345.439.893			$ -
$ 893.520	$ 12.258	$ 398	$ 355.803.089			$ -
$ 893.520	$ 11.144	$ 410	$ 366.477.182			$ -
$ 893.520	$ 10.131	$ 422	$ 377.471.497			$ -
$ 893.520	$ 9.210	$ 435	$ 388.795.642			$ -
$ 893.520	$ 8.373	$ 448	$ 400.459.512			$ -
$ 893.520	$ 7.611	$ 462	$ 412.473.297			$ -
$ 893.520	$ 6.920	$ 475	$ 424.847.496			$ -
$ 893.520	$ 6.290	$ 490	$ 437.592.921			$ -
$ 893.520	$ 5.719	$ 504	$ 450.720.708			$ -
$ 893.520	$ 5.199	$ 520	$ 464.242.330			$ -
$ 893.520	$ 4.726	$ 535	$ 478.169.600			$ -
$ 893.520	$ 4.296	$ 551	$ 492.514.688			$ -
$ 893.520	$ 3.906	$ 568	$ 507.290.128			$ -
$ 893.520	$ 3.551	$ 585	$ 522.508.832			$ -
$ 893.520	$ 3.228	$ 602	$ 538.184.097			$ -
$ 893.520	$ 2.935	$ 620	$ 554.329.620			$ -
$ 893.520	$ 2.668	$ 639	$ 570.959.509			$ -
$ -	$ -	$ 658	$ -			$ -
$ 53.611.200	$ 8.096.231					

Cash Flow Calculation

CASH FLOWS								
EBITDA	D&A		EBITDA	TAX	NET INCOME	OCF	FCF	Discounted FCF
	D&A profile	D&A						
$ -18.785.884	$ -	$ -	$ -18.785.884	$ -7.138.636	$ -11.647.248	$ -11.647.248	$ -413.956.938	$ -413.956.938
$ -17.224.334	0,00%	$ -	$ -17.224.334	$ -6.545.247	$ -10.679.087	$ -10.679.087	$ -278.885.547	$ -253.532.316
$ 84.025.378	3,33%	$ 22.350.538	$ 61.674.840	$ 23.436.439	$ 38.238.401	$ 60.588.939	$ 60.588.939	$ 50.073.503
$ 88.332.517	3,33%	$ 22.350.538	$ 65.981.979	$ 25.073.152	$ 40.908.827	$ 63.259.365	$ 63.259.365	$ 47.527.697
$ 92.620.330	3,33%	$ 22.350.538	$ 70.269.791	$ 26.702.521	$ 43.567.271	$ 65.917.809	$ 65.917.809	$ 45.022.751
$ 96.900.596	3,33%	$ 22.350.538	$ 74.550.057	$ 28.329.022	$ 46.221.036	$ 68.571.574	$ 68.571.574	$ 42.577.552
$ 101.184.419	3,33%	$ 22.350.538	$ 78.833.880	$ 29.956.875	$ 48.877.006	$ 71.227.544	$ 71.227.544	$ 40.206.092
$ 105.482.292	3,33%	$ 22.350.538	$ 83.131.753	$ 31.590.066	$ 51.541.687	$ 73.892.226	$ 73.892.226	$ 37.918.395
$ 109.804.159	3,33%	$ 22.350.538	$ 87.453.621	$ 33.232.376	$ 54.221.245	$ 76.571.783	$ 76.571.783	$ 35.721.302
$ 114.159.470	3,33%	$ 22.350.538	$ 91.808.931	$ 34.887.394	$ 56.921.538	$ 79.272.076	$ 79.272.076	$ 33.619.099
$ 118.557.230	3,33%	$ 22.350.538	$ 96.206.692	$ 36.558.543	$ 59.648.149	$ 81.998.687	$ 81.998.687	$ 31.614.044
$ 123.006.050	3,33%	$ 22.350.538	$ 100.655.512	$ 38.249.095	$ 62.406.417	$ 84.756.956	$ 84.756.956	$ 29.706.796
$ 127.514.188	3,33%	$ 22.350.538	$ 105.163.650	$ 39.962.187	$ 65.201.463	$ 87.552.001	$ 87.552.001	$ 27.896.766
$ 132.089.590	3,33%	$ 22.350.538	$ 109.739.052	$ 41.700.840	$ 68.038.212	$ 90.388.751	$ 90.388.751	$ 26.182.401
$ 136.739.927	3,33%	$ 22.350.538	$ 114.389.389	$ 43.467.968	$ 70.921.421	$ 93.271.959	$ 93.271.959	$ 24.561.422
$ 141.472.630	3,33%	$ 22.350.538	$ 119.122.092	$ 45.266.395	$ 73.855.697	$ 96.206.235	$ 96.206.235	$ 23.031.008
$ 146.294.922	3,33%	$ 22.350.538	$ 123.944.383	$ 47.098.866	$ 76.845.518	$ 99.196.056	$ 99.196.056	$ 21.587.952
$ 151.213.845	3,33%	$ 22.350.538	$ 128.863.307	$ 48.968.057	$ 79.895.250	$ 102.245.789	$ 102.245.789	$ 20.228.784
$ 156.236.294	3,33%	$ 22.350.538	$ 133.885.756	$ 50.876.587	$ 83.009.169	$ 105.359.707	$ 105.359.707	$ 18.949.869
$ 161.369.036	3,33%	$ 22.350.538	$ 139.018.498	$ 52.827.029	$ 86.191.469	$ 108.542.007	$ 108.542.007	$ 17.747.485
$ 166.618.736	3,33%	$ 22.350.538	$ 144.268.198	$ 54.821.915	$ 89.446.283	$ 111.796.821	$ 111.796.821	$ 16.617.885
$ 171.991.981	3,33%	$ 22.350.538	$ 149.641.442	$ 56.863.748	$ 92.777.694	$ 115.128.233	$ 115.128.233	$ 15.557.344
$ 177.495.298	3,33%	$ 22.350.538	$ 155.144.760	$ 58.955.009	$ 96.189.751	$ 118.540.289	$ 118.540.289	$ 14.562.197
$ 183.135.178	3,33%	$ 22.350.538	$ 160.784.639	$ 61.098.163	$ 99.686.476	$ 122.037.015	$ 122.037.015	$ 13.628.869
$ 188.918.088	3,33%	$ 22.350.538	$ 166.567.550	$ 63.295.669	$ 103.271.881	$ 125.622.419	$ 125.622.419	$ 12.753.891
$ 194.850.495	3,33%	$ 22.350.538	$ 172.499.956	$ 65.549.983	$ 106.949.973	$ 129.300.511	$ 129.300.511	$ 11.933.920
$ 200.938.876	3,33%	$ 22.350.538	$ 178.588.338	$ 67.863.568	$ 110.724.770	$ 133.075.308	$ 133.075.308	$ 11.165.744
$ 207.189.740	3,33%	$ 22.350.538	$ 184.839.202	$ 70.238.897	$ 114.600.305	$ 136.950.843	$ 136.950.843	$ 10.446.293
$ 213.609.636	3,33%	$ 22.350.538	$ 191.259.098	$ 72.678.457	$ 118.580.641	$ 140.931.179	$ 140.931.179	$ 9.772.640
$ 220.205.173	3,33%	$ 22.350.538	$ 197.854.635	$ 75.184.761	$ 122.669.873	$ 145.020.412	$ 145.020.412	$ 9.142.001
$ 226.983.028	3,33%	$ 22.350.538	$ 204.632.490	$ 77.760.346	$ 126.872.144	$ 149.222.682	$ 149.222.682	$ 8.551.736
$ 233.949.962	3,33%	$ 22.350.538	$ 211.599.424	$ 80.407.781	$ 131.191.643	$ 153.542.181	$ 153.542.181	$ 7.999.346
$ 241.112.833	0,00%	$ -	$ 241.112.833	$ 91.622.877	$ 149.489.957	$ 149.489.957	$ 149.489.957	$ 7.080.209
$ 248.478.605	0,00%	$ -	$ 248.478.605	$ 94.421.870	$ 154.056.735	$ 154.056.735	$ 154.056.735	$ 6.633.185
$ 256.054.359	0,00%	$ -	$ 256.054.359	$ 97.300.656	$ 158.753.702	$ 158.753.702	$ 158.753.702	$ 6.214.019
$ 263.847.308	0,00%	$ -	$ 263.847.308	$ 100.261.977	$ 163.585.331	$ 163.585.331	$ 163.585.331	$ 5.821.037
$ 271.864.806	0,00%	$ -	$ 271.864.806	$ 103.308.626	$ 168.556.180	$ 168.556.180	$ 168.556.180	$ 5.452.655
$ 280.114.356	0,00%	$ -	$ 280.114.356	$ 106.443.455	$ 173.670.901	$ 173.670.901	$ 173.670.901	$ 5.107.375
$ 288.603.623	0,00%	$ -	$ 288.603.623	$ 109.669.377	$ 178.934.247	$ 178.934.247	$ 178.934.247	$ 4.783.783
$ 297.340.445	0,00%	$ -	$ 297.340.445	$ 112.989.369	$ 184.351.076	$ 184.351.076	$ 184.351.076	$ 4.480.546
$ 306.332.839	0,00%	$ -	$ 306.332.839	$ 116.406.479	$ 189.926.360	$ 189.926.360	$ 189.926.360	$ 4.196.409
$ 315.589.014	0,00%	$ -	$ 315.589.014	$ 119.923.825	$ 195.665.189	$ 195.665.189	$ 195.665.189	$ 3.930.189
$ 325.117.383	0%	$ -	$ 325.117.383	$ 123.544.605	$ 201.572.777	$ 201.572.777	$ 201.572.777	$ 3.680.774
$ 334.926.566	0%	$ -	$ 334.926.566	$ 127.272.095	$ 207.654.471	$ 207.654.471	$ 207.654.471	$ 3.447.115
$ 345.025.406	0%	$ -	$ 345.025.406	$ 131.109.654	$ 213.915.751	$ 213.915.751	$ 213.915.751	$ 3.228.231
$ 355.422.976	0%	$ -	$ 355.422.976	$ 135.060.731	$ 220.362.245	$ 220.362.245	$ 220.362.245	$ 3.023.196
$ 366.128.590	0%	$ -	$ 366.128.590	$ 139.128.864	$ 226.999.726	$ 226.999.726	$ 226.999.726	$ 2.831.143
$ 377.151.811	0%	$ -	$ 377.151.811	$ 143.317.688	$ 233.834.123	$ 233.834.123	$ 233.834.123	$ 2.651.256
$ 388.502.464	0%	$ -	$ 388.502.464	$ 147.630.936	$ 240.871.527	$ 240.871.527	$ 240.871.527	$ 2.482.771
$ 400.190.641	0%	$ -	$ 400.190.641	$ 152.072.444	$ 248.118.198	$ 248.118.198	$ 248.118.198	$ 2.324.968
$ 412.226.719	0%	$ -	$ 412.226.719	$ 156.646.153	$ 255.580.566	$ 255.580.566	$ 255.580.566	$ 2.177.176
$ 424.621.360	0%	$ -	$ 424.621.360	$ 161.356.117	$ 263.265.243	$ 263.265.243	$ 263.265.243	$ 2.038.762
$ 437.385.532	0%	$ -	$ 437.385.532	$ 166.206.502	$ 271.179.030	$ 271.179.030	$ 271.179.030	$ 1.909.134
$ 450.530.512	0%	$ -	$ 450.530.512	$ 171.201.594	$ 279.328.917	$ 279.328.917	$ 279.328.917	$ 1.787.737
$ 464.067.899	0%	$ -	$ 464.067.899	$ 176.345.802	$ 287.722.097	$ 287.722.097	$ 287.722.097	$ 1.674.049
$ 478.009.627	0%	$ -	$ 478.009.627	$ 181.643.658	$ 296.365.969	$ 296.365.969	$ 296.365.969	$ 1.567.583
$ 492.367.974	0%	$ -	$ 492.367.974	$ 187.099.830	$ 305.268.144	$ 305.268.144	$ 305.268.144	$ 1.467.882
$ 507.155.575	0%	$ -	$ 507.155.575	$ 192.719.118	$ 314.436.456	$ 314.436.456	$ 314.436.456	$ 1.374.516
$ 522.385.430	0%	$ -	$ 522.385.430	$ 198.506.463	$ 323.878.967	$ 323.878.967	$ 323.878.967	$ 1.287.084
$ 538.070.922	0%	$ -	$ 538.070.922	$ 204.466.950	$ 333.603.971	$ 333.603.971	$ 333.603.971	$ 1.205.210
$ 554.225.823	0%	$ -	$ 554.225.823	$ 210.605.813	$ 343.620.010	$ 343.620.010	$ 343.620.010	$ 1.128.541
$ 570.864.313	0%	$ -	$ 570.864.313	$ 216.928.439	$ 353.935.874	$ 353.935.874	$ 353.935.874	$ 1.056.746
$ -87.308	0%	$ -	$ -87.308	$ -33.177	$ -54.131	$ -54.131	$ -939.038.287	$ -2.548.806

I. No Debt Considered

Imputs

Fuel $/MWh	$	6
O&M $/Mwh	$	15
Capital $/Mwh	$	5.587.635
Decomissioning $/Mwh	$	1.251.898
Electicity price $/Mwh	$	105
WACC %		10%
Byprod percentage %		0%

Outputs

RESULTS			
Net Present Value		$	142.310.008
IRR			12%
Payback period	**disccounted**	$	25,69
	Aprox	$	10,63
LCOE	**construction**	$	79,81
	decomissioning	$	0,31
	fuel	$	7,69
	O&M	$	20,12
	TOTAL	$	107,93

Cost Calculation

	COSTS													
	Construction profile				Decomissioning				Fuel			O&M		
Year	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Profile	Cost [$/MW]	Cost [$]	Discco	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]
$ -	60%	$ 5.587.635	$ 402.309.690	$ 402.309.690	0%	$ 1.251.898	$ -	$ -	$ 6	$ 5.395.096	$ 5.395.096	$ 15	$ 13.390.788	$ 13.390.788
$ 1	40%	$ 5.587.635	$ 268.206.460	$ 243.824.055	0%	$ 1.289.455	$ -	$ -	$ 6	$ 5.422.072	$ 4.929.156	$ 15	$ 13.524.695	$ 12.295.178
$ 2	0%	$ 5.587.635	$ -	$ -	0%	$ 1.328.139	$ -	$ -	$ 6	$ 5.449.182	$ 4.503.456	$ 15	$ 13.659.942	$ 11.289.209
$ 3	0%	$ 5.587.635	$ -	$ -	0%	$ 1.367.983	$ -	$ -	$ 6	$ 5.476.428	$ 4.114.521	$ 15	$ 13.796.542	$ 10.365.546
$ 4	0%	$ 5.587.635	$ -	$ -	0%	$ 1.409.023	$ -	$ -	$ 6	$ 5.503.810	$ 3.759.176	$ 16	$ 13.934.507	$ 9.517.456
$ 5	0%	$ 5.587.635	$ -	$ -	0%	$ 1.451.293	$ -	$ -	$ 6	$ 5.531.329	$ 3.434.520	$ 16	$ 14.073.852	$ 8.738.755
$ 6	0%	$ 5.587.635	$ -	$ -	0%	$ 1.494.832	$ -	$ -	$ 6	$ 5.558.986	$ 3.137.903	$ 16	$ 14.214.591	$ 8.023.766
$ 7	0%	$ 5.587.635	$ -	$ -	0%	$ 1.539.677	$ -	$ -	$ 6	$ 5.586.781	$ 2.866.902	$ 16	$ 14.356.737	$ 7.367.276
$ 8	0%	$ 5.587.635	$ -	$ -	0%	$ 1.585.867	$ -	$ -	$ 6	$ 5.614.715	$ 2.619.306	$ 16	$ 14.500.304	$ 6.764.499
$ 9	0%	$ 5.587.635	$ -	$ -	0%	$ 1.633.443	$ -	$ -	$ 6	$ 5.642.788	$ 2.393.093	$ 16	$ 14.645.307	$ 6.211.040
$ 10	0%	$ 5.587.635	$ -	$ -	0%	$ 1.682.447	$ -	$ -	$ 6	$ 5.671.002	$ 2.186.417	$ 17	$ 14.791.760	$ 5.702.864
$ 11	0%	$ 5.587.635	$ -	$ -	0%	$ 1.732.920	$ -	$ -	$ 6	$ 5.699.357	$ 1.997.590	$ 17	$ 14.939.678	$ 5.236.266
$ 12	0%	$ 5.587.635	$ -	$ -	0%	$ 1.784.908	$ -	$ -	$ 6	$ 5.727.854	$ 1.825.071	$ 17	$ 15.089.075	$ 4.807.844
$ 13	0%	$ 5.587.635	$ -	$ -	0%	$ 1.838.455	$ -	$ -	$ 6	$ 5.756.493	$ 1.667.451	$ 17	$ 15.239.965	$ 4.414.475
$ 14	0%	$ 5.587.635	$ -	$ -	0%	$ 1.893.609	$ -	$ -	$ 6	$ 5.785.276	$ 1.523.444	$ 17	$ 15.392.365	$ 4.053.291
$ 15	0%	$ 5.587.635	$ -	$ -	0%	$ 1.950.417	$ -	$ -	$ 7	$ 5.814.202	$ 1.391.874	$ 17	$ 15.546.289	$ 3.721.658
$ 16	0%	$ 5.587.635	$ -	$ -	0%	$ 2.008.929	$ -	$ -	$ 7	$ 5.843.273	$ 1.271.666	$ 18	$ 15.701.752	$ 3.417.159
$ 17	0%	$ 5.587.635	$ -	$ -	0%	$ 2.069.197	$ -	$ -	$ 7	$ 5.872.489	$ 1.161.841	$ 18	$ 15.858.769	$ 3.137.573
$ 18	0%	$ 5.587.635	$ -	$ -	0%	$ 2.131.273	$ -	$ -	$ 7	$ 5.901.852	$ 1.061.500	$ 18	$ 16.017.357	$ 2.880.862
$ 19	0%	$ 5.587.635	$ -	$ -	0%	$ 2.195.211	$ -	$ -	$ 7	$ 5.931.361	$ 969.825	$ 18	$ 16.177.530	$ 2.645.155
$ 20	0%	$ 5.587.635	$ -	$ -	0%	$ 2.261.068	$ -	$ -	$ 7	$ 5.961.018	$ 886.067	$ 18	$ 16.339.306	$ 2.428.734
$ 21	0%	$ 5.587.635	$ -	$ -	0%	$ 2.328.900	$ -	$ -	$ 7	$ 5.990.823	$ 809.543	$ 18	$ 16.502.699	$ 2.230.019
$ 22	0%	$ 5.587.635	$ -	$ -	0%	$ 2.398.767	$ -	$ -	$ 7	$ 6.020.777	$ 739.628	$ 19	$ 16.667.726	$ 2.047.563
$ 23	0%	$ 5.587.635	$ -	$ -	0%	$ 2.470.730	$ -	$ -	$ 7	$ 6.050.881	$ 675.751	$ 19	$ 16.834.403	$ 1.880.035
$ 24	0%	$ 5.587.635	$ -	$ -	0%	$ 2.544.852	$ -	$ -	$ 7	$ 6.081.135	$ 617.391	$ 19	$ 17.002.747	$ 1.726.214
$ 25	0%	$ 5.587.635	$ -	$ -	0%	$ 2.621.197	$ -	$ -	$ 7	$ 6.111.541	$ 564.071	$ 19	$ 17.172.774	$ 1.584.978
$ 26	0%	$ 5.587.635	$ -	$ -	0%	$ 2.699.833	$ -	$ -	$ 7	$ 6.142.099	$ 515.356	$ 19	$ 17.344.502	$ 1.455.298
$ 27	0%	$ 5.587.635	$ -	$ -	0%	$ 2.780.828	$ -	$ -	$ 7	$ 6.172.809	$ 470.848	$ 20	$ 17.517.947	$ 1.336.228
$ 28	0%	$ 5.587.635	$ -	$ -	0%	$ 2.864.253	$ -	$ -	$ 7	$ 6.203.673	$ 430.183	$ 20	$ 17.693.127	$ 1.226.901
$ 29	0%	$ 5.587.635	$ -	$ -	0%	$ 2.950.181	$ -	$ -	$ 7	$ 6.234.692	$ 393.031	$ 20	$ 17.870.058	$ 1.126.518
$ 30	0%	$ 5.587.635	$ -	$ -	0%	$ 3.038.686	$ -	$ -	$ 7	$ 6.265.865	$ 359.088	$ 20	$ 18.048.758	$ 1.034.348
$ 31	0%	$ 5.587.635	$ -	$ -	0%	$ 3.129.847	$ -	$ -	$ 7	$ 6.297.195	$ 328.076	$ 20	$ 18.229.246	$ 949.720
$ 32	0%	$ 5.587.635	$ -	$ -	0%	$ 3.223.742	$ -	$ -	$ 7	$ 6.328.681	$ 299.742	$ 21	$ 18.411.539	$ 872.015
$ 33	0%	$ 5.587.635	$ -	$ -	0%	$ 3.320.454	$ -	$ -	$ 7	$ 6.360.324	$ 273.855	$ 21	$ 18.595.654	$ 800.669
$ 34	0%	$ 5.587.635	$ -	$ -	0%	$ 3.420.068	$ -	$ -	$ 7	$ 6.392.126	$ 250.204	$ 21	$ 18.781.610	$ 735.159
$ 35	0%	$ 5.587.635	$ -	$ -	0%	$ 3.522.670	$ -	$ -	$ 7	$ 6.424.086	$ 228.595	$ 21	$ 18.969.427	$ 675.010
$ 36	0%	$ 5.587.635	$ -	$ -	0%	$ 3.628.350	$ -	$ -	$ 7	$ 6.456.207	$ 208.853	$ 21	$ 19.159.121	$ 619.782
$ 37	0%	$ 5.587.635	$ -	$ -	0%	$ 3.737.201	$ -	$ -	$ 7	$ 6.488.488	$ 190.816	$ 22	$ 19.350.712	$ 569.073
$ 38	0%	$ 5.587.635	$ -	$ -	0%	$ 3.849.317	$ -	$ -	$ 7	$ 6.520.930	$ 174.336	$ 22	$ 19.544.219	$ 522.512
$ 39	0%	$ 5.587.635	$ -	$ -	0%	$ 3.964.796	$ -	$ -	$ 7	$ 6.553.535	$ 159.280	$ 22	$ 19.739.661	$ 479.761
$ 40	0%	$ 5.587.635	$ -	$ -	0%	$ 4.083.740	$ -	$ -	$ 7	$ 6.586.302	$ 145.524	$ 22	$ 19.937.058	$ 440.508
$ 41	0%	$ 5.587.635	$ -	$ -	0%	$ 4.206.252	$ -	$ -	$ 7	$ 6.619.234	$ 132.956	$ 23	$ 20.136.429	$ 404.466
$ 42	0%	$ 5.587.635	$ -	$ -	0%	$ 4.332.440	$ -	$ -	$ 7	$ 6.652.330	$ 121.473	$ 23	$ 20.337.793	$ 371.374
$ 43	0%	$ 5.587.635	$ -	$ -	0%	$ 4.462.413	$ -	$ -	$ 7	$ 6.685.592	$ 110.982	$ 23	$ 20.541.171	$ 340.988
$ 44	0%	$ 5.587.635	$ -	$ -	0%	$ 4.596.285	$ -	$ -	$ 8	$ 6.719.020	$ 101.398	$ 23	$ 20.746.582	$ 313.089
$ 45	0%	$ 5.587.635	$ -	$ -	0%	$ 4.734.174	$ -	$ -	$ 8	$ 6.752.615	$ 92.641	$ 23	$ 20.954.048	$ 287.473
$ 46	0%	$ 5.587.635	$ -	$ -	0%	$ 4.876.199	$ -	$ -	$ 8	$ 6.786.378	$ 84.640	$ 24	$ 21.163.589	$ 263.953
$ 47	0%	$ 5.587.635	$ -	$ -	0%	$ 5.022.485	$ -	$ -	$ 8	$ 6.820.310	$ 77.330	$ 24	$ 21.375.225	$ 242.356
$ 48	0%	$ 5.587.635	$ -	$ -	0%	$ 5.173.160	$ -	$ -	$ 8	$ 6.854.411	$ 70.651	$ 24	$ 21.588.977	$ 222.527
$ 49	0%	$ 5.587.635	$ -	$ -	0%	$ 5.328.354	$ -	$ -	$ 8	$ 6.888.683	$ 64.550	$ 24	$ 21.804.867	$ 204.320
$ 50	0%	$ 5.587.635	$ -	$ -	0%	$ 5.488.205	$ -	$ -	$ 8	$ 6.923.127	$ 58.975	$ 25	$ 22.022.915	$ 187.603
$ 51	0%	$ 5.587.635	$ -	$ -	0%	$ 5.652.851	$ -	$ -	$ 8	$ 6.957.742	$ 53.882	$ 25	$ 22.243.144	$ 172.254
$ 52	0%	$ 5.587.635	$ -	$ -	0%	$ 5.822.437	$ -	$ -	$ 8	$ 6.992.531	$ 49.228	$ 25	$ 22.465.576	$ 158.160
$ 53	0%	$ 5.587.635	$ -	$ -	0%	$ 5.997.110	$ -	$ -	$ 8	$ 7.027.494	$ 44.977	$ 25	$ 22.690.232	$ 145.220
$ 54	0%	$ 5.587.635	$ -	$ -	0%	$ 6.177.023	$ -	$ -	$ 8	$ 7.062.631	$ 41.092	$ 26	$ 22.917.134	$ 133.338
$ 55	0%	$ 5.587.635	$ -	$ -	0%	$ 6.362.334	$ -	$ -	$ 8	$ 7.097.944	$ 37.544	$ 26	$ 23.146.305	$ 122.429
$ 56	0%	$ 5.587.635	$ -	$ -	0%	$ 6.553.204	$ -	$ -	$ 8	$ 7.133.434	$ 34.301	$ 26	$ 23.377.768	$ 112.412
$ 57	0%	$ 5.587.635	$ -	$ -	0%	$ 6.749.800	$ -	$ -	$ 8	$ 7.169.101	$ 31.339	$ 26	$ 23.611.546	$ 103.215
$ 58	0%	$ 5.587.635	$ -	$ -	0%	$ 6.952.294	$ -	$ -	$ 8	$ 7.204.947	$ 28.632	$ 27	$ 23.847.662	$ 94.770
$ 59	0%	$ 5.587.635	$ -	$ -	0%	$ 7.160.863	$ -	$ -	$ 8	$ 7.240.972	$ 26.159	$ 27	$ 24.086.138	$ 87.016
$ 60	0%	$ 5.587.635	$ -	$ -	0%	$ 7.375.689	$ -	$ -	$ 8	$ 7.277.176	$ 23.900	$ 27	$ 24.327.000	$ 79.896
$ 61	0%	$ 5.587.635	$ -	$ -	0%	$ 7.596.959	$ -	$ -	$ 8	$ 7.313.562	$ 21.836	$ 27	$ 24.570.270	$ 73.359
$ 62	0%	$ 5.587.635	$ -	$ -	100%	$ 7.824.868	#######	#####	$ 8	$ 7.350.130	$ 19.950	$ 28	$ 24.815.972	$ 67.357
			$ 670.516.150	$ 646.133.745			#######	#####		$ 398.356.899	$ 62.258.483		$ 1.167.334.440	$ 162.909.282

Revenue Calculation

REVENUES						
Electicity				by-products		
Generation [MWh]	Discounted Generation	Price [$/MWh]	Sales [$]	Generation [MWh	Price [$/MWh]	Sales [$]
$ -	$ -	$ 105	$ -			$ -
$ -	$ -	$ 108	$ -			$ -
$ 893.520	$ 738.446	$ 112	$ 99.818.043			$ -
$ 893.520	$ 671.315	$ 115	$ 102.812.585			$ -
$ 893.520	$ 610.286	$ 119	$ 105.896.962			$ -
$ 893.520	$ 554.806	$ 122	$ 109.073.871			$ -
$ 893.520	$ 504.369	$ 126	$ 112.346.087			$ -
$ 893.520	$ 458.517	$ 130	$ 115.716.470			$ -
$ 893.520	$ 416.834	$ 133	$ 119.187.964			$ -
$ 893.520	$ 378.940	$ 137	$ 122.763.603			$ -
$ 893.520	$ 344.491	$ 142	$ 126.446.511			$ -
$ 893.520	$ 313.173	$ 146	$ 130.239.906			$ -
$ 893.520	$ 284.703	$ 150	$ 134.147.103			$ -
$ 893.520	$ 258.821	$ 155	$ 138.171.516			$ -
$ 893.520	$ 235.292	$ 159	$ 142.316.662			$ -
$ 893.520	$ 213.902	$ 164	$ 146.586.162			$ -
$ 893.520	$ 194.456	$ 169	$ 150.983.747			$ -
$ 893.520	$ 176.778	$ 174	$ 155.513.259			$ -
$ 893.520	$ 160.707	$ 179	$ 160.178.657			$ -
$ 893.520	$ 146.098	$ 185	$ 164.984.017			$ -
$ 893.520	$ 132.816	$ 190	$ 169.933.537			$ -
$ 893.520	$ 120.742	$ 196	$ 175.031.543			$ -
$ 893.520	$ 109.765	$ 202	$ 180.282.489			$ -
$ 893.520	$ 99.787	$ 208	$ 185.690.964			$ -
$ 893.520	$ 90.715	$ 214	$ 191.261.693			$ -
$ 893.520	$ 82.468	$ 220	$ 196.999.544			$ -
$ 893.520	$ 74.971	$ 227	$ 202.909.530			$ -
$ 893.520	$ 68.156	$ 234	$ 208.996.816			$ -
$ 893.520	$ 61.960	$ 241	$ 215.266.721			$ -
$ 893.520	$ 56.327	$ 248	$ 221.724.722			$ -
$ 893.520	$ 51.206	$ 256	$ 228.376.464			$ -
$ 893.520	$ 46.551	$ 263	$ 235.227.758			$ -
$ 893.520	$ 42.319	$ 271	$ 242.284.590			$ -
$ 893.520	$ 38.472	$ 279	$ 249.553.128			$ -
$ 893.520	$ 34.975	$ 288	$ 257.039.722			$ -
$ 893.520	$ 31.795	$ 296	$ 264.750.914			$ -
$ 893.520	$ 28.905	$ 305	$ 272.693.441			$ -
$ 893.520	$ 26.277	$ 314	$ 280.874.244			$ -
$ 893.520	$ 23.888	$ 324	$ 289.300.472			$ -
$ 893.520	$ 21.716	$ 333	$ 297.979.486			$ -
$ 893.520	$ 19.742	$ 343	$ 306.918.870			$ -
$ 893.520	$ 17.948	$ 354	$ 316.126.436			$ -
$ 893.520	$ 16.316	$ 364	$ 325.610.230			$ -
$ 893.520	$ 14.833	$ 375	$ 335.378.536			$ -
$ 893.520	$ 13.484	$ 387	$ 345.439.893			$ -
$ 893.520	$ 12.258	$ 398	$ 355.803.089			$ -
$ 893.520	$ 11.144	$ 410	$ 366.477.182			$ -
$ 893.520	$ 10.131	$ 422	$ 377.471.497			$ -
$ 893.520	$ 9.210	$ 435	$ 388.795.642			$ -
$ 893.520	$ 8.373	$ 448	$ 400.459.512			$ -
$ 893.520	$ 7.611	$ 462	$ 412.473.297			$ -
$ 893.520	$ 6.920	$ 475	$ 424.847.496			$ -
$ 893.520	$ 6.290	$ 490	$ 437.592.921			$ -
$ 893.520	$ 5.719	$ 504	$ 450.720.708			$ -
$ 893.520	$ 5.199	$ 520	$ 464.242.330			$ -
$ 893.520	$ 4.726	$ 535	$ 478.169.600			$ -
$ 893.520	$ 4.296	$ 551	$ 492.514.688			$ -
$ 893.520	$ 3.906	$ 568	$ 507.290.128			$ -
$ 893.520	$ 3.551	$ 585	$ 522.508.832			$ -
$ 893.520	$ 3.228	$ 602	$ 538.184.097			$ -
$ 893.520	$ 2.935	$ 620	$ 554.329.620			$ -
$ 893.520	$ 2.668	$ 639	$ 570.959.509			$ -
$ -	$ -	$ 658	$ -			$ -
$ 53.611.200	$ 8.096.231					

Cash Flow Calculation

CASH FLOWS								
EBITDA	D&A		EBITDA	TAX	NET INCOME	OCF	FCF	Discounted FCF
	D&A profile	D&A						
$ -18.785.884	$ -	$ -	$ -18.785.884	$ -7.138.636	$ -11.647.248	$ -11.647.248	$ -413.956.938	$ -413.956.938
$ -17.224.334	0,00%	$ -	$ -17.224.334	$ -6.545.247	$ -10.679.087	$ -10.679.087	$ -278.885.547	$ -253.532.316
$ 84.025.378	3,33%	$ 22.350.538	$ 61.674.840	$ 23.436.439	$ 38.238.401	$ 60.588.939	$ 60.588.939	$ 50.073.503
$ 88.332.517	3,33%	$ 22.350.538	$ 65.981.979	$ 25.073.152	$ 40.908.827	$ 63.259.365	$ 63.259.365	$ 47.527.697
$ 92.620.330	3,33%	$ 22.350.538	$ 70.269.791	$ 26.702.521	$ 43.567.271	$ 65.917.809	$ 65.917.809	$ 45.022.751
$ 96.900.596	3,33%	$ 22.350.538	$ 74.550.057	$ 28.329.022	$ 46.221.036	$ 68.571.574	$ 68.571.574	$ 42.577.552
$ 101.184.419	3,33%	$ 22.350.538	$ 78.833.880	$ 29.956.875	$ 48.877.006	$ 71.227.544	$ 71.227.544	$ 40.206.092
$ 105.482.292	3,33%	$ 22.350.538	$ 83.131.753	$ 31.590.066	$ 51.541.687	$ 73.892.226	$ 73.892.226	$ 37.918.395
$ 109.804.159	3,33%	$ 22.350.538	$ 87.453.621	$ 33.232.376	$ 54.221.245	$ 76.571.783	$ 76.571.783	$ 35.721.302
$ 114.159.470	3,33%	$ 22.350.538	$ 91.808.931	$ 34.887.394	$ 56.921.538	$ 79.272.076	$ 79.272.076	$ 33.619.099
$ 118.557.230	3,33%	$ 22.350.538	$ 96.206.692	$ 36.558.543	$ 59.648.149	$ 81.998.687	$ 81.998.687	$ 31.614.044
$ 123.006.050	3,33%	$ 22.350.538	$ 100.655.512	$ 38.249.095	$ 62.406.417	$ 84.756.956	$ 84.756.956	$ 29.706.796
$ 127.514.188	3,33%	$ 22.350.538	$ 105.163.650	$ 39.962.187	$ 65.201.463	$ 87.552.001	$ 87.552.001	$ 27.896.766
$ 132.089.590	3,33%	$ 22.350.538	$ 109.739.052	$ 41.700.840	$ 68.038.212	$ 90.388.751	$ 90.388.751	$ 26.182.401
$ 136.739.927	3,33%	$ 22.350.538	$ 114.389.389	$ 43.467.968	$ 70.921.421	$ 93.271.959	$ 93.271.959	$ 24.561.422
$ 141.472.630	3,33%	$ 22.350.538	$ 119.122.092	$ 45.266.395	$ 73.855.697	$ 96.206.235	$ 96.206.235	$ 23.031.008
$ 146.294.922	3,33%	$ 22.350.538	$ 123.944.383	$ 47.098.866	$ 76.845.518	$ 99.196.056	$ 99.196.056	$ 21.587.952
$ 151.213.845	3,33%	$ 22.350.538	$ 128.863.307	$ 48.968.057	$ 79.895.250	$ 102.245.789	$ 102.245.789	$ 20.228.784
$ 156.236.294	3,33%	$ 22.350.538	$ 133.885.756	$ 50.876.587	$ 83.009.169	$ 105.359.707	$ 105.359.707	$ 18.949.869
$ 161.369.036	3,33%	$ 22.350.538	$ 139.018.498	$ 52.827.029	$ 86.191.469	$ 108.542.007	$ 108.542.007	$ 17.747.485
$ 166.618.736	3,33%	$ 22.350.538	$ 144.268.198	$ 54.821.915	$ 89.446.283	$ 111.796.821	$ 111.796.821	$ 16.617.885
$ 171.991.981	3,33%	$ 22.350.538	$ 149.641.442	$ 56.863.748	$ 92.777.694	$ 115.128.233	$ 115.128.233	$ 15.557.344
$ 177.495.298	3,33%	$ 22.350.538	$ 155.144.760	$ 58.955.009	$ 96.189.751	$ 118.540.289	$ 118.540.289	$ 14.562.197
$ 183.135.178	3,33%	$ 22.350.538	$ 160.784.639	$ 61.098.163	$ 99.686.476	$ 122.037.015	$ 122.037.015	$ 13.628.869
$ 188.918.088	3,33%	$ 22.350.538	$ 166.567.550	$ 63.295.669	$ 103.271.881	$ 125.622.419	$ 125.622.419	$ 12.753.891
$ 194.850.495	3,33%	$ 22.350.538	$ 172.499.956	$ 65.549.983	$ 106.949.973	$ 129.300.511	$ 129.300.511	$ 11.933.920
$ 200.938.876	3,33%	$ 22.350.538	$ 178.588.338	$ 67.863.568	$ 110.724.770	$ 133.075.308	$ 133.075.308	$ 11.165.744
$ 207.189.740	3,33%	$ 22.350.538	$ 184.839.202	$ 70.238.897	$ 114.600.305	$ 136.950.843	$ 136.950.843	$ 10.446.293
$ 213.609.636	3,33%	$ 22.350.538	$ 191.259.098	$ 72.678.457	$ 118.580.641	$ 140.931.179	$ 140.931.179	$ 9.772.640
$ 220.205.173	3,33%	$ 22.350.538	$ 197.854.635	$ 75.184.761	$ 122.669.873	$ 145.020.412	$ 145.020.412	$ 9.142.001
$ 226.983.028	3,33%	$ 22.350.538	$ 204.632.490	$ 77.760.346	$ 126.872.144	$ 149.222.682	$ 149.222.682	$ 8.551.736
$ 233.949.962	3,33%	$ 22.350.538	$ 211.599.424	$ 80.407.781	$ 131.191.643	$ 153.542.181	$ 153.542.181	$ 7.999.346
$ 241.112.833	0,00%	$ -	$ 241.112.833	$ 91.622.877	$ 149.489.957	$ 149.489.957	$ 149.489.957	$ 7.080.209
$ 248.478.605	0,00%	$ -	$ 248.478.605	$ 94.421.870	$ 154.056.735	$ 154.056.735	$ 154.056.735	$ 6.633.185
$ 256.054.359	0,00%	$ -	$ 256.054.359	$ 97.300.656	$ 158.753.702	$ 158.753.702	$ 158.753.702	$ 6.214.019
$ 263.847.308	0,00%	$ -	$ 263.847.308	$ 100.261.977	$ 163.585.331	$ 163.585.331	$ 163.585.331	$ 5.821.037
$ 271.864.806	0,00%	$ -	$ 271.864.806	$ 103.308.626	$ 168.556.180	$ 168.556.180	$ 168.556.180	$ 5.452.655
$ 280.114.356	0,00%	$ -	$ 280.114.356	$ 106.443.455	$ 173.670.901	$ 173.670.901	$ 173.670.901	$ 5.107.375
$ 288.603.623	0,00%	$ -	$ 288.603.623	$ 109.669.377	$ 178.934.247	$ 178.934.247	$ 178.934.247	$ 4.783.783
$ 297.340.445	0,00%	$ -	$ 297.340.445	$ 112.989.369	$ 184.351.076	$ 184.351.076	$ 184.351.076	$ 4.480.546
$ 306.332.839	0,00%	$ -	$ 306.332.839	$ 116.406.479	$ 189.926.360	$ 189.926.360	$ 189.926.360	$ 4.196.409
$ 315.589.014	0,00%	$ -	$ 315.589.014	$ 119.923.825	$ 195.665.189	$ 195.665.189	$ 195.665.189	$ 3.930.189
$ 325.117.383	0%	$ -	$ 325.117.383	$ 123.544.605	$ 201.572.777	$ 201.572.777	$ 201.572.777	$ 3.680.774
$ 334.926.566	0%	$ -	$ 334.926.566	$ 127.272.095	$ 207.654.471	$ 207.654.471	$ 207.654.471	$ 3.447.115
$ 345.025.406	0%	$ -	$ 345.025.406	$ 131.109.654	$ 213.915.751	$ 213.915.751	$ 213.915.751	$ 3.228.231
$ 355.422.976	0%	$ -	$ 355.422.976	$ 135.060.731	$ 220.362.245	$ 220.362.245	$ 220.362.245	$ 3.023.196
$ 366.128.590	0%	$ -	$ 366.128.590	$ 139.128.864	$ 226.999.726	$ 226.999.726	$ 226.999.726	$ 2.831.143
$ 377.151.811	0%	$ -	$ 377.151.811	$ 143.317.688	$ 233.834.123	$ 233.834.123	$ 233.834.123	$ 2.651.256
$ 388.502.464	0%	$ -	$ 388.502.464	$ 147.630.936	$ 240.871.527	$ 240.871.527	$ 240.871.527	$ 2.482.771
$ 400.190.641	0%	$ -	$ 400.190.641	$ 152.072.444	$ 248.118.198	$ 248.118.198	$ 248.118.198	$ 2.324.968
$ 412.226.719	0%	$ -	$ 412.226.719	$ 156.646.153	$ 255.580.566	$ 255.580.566	$ 255.580.566	$ 2.177.176
$ 424.621.360	0%	$ -	$ 424.621.360	$ 161.356.117	$ 263.265.243	$ 263.265.243	$ 263.265.243	$ 2.038.762
$ 437.385.532	0%	$ -	$ 437.385.532	$ 166.206.502	$ 271.179.030	$ 271.179.030	$ 271.179.030	$ 1.909.134
$ 450.530.512	0%	$ -	$ 450.530.512	$ 171.201.594	$ 279.328.917	$ 279.328.917	$ 279.328.917	$ 1.787.737
$ 464.067.899	0%	$ -	$ 464.067.899	$ 176.345.802	$ 287.722.097	$ 287.722.097	$ 287.722.097	$ 1.674.049
$ 478.009.627	0%	$ -	$ 478.009.627	$ 181.643.658	$ 296.365.969	$ 296.365.969	$ 296.365.969	$ 1.567.583
$ 492.367.974	0%	$ -	$ 492.367.974	$ 187.099.830	$ 305.268.144	$ 305.268.144	$ 305.268.144	$ 1.467.882
$ 507.155.575	0%	$ -	$ 507.155.575	$ 192.719.118	$ 314.436.456	$ 314.436.456	$ 314.436.456	$ 1.374.516
$ 522.385.430	0%	$ -	$ 522.385.430	$ 198.506.463	$ 323.878.967	$ 323.878.967	$ 323.878.967	$ 1.287.084
$ 538.070.922	0%	$ -	$ 538.070.922	$ 204.466.950	$ 333.603.971	$ 333.603.971	$ 333.603.971	$ 1.205.210
$ 554.225.823	0%	$ -	$ 554.225.823	$ 210.605.813	$ 343.620.010	$ 343.620.010	$ 343.620.010	$ 1.128.541
$ 570.864.313	0%	$ -	$ 570.864.313	$ 216.928.439	$ 353.935.874	$ 353.935.874	$ 353.935.874	$ 1.056.746
$ -87.308	0%	$ -	$ -87.308	$ -33.177	$ -54.131	$ -54.131	$ -939.038.287	$ -2.548.806

Appendix B Pessimistic Scenario

I. No Debt Considered

Imputs

Fuel $/MWh	$	12
O&M $/Mwh	$	19
Capital $/Mwh	$	6.828.537
Decomissioning $/Mwh	$	1.365.707
Electicity price $/Mwh	$	101
WACC %		10%
Byprod percentage %		0%

Outputs

RESULTS			
Net Present Value		$	-51.185.434
	IRR		10%
Payback period	disccounted	$	43,59
	Aprox	$	13,02
LCOE	construction	$	97,53
	decomissioning	$	0,34
	fuel	$	14,99
	O&M	$	26,13
	TOTAL	$	139,00

Cost Calculation

	COSTS													
	Construction profile				Decomissioning				Fuel			O&M		
Year	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Profile	Cost [$/MW]	Cost [$]	Disccounte	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]
$ -	60%	$ 6.828.537	$ 491.654.647	$ 491.654.647	0%	$ 1.365.707	$ -	$ -	$ 12	$ 10.518.207	$ 10.518.207	$ 19	$ 17.389.111	$ 17.389.111
$ 1	40%	$ 6.828.537	$ 327.769.765	$ 297.972.513	0%	$ 1.406.679	$ -	$ -	$ 12	$ 10.570.798	$ 9.609.817	$ 20	$ 17.563.002	$ 15.966.366
$ 2	0%	$ 6.828.537	$ -	$ -	0%	$ 1.448.879	$ -	$ -	$ 12	$ 10.623.652	$ 8.779.878	$ 20	$ 17.738.632	$ 14.660.027
$ 3	0%	$ 6.828.537	$ -	$ -	0%	$ 1.492.345	$ -	$ -	$ 12	$ 10.676.771	$ 8.021.616	$ 20	$ 17.916.019	$ 13.460.570
$ 4	0%	$ 6.828.537	$ -	$ -	0%	$ 1.537.116	$ -	$ -	$ 12	$ 10.730.154	$ 7.328.840	$ 20	$ 18.095.179	$ 12.359.251
$ 5	0%	$ 6.828.537	$ -	$ -	0%	$ 1.583.229	$ -	$ -	$ 12	$ 10.783.805	$ 6.695.895	$ 20	$ 18.276.131	$ 11.348.039
$ 6	0%	$ 6.828.537	$ -	$ -	0%	$ 1.630.726	$ -	$ -	$ 12	$ 10.837.724	$ 6.117.613	$ 21	$ 18.458.892	$ 10.419.563
$ 7	0%	$ 6.828.537	$ -	$ -	0%	$ 1.679.648	$ -	$ -	$ 12	$ 10.891.913	$ 5.589.274	$ 21	$ 18.643.481	$ 9.567.054
$ 8	0%	$ 6.828.537	$ -	$ -	0%	$ 1.730.037	$ -	$ -	$ 12	$ 10.946.372	$ 5.106.564	$ 21	$ 18.829.916	$ 8.784.295
$ 9	0%	$ 6.828.537	$ -	$ -	0%	$ 1.781.938	$ -	$ -	$ 12	$ 11.001.104	$ 4.665.542	$ 21	$ 19.018.215	$ 8.065.580
$ 10	0%	$ 6.828.537	$ -	$ -	0%	$ 1.835.396	$ -	$ -	$ 12	$ 11.056.110	$ 4.262.609	$ 21	$ 19.208.397	$ 7.405.669
$ 11	0%	$ 6.828.537	$ -	$ -	0%	$ 1.890.458	$ -	$ -	$ 12	$ 11.111.390	$ 3.894.475	$ 22	$ 19.400.481	$ 6.799.750
$ 12	0%	$ 6.828.537	$ -	$ -	0%	$ 1.947.172	$ -	$ -	$ 12	$ 11.166.947	$ 3.558.134	$ 22	$ 19.594.486	$ 6.243.407
$ 13	0%	$ 6.828.537	$ -	$ -	0%	$ 2.005.587	$ -	$ -	$ 13	$ 11.222.782	$ 3.250.840	$ 22	$ 19.790.431	$ 5.732.583
$ 14	0%	$ 6.828.537	$ -	$ -	0%	$ 2.065.755	$ -	$ -	$ 13	$ 11.278.896	$ 2.970.086	$ 22	$ 19.988.335	$ 5.263.553
$ 15	0%	$ 6.828.537	$ -	$ -	0%	$ 2.127.728	$ -	$ -	$ 13	$ 11.335.290	$ 2.713.578	$ 23	$ 20.188.218	$ 4.832.899
$ 16	0%	$ 6.828.537	$ -	$ -	0%	$ 2.191.559	$ -	$ -	$ 13	$ 11.391.967	$ 2.479.224	$ 23	$ 20.390.100	$ 4.437.480
$ 17	0%	$ 6.828.537	$ -	$ -	0%	$ 2.257.306	$ -	$ -	$ 13	$ 11.448.927	$ 2.265.109	$ 23	$ 20.594.001	$ 4.074.413
$ 18	0%	$ 6.828.537	$ -	$ -	0%	$ 2.325.025	$ -	$ -	$ 13	$ 11.506.171	$ 2.069.486	$ 23	$ 20.799.941	$ 3.741.052
$ 19	0%	$ 6.828.537	$ -	$ -	0%	$ 2.394.776	$ -	$ -	$ 13	$ 11.563.702	$ 1.890.758	$ 24	$ 21.007.941	$ 3.434.966
$ 20	0%	$ 6.828.537	$ -	$ -	0%	$ 2.466.619	$ -	$ -	$ 13	$ 11.621.521	$ 1.727.465	$ 24	$ 21.218.020	$ 3.153.923
$ 21	0%	$ 6.828.537	$ -	$ -	0%	$ 2.540.618	$ -	$ -	$ 13	$ 11.679.628	$ 1.578.275	$ 24	$ 21.430.200	$ 2.895.875
$ 22	0%	$ 6.828.537	$ -	$ -	0%	$ 2.616.837	$ -	$ -	$ 13	$ 11.738.026	$ 1.441.969	$ 24	$ 21.644.502	$ 2.658.940
$ 23	0%	$ 6.828.537	$ -	$ -	0%	$ 2.695.342	$ -	$ -	$ 13	$ 11.796.717	$ 1.317.436	$ 24	$ 21.860.947	$ 2.441.390
$ 24	0%	$ 6.828.537	$ -	$ -	0%	$ 2.776.202	$ -	$ -	$ 13	$ 11.855.700	$ 1.203.657	$ 25	$ 22.079.557	$ 2.241.640
$ 25	0%	$ 6.828.537	$ -	$ -	0%	$ 2.859.488	$ -	$ -	$ 13	$ 11.914.979	$ 1.099.705	$ 25	$ 22.300.352	$ 2.058.233
$ 26	0%	$ 6.828.537	$ -	$ -	0%	$ 2.945.273	$ -	$ -	$ 13	$ 11.974.554	$ 1.004.730	$ 25	$ 22.523.356	$ 1.889.832
$ 27	0%	$ 6.828.537	$ -	$ -	0%	$ 3.033.631	$ -	$ -	$ 13	$ 12.034.426	$ 917.958	$ 25	$ 22.748.590	$ 1.735.210
$ 28	0%	$ 6.828.537	$ -	$ -	0%	$ 3.124.640	$ -	$ -	$ 14	$ 12.094.598	$ 838.680	$ 26	$ 22.976.075	$ 1.593.238
$ 29	0%	$ 6.828.537	$ -	$ -	0%	$ 3.218.379	$ -	$ -	$ 14	$ 12.155.071	$ 766.249	$ 26	$ 23.205.836	$ 1.462.882
$ 30	0%	$ 6.828.537	$ -	$ -	0%	$ 3.314.930	$ -	$ -	$ 14	$ 12.215.847	$ 700.073	$ 26	$ 23.437.895	$ 1.343.192
$ 31	0%	$ 6.828.537	$ -	$ -	0%	$ 3.414.378	$ -	$ -	$ 14	$ 12.276.926	$ 639.612	$ 26	$ 23.672.273	$ 1.233.294
$ 32	0%	$ 6.828.537	$ -	$ -	0%	$ 3.516.809	$ -	$ -	$ 14	$ 12.338.311	$ 584.373	$ 27	$ 23.908.996	$ 1.132.388
$ 33	0%	$ 6.828.537	$ -	$ -	0%	$ 3.622.314	$ -	$ -	$ 14	$ 12.400.002	$ 533.904	$ 27	$ 24.148.086	$ 1.039.738
$ 34	0%	$ 6.828.537	$ -	$ -	0%	$ 3.730.983	$ -	$ -	$ 14	$ 12.462.002	$ 487.794	$ 27	$ 24.389.567	$ 954.669
$ 35	0%	$ 6.828.537	$ -	$ -	0%	$ 3.842.913	$ -	$ -	$ 14	$ 12.524.312	$ 445.666	$ 28	$ 24.633.463	$ 876.560
$ 36	0%	$ 6.828.537	$ -	$ -	0%	$ 3.958.200	$ -	$ -	$ 14	$ 12.586.934	$ 407.177	$ 28	$ 24.879.797	$ 804.841
$ 37	0%	$ 6.828.537	$ -	$ -	0%	$ 4.076.946	$ -	$ -	$ 14	$ 12.649.868	$ 372.012	$ 28	$ 25.128.595	$ 738.991
$ 38	0%	$ 6.828.537	$ -	$ -	0%	$ 4.199.254	$ -	$ -	$ 14	$ 12.713.118	$ 339.883	$ 28	$ 25.379.881	$ 678.528
$ 39	0%	$ 6.828.537	$ -	$ -	0%	$ 4.325.232	$ -	$ -	$ 14	$ 12.776.683	$ 310.530	$ 29	$ 25.633.680	$ 623.012
$ 40	0%	$ 6.828.537	$ -	$ -	0%	$ 4.454.989	$ -	$ -	$ 14	$ 12.840.567	$ 283.711	$ 29	$ 25.890.017	$ 572.038
$ 41	0%	$ 6.828.537	$ -	$ -	0%	$ 4.588.639	$ -	$ -	$ 14	$ 12.904.770	$ 259.209	$ 29	$ 26.148.917	$ 525.235
$ 42	0%	$ 6.828.537	$ -	$ -	0%	$ 4.726.298	$ -	$ -	$ 15	$ 12.969.294	$ 236.823	$ 30	$ 26.410.406	$ 482.261
$ 43	0%	$ 6.828.537	$ -	$ -	0%	$ 4.868.087	$ -	$ -	$ 15	$ 13.034.140	$ 216.370	$ 30	$ 26.674.510	$ 442.803
$ 44	0%	$ 6.828.537	$ -	$ -	0%	$ 5.014.129	$ -	$ -	$ 15	$ 13.099.311	$ 197.683	$ 30	$ 26.941.255	$ 406.574
$ 45	0%	$ 6.828.537	$ -	$ -	0%	$ 5.164.553	$ -	$ -	$ 15	$ 13.164.807	$ 180.611	$ 30	$ 27.210.668	$ 373.309
$ 46	0%	$ 6.828.537	$ -	$ -	0%	$ 5.319.490	$ -	$ -	$ 15	$ 13.230.631	$ 165.013	$ 31	$ 27.482.775	$ 342.765
$ 47	0%	$ 6.828.537	$ -	$ -	0%	$ 5.479.075	$ -	$ -	$ 15	$ 13.296.784	$ 150.761	$ 31	$ 27.757.602	$ 314.721
$ 48	0%	$ 6.828.537	$ -	$ -	0%	$ 5.643.447	$ -	$ -	$ 15	$ 13.363.268	$ 137.741	$ 31	$ 28.035.178	$ 288.971
$ 49	0%	$ 6.828.537	$ -	$ -	0%	$ 5.812.750	$ -	$ -	$ 15	$ 13.430.085	$ 125.845	$ 32	$ 28.315.530	$ 265.328
$ 50	0%	$ 6.828.537	$ -	$ -	0%	$ 5.987.133	$ -	$ -	$ 15	$ 13.497.235	$ 114.977	$ 32	$ 28.598.685	$ 243.619
$ 51	0%	$ 6.828.537	$ -	$ -	0%	$ 6.166.747	$ -	$ -	$ 15	$ 13.564.721	$ 105.047	$ 32	$ 28.884.672	$ 223.687
$ 52	0%	$ 6.828.537	$ -	$ -	0%	$ 6.351.749	$ -	$ -	$ 15	$ 13.632.545	$ 95.975	$ 33	$ 29.173.519	$ 205.385
$ 53	0%	$ 6.828.537	$ -	$ -	0%	$ 6.542.302	$ -	$ -	$ 15	$ 13.700.708	$ 87.686	$ 33	$ 29.465.254	$ 188.581
$ 54	0%	$ 6.828.537	$ -	$ -	0%	$ 6.738.571	$ -	$ -	$ 15	$ 13.769.211	$ 80.113	$ 33	$ 29.759.907	$ 173.152
$ 55	0%	$ 6.828.537	$ -	$ -	0%	$ 6.940.728	$ -	$ -	$ 15	$ 13.838.057	$ 73.194	$ 34	$ 30.057.506	$ 158.985
$ 56	0%	$ 6.828.537	$ -	$ -	0%	$ 7.148.950	$ -	$ -	$ 16	$ 13.907.248	$ 66.873	$ 34	$ 30.358.081	$ 145.977
$ 57	0%	$ 6.828.537	$ -	$ -	0%	$ 7.363.418	$ -	$ -	$ 16	$ 13.976.784	$ 61.098	$ 34	$ 30.661.662	$ 134.033
$ 58	0%	$ 6.828.537	$ -	$ -	0%	$ 7.584.321	$ -	$ -	$ 16	$ 14.046.668	$ 55.821	$ 35	$ 30.968.278	$ 123.067
$ 59	0%	$ 6.828.537	$ -	$ -	0%	$ 7.811.850	$ -	$ -	$ 16	$ 14.116.901	$ 51.000	$ 35	$ 31.277.961	$ 112.998
$ 60	0%	$ 6.828.537	$ -	$ -	0%	$ 8.046.206	$ -	$ -	$ 16	$ 14.187.486	$ 46.596	$ 35	$ 31.590.741	$ 103.753
$ 61	0%	$ 6.828.537	$ -	$ -	0%	$ 8.287.592	$ -	$ -	$ 16	$ 14.258.423	$ 42.571	$ 36	$ 31.906.648	$ 95.264
$ 62	0%	$ 6.828.537	$ -	$ -	100%	$ 8.536.220	$ 1.024.346.352	########	$ 16	$ 14.329.715	$ 38.895	$ 36	$ 32.225.715	$ 87.469

Revenue Calculation

REVENUES						
Electicity				by-products		
Generation [MWh]	Discounted Generation	Price [$/MWh]	Sales [$]	Generation [MWh	Price [$/MWh]	Sales [$]
$ -	$ -	$ 101	$ -			$ -
$ -	$ -	$ 104	$ -			$ -
$ 893.520	$ 738.446	$ 107	$ 95.741.472			$ -
$ 893.520	$ 671.315	$ 110	$ 98.613.716			$ -
$ 893.520	$ 610.286	$ 114	$ 101.572.128			$ -
$ 893.520	$ 554.806	$ 117	$ 104.619.292			$ -
$ 893.520	$ 504.369	$ 121	$ 107.757.870			$ -
$ 893.520	$ 458.517	$ 124	$ 110.990.607			$ -
$ 893.520	$ 416.834	$ 128	$ 114.320.325			$ -
$ 893.520	$ 378.940	$ 132	$ 117.749.934			$ -
$ 893.520	$ 344.491	$ 136	$ 121.282.432			$ -
$ 893.520	$ 313.173	$ 140	$ 124.920.905			$ -
$ 893.520	$ 284.703	$ 144	$ 128.668.533			$ -
$ 893.520	$ 258.821	$ 148	$ 132.528.589			$ -
$ 893.520	$ 235.292	$ 153	$ 136.504.446			$ -
$ 893.520	$ 213.902	$ 157	$ 140.599.580			$ -
$ 893.520	$ 194.456	$ 162	$ 144.817.567			$ -
$ 893.520	$ 176.778	$ 167	$ 149.162.094			$ -
$ 893.520	$ 160.707	$ 172	$ 153.636.957			$ -
$ 893.520	$ 146.098	$ 177	$ 158.246.066			$ -
$ 893.520	$ 132.816	$ 182	$ 162.993.448			$ -
$ 893.520	$ 120.742	$ 188	$ 167.883.251			$ -
$ 893.520	$ 109.765	$ 194	$ 172.919.749			$ -
$ 893.520	$ 99.787	$ 199	$ 178.107.341			$ -
$ 893.520	$ 90.715	$ 205	$ 183.450.561			$ -
$ 893.520	$ 82.468	$ 211	$ 188.954.078			$ -
$ 893.520	$ 74.971	$ 218	$ 194.622.700			$ -
$ 893.520	$ 68.156	$ 224	$ 200.461.381			$ -
$ 893.520	$ 61.960	$ 231	$ 206.475.223			$ -
$ 893.520	$ 56.327	$ 238	$ 212.669.480			$ -
$ 893.520	$ 51.206	$ 245	$ 219.049.564			$ -
$ 893.520	$ 46.551	$ 253	$ 225.621.051			$ -
$ 893.520	$ 42.319	$ 260	$ 232.389.682			$ -
$ 893.520	$ 38.472	$ 268	$ 239.361.373			$ -
$ 893.520	$ 34.975	$ 276	$ 246.542.214			$ -
$ 893.520	$ 31.795	$ 284	$ 253.938.480			$ -
$ 893.520	$ 28.905	$ 293	$ 261.556.635			$ -
$ 893.520	$ 26.277	$ 302	$ 269.403.334			$ -
$ 893.520	$ 23.888	$ 311	$ 277.485.434			$ -
$ 893.520	$ 21.716	$ 320	$ 285.809.997			$ -
$ 893.520	$ 19.742	$ 329	$ 294.384.297			$ -
$ 893.520	$ 17.948	$ 339	$ 303.215.826			$ -
$ 893.520	$ 16.316	$ 350	$ 312.312.300			$ -
$ 893.520	$ 14.833	$ 360	$ 321.681.669			$ -
$ 893.520	$ 13.484	$ 371	$ 331.332.120			$ -
$ 893.520	$ 12.258	$ 382	$ 341.272.083			$ -
$ 893.520	$ 11.144	$ 393	$ 351.510.246			$ -
$ 893.520	$ 10.131	$ 405	$ 362.055.553			$ -
$ 893.520	$ 9.210	$ 417	$ 372.917.220			$ -
$ 893.520	$ 8.373	$ 430	$ 384.104.736			$ -
$ 893.520	$ 7.611	$ 443	$ 395.627.878			$ -
$ 893.520	$ 6.920	$ 456	$ 407.496.715			$ -
$ 893.520	$ 6.290	$ 470	$ 419.721.616			$ -
$ 893.520	$ 5.719	$ 484	$ 432.313.265			$ -
$ 893.520	$ 5.199	$ 498	$ 445.282.662			$ -
$ 893.520	$ 4.726	$ 513	$ 458.641.142			$ -
$ 893.520	$ 4.296	$ 529	$ 472.400.377			$ -
$ 893.520	$ 3.906	$ 545	$ 486.572.388			$ -
$ 893.520	$ 3.551	$ 561	$ 501.169.560			$ -
$ 893.520	$ 3.228	$ 578	$ 516.204.646			$ -
$ 893.520	$ 2.935	$ 595	$ 531.690.786			$ -
$ 893.520	$ 2.668	$ 613	$ 547.641.509			$ -
$ -	$ -	$ 631	$ -			$ -
$ 53.611.200	$ 8.096.231					

Cash Flow Calculation

	CASH FLOWS							
EBITDA	D&A		EBITDA	TAX	NET INCOME	OCF	FCF	Discounted FCF
	D&A profile	D&A						
$ -27.907.318	$ -	$ -	$ -27.907.318	$ -10.604.781	$ -17.302.537	$ -17.302.537	$ -508.957.184	$ -508.957.184
$ -25.576.182	0,00%	$ -	$ -25.576.182	$ -9.718.949	$ -15.857.233	$ -15.857.233	$ -343.626.998	$ -312.388.180
$ 72.301.568	3,33%	$ 27.314.147	$ 44.987.421	$ 17.095.220	$ 27.892.201	$ 55.206.348	$ 55.206.348	$ 45.625.081
$ 77.131.531	3,33%	$ 27.314.147	$ 49.817.384	$ 18.930.606	$ 30.886.778	$ 58.200.925	$ 58.200.925	$ 43.727.216
$ 81.884.037	3,33%	$ 27.314.147	$ 54.569.890	$ 20.736.558	$ 33.833.332	$ 61.147.479	$ 61.147.479	$ 41.764.551
$ 86.575.358	3,33%	$ 27.314.147	$ 59.261.211	$ 22.519.260	$ 36.741.951	$ 64.056.098	$ 64.056.098	$ 39.773.797
$ 91.220.694	3,33%	$ 27.314.147	$ 63.906.547	$ 24.284.488	$ 39.622.059	$ 66.936.206	$ 66.936.206	$ 37.783.743
$ 95.834.280	3,33%	$ 27.314.147	$ 68.520.132	$ 26.037.650	$ 42.482.482	$ 69.796.629	$ 69.796.629	$ 35.816.707
$ 100.429.467	3,33%	$ 27.314.147	$ 73.115.320	$ 27.783.821	$ 45.331.498	$ 72.645.645	$ 72.645.645	$ 33.889.730
$ 105.018.813	3,33%	$ 27.314.147	$ 77.704.666	$ 29.527.773	$ 48.176.893	$ 75.491.040	$ 75.491.040	$ 32.015.570
$ 109.614.155	3,33%	$ 27.314.147	$ 82.300.008	$ 31.274.003	$ 51.026.005	$ 78.340.152	$ 78.340.152	$ 30.203.520
$ 114.226.681	3,33%	$ 27.314.147	$ 86.912.534	$ 33.026.763	$ 53.885.771	$ 81.199.918	$ 81.199.918	$ 28.460.076
$ 118.866.992	3,33%	$ 27.314.147	$ 91.552.845	$ 34.790.081	$ 56.762.764	$ 84.076.911	$ 84.076.911	$ 26.789.495
$ 123.545.166	3,33%	$ 27.314.147	$ 96.231.019	$ 36.567.787	$ 59.663.232	$ 86.977.379	$ 86.977.379	$ 25.194.248
$ 128.270.807	3,33%	$ 27.314.147	$ 100.956.660	$ 38.363.531	$ 62.593.129	$ 89.907.276	$ 89.907.276	$ 23.675.396
$ 133.053.102	3,33%	$ 27.314.147	$ 105.738.955	$ 40.180.803	$ 65.558.152	$ 92.872.299	$ 92.872.299	$ 22.232.890
$ 137.900.863	3,33%	$ 27.314.147	$ 110.586.716	$ 42.022.952	$ 68.563.764	$ 95.877.911	$ 95.877.911	$ 20.865.827
$ 142.822.572	3,33%	$ 27.314.147	$ 115.508.425	$ 43.893.201	$ 71.615.223	$ 98.929.370	$ 98.929.370	$ 19.572.649
$ 147.826.419	3,33%	$ 27.314.147	$ 120.512.271	$ 45.794.663	$ 74.717.608	$ 102.031.755	$ 102.031.755	$ 18.351.308
$ 152.920.342	3,33%	$ 27.314.147	$ 125.606.195	$ 47.730.354	$ 77.875.841	$ 105.189.988	$ 105.189.988	$ 17.199.404
$ 158.112.059	3,33%	$ 27.314.147	$ 130.797.912	$ 49.703.207	$ 81.094.705	$ 108.408.852	$ 108.408.852	$ 16.114.285
$ 163.409.101	3,33%	$ 27.314.147	$ 136.094.954	$ 51.716.082	$ 84.378.871	$ 111.693.018	$ 111.693.018	$ 15.093.141
$ 168.818.839	3,33%	$ 27.314.147	$ 141.504.692	$ 53.771.783	$ 87.732.909	$ 115.047.056	$ 115.047.056	$ 14.133.068
$ 174.348.515	3,33%	$ 27.314.147	$ 147.034.368	$ 55.873.060	$ 91.161.308	$ 118.475.455	$ 118.475.455	$ 13.231.121
$ 180.005.264	3,33%	$ 27.314.147	$ 152.691.117	$ 58.022.624	$ 94.668.492	$ 121.982.640	$ 121.982.640	$ 12.384.360
$ 185.796.140	3,33%	$ 27.314.147	$ 158.481.993	$ 60.223.157	$ 98.258.836	$ 125.572.983	$ 125.572.983	$ 11.589.884
$ 191.728.138	3,33%	$ 27.314.147	$ 164.413.991	$ 62.477.316	$ 101.936.674	$ 129.250.821	$ 129.250.821	$ 10.844.849
$ 197.808.213	3,33%	$ 27.314.147	$ 170.494.066	$ 64.787.745	$ 105.706.321	$ 133.020.468	$ 133.020.468	$ 10.146.493
$ 204.043.305	3,33%	$ 27.314.147	$ 176.729.158	$ 67.157.080	$ 109.572.078	$ 136.886.225	$ 136.886.225	$ 9.492.149
$ 210.440.349	3,33%	$ 27.314.147	$ 183.126.202	$ 69.587.957	$ 113.538.245	$ 140.852.392	$ 140.852.392	$ 8.879.252
$ 217.006.300	3,33%	$ 27.314.147	$ 189.692.153	$ 72.083.018	$ 117.609.135	$ 144.923.282	$ 144.923.282	$ 8.305.344
$ 223.748.145	3,33%	$ 27.314.147	$ 196.433.998	$ 74.644.919	$ 121.789.079	$ 149.103.226	$ 149.103.226	$ 7.768.082
$ 230.672.921	0,00%	$ -	$ 230.672.921	$ 87.655.710	$ 143.017.211	$ 143.017.211	$ 143.017.211	$ 6.773.644
$ 237.787.730	0,00%	$ -	$ 237.787.730	$ 90.359.338	$ 147.428.393	$ 147.428.393	$ 147.428.393	$ 6.347.790
$ 245.099.751	0,00%	$ -	$ 245.099.751	$ 93.137.905	$ 151.961.846	$ 151.961.846	$ 151.961.846	$ 5.948.169
$ 252.616.254	0,00%	$ -	$ 252.616.254	$ 95.994.177	$ 156.622.078	$ 156.622.078	$ 156.622.078	$ 5.573.256
$ 260.344.617	0,00%	$ -	$ 260.344.617	$ 98.930.954	$ 161.413.662	$ 161.413.662	$ 161.413.662	$ 5.221.600
$ 268.292.332	0,00%	$ -	$ 268.292.332	$ 101.951.086	$ 166.341.246	$ 166.341.246	$ 166.341.246	$ 4.891.821
$ 276.467.023	0,00%	$ -	$ 276.467.023	$ 105.057.469	$ 171.409.554	$ 171.409.554	$ 171.409.554	$ 4.582.611
$ 284.876.455	0,00%	$ -	$ 284.876.455	$ 108.253.053	$ 176.623.402	$ 176.623.402	$ 176.623.402	$ 4.292.730
$ 293.528.547	0,00%	$ -	$ 293.528.547	$ 111.540.848	$ 181.987.699	$ 181.987.699	$ 181.987.699	$ 4.021.005
$ 302.431.382	0,00%	$ -	$ 302.431.382	$ 114.923.925	$ 187.507.457	$ 187.507.457	$ 187.507.457	$ 3.766.331
$ 311.593.216	0%	$ -	$ 311.593.216	$ 118.405.422	$ 193.187.794	$ 193.187.794	$ 193.187.794	$ 3.527.662
$ 321.022.496	0%	$ -	$ 321.022.496	$ 121.988.549	$ 199.033.948	$ 199.033.948	$ 199.033.948	$ 3.304.013
$ 330.727.862	0%	$ -	$ 330.727.862	$ 125.676.588	$ 205.051.274	$ 205.051.274	$ 205.051.274	$ 3.094.456
$ 340.718.163	0%	$ -	$ 340.718.163	$ 129.472.902	$ 211.245.261	$ 211.245.261	$ 211.245.261	$ 2.898.119
$ 351.002.468	0%	$ -	$ 351.002.468	$ 133.380.938	$ 217.621.530	$ 217.621.530	$ 217.621.530	$ 2.714.178
$ 361.590.071	0%	$ -	$ 361.590.071	$ 137.404.227	$ 224.185.844	$ 224.185.844	$ 224.185.844	$ 2.541.862
$ 372.490.507	0%	$ -	$ 372.490.507	$ 141.546.393	$ 230.944.115	$ 230.944.115	$ 230.944.115	$ 2.380.444
$ 383.713.563	0%	$ -	$ 383.713.563	$ 145.811.154	$ 237.902.409	$ 237.902.409	$ 237.902.409	$ 2.229.242
$ 395.269.282	0%	$ -	$ 395.269.282	$ 150.202.327	$ 245.066.955	$ 245.066.955	$ 245.066.955	$ 2.087.615
$ 407.167.981	0%	$ -	$ 407.167.981	$ 154.723.833	$ 252.444.148	$ 252.444.148	$ 252.444.148	$ 1.954.962
$ 419.420.256	0%	$ -	$ 419.420.256	$ 159.379.697	$ 260.040.559	$ 260.040.559	$ 260.040.559	$ 1.830.718
$ 432.036.997	0%	$ -	$ 432.036.997	$ 164.174.059	$ 267.862.938	$ 267.862.938	$ 267.862.938	$ 1.714.353
$ 445.029.398	0%	$ -	$ 445.029.398	$ 169.111.171	$ 275.918.227	$ 275.918.227	$ 275.918.227	$ 1.605.371
$ 458.408.963	0%	$ -	$ 458.408.963	$ 174.195.406	$ 284.213.557	$ 284.213.557	$ 284.213.557	$ 1.503.305
$ 472.187.527	0%	$ -	$ 472.187.527	$ 179.431.260	$ 292.756.267	$ 292.756.267	$ 292.756.267	$ 1.407.719
$ 486.377.257	0%	$ -	$ 486.377.257	$ 184.823.358	$ 301.553.899	$ 301.553.899	$ 301.553.899	$ 1.318.202
$ 500.990.672	0%	$ -	$ 500.990.672	$ 190.376.455	$ 310.614.216	$ 310.614.216	$ 310.614.216	$ 1.234.371
$ 516.040.648	0%	$ -	$ 516.040.648	$ 196.095.446	$ 319.945.202	$ 319.945.202	$ 319.945.202	$ 1.155.865
$ 531.540.438	0%	$ -	$ 531.540.438	$ 201.985.366	$ 329.555.071	$ 329.555.071	$ 329.555.071	$ 1.082.348
$ 547.503.674	0%	$ -	$ 547.503.674	$ 208.051.396	$ 339.452.278	$ 339.452.278	$ 339.452.278	$ 1.013.503
$ -126.364	0%	$ -	$ -126.364	$ -48.018	$ -78.346	$ -78.346	$ -1.024.424.698	$ -2.780.568

I. Debt Considered

Imputs

Fuel $/MWh	$ 12	
O&M $/Mwh	$ 19	
Capital $/Mwh	$ 6.828.537	
Decomissioning $/Mwh	$ 1.365.707	
Electicity price $/Mwh	$ 101	
WACC %	10%	
Byprod percentage %	0%	
debt percentage	50%	
Debt term	30	
debt increase rate	int. Rate	Debt
0,00%	8%	$ 409.712.206

Outputs

RESULTS		
Net Present Value		$ -201.967.907
IRR		8%
Payback period	disccounted	$ -10,64
	Aprox	$ 15,61
LCOE	construction	$ 97,53
	decomissioning	$ 0,34
	fuel	$ 14,99
	O&M	$ 26,13
	TOTAL	$ 139,00

Cost Calculation

	COSTS													
	Construction profile				Decomissioning				Fuel			O&M		
Year	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]
$ -	60%	$ 6.828.537	$ 491.654.647	$ 491.654.647	0%	$ 1.365.707	$ -	$ -	$ 12	$ 10.518.207	$ 10.518.207	$ 19	$ 17.389.111	$ 17.389.111
$ 1	40%	$ 6.828.537	$ 327.769.765	$ 297.972.513	0%	$ 1.406.679	$ -	$ -	$ 12	$ 10.570.798	$ 9.609.817	$ 20	$ 17.563.002	$ 15.966.366
$ 2	0%	$ 6.828.537	$ -	$ -	0%	$ 1.448.879	$ -	$ -	$ 12	$ 10.623.652	$ 8.779.878	$ 20	$ 17.738.632	$ 14.660.027
$ 3	0%	$ 6.828.537	$ -	$ -	0%	$ 1.492.345	$ -	$ -	$ 12	$ 10.676.771	$ 8.021.616	$ 20	$ 17.916.019	$ 13.460.570
$ 4	0%	$ 6.828.537	$ -	$ -	0%	$ 1.537.116	$ -	$ -	$ 12	$ 10.730.154	$ 7.328.840	$ 20	$ 18.095.179	$ 12.359.251
$ 5	0%	$ 6.828.537	$ -	$ -	0%	$ 1.583.229	$ -	$ -	$ 12	$ 10.783.805	$ 6.695.895	$ 20	$ 18.276.131	$ 11.348.039
$ 6	0%	$ 6.828.537	$ -	$ -	0%	$ 1.630.726	$ -	$ -	$ 12	$ 10.837.724	$ 6.117.613	$ 21	$ 18.458.892	$ 10.419.563
$ 7	0%	$ 6.828.537	$ -	$ -	0%	$ 1.679.648	$ -	$ -	$ 12	$ 10.891.913	$ 5.589.274	$ 21	$ 18.643.481	$ 9.567.054
$ 8	0%	$ 6.828.537	$ -	$ -	0%	$ 1.730.037	$ -	$ -	$ 12	$ 10.946.372	$ 5.106.564	$ 21	$ 18.829.916	$ 8.784.295
$ 9	0%	$ 6.828.537	$ -	$ -	0%	$ 1.781.938	$ -	$ -	$ 12	$ 11.001.104	$ 4.665.542	$ 21	$ 19.018.215	$ 8.065.580
$ 10	0%	$ 6.828.537	$ -	$ -	0%	$ 1.835.396	$ -	$ -	$ 12	$ 11.056.110	$ 4.262.609	$ 21	$ 19.208.397	$ 7.405.669
$ 11	0%	$ 6.828.537	$ -	$ -	0%	$ 1.890.458	$ -	$ -	$ 12	$ 11.111.390	$ 3.894.475	$ 22	$ 19.400.481	$ 6.799.750
$ 12	0%	$ 6.828.537	$ -	$ -	0%	$ 1.947.172	$ -	$ -	$ 12	$ 11.166.947	$ 3.558.134	$ 22	$ 19.594.486	$ 6.243.407
$ 13	0%	$ 6.828.537	$ -	$ -	0%	$ 2.005.587	$ -	$ -	$ 13	$ 11.222.782	$ 3.250.840	$ 22	$ 19.790.431	$ 5.732.583
$ 14	0%	$ 6.828.537	$ -	$ -	0%	$ 2.065.755	$ -	$ -	$ 13	$ 11.278.896	$ 2.970.086	$ 22	$ 19.988.335	$ 5.263.553
$ 15	0%	$ 6.828.537	$ -	$ -	0%	$ 2.127.728	$ -	$ -	$ 13	$ 11.335.290	$ 2.713.578	$ 23	$ 20.188.218	$ 4.832.899
$ 16	0%	$ 6.828.537	$ -	$ -	0%	$ 2.191.559	$ -	$ -	$ 13	$ 11.391.967	$ 2.479.224	$ 23	$ 20.390.100	$ 4.437.480
$ 17	0%	$ 6.828.537	$ -	$ -	0%	$ 2.257.306	$ -	$ -	$ 13	$ 11.448.927	$ 2.265.109	$ 23	$ 20.594.001	$ 4.074.413
$ 18	0%	$ 6.828.537	$ -	$ -	0%	$ 2.325.025	$ -	$ -	$ 13	$ 11.506.171	$ 2.069.486	$ 23	$ 20.799.941	$ 3.741.052
$ 19	0%	$ 6.828.537	$ -	$ -	0%	$ 2.394.776	$ -	$ -	$ 13	$ 11.563.702	$ 1.890.758	$ 24	$ 21.007.941	$ 3.434.966
$ 20	0%	$ 6.828.537	$ -	$ -	0%	$ 2.466.619	$ -	$ -	$ 13	$ 11.621.521	$ 1.727.465	$ 24	$ 21.218.020	$ 3.153.923
$ 21	0%	$ 6.828.537	$ -	$ -	0%	$ 2.540.618	$ -	$ -	$ 13	$ 11.679.628	$ 1.578.275	$ 24	$ 21.430.200	$ 2.895.875
$ 22	0%	$ 6.828.537	$ -	$ -	0%	$ 2.616.837	$ -	$ -	$ 13	$ 11.738.026	$ 1.441.969	$ 24	$ 21.644.502	$ 2.658.940
$ 23	0%	$ 6.828.537	$ -	$ -	0%	$ 2.695.342	$ -	$ -	$ 13	$ 11.796.717	$ 1.317.436	$ 24	$ 21.860.947	$ 2.441.390
$ 24	0%	$ 6.828.537	$ -	$ -	0%	$ 2.776.202	$ -	$ -	$ 13	$ 11.855.700	$ 1.203.657	$ 25	$ 22.079.557	$ 2.241.640
$ 25	0%	$ 6.828.537	$ -	$ -	0%	$ 2.859.488	$ -	$ -	$ 13	$ 11.914.979	$ 1.099.705	$ 25	$ 22.300.352	$ 2.058.233
$ 26	0%	$ 6.828.537	$ -	$ -	0%	$ 2.945.273	$ -	$ -	$ 13	$ 11.974.554	$ 1.004.730	$ 25	$ 22.523.356	$ 1.889.832
$ 27	0%	$ 6.828.537	$ -	$ -	0%	$ 3.033.631	$ -	$ -	$ 13	$ 12.034.426	$ 917.958	$ 25	$ 22.748.590	$ 1.735.210
$ 28	0%	$ 6.828.537	$ -	$ -	0%	$ 3.124.640	$ -	$ -	$ 14	$ 12.094.598	$ 838.680	$ 26	$ 22.976.075	$ 1.593.238
$ 29	0%	$ 6.828.537	$ -	$ -	0%	$ 3.218.379	$ -	$ -	$ 14	$ 12.155.071	$ 766.249	$ 26	$ 23.205.836	$ 1.462.882
$ 30	0%	$ 6.828.537	$ -	$ -	0%	$ 3.314.930	$ -	$ -	$ 14	$ 12.215.847	$ 700.073	$ 26	$ 23.437.895	$ 1.343.192
$ 31	0%	$ 6.828.537	$ -	$ -	0%	$ 3.414.378	$ -	$ -	$ 14	$ 12.276.926	$ 639.612	$ 26	$ 23.672.273	$ 1.233.294
$ 32	0%	$ 6.828.537	$ -	$ -	0%	$ 3.516.809	$ -	$ -	$ 14	$ 12.338.311	$ 584.373	$ 27	$ 23.908.996	$ 1.132.388
$ 33	0%	$ 6.828.537	$ -	$ -	0%	$ 3.622.314	$ -	$ -	$ 14	$ 12.400.002	$ 533.904	$ 27	$ 24.148.086	$ 1.039.738
$ 34	0%	$ 6.828.537	$ -	$ -	0%	$ 3.730.983	$ -	$ -	$ 14	$ 12.462.002	$ 487.794	$ 27	$ 24.389.567	$ 954.669
$ 35	0%	$ 6.828.537	$ -	$ -	0%	$ 3.842.913	$ -	$ -	$ 14	$ 12.524.312	$ 445.666	$ 28	$ 24.633.463	$ 876.560
$ 36	0%	$ 6.828.537	$ -	$ -	0%	$ 3.958.200	$ -	$ -	$ 14	$ 12.586.934	$ 407.177	$ 28	$ 24.879.797	$ 804.841
$ 37	0%	$ 6.828.537	$ -	$ -	0%	$ 4.076.946	$ -	$ -	$ 14	$ 12.649.868	$ 372.012	$ 28	$ 25.128.595	$ 738.991
$ 38	0%	$ 6.828.537	$ -	$ -	0%	$ 4.199.254	$ -	$ -	$ 14	$ 12.713.118	$ 339.883	$ 28	$ 25.379.881	$ 678.528
$ 39	0%	$ 6.828.537	$ -	$ -	0%	$ 4.325.232	$ -	$ -	$ 14	$ 12.776.683	$ 310.530	$ 29	$ 25.633.680	$ 623.012
$ 40	0%	$ 6.828.537	$ -	$ -	0%	$ 4.454.989	$ -	$ -	$ 14	$ 12.840.567	$ 283.711	$ 29	$ 25.890.017	$ 572.038
$ 41	0%	$ 6.828.537	$ -	$ -	0%	$ 4.588.639	$ -	$ -	$ 14	$ 12.904.770	$ 259.209	$ 29	$ 26.148.917	$ 525.235
$ 42	0%	$ 6.828.537	$ -	$ -	0%	$ 4.726.298	$ -	$ -	$ 15	$ 12.969.294	$ 236.823	$ 30	$ 26.410.406	$ 482.261
$ 43	0%	$ 6.828.537	$ -	$ -	0%	$ 4.868.087	$ -	$ -	$ 15	$ 13.034.140	$ 216.370	$ 30	$ 26.674.510	$ 442.803
$ 44	0%	$ 6.828.537	$ -	$ -	0%	$ 5.014.129	$ -	$ -	$ 15	$ 13.099.311	$ 197.683	$ 30	$ 26.941.255	$ 406.574
$ 45	0%	$ 6.828.537	$ -	$ -	0%	$ 5.164.553	$ -	$ -	$ 15	$ 13.164.807	$ 180.611	$ 30	$ 27.210.668	$ 373.309
$ 46	0%	$ 6.828.537	$ -	$ -	0%	$ 5.319.490	$ -	$ -	$ 15	$ 13.230.631	$ 165.013	$ 31	$ 27.482.775	$ 342.765
$ 47	0%	$ 6.828.537	$ -	$ -	0%	$ 5.479.075	$ -	$ -	$ 15	$ 13.296.784	$ 150.761	$ 31	$ 27.757.602	$ 314.721
$ 48	0%	$ 6.828.537	$ -	$ -	0%	$ 5.643.447	$ -	$ -	$ 15	$ 13.363.268	$ 137.741	$ 31	$ 28.035.178	$ 288.971
$ 49	0%	$ 6.828.537	$ -	$ -	0%	$ 5.812.750	$ -	$ -	$ 15	$ 13.430.085	$ 125.845	$ 32	$ 28.315.530	$ 265.328
$ 50	0%	$ 6.828.537	$ -	$ -	0%	$ 5.987.133	$ -	$ -	$ 15	$ 13.497.235	$ 114.977	$ 32	$ 28.598.685	$ 243.619
$ 51	0%	$ 6.828.537	$ -	$ -	0%	$ 6.166.747	$ -	$ -	$ 15	$ 13.564.721	$ 105.047	$ 32	$ 28.884.672	$ 223.687
$ 52	0%	$ 6.828.537	$ -	$ -	0%	$ 6.351.749	$ -	$ -	$ 15	$ 13.632.545	$ 95.975	$ 33	$ 29.173.519	$ 205.385
$ 53	0%	$ 6.828.537	$ -	$ -	0%	$ 6.542.302	$ -	$ -	$ 15	$ 13.700.708	$ 87.686	$ 33	$ 29.465.254	$ 188.581
$ 54	0%	$ 6.828.537	$ -	$ -	0%	$ 6.738.571	$ -	$ -	$ 15	$ 13.769.211	$ 80.113	$ 33	$ 29.759.907	$ 173.152
$ 55	0%	$ 6.828.537	$ -	$ -	0%	$ 6.940.728	$ -	$ -	$ 15	$ 13.838.057	$ 73.194	$ 34	$ 30.057.506	$ 158.985
$ 56	0%	$ 6.828.537	$ -	$ -	0%	$ 7.148.950	$ -	$ -	$ 16	$ 13.907.248	$ 66.873	$ 34	$ 30.358.081	$ 145.977
$ 57	0%	$ 6.828.537	$ -	$ -	0%	$ 7.363.418	$ -	$ -	$ 16	$ 13.976.784	$ 61.098	$ 34	$ 30.661.662	$ 134.033
$ 58	0%	$ 6.828.537	$ -	$ -	0%	$ 7.584.321	$ -	$ -	$ 16	$ 14.046.668	$ 55.821	$ 35	$ 30.968.278	$ 123.067
$ 59	0%	$ 6.828.537	$ -	$ -	0%	$ 7.811.850	$ -	$ -	$ 16	$ 14.116.901	$ 51.000	$ 35	$ 31.277.961	$ 112.998
$ 60	0%	$ 6.828.537	$ -	$ -	0%	$ 8.046.206	$ -	$ -	$ 16	$ 14.187.486	$ 46.596	$ 35	$ 31.590.741	$ 103.753
$ 61	0%	$ 6.828.537	$ -	$ -	0%	$ 8.287.592	$ -	$ -	$ 16	$ 14.258.423	$ 42.571	$ 36	$ 31.906.648	$ 95.264
$ 62	0%	$ 6.828.537	$ -	$ -	100%	$ 8.536.220	$ 1.024.346.352	$ 2.780.356	$ 16	$ 14.329.715	$ 38.895	$ 36	$ 32.225.715	$ 87.469

Revenue Calculation

REVENUES						
Electicity				by-products		
Generation [MWh]	Discounted Generation	Price [$/MWh]	Sales [$]	Generation [MWh]	Price [$/MWh]	Sales [$]
$ -	$ -	$ 101	$ -			$ -
$ -	$ -	$ 104	$ -			$ -
$ 893.520	$ 738.446	$ 107	$ 95.741.472			$ -
$ 893.520	$ 671.315	$ 110	$ 98.613.716			$ -
$ 893.520	$ 610.286	$ 114	$ 101.572.128			$ -
$ 893.520	$ 554.806	$ 117	$ 104.619.292			$ -
$ 893.520	$ 504.369	$ 121	$ 107.757.870			$ -
$ 893.520	$ 458.517	$ 124	$ 110.990.607			$ -
$ 893.520	$ 416.834	$ 128	$ 114.320.325			$ -
$ 893.520	$ 378.940	$ 132	$ 117.749.934			$ -
$ 893.520	$ 344.491	$ 136	$ 121.282.432			$ -
$ 893.520	$ 313.173	$ 140	$ 124.920.905			$ -
$ 893.520	$ 284.703	$ 144	$ 128.668.533			$ -
$ 893.520	$ 258.821	$ 148	$ 132.528.589			$ -
$ 893.520	$ 235.292	$ 153	$ 136.504.446			$ -
$ 893.520	$ 213.902	$ 157	$ 140.599.580			$ -
$ 893.520	$ 194.456	$ 162	$ 144.817.567			$ -
$ 893.520	$ 176.778	$ 167	$ 149.162.094			$ -
$ 893.520	$ 160.707	$ 172	$ 153.636.957			$ -
$ 893.520	$ 146.098	$ 177	$ 158.246.066			$ -
$ 893.520	$ 132.816	$ 182	$ 162.993.448			$ -
$ 893.520	$ 120.742	$ 188	$ 167.883.251			$ -
$ 893.520	$ 109.765	$ 194	$ 172.919.749			$ -
$ 893.520	$ 99.787	$ 199	$ 178.107.341			$ -
$ 893.520	$ 90.715	$ 205	$ 183.450.561			$ -
$ 893.520	$ 82.468	$ 211	$ 188.954.078			$ -
$ 893.520	$ 74.971	$ 218	$ 194.622.700			$ -
$ 893.520	$ 68.156	$ 224	$ 200.461.381			$ -
$ 893.520	$ 61.960	$ 231	$ 206.475.223			$ -
$ 893.520	$ 56.327	$ 238	$ 212.669.480			$ -
$ 893.520	$ 51.206	$ 245	$ 219.049.564			$ -
$ 893.520	$ 46.551	$ 253	$ 225.621.051			$ -
$ 893.520	$ 42.319	$ 260	$ 232.389.682			$ -
$ 893.520	$ 38.472	$ 268	$ 239.361.373			$ -
$ 893.520	$ 34.975	$ 276	$ 246.542.214			$ -
$ 893.520	$ 31.795	$ 284	$ 253.938.480			$ -
$ 893.520	$ 28.905	$ 293	$ 261.556.635			$ -
$ 893.520	$ 26.277	$ 302	$ 269.403.334			$ -
$ 893.520	$ 23.888	$ 311	$ 277.485.434			$ -
$ 893.520	$ 21.716	$ 320	$ 285.809.997			$ -
$ 893.520	$ 19.742	$ 329	$ 294.384.297			$ -
$ 893.520	$ 17.948	$ 339	$ 303.215.826			$ -
$ 893.520	$ 16.316	$ 350	$ 312.312.300			$ -
$ 893.520	$ 14.833	$ 360	$ 321.681.669			$ -
$ 893.520	$ 13.484	$ 371	$ 331.332.120			$ -
$ 893.520	$ 12.258	$ 382	$ 341.272.083			$ -
$ 893.520	$ 11.144	$ 393	$ 351.510.246			$ -
$ 893.520	$ 10.131	$ 405	$ 362.055.553			$ -
$ 893.520	$ 9.210	$ 417	$ 372.917.220			$ -
$ 893.520	$ 8.373	$ 430	$ 384.104.736			$ -
$ 893.520	$ 7.611	$ 443	$ 395.627.878			$ -
$ 893.520	$ 6.920	$ 456	$ 407.496.715			$ -
$ 893.520	$ 6.290	$ 470	$ 419.721.616			$ -
$ 893.520	$ 5.719	$ 484	$ 432.313.265			$ -
$ 893.520	$ 5.199	$ 498	$ 445.282.662			$ -
$ 893.520	$ 4.726	$ 513	$ 458.641.142			$ -
$ 893.520	$ 4.296	$ 529	$ 472.400.377			$ -
$ 893.520	$ 3.906	$ 545	$ 486.572.388			$ -
$ 893.520	$ 3.551	$ 561	$ 501.169.560			$ -
$ 893.520	$ 3.228	$ 578	$ 516.204.646			$ -
$ 893.520	$ 2.935	$ 595	$ 531.690.786			$ -
$ 893.520	$ 2.668	$ 613	$ 547.641.509			$ -
$ -	$ -	$ 631	$ -			$ -
$ 53.611.200	$ 8.096.231					

Cash Flow Calculation

CASH FLOWS											
EBITDA	D&A		EBIT	Dept payment	Interest	EBT	TAX	NET INCOME	OCF	FCF	Discounted FCF
	D&A profile	D&A									
$ -27.907.318	$ -	$ -	$ -27.907.318	$ 13.657.074	$ 1.092.566	$ -28.999.884	$ -11.019.956	$ -17.979.928	$ -17.979.928	$ -523.291.649	$ -523.291.649
$ -25.576.182	0,00%	$ -	$ -25.576.182	$ 13.657.074	$ 1.125.343	$ -26.701.525	$ -10.146.580	$ -16.554.946	$ -16.554.946	$ -357.981.784	$ -325.437.985
$ 72.301.568	3,33%	$ 27.314.147	$ 44.987.421	$ 13.657.074	$ 1.159.103	$ 43.828.317	$ 16.654.761	$ 27.173.557	$ 54.487.704	$ 40.830.630	$ 33.744.323
$ 77.131.531	3,33%	$ 27.314.147	$ 49.817.384	$ 13.657.074	$ 1.193.876	$ 48.623.507	$ 18.476.933	$ 30.146.575	$ 57.460.722	$ 43.803.648	$ 32.910.329
$ 81.884.037	3,33%	$ 27.314.147	$ 54.569.890	$ 13.657.074	$ 1.229.693	$ 53.340.198	$ 20.269.275	$ 33.070.923	$ 60.385.070	$ 46.727.996	$ 31.915.850
$ 86.575.358	3,33%	$ 27.314.147	$ 59.261.211	$ 13.657.074	$ 1.266.583	$ 57.994.628	$ 22.037.958	$ 35.956.669	$ 63.270.816	$ 49.613.743	$ 30.806.231
$ 91.220.694	3,33%	$ 27.314.147	$ 63.906.547	$ 13.657.074	$ 1.304.581	$ 62.601.967	$ 23.788.747	$ 38.813.219	$ 66.127.366	$ 52.470.293	$ 29.618.112
$ 95.834.280	3,33%	$ 27.314.147	$ 68.520.132	$ 13.657.074	$ 1.343.718	$ 67.176.414	$ 25.527.037	$ 41.649.377	$ 68.963.524	$ 55.306.450	$ 28.380.954
$ 100.429.467	3,33%	$ 27.314.147	$ 73.115.320	$ 13.657.074	$ 1.384.030	$ 71.731.290	$ 27.257.890	$ 44.473.400	$ 71.787.547	$ 58.130.473	$ 27.118.295
$ 105.018.813	3,33%	$ 27.314.147	$ 77.704.666	$ 13.657.074	$ 1.425.551	$ 76.279.115	$ 28.986.064	$ 47.293.051	$ 74.607.198	$ 60.950.125	$ 25.848.803
$ 109.614.155	3,33%	$ 27.314.147	$ 82.300.008	$ 13.657.074	$ 1.468.317	$ 80.831.691	$ 30.716.043	$ 50.115.648	$ 77.429.795	$ 63.772.722	$ 24.587.145
$ 114.226.681	3,33%	$ 27.314.147	$ 86.912.534	$ 13.657.074	$ 1.512.367	$ 85.400.167	$ 32.452.063	$ 52.948.104	$ 80.262.251	$ 66.605.177	$ 23.344.708
$ 118.866.992	3,33%	$ 27.314.147	$ 91.552.845	$ 13.657.074	$ 1.557.738	$ 89.995.107	$ 34.198.141	$ 55.796.967	$ 83.111.114	$ 69.454.040	$ 22.130.198
$ 123.545.166	3,33%	$ 27.314.147	$ 96.231.019	$ 13.657.074	$ 1.604.470	$ 94.626.549	$ 35.958.089	$ 58.668.460	$ 85.982.607	$ 72.325.534	$ 20.950.131
$ 128.270.807	3,33%	$ 27.314.147	$ 100.956.660	$ 13.657.074	$ 1.652.604	$ 99.304.056	$ 37.735.541	$ 61.568.515	$ 88.882.662	$ 75.225.588	$ 19.809.249
$ 133.053.102	3,33%	$ 27.314.147	$ 105.738.955	$ 13.657.074	$ 1.702.182	$ 104.036.773	$ 39.533.974	$ 64.502.799	$ 91.816.946	$ 78.159.873	$ 18.710.852
$ 137.900.863	3,33%	$ 27.314.147	$ 110.586.716	$ 13.657.074	$ 1.753.248	$ 108.833.469	$ 41.356.718	$ 67.476.751	$ 94.790.898	$ 81.133.824	$ 17.657.084
$ 142.822.572	3,33%	$ 27.314.147	$ 115.508.425	$ 13.657.074	$ 1.805.845	$ 113.702.580	$ 43.206.980	$ 70.495.599	$ 97.809.746	$ 84.152.673	$ 16.649.158
$ 147.826.419	3,33%	$ 27.314.147	$ 120.512.271	$ 13.657.074	$ 1.860.020	$ 118.652.251	$ 45.087.855	$ 73.564.396	$ 100.878.543	$ 87.221.469	$ 15.687.548
$ 152.920.342	3,33%	$ 27.314.147	$ 125.606.195	$ 13.657.074	$ 1.915.821	$ 123.690.374	$ 47.002.342	$ 76.688.032	$ 104.002.179	$ 90.345.105	$ 14.772.147
$ 158.112.059	3,33%	$ 27.314.147	$ 130.797.912	$ 13.657.074	$ 1.973.296	$ 128.824.616	$ 48.953.354	$ 79.871.262	$ 107.185.409	$ 93.528.336	$ 13.902.391
$ 163.409.101	3,33%	$ 27.314.147	$ 136.094.954	$ 13.657.074	$ 2.032.494	$ 134.062.459	$ 50.943.735	$ 83.118.725	$ 110.432.872	$ 96.775.798	$ 13.077.369
$ 168.818.839	3,33%	$ 27.314.147	$ 141.504.692	$ 13.657.074	$ 2.093.469	$ 139.411.223	$ 52.976.265	$ 86.434.958	$ 113.749.105	$ 100.092.032	$ 12.295.903
$ 174.348.515	3,33%	$ 27.314.147	$ 147.034.368	$ 13.657.074	$ 2.156.273	$ 144.878.095	$ 55.053.676	$ 89.824.419	$ 117.138.566	$ 103.481.492	$ 11.556.622
$ 180.005.264	3,33%	$ 27.314.147	$ 152.691.117	$ 13.657.074	$ 2.220.961	$ 150.470.155	$ 57.178.659	$ 93.291.496	$ 120.605.643	$ 106.948.570	$ 10.858.018
$ 185.796.140	3,33%	$ 27.314.147	$ 158.481.993	$ 13.657.074	$ 2.287.590	$ 156.194.403	$ 59.353.873	$ 96.840.530	$ 124.154.677	$ 110.497.603	$ 10.198.487
$ 191.728.138	3,33%	$ 27.314.147	$ 164.413.991	$ 13.657.074	$ 2.356.218	$ 162.057.773	$ 61.581.954	$ 100.475.819	$ 127.789.966	$ 114.132.893	$ 9.576.372
$ 197.808.213	3,33%	$ 27.314.147	$ 170.494.066	$ 13.657.074	$ 2.426.905	$ 168.067.162	$ 63.865.522	$ 104.201.640	$ 131.515.787	$ 117.858.714	$ 8.989.990
$ 204.043.305	3,33%	$ 27.314.147	$ 176.729.158	$ 13.657.074	$ 2.499.712	$ 174.229.446	$ 66.207.190	$ 108.022.257	$ 135.336.404	$ 121.679.330	$ 8.437.652
$ 210.440.349	3,33%	$ 27.314.147	$ 183.126.202	$ 13.657.074	$ 2.574.703	$ 180.551.499	$ 68.609.569	$ 111.941.929	$ 139.256.076	$ 125.599.003	$ 7.917.687
$ 217.006.300	3,33%	$ 27.314.147	$ 189.692.153	$ -	$ -	$ 189.692.153	$ 72.083.018	$ 117.609.135	$ 144.923.282	$ 144.923.282	$ 8.305.344
$ 223.748.145	3,33%	$ 27.314.147	$ 196.433.998	$ -	$ -	$ 196.433.998	$ 74.644.919	$ 121.789.079	$ 149.103.226	$ 149.103.226	$ 7.768.082
$ 230.672.921	0,00%	$ -	$ 230.672.921	$ -	$ -	$ 230.672.921	$ 87.655.710	$ 143.017.211	$ 143.017.211	$ 143.017.211	$ 6.773.644
$ 237.787.730	0,00%	$ -	$ 237.787.730	$ -	$ -	$ 237.787.730	$ 90.359.338	$ 147.428.393	$ 147.428.393	$ 147.428.393	$ 6.347.790
$ 245.099.751	0,00%	$ -	$ 245.099.751	$ -	$ -	$ 245.099.751	$ 93.137.905	$ 151.961.846	$ 151.961.846	$ 151.961.846	$ 5.948.169
$ 252.616.254	0,00%	$ -	$ 252.616.254	$ -	$ -	$ 252.616.254	$ 95.994.177	$ 156.622.078	$ 156.622.078	$ 156.622.078	$ 5.573.256
$ 260.344.617	0,00%	$ -	$ 260.344.617	$ -	$ -	$ 260.344.617	$ 98.930.954	$ 161.413.662	$ 161.413.662	$ 161.413.662	$ 5.221.600
$ 268.292.332	0,00%	$ -	$ 268.292.332	$ -	$ -	$ 268.292.332	$ 101.951.086	$ 166.341.246	$ 166.341.246	$ 166.341.246	$ 4.891.821
$ 276.467.023	0,00%	$ -	$ 276.467.023	$ -	$ -	$ 276.467.023	$ 105.057.469	$ 171.409.554	$ 171.409.554	$ 171.409.554	$ 4.582.611
$ 284.876.455	0,00%	$ -	$ 284.876.455	$ -	$ -	$ 284.876.455	$ 108.253.053	$ 176.623.402	$ 176.623.402	$ 176.623.402	$ 4.292.730
$ 293.528.547	0,00%	$ -	$ 293.528.547	$ -	$ -	$ 293.528.547	$ 111.540.848	$ 181.987.699	$ 181.987.699	$ 181.987.699	$ 4.021.005
$ 302.431.382	0,00%	$ -	$ 302.431.382	$ -	$ -	$ 302.431.382	$ 114.923.925	$ 187.507.457	$ 187.507.457	$ 187.507.457	$ 3.766.331
$ 311.593.216	0%	$ -	$ 311.593.216	$ -	$ -	$ 311.593.216	$ 118.405.422	$ 193.187.794	$ 193.187.794	$ 193.187.794	$ 3.527.662
$ 321.022.496	0%	$ -	$ 321.022.496	$ -	$ -	$ 321.022.496	$ 121.988.549	$ 199.033.948	$ 199.033.948	$ 199.033.948	$ 3.304.013
$ 330.727.862	0%	$ -	$ 330.727.862	$ -	$ -	$ 330.727.862	$ 125.676.588	$ 205.051.274	$ 205.051.274	$ 205.051.274	$ 3.094.456
$ 340.718.163	0%	$ -	$ 340.718.163	$ -	$ -	$ 340.718.163	$ 129.472.902	$ 211.245.261	$ 211.245.261	$ 211.245.261	$ 2.898.119
$ 351.002.468	0%	$ -	$ 351.002.468	$ -	$ -	$ 351.002.468	$ 133.380.938	$ 217.621.530	$ 217.621.530	$ 217.621.530	$ 2.714.178
$ 361.590.071	0%	$ -	$ 361.590.071	$ -	$ -	$ 361.590.071	$ 137.404.227	$ 224.185.844	$ 224.185.844	$ 224.185.844	$ 2.541.862
$ 372.490.507	0%	$ -	$ 372.490.507	$ -	$ -	$ 372.490.507	$ 141.546.393	$ 230.944.115	$ 230.944.115	$ 230.944.115	$ 2.380.444
$ 383.713.563	0%	$ -	$ 383.713.563	$ -	$ -	$ 383.713.563	$ 145.811.154	$ 237.902.409	$ 237.902.409	$ 237.902.409	$ 2.229.242
$ 395.269.282	0%	$ -	$ 395.269.282	$ -	$ -	$ 395.269.282	$ 150.202.327	$ 245.066.955	$ 245.066.955	$ 245.066.955	$ 2.087.615
$ 407.167.981	0%	$ -	$ 407.167.981	$ -	$ -	$ 407.167.981	$ 154.723.833	$ 252.444.148	$ 252.444.148	$ 252.444.148	$ 1.954.962
$ 419.420.256	0%	$ -	$ 419.420.256	$ -	$ -	$ 419.420.256	$ 159.379.697	$ 260.040.559	$ 260.040.559	$ 260.040.559	$ 1.830.718
$ 432.036.997	0%	$ -	$ 432.036.997	$ -	$ -	$ 432.036.997	$ 164.174.059	$ 267.862.938	$ 267.862.938	$ 267.862.938	$ 1.714.353
$ 445.029.398	0%	$ -	$ 445.029.398	$ -	$ -	$ 445.029.398	$ 169.111.171	$ 275.918.227	$ 275.918.227	$ 275.918.227	$ 1.605.371
$ 458.408.963	0%	$ -	$ 458.408.963	$ -	$ -	$ 458.408.963	$ 174.195.406	$ 284.213.557	$ 284.213.557	$ 284.213.557	$ 1.503.305
$ 472.187.527	0%	$ -	$ 472.187.527	$ -	$ -	$ 472.187.527	$ 179.431.260	$ 292.756.267	$ 292.756.267	$ 292.756.267	$ 1.407.719
$ 486.377.257	0%	$ -	$ 486.377.257	$ -	$ -	$ 486.377.257	$ 184.823.358	$ 301.553.899	$ 301.553.899	$ 301.553.899	$ 1.318.202
$ 500.990.672	0%	$ -	$ 500.990.672	$ -	$ -	$ 500.990.672	$ 190.376.455	$ 310.614.216	$ 310.614.216	$ 310.614.216	$ 1.234.371
$ 516.040.648	0%	$ -	$ 516.040.648	$ -	$ -	$ 516.040.648	$ 196.095.446	$ 319.945.202	$ 319.945.202	$ 319.945.202	$ 1.155.865
$ 531.540.438	0%	$ -	$ 531.540.438	$ -	$ -	$ 531.540.438	$ 201.985.366	$ 329.555.071	$ 329.555.071	$ 329.555.071	$ 1.082.348
$ 547.503.674	0%	$ -	$ 547.503.674	$ -	$ -	$ 547.503.674	$ 208.051.396	$ 339.452.278	$ 339.452.278	$ 339.452.278	$ 1.013.503
$ -126.364	0%	$ -	$ -126.364	$ -	$ -	$ -126.364	$ -48.018	$ -78.346	$ -78.346	$ -1.024.424.698	$ -2.780.568

Appendix C Optimistic Scenario

I. No Debt Considered

Imputs

Fuel $/MWh	$	4
O&M $/Mwh	$	10
Capital $/Mwh	$	4.243.920
Decomissioning $/Mwh	$	1.138.089
Electicity price $/Mwh	$	110
WACC %		10%
Byprod percentage %		0%

Outputs

RESULTS			
Net Present Value		$	336.481.399
IRR			15%
Payback period	**disccounted**	$	14,45
	Aprox	$	8,26
LCOE	**construction**	$	60,61
	decomissioning	$	0,29
	fuel	$	5,25
	O&M	$	13,06
	TOTAL	$	79,22

Cost Calculation

	COSTS													
	Construction profile				Decomissioning				Fuel			O&M		
Year	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Profile	Cost [$/MW]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]	Cost [$/MWh]	Cost [$]	Disccounted Cost [$]
$ -	60%	$ 4.243.920	$ 305.562.218	$ 305.562.218	0%	$ 1.138.089	$ -	$ -	$ 4	$ 3.685.446	$ 3.685.446	$ 10	$ 8.694.556	$ 8.694.556
$ 1	40%	$ 4.243.920	$ 203.708.145	$ 185.189.223	0%	$ 1.172.232	$ -	$ -	$ 4	$ 3.703.873	$ 3.367.158	$ 10	$ 8.781.501	$ 7.983.183
$ 2	0%	$ 4.243.920	$ -	$ -	0%	$ 1.207.399	$ -	$ -	$ 4	$ 3.722.393	$ 3.076.358	$ 10	$ 8.869.316	$ 7.330.013
$ 3	0%	$ 4.243.920	$ -	$ -	0%	$ 1.243.621	$ -	$ -	$ 4	$ 3.741.005	$ 2.810.672	$ 10	$ 8.958.009	$ 6.730.285
$ 4	0%	$ 4.243.920	$ -	$ -	0%	$ 1.280.930	$ -	$ -	$ 4	$ 3.759.710	$ 2.567.932	$ 10	$ 9.047.589	$ 6.179.625
$ 5	0%	$ 4.243.920	$ -	$ -	0%	$ 1.319.358	$ -	$ -	$ 4	$ 3.778.508	$ 2.346.156	$ 10	$ 9.138.065	$ 5.674.020
$ 6	0%	$ 4.243.920	$ -	$ -	0%	$ 1.358.938	$ -	$ -	$ 4	$ 3.797.401	$ 2.143.534	$ 10	$ 9.229.446	$ 5.209.782
$ 7	0%	$ 4.243.920	$ -	$ -	0%	$ 1.399.706	$ -	$ -	$ 4	$ 3.816.388	$ 1.958.410	$ 10	$ 9.321.740	$ 4.783.527
$ 8	0%	$ 4.243.920	$ -	$ -	0%	$ 1.441.698	$ -	$ -	$ 4	$ 3.835.470	$ 1.789.275	$ 11	$ 9.414.958	$ 4.392.147
$ 9	0%	$ 4.243.920	$ -	$ -	0%	$ 1.484.949	$ -	$ -	$ 4	$ 3.854.647	$ 1.634.747	$ 11	$ 9.509.107	$ 4.032.790
$ 10	0%	$ 4.243.920	$ -	$ -	0%	$ 1.529.497	$ -	$ -	$ 4	$ 3.873.920	$ 1.493.564	$ 11	$ 9.604.198	$ 3.702.834
$ 11	0%	$ 4.243.920	$ -	$ -	0%	$ 1.575.382	$ -	$ -	$ 4	$ 3.893.290	$ 1.364.574	$ 11	$ 9.700.240	$ 3.399.875
$ 12	0%	$ 4.243.920	$ -	$ -	0%	$ 1.622.643	$ -	$ -	$ 4	$ 3.912.756	$ 1.246.725	$ 11	$ 9.797.243	$ 3.121.703
$ 13	0%	$ 4.243.920	$ -	$ -	0%	$ 1.671.323	$ -	$ -	$ 4	$ 3.932.320	$ 1.139.053	$ 11	$ 9.895.215	$ 2.866.291
$ 14	0%	$ 4.243.920	$ -	$ -	0%	$ 1.721.462	$ -	$ -	$ 4	$ 3.951.982	$ 1.040.680	$ 11	$ 9.994.167	$ 2.631.777
$ 15	0%	$ 4.243.920	$ -	$ -	0%	$ 1.773.106	$ -	$ -	$ 4	$ 3.971.742	$ 950.803	$ 11	$ 10.094.109	$ 2.416.449
$ 16	0%	$ 4.243.920	$ -	$ -	0%	$ 1.826.299	$ -	$ -	$ 4	$ 3.991.600	$ 868.689	$ 11	$ 10.195.050	$ 2.218.740
$ 17	0%	$ 4.243.920	$ -	$ -	0%	$ 1.881.088	$ -	$ -	$ 4	$ 4.011.558	$ 793.665	$ 12	$ 10.297.001	$ 2.037.207
$ 18	0%	$ 4.243.920	$ -	$ -	0%	$ 1.937.521	$ -	$ -	$ 5	$ 4.031.616	$ 725.122	$ 12	$ 10.399.971	$ 1.870.526
$ 19	0%	$ 4.243.920	$ -	$ -	0%	$ 1.995.647	$ -	$ -	$ 5	$ 4.051.774	$ 662.497	$ 12	$ 10.503.970	$ 1.717.483
$ 20	0%	$ 4.243.920	$ -	$ -	0%	$ 2.055.516	$ -	$ -	$ 5	$ 4.072.033	$ 605.282	$ 12	$ 10.609.010	$ 1.576.962
$ 21	0%	$ 4.243.920	$ -	$ -	0%	$ 2.117.182	$ -	$ -	$ 5	$ 4.092.393	$ 553.007	$ 12	$ 10.715.100	$ 1.447.938
$ 22	0%	$ 4.243.920	$ -	$ -	0%	$ 2.180.697	$ -	$ -	$ 5	$ 4.112.855	$ 505.248	$ 12	$ 10.822.251	$ 1.329.470
$ 23	0%	$ 4.243.920	$ -	$ -	0%	$ 2.246.118	$ -	$ -	$ 5	$ 4.133.419	$ 461.613	$ 12	$ 10.930.474	$ 1.220.695
$ 24	0%	$ 4.243.920	$ -	$ -	0%	$ 2.313.502	$ -	$ -	$ 5	$ 4.154.087	$ 421.746	$ 12	$ 11.039.778	$ 1.120.820
$ 25	0%	$ 4.243.920	$ -	$ -	0%	$ 2.382.907	$ -	$ -	$ 5	$ 4.174.857	$ 385.323	$ 12	$ 11.150.176	$ 1.029.117
$ 26	0%	$ 4.243.920	$ -	$ -	0%	$ 2.454.394	$ -	$ -	$ 5	$ 4.195.731	$ 352.045	$ 13	$ 11.261.678	$ 944.916
$ 27	0%	$ 4.243.920	$ -	$ -	0%	$ 2.528.026	$ -	$ -	$ 5	$ 4.216.710	$ 321.641	$ 13	$ 11.374.295	$ 867.605
$ 28	0%	$ 4.243.920	$ -	$ -	0%	$ 2.603.866	$ -	$ -	$ 5	$ 4.237.793	$ 293.863	$ 13	$ 11.488.038	$ 796.619
$ 29	0%	$ 4.243.920	$ -	$ -	0%	$ 2.681.982	$ -	$ -	$ 5	$ 4.258.982	$ 268.484	$ 13	$ 11.602.918	$ 731.441
$ 30	0%	$ 4.243.920	$ -	$ -	0%	$ 2.762.442	$ -	$ -	$ 5	$ 4.280.277	$ 245.297	$ 13	$ 11.718.947	$ 671.596
$ 31	0%	$ 4.243.920	$ -	$ -	0%	$ 2.845.315	$ -	$ -	$ 5	$ 4.301.679	$ 224.112	$ 13	$ 11.836.137	$ 616.647
$ 32	0%	$ 4.243.920	$ -	$ -	0%	$ 2.930.675	$ -	$ -	$ 5	$ 4.323.187	$ 204.757	$ 13	$ 11.954.498	$ 566.194
$ 33	0%	$ 4.243.920	$ -	$ -	0%	$ 3.018.595	$ -	$ -	$ 5	$ 4.344.803	$ 187.073	$ 14	$ 12.074.043	$ 519.869
$ 34	0%	$ 4.243.920	$ -	$ -	0%	$ 3.109.153	$ -	$ -	$ 5	$ 4.366.527	$ 170.917	$ 14	$ 12.194.784	$ 477.334
$ 35	0%	$ 4.243.920	$ -	$ -	0%	$ 3.202.427	$ -	$ -	$ 5	$ 4.388.360	$ 156.156	$ 14	$ 12.316.731	$ 438.280
$ 36	0%	$ 4.243.920	$ -	$ -	0%	$ 3.298.500	$ -	$ -	$ 5	$ 4.410.301	$ 142.670	$ 14	$ 12.439.899	$ 402.421
$ 37	0%	$ 4.243.920	$ -	$ -	0%	$ 3.397.455	$ -	$ -	$ 5	$ 4.432.353	$ 130.348	$ 14	$ 12.564.298	$ 369.495
$ 38	0%	$ 4.243.920	$ -	$ -	0%	$ 3.499.379	$ -	$ -	$ 5	$ 4.454.515	$ 119.091	$ 14	$ 12.689.941	$ 339.264
$ 39	0%	$ 4.243.920	$ -	$ -	0%	$ 3.604.360	$ -	$ -	$ 5	$ 4.476.787	$ 108.806	$ 14	$ 12.816.840	$ 311.506
$ 40	0%	$ 4.243.920	$ -	$ -	0%	$ 3.712.491	$ -	$ -	$ 5	$ 4.499.171	$ 99.409	$ 14	$ 12.945.008	$ 286.019
$ 41	0%	$ 4.243.920	$ -	$ -	0%	$ 3.823.866	$ -	$ -	$ 5	$ 4.521.667	$ 90.824	$ 15	$ 13.074.459	$ 262.617
$ 42	0%	$ 4.243.920	$ -	$ -	0%	$ 3.938.582	$ -	$ -	$ 5	$ 4.544.275	$ 82.980	$ 15	$ 13.205.203	$ 241.131
$ 43	0%	$ 4.243.920	$ -	$ -	0%	$ 4.056.739	$ -	$ -	$ 5	$ 4.566.997	$ 75.813	$ 15	$ 13.337.255	$ 221.402
$ 44	0%	$ 4.243.920	$ -	$ -	0%	$ 4.178.441	$ -	$ -	$ 5	$ 4.589.832	$ 69.266	$ 15	$ 13.470.628	$ 203.287
$ 45	0%	$ 4.243.920	$ -	$ -	0%	$ 4.303.794	$ -	$ -	$ 5	$ 4.612.781	$ 63.284	$ 15	$ 13.605.334	$ 186.654
$ 46	0%	$ 4.243.920	$ -	$ -	0%	$ 4.432.908	$ -	$ -	$ 5	$ 4.635.845	$ 57.818	$ 15	$ 13.741.387	$ 171.383
$ 47	0%	$ 4.243.920	$ -	$ -	0%	$ 4.565.895	$ -	$ -	$ 5	$ 4.659.024	$ 52.825	$ 16	$ 13.878.801	$ 157.361
$ 48	0%	$ 4.243.920	$ -	$ -	0%	$ 4.702.872	$ -	$ -	$ 5	$ 4.682.319	$ 48.263	$ 16	$ 14.017.589	$ 144.486
$ 49	0%	$ 4.243.920	$ -	$ -	0%	$ 4.843.958	$ -	$ -	$ 5	$ 4.705.731	$ 44.095	$ 16	$ 14.157.765	$ 132.664
$ 50	0%	$ 4.243.920	$ -	$ -	0%	$ 4.989.277	$ -	$ -	$ 5	$ 4.729.259	$ 40.286	$ 16	$ 14.299.343	$ 121.810
$ 51	0%	$ 4.243.920	$ -	$ -	0%	$ 5.138.956	$ -	$ -	$ 5	$ 4.752.906	$ 36.807	$ 16	$ 14.442.336	$ 111.843
$ 52	0%	$ 4.243.920	$ -	$ -	0%	$ 5.293.124	$ -	$ -	$ 5	$ 4.776.670	$ 33.628	$ 16	$ 14.586.760	$ 102.693
$ 53	0%	$ 4.243.920	$ -	$ -	0%	$ 5.451.918	$ -	$ -	$ 5	$ 4.800.554	$ 30.724	$ 16	$ 14.732.627	$ 94.290
$ 54	0%	$ 4.243.920	$ -	$ -	0%	$ 5.615.475	$ -	$ -	$ 5	$ 4.824.556	$ 28.071	$ 17	$ 14.879.953	$ 86.576
$ 55	0%	$ 4.243.920	$ -	$ -	0%	$ 5.783.940	$ -	$ -	$ 5	$ 4.848.679	$ 25.646	$ 17	$ 15.028.753	$ 79.492
$ 56	0%	$ 4.243.920	$ -	$ -	0%	$ 5.957.458	$ -	$ -	$ 5	$ 4.872.923	$ 23.431	$ 17	$ 15.179.040	$ 72.988
$ 57	0%	$ 4.243.920	$ -	$ -	0%	$ 6.136.182	$ -	$ -	$ 5	$ 4.897.287	$ 21.408	$ 17	$ 15.330.831	$ 67.017
$ 58	0%	$ 4.243.920	$ -	$ -	0%	$ 6.320.267	$ -	$ -	$ 6	$ 4.921.774	$ 19.559	$ 17	$ 15.484.139	$ 61.533
$ 59	0%	$ 4.243.920	$ -	$ -	0%	$ 6.509.875	$ -	$ -	$ 6	$ 4.946.383	$ 17.870	$ 18	$ 15.638.981	$ 56.499
$ 60	0%	$ 4.243.920	$ -	$ -	0%	$ 6.705.171	$ -	$ -	$ 6	$ 4.971.114	$ 16.326	$ 18	$ 15.795.370	$ 51.876
$ 61	0%	$ 4.243.920	$ -	$ -	0%	$ 6.906.327	$ -	$ -	$ 6	$ 4.995.970	$ 14.916	$ 18	$ 15.953.324	$ 47.632
$ 62	0%	$ 4.243.920	$ -	$ -	100%	$ 7.113.516	$ 853.621.960	$ 2.316.963	$ 6	$ 5.020.950	$ 13.628	$ 18	$ 16.112.857	$ 43.735

Revenue Calculation

REVENUES						
Electicity				by-products		
Generation [MWh]	**Discounted Generation**	**Price [$/MWh]**	**Sales [$]**	**Generation [MWh**	**Price [$/MWh]**	**Sales [$]**
$ -	$ -	$ 110	$ -			$ -
$ -	$ -	$ 113	$ -			$ -
$ 893.520	$ 738.446	$ 116	$ 103.894.614			$ -
$ 893.520	$ 671.315	$ 120	$ 107.011.453			$ -
$ 893.520	$ 610.286	$ 123	$ 110.221.796			$ -
$ 893.520	$ 554.806	$ 127	$ 113.528.450			$ -
$ 893.520	$ 504.369	$ 131	$ 116.934.304			$ -
$ 893.520	$ 458.517	$ 135	$ 120.442.333			$ -
$ 893.520	$ 416.834	$ 139	$ 124.055.603			$ -
$ 893.520	$ 378.940	$ 143	$ 127.777.271			$ -
$ 893.520	$ 344.491	$ 147	$ 131.610.589			$ -
$ 893.520	$ 313.173	$ 152	$ 135.558.907			$ -
$ 893.520	$ 284.703	$ 156	$ 139.625.674			$ -
$ 893.520	$ 258.821	$ 161	$ 143.814.444			$ -
$ 893.520	$ 235.292	$ 166	$ 148.128.878			$ -
$ 893.520	$ 213.902	$ 171	$ 152.572.744			$ -
$ 893.520	$ 194.456	$ 176	$ 157.149.926			$ -
$ 893.520	$ 176.778	$ 181	$ 161.864.424			$ -
$ 893.520	$ 160.707	$ 187	$ 166.720.357			$ -
$ 893.520	$ 146.098	$ 192	$ 171.721.967			$ -
$ 893.520	$ 132.816	$ 198	$ 176.873.627			$ -
$ 893.520	$ 120.742	$ 204	$ 182.179.835			$ -
$ 893.520	$ 109.765	$ 210	$ 187.645.230			$ -
$ 893.520	$ 99.787	$ 216	$ 193.274.587			$ -
$ 893.520	$ 90.715	$ 223	$ 199.072.825			$ -
$ 893.520	$ 82.468	$ 229	$ 205.045.010			$ -
$ 893.520	$ 74.971	$ 236	$ 211.196.360			$ -
$ 893.520	$ 68.156	$ 243	$ 217.532.251			$ -
$ 893.520	$ 61.960	$ 251	$ 224.058.218			$ -
$ 893.520	$ 56.327	$ 258	$ 230.779.965			$ -
$ 893.520	$ 51.206	$ 266	$ 237.703.364			$ -
$ 893.520	$ 46.551	$ 274	$ 244.834.465			$ -
$ 893.520	$ 42.319	$ 282	$ 252.179.499			$ -
$ 893.520	$ 38.472	$ 291	$ 259.744.884			$ -
$ 893.520	$ 34.975	$ 299	$ 267.537.230			$ -
$ 893.520	$ 31.795	$ 308	$ 275.563.347			$ -
$ 893.520	$ 28.905	$ 318	$ 283.830.247			$ -
$ 893.520	$ 26.277	$ 327	$ 292.345.155			$ -
$ 893.520	$ 23.888	$ 337	$ 301.115.509			$ -
$ 893.520	$ 21.716	$ 347	$ 310.148.975			$ -
$ 893.520	$ 19.742	$ 358	$ 319.453.444			$ -
$ 893.520	$ 17.948	$ 368	$ 329.037.047			$ -
$ 893.520	$ 16.316	$ 379	$ 338.908.159			$ -
$ 893.520	$ 14.833	$ 391	$ 349.075.403			$ -
$ 893.520	$ 13.484	$ 402	$ 359.547.666			$ -
$ 893.520	$ 12.258	$ 414	$ 370.334.096			$ -
$ 893.520	$ 11.144	$ 427	$ 381.444.118			$ -
$ 893.520	$ 10.131	$ 440	$ 392.887.442			$ -
$ 893.520	$ 9.210	$ 453	$ 404.674.065			$ -
$ 893.520	$ 8.373	$ 466	$ 416.814.287			$ -
$ 893.520	$ 7.611	$ 480	$ 429.318.716			$ -
$ 893.520	$ 6.920	$ 495	$ 442.198.277			$ -
$ 893.520	$ 6.290	$ 510	$ 455.464.226			$ -
$ 893.520	$ 5.719	$ 525	$ 469.128.152			$ -
$ 893.520	$ 5.199	$ 541	$ 483.201.997			$ -
$ 893.520	$ 4.726	$ 557	$ 497.698.057			$ -
$ 893.520	$ 4.296	$ 574	$ 512.628.999			$ -
$ 893.520	$ 3.906	$ 591	$ 528.007.868			$ -
$ 893.520	$ 3.551	$ 609	$ 543.848.105			$ -
$ 893.520	$ 3.228	$ 627	$ 560.163.548			$ -
$ 893.520	$ 2.935	$ 646	$ 576.968.454			$ -
$ 893.520	$ 2.668	$ 665	$ 594.277.508			$ -
$ -	$ -	$ 685	$ -			$ -
$ 53.611.200	$ 8.096.231					

Cash Flow Calculation

CASH FLOWS								
EBITDA	D&A		EBITDA	TAX	NET INCOME	OCF	FCF	Discounted FCF
	D&A profile	D&A						
$ -12.380.002	$ -	$ -	$ -12.380.002	$ -4.704.401	$ -7.675.601	$ -7.675.601	$ -313.237.819	$ -313.237.819
$ -11.350.340	0,00%	$ -	$ -11.350.340	$ -4.313.129	$ -7.037.211	$ -7.037.211	$ -210.745.356	$ -191.586.688
$ 93.488.244	3,33%	$ 16.975.679	$ 76.512.565	$ 29.074.775	$ 47.437.790	$ 64.413.469	$ 64.413.469	$ 53.234.272
$ 97.470.496	3,33%	$ 16.975.679	$ 80.494.817	$ 30.588.030	$ 49.906.787	$ 66.882.465	$ 66.882.465	$ 50.249.786
$ 101.474.239	3,33%	$ 16.975.679	$ 84.498.560	$ 32.109.453	$ 52.389.107	$ 69.364.786	$ 69.364.786	$ 47.377.082
$ 105.508.275	3,33%	$ 16.975.679	$ 88.532.596	$ 33.642.386	$ 54.890.209	$ 71.865.888	$ 71.865.888	$ 44.623.062
$ 109.580.989	3,33%	$ 16.975.679	$ 92.605.310	$ 35.190.018	$ 57.415.292	$ 74.390.971	$ 74.390.971	$ 41.991.764
$ 113.700.396	3,33%	$ 16.975.679	$ 96.724.717	$ 36.755.393	$ 59.969.325	$ 76.945.003	$ 76.945.003	$ 39.484.953
$ 117.874.181	3,33%	$ 16.975.679	$ 100.898.502	$ 38.341.431	$ 62.557.071	$ 79.532.750	$ 79.532.750	$ 37.102.615
$ 122.109.735	3,33%	$ 16.975.679	$ 105.134.056	$ 39.950.941	$ 65.183.115	$ 82.158.793	$ 82.158.793	$ 34.843.349
$ 126.414.191	3,33%	$ 16.975.679	$ 109.438.512	$ 41.586.635	$ 67.851.878	$ 84.827.556	$ 84.827.556	$ 32.704.695
$ 130.794.457	3,33%	$ 16.975.679	$ 113.818.779	$ 43.251.136	$ 70.567.643	$ 87.543.322	$ 87.543.322	$ 30.683.400
$ 135.257.246	3,33%	$ 16.975.679	$ 118.281.567	$ 44.946.995	$ 73.334.572	$ 90.310.250	$ 90.310.250	$ 28.775.629
$ 139.809.100	3,33%	$ 16.975.679	$ 122.833.421	$ 46.676.700	$ 76.156.721	$ 93.132.400	$ 93.132.400	$ 26.977.139
$ 144.456.421	3,33%	$ 16.975.679	$ 127.480.742	$ 48.442.682	$ 79.038.060	$ 96.013.739	$ 96.013.739	$ 25.283.418
$ 149.205.491	3,33%	$ 16.975.679	$ 132.229.812	$ 50.247.329	$ 81.982.484	$ 98.958.162	$ 98.958.162	$ 23.689.797
$ 154.062.498	3,33%	$ 16.975.679	$ 137.086.819	$ 52.092.991	$ 84.993.828	$ 101.969.507	$ 101.969.507	$ 22.191.536
$ 159.033.552	3,33%	$ 16.975.679	$ 142.057.873	$ 53.981.992	$ 88.075.881	$ 105.051.560	$ 105.051.560	$ 20.783.891
$ 164.124.709	3,33%	$ 16.975.679	$ 147.149.030	$ 55.916.632	$ 91.232.399	$ 108.208.078	$ 108.208.078	$ 19.462.174
$ 169.341.987	3,33%	$ 16.975.679	$ 152.366.308	$ 57.899.197	$ 94.467.111	$ 111.442.790	$ 111.442.790	$ 18.221.787
$ 174.691.383	3,33%	$ 16.975.679	$ 157.715.704	$ 59.931.968	$ 97.783.737	$ 114.759.415	$ 114.759.415	$ 17.058.256
$ 180.178.890	3,33%	$ 16.975.679	$ 163.203.211	$ 62.017.220	$ 101.185.991	$ 118.161.670	$ 118.161.670	$ 15.967.254
$ 185.810.513	3,33%	$ 16.975.679	$ 168.834.834	$ 64.157.237	$ 104.677.597	$ 121.653.276	$ 121.653.276	$ 14.944.615
$ 191.592.279	3,33%	$ 16.975.679	$ 174.616.601	$ 66.354.308	$ 108.262.292	$ 125.237.971	$ 125.237.971	$ 13.986.346
$ 197.530.259	3,33%	$ 16.975.679	$ 180.554.580	$ 68.610.740	$ 111.943.840	$ 128.919.518	$ 128.919.518	$ 13.088.631
$ 203.630.570	3,33%	$ 16.975.679	$ 186.654.892	$ 70.928.859	$ 115.726.033	$ 132.701.712	$ 132.701.712	$ 12.247.837
$ 209.899.399	3,33%	$ 16.975.679	$ 192.923.720	$ 73.311.014	$ 119.612.707	$ 136.588.385	$ 136.588.385	$ 11.460.510
$ 216.343.005	3,33%	$ 16.975.679	$ 199.367.326	$ 75.759.584	$ 123.607.742	$ 140.583.421	$ 140.583.421	$ 10.723.378
$ 222.967.736	3,33%	$ 16.975.679	$ 205.992.058	$ 78.276.982	$ 127.715.076	$ 144.690.755	$ 144.690.755	$ 10.033.342
$ 229.780.040	3,33%	$ 16.975.679	$ 212.804.361	$ 80.865.657	$ 131.938.704	$ 148.914.383	$ 148.914.383	$ 9.387.475
$ 236.786.471	3,33%	$ 16.975.679	$ 219.810.793	$ 83.528.101	$ 136.282.691	$ 153.258.370	$ 153.258.370	$ 8.783.015
$ 243.993.706	3,33%	$ 16.975.679	$ 227.018.027	$ 86.266.850	$ 140.751.177	$ 157.726.855	$ 157.726.855	$ 8.217.362
$ 251.408.548	0,00%	$ -	$ 251.408.548	$ 95.535.248	$ 155.873.300	$ 155.873.300	$ 155.873.300	$ 7.382.540
$ 259.037.941	0,00%	$ -	$ 259.037.941	$ 98.434.418	$ 160.603.524	$ 160.603.524	$ 160.603.524	$ 6.915.068
$ 266.888.979	0,00%	$ -	$ 266.888.979	$ 101.417.812	$ 165.471.167	$ 165.471.167	$ 165.471.167	$ 6.476.957
$ 274.968.911	0,00%	$ -	$ 274.968.911	$ 104.488.186	$ 170.480.725	$ 170.480.725	$ 170.480.725	$ 6.066.404
$ 283.285.157	0,00%	$ -	$ 283.285.157	$ 107.648.360	$ 175.636.797	$ 175.636.797	$ 175.636.797	$ 5.681.707
$ 291.845.311	0,00%	$ -	$ 291.845.311	$ 110.901.218	$ 180.944.093	$ 180.944.093	$ 180.944.093	$ 5.321.267
$ 300.657.155	0,00%	$ -	$ 300.657.155	$ 114.249.719	$ 186.407.436	$ 186.407.436	$ 186.407.436	$ 4.983.577
$ 309.728.663	0,00%	$ -	$ 309.728.663	$ 117.696.892	$ 192.031.771	$ 192.031.771	$ 192.031.771	$ 4.667.221
$ 319.068.016	0,00%	$ -	$ 319.068.016	$ 121.245.846	$ 197.822.170	$ 197.822.170	$ 197.822.170	$ 4.370.867
$ 328.683.606	0,00%	$ -	$ 328.683.606	$ 124.899.770	$ 203.783.836	$ 203.783.836	$ 203.783.836	$ 4.093.263
$ 338.584.048	0%	$ -	$ 338.584.048	$ 128.661.938	$ 209.922.110	$ 209.922.110	$ 209.922.110	$ 3.833.235
$ 348.778.188	0%	$ -	$ 348.778.188	$ 132.535.712	$ 216.242.477	$ 216.242.477	$ 216.242.477	$ 3.589.678
$ 359.275.113	0%	$ -	$ 359.275.113	$ 136.524.543	$ 222.750.570	$ 222.750.570	$ 222.750.570	$ 3.361.559
$ 370.084.157	0%	$ -	$ 370.084.157	$ 140.631.980	$ 229.452.178	$ 229.452.178	$ 229.452.178	$ 3.147.903
$ 381.214.917	0%	$ -	$ 381.214.917	$ 144.861.669	$ 236.353.249	$ 236.353.249	$ 236.353.249	$ 2.947.800
$ 392.677.257	0%	$ -	$ 392.677.257	$ 149.217.357	$ 243.459.899	$ 243.459.899	$ 243.459.899	$ 2.760.395
$ 404.481.317	0%	$ -	$ 404.481.317	$ 153.702.900	$ 250.778.416	$ 250.778.416	$ 250.778.416	$ 2.584.885
$ 416.637.529	0%	$ -	$ 416.637.529	$ 158.322.261	$ 258.315.268	$ 258.315.268	$ 258.315.268	$ 2.420.519
$ 429.156.620	0%	$ -	$ 429.156.620	$ 163.079.515	$ 266.077.104	$ 266.077.104	$ 266.077.104	$ 2.266.591
$ 442.049.627	0%	$ -	$ 442.049.627	$ 167.978.858	$ 274.070.769	$ 274.070.769	$ 274.070.769	$ 2.122.442
$ 455.327.905	0%	$ -	$ 455.327.905	$ 173.024.604	$ 282.303.301	$ 282.303.301	$ 282.303.301	$ 1.987.451
$ 469.003.138	0%	$ -	$ 469.003.138	$ 178.221.192	$ 290.781.945	$ 290.781.945	$ 290.781.945	$ 1.861.038
$ 483.087.350	0%	$ -	$ 483.087.350	$ 183.573.193	$ 299.514.157	$ 299.514.157	$ 299.514.157	$ 1.742.659
$ 497.592.918	0%	$ -	$ 497.592.918	$ 189.085.309	$ 308.507.609	$ 308.507.609	$ 308.507.609	$ 1.631.805
$ 512.532.579	0%	$ -	$ 512.532.579	$ 194.762.380	$ 317.770.199	$ 317.770.199	$ 317.770.199	$ 1.527.998
$ 527.919.444	0%	$ -	$ 527.919.444	$ 200.609.389	$ 327.310.055	$ 327.310.055	$ 327.310.055	$ 1.430.791
$ 543.767.012	0%	$ -	$ 543.767.012	$ 206.631.465	$ 337.135.548	$ 337.135.548	$ 337.135.548	$ 1.339.766
$ 560.089.179	0%	$ -	$ 560.089.179	$ 212.833.888	$ 347.255.291	$ 347.255.291	$ 347.255.291	$ 1.254.528
$ 576.900.251	0%	$ -	$ 576.900.251	$ 219.222.096	$ 357.678.156	$ 357.678.156	$ 357.678.156	$ 1.174.712
$ 594.214.959	0%	$ -	$ 594.214.959	$ 225.801.685	$ 368.413.275	$ 368.413.275	$ 368.413.275	$ 1.099.972
$ -57.363	0%	$ -	$ -57.363	$ -21.798	$ -35.565	$ -35.565	$ -853.657.525	$ -2.317.060

I. Debt Considered

Imputs

Fuel $/MWh	$	4
O&M $/Mwh	$	10
Capital $/Mwh	$	4.243.920
Decomissioning $/Mwh	$	1.138.089
Electicity price $/Mwh	$	110
WACC %		10%
Byprod percentage %		0%
debt percentage		50%
Debt term		30
debt increase rate	int. Rate	Debt
0,00%	8%	$ 254.635.182

Outputs

RESULTS			
Net Present Value		$	242.770.443
IRR			13%
Payback period	**disccounted**	$	18,46
	Aprox	$	9,38
LCOE	**construction**	$	60,61
	decomissioning	$	0,29
	fuel	$	5,25
	O&M	$	13,06
	TOTAL	$	79,22

Cost Calculation

	COSTS													
	Construction profile				**Decomissioning**				**Fuel**			**O&M**		
Year	**Profile**	**Cost [$/MW]**	**Cost [$]**	**Disccounted Cost [$]**	**Profile**	**Cost [$/MW]**	**Cost [$]**	**Disccounted Cost [$]**	**Cost [$/MWh]**	**Cost [$]**	**Disccounted Cost [$]**	**Cost [$/MWh]**	**Cost [$]**	**Disccounted Cost [$]**
$ -	60%	$ 4.243.920	$ 305.562.218	$ 305.562.218	0%	$ 1.138.089	$ -	$ -	$ 4	$ 3.685.446	$ 3.685.446	$ 10	$ 8.694.556	$ 8.694.556
$ 1	40%	$ 4.243.920	$ 203.708.145	$ 185.189.223	0%	$ 1.172.232	$ -	$ -	$ 4	$ 3.703.873	$ 3.367.158	$ 10	$ 8.781.501	$ 7.983.183
$ 2	0%	$ 4.243.920	$ -	$ -	0%	$ 1.207.399	$ -	$ -	$ 4	$ 3.722.393	$ 3.076.358	$ 10	$ 8.869.316	$ 7.330.013
$ 3	0%	$ 4.243.920	$ -	$ -	0%	$ 1.243.621	$ -	$ -	$ 4	$ 3.741.005	$ 2.810.672	$ 10	$ 8.958.009	$ 6.730.285
$ 4	0%	$ 4.243.920	$ -	$ -	0%	$ 1.280.930	$ -	$ -	$ 4	$ 3.759.710	$ 2.567.932	$ 10	$ 9.047.589	$ 6.179.625
$ 5	0%	$ 4.243.920	$ -	$ -	0%	$ 1.319.358	$ -	$ -	$ 4	$ 3.778.508	$ 2.346.156	$ 10	$ 9.138.065	$ 5.674.020
$ 6	0%	$ 4.243.920	$ -	$ -	0%	$ 1.358.938	$ -	$ -	$ 4	$ 3.797.401	$ 2.143.534	$ 10	$ 9.229.446	$ 5.209.782
$ 7	0%	$ 4.243.920	$ -	$ -	0%	$ 1.399.706	$ -	$ -	$ 4	$ 3.816.388	$ 1.958.410	$ 10	$ 9.321.740	$ 4.783.527
$ 8	0%	$ 4.243.920	$ -	$ -	0%	$ 1.441.698	$ -	$ -	$ 4	$ 3.835.470	$ 1.789.275	$ 11	$ 9.414.958	$ 4.392.147
$ 9	0%	$ 4.243.920	$ -	$ -	0%	$ 1.484.949	$ -	$ -	$ 4	$ 3.854.647	$ 1.634.747	$ 11	$ 9.509.107	$ 4.032.790
$ 10	0%	$ 4.243.920	$ -	$ -	0%	$ 1.529.497	$ -	$ -	$ 4	$ 3.873.920	$ 1.493.564	$ 11	$ 9.604.198	$ 3.702.834
$ 11	0%	$ 4.243.920	$ -	$ -	0%	$ 1.575.382	$ -	$ -	$ 4	$ 3.893.290	$ 1.364.574	$ 11	$ 9.700.240	$ 3.399.875
$ 12	0%	$ 4.243.920	$ -	$ -	0%	$ 1.622.643	$ -	$ -	$ 4	$ 3.912.756	$ 1.246.725	$ 11	$ 9.797.243	$ 3.121.703
$ 13	0%	$ 4.243.920	$ -	$ -	0%	$ 1.671.323	$ -	$ -	$ 4	$ 3.932.320	$ 1.139.053	$ 11	$ 9.895.215	$ 2.866.291
$ 14	0%	$ 4.243.920	$ -	$ -	0%	$ 1.721.462	$ -	$ -	$ 4	$ 3.951.982	$ 1.040.680	$ 11	$ 9.994.167	$ 2.631.777
$ 15	0%	$ 4.243.920	$ -	$ -	0%	$ 1.773.106	$ -	$ -	$ 4	$ 3.971.742	$ 950.803	$ 11	$ 10.094.109	$ 2.416.449
$ 16	0%	$ 4.243.920	$ -	$ -	0%	$ 1.826.299	$ -	$ -	$ 4	$ 3.991.600	$ 868.689	$ 11	$ 10.195.050	$ 2.218.740
$ 17	0%	$ 4.243.920	$ -	$ -	0%	$ 1.881.088	$ -	$ -	$ 4	$ 4.011.558	$ 793.665	$ 12	$ 10.297.001	$ 2.037.207
$ 18	0%	$ 4.243.920	$ -	$ -	0%	$ 1.937.521	$ -	$ -	$ 5	$ 4.031.616	$ 725.122	$ 12	$ 10.399.971	$ 1.870.526
$ 19	0%	$ 4.243.920	$ -	$ -	0%	$ 1.995.647	$ -	$ -	$ 5	$ 4.051.774	$ 662.497	$ 12	$ 10.503.970	$ 1.717.483
$ 20	0%	$ 4.243.920	$ -	$ -	0%	$ 2.055.516	$ -	$ -	$ 5	$ 4.072.033	$ 605.282	$ 12	$ 10.609.010	$ 1.576.962
$ 21	0%	$ 4.243.920	$ -	$ -	0%	$ 2.117.182	$ -	$ -	$ 5	$ 4.092.393	$ 553.007	$ 12	$ 10.715.100	$ 1.447.938
$ 22	0%	$ 4.243.920	$ -	$ -	0%	$ 2.180.697	$ -	$ -	$ 5	$ 4.112.855	$ 505.248	$ 12	$ 10.822.251	$ 1.329.470
$ 23	0%	$ 4.243.920	$ -	$ -	0%	$ 2.246.118	$ -	$ -	$ 5	$ 4.133.419	$ 461.613	$ 12	$ 10.930.474	$ 1.220.695
$ 24	0%	$ 4.243.920	$ -	$ -	0%	$ 2.313.502	$ -	$ -	$ 5	$ 4.154.087	$ 421.746	$ 12	$ 11.039.778	$ 1.120.820
$ 25	0%	$ 4.243.920	$ -	$ -	0%	$ 2.382.907	$ -	$ -	$ 5	$ 4.174.857	$ 385.323	$ 12	$ 11.150.176	$ 1.029.117
$ 26	0%	$ 4.243.920	$ -	$ -	0%	$ 2.454.394	$ -	$ -	$ 5	$ 4.195.731	$ 352.045	$ 13	$ 11.261.678	$ 944.916
$ 27	0%	$ 4.243.920	$ -	$ -	0%	$ 2.528.026	$ -	$ -	$ 5	$ 4.216.710	$ 321.641	$ 13	$ 11.374.295	$ 867.605
$ 28	0%	$ 4.243.920	$ -	$ -	0%	$ 2.603.866	$ -	$ -	$ 5	$ 4.237.793	$ 293.863	$ 13	$ 11.488.038	$ 796.619
$ 29	0%	$ 4.243.920	$ -	$ -	0%	$ 2.681.982	$ -	$ -	$ 5	$ 4.258.982	$ 268.484	$ 13	$ 11.602.918	$ 731.441
$ 30	0%	$ 4.243.920	$ -	$ -	0%	$ 2.762.442	$ -	$ -	$ 5	$ 4.280.277	$ 245.297	$ 13	$ 11.718.947	$ 671.596
$ 31	0%	$ 4.243.920	$ -	$ -	0%	$ 2.845.315	$ -	$ -	$ 5	$ 4.301.679	$ 224.112	$ 13	$ 11.836.137	$ 616.647
$ 32	0%	$ 4.243.920	$ -	$ -	0%	$ 2.930.675	$ -	$ -	$ 5	$ 4.323.187	$ 204.757	$ 13	$ 11.954.498	$ 566.194
$ 33	0%	$ 4.243.920	$ -	$ -	0%	$ 3.018.595	$ -	$ -	$ 5	$ 4.344.803	$ 187.073	$ 14	$ 12.074.043	$ 519.869
$ 34	0%	$ 4.243.920	$ -	$ -	0%	$ 3.109.153	$ -	$ -	$ 5	$ 4.366.527	$ 170.917	$ 14	$ 12.194.784	$ 477.334
$ 35	0%	$ 4.243.920	$ -	$ -	0%	$ 3.202.427	$ -	$ -	$ 5	$ 4.388.360	$ 156.156	$ 14	$ 12.316.731	$ 438.280
$ 36	0%	$ 4.243.920	$ -	$ -	0%	$ 3.298.500	$ -	$ -	$ 5	$ 4.410.301	$ 142.670	$ 14	$ 12.439.899	$ 402.421
$ 37	0%	$ 4.243.920	$ -	$ -	0%	$ 3.397.455	$ -	$ -	$ 5	$ 4.432.353	$ 130.348	$ 14	$ 12.564.298	$ 369.495
$ 38	0%	$ 4.243.920	$ -	$ -	0%	$ 3.499.379	$ -	$ -	$ 5	$ 4.454.515	$ 119.091	$ 14	$ 12.689.941	$ 339.264
$ 39	0%	$ 4.243.920	$ -	$ -	0%	$ 3.604.360	$ -	$ -	$ 5	$ 4.476.787	$ 108.806	$ 14	$ 12.816.840	$ 311.506
$ 40	0%	$ 4.243.920	$ -	$ -	0%	$ 3.712.491	$ -	$ -	$ 5	$ 4.499.171	$ 99.409	$ 14	$ 12.945.008	$ 286.019
$ 41	0%	$ 4.243.920	$ -	$ -	0%	$ 3.823.866	$ -	$ -	$ 5	$ 4.521.667	$ 90.824	$ 15	$ 13.074.459	$ 262.617
$ 42	0%	$ 4.243.920	$ -	$ -	0%	$ 3.938.582	$ -	$ -	$ 5	$ 4.544.275	$ 82.980	$ 15	$ 13.205.203	$ 241.131
$ 43	0%	$ 4.243.920	$ -	$ -	0%	$ 4.056.739	$ -	$ -	$ 5	$ 4.566.997	$ 75.813	$ 15	$ 13.337.255	$ 221.402
$ 44	0%	$ 4.243.920	$ -	$ -	0%	$ 4.178.441	$ -	$ -	$ 5	$ 4.589.832	$ 69.266	$ 15	$ 13.470.628	$ 203.287
$ 45	0%	$ 4.243.920	$ -	$ -	0%	$ 4.303.794	$ -	$ -	$ 5	$ 4.612.781	$ 63.284	$ 15	$ 13.605.334	$ 186.654
$ 46	0%	$ 4.243.920	$ -	$ -	0%	$ 4.432.908	$ -	$ -	$ 5	$ 4.635.845	$ 57.818	$ 15	$ 13.741.387	$ 171.383
$ 47	0%	$ 4.243.920	$ -	$ -	0%	$ 4.565.895	$ -	$ -	$ 5	$ 4.659.024	$ 52.825	$ 16	$ 13.878.801	$ 157.361
$ 48	0%	$ 4.243.920	$ -	$ -	0%	$ 4.702.872	$ -	$ -	$ 5	$ 4.682.319	$ 48.263	$ 16	$ 14.017.589	$ 144.486
$ 49	0%	$ 4.243.920	$ -	$ -	0%	$ 4.843.958	$ -	$ -	$ 5	$ 4.705.731	$ 44.095	$ 16	$ 14.157.765	$ 132.664
$ 50	0%	$ 4.243.920	$ -	$ -	0%	$ 4.989.277	$ -	$ -	$ 5	$ 4.729.259	$ 40.286	$ 16	$ 14.299.343	$ 121.810
$ 51	0%	$ 4.243.920	$ -	$ -	0%	$ 5.138.956	$ -	$ -	$ 5	$ 4.752.906	$ 36.807	$ 16	$ 14.442.336	$ 111.843
$ 52	0%	$ 4.243.920	$ -	$ -	0%	$ 5.293.124	$ -	$ -	$ 5	$ 4.776.670	$ 33.628	$ 16	$ 14.586.760	$ 102.693
$ 53	0%	$ 4.243.920	$ -	$ -	0%	$ 5.451.918	$ -	$ -	$ 5	$ 4.800.554	$ 30.724	$ 16	$ 14.732.627	$ 94.290
$ 54	0%	$ 4.243.920	$ -	$ -	0%	$ 5.615.475	$ -	$ -	$ 5	$ 4.824.556	$ 28.071	$ 17	$ 14.879.953	$ 86.576
$ 55	0%	$ 4.243.920	$ -	$ -	0%	$ 5.783.940	$ -	$ -	$ 5	$ 4.848.679	$ 25.646	$ 17	$ 15.028.753	$ 79.492
$ 56	0%	$ 4.243.920	$ -	$ -	0%	$ 5.957.458	$ -	$ -	$ 5	$ 4.872.923	$ 23.431	$ 17	$ 15.179.040	$ 72.988
$ 57	0%	$ 4.243.920	$ -	$ -	0%	$ 6.136.182	$ -	$ -	$ 5	$ 4.897.287	$ 21.408	$ 17	$ 15.330.831	$ 67.017
$ 58	0%	$ 4.243.920	$ -	$ -	0%	$ 6.320.267	$ -	$ -	$ 6	$ 4.921.774	$ 19.559	$ 17	$ 15.484.139	$ 61.533
$ 59	0%	$ 4.243.920	$ -	$ -	0%	$ 6.509.875	$ -	$ -	$ 6	$ 4.946.383	$ 17.870	$ 18	$ 15.638.981	$ 56.499
$ 60	0%	$ 4.243.920	$ -	$ -	0%	$ 6.705.171	$ -	$ -	$ 6	$ 4.971.114	$ 16.326	$ 18	$ 15.795.370	$ 51.876
$ 61	0%	$ 4.243.920	$ -	$ -	0%	$ 6.906.327	$ -	$ -	$ 6	$ 4.995.970	$ 14.916	$ 18	$ 15.953.324	$ 47.632
$ 62	0%	$ 4.243.920	$ -	$ -	100%	$ 7.113.516	$ 853.621.960	$ 2.316.963	$ 6	$ 5.020.950	$ 13.628	$ 18	$ 16.112.857	$ 43.735

Revenue Calculation

REVENUES						
Electicity				by-products		
Generation [MWh]	Discounted Generation	Price [$/MWh]	Sales [$]	Generation [MWh]	Price [$/MWh]	Sales [$]
$ -	$ -	$ 110	$ -			$ -
$ -	$ -	$ 113	$ -			$ -
$ 893.520	$ 738.446	$ 116	$ 103.894.614			$ -
$ 893.520	$ 671.315	$ 120	$ 107.011.453			$ -
$ 893.520	$ 610.286	$ 123	$ 110.221.796			$ -
$ 893.520	$ 554.806	$ 127	$ 113.528.450			$ -
$ 893.520	$ 504.369	$ 131	$ 116.934.304			$ -
$ 893.520	$ 458.517	$ 135	$ 120.442.333			$ -
$ 893.520	$ 416.834	$ 139	$ 124.055.603			$ -
$ 893.520	$ 378.940	$ 143	$ 127.777.271			$ -
$ 893.520	$ 344.491	$ 147	$ 131.610.589			$ -
$ 893.520	$ 313.173	$ 152	$ 135.558.907			$ -
$ 893.520	$ 284.703	$ 156	$ 139.625.674			$ -
$ 893.520	$ 258.821	$ 161	$ 143.814.444			$ -
$ 893.520	$ 235.292	$ 166	$ 148.128.878			$ -
$ 893.520	$ 213.902	$ 171	$ 152.572.744			$ -
$ 893.520	$ 194.456	$ 176	$ 157.149.926			$ -
$ 893.520	$ 176.778	$ 181	$ 161.864.424			$ -
$ 893.520	$ 160.707	$ 187	$ 166.720.357			$ -
$ 893.520	$ 146.098	$ 192	$ 171.721.967			$ -
$ 893.520	$ 132.816	$ 198	$ 176.873.627			$ -
$ 893.520	$ 120.742	$ 204	$ 182.179.835			$ -
$ 893.520	$ 109.765	$ 210	$ 187.645.230			$ -
$ 893.520	$ 99.787	$ 216	$ 193.274.587			$ -
$ 893.520	$ 90.715	$ 223	$ 199.072.825			$ -
$ 893.520	$ 82.468	$ 229	$ 205.045.010			$ -
$ 893.520	$ 74.971	$ 236	$ 211.196.360			$ -
$ 893.520	$ 68.156	$ 243	$ 217.532.251			$ -
$ 893.520	$ 61.960	$ 251	$ 224.058.218			$ -
$ 893.520	$ 56.327	$ 258	$ 230.779.965			$ -
$ 893.520	$ 51.206	$ 266	$ 237.703.364			$ -
$ 893.520	$ 46.551	$ 274	$ 244.834.465			$ -
$ 893.520	$ 42.319	$ 282	$ 252.179.499			$ -
$ 893.520	$ 38.472	$ 291	$ 259.744.884			$ -
$ 893.520	$ 34.975	$ 299	$ 267.537.230			$ -
$ 893.520	$ 31.795	$ 308	$ 275.563.347			$ -
$ 893.520	$ 28.905	$ 318	$ 283.830.247			$ -
$ 893.520	$ 26.277	$ 327	$ 292.345.155			$ -
$ 893.520	$ 23.888	$ 337	$ 301.115.509			$ -
$ 893.520	$ 21.716	$ 347	$ 310.148.975			$ -
$ 893.520	$ 19.742	$ 358	$ 319.453.444			$ -
$ 893.520	$ 17.948	$ 368	$ 329.037.047			$ -
$ 893.520	$ 16.316	$ 379	$ 338.908.159			$ -
$ 893.520	$ 14.833	$ 391	$ 349.075.403			$ -
$ 893.520	$ 13.484	$ 402	$ 359.547.666			$ -
$ 893.520	$ 12.258	$ 414	$ 370.334.096			$ -
$ 893.520	$ 11.144	$ 427	$ 381.444.118			$ -
$ 893.520	$ 10.131	$ 440	$ 392.887.442			$ -
$ 893.520	$ 9.210	$ 453	$ 404.674.065			$ -
$ 893.520	$ 8.373	$ 466	$ 416.814.287			$ -
$ 893.520	$ 7.611	$ 480	$ 429.318.716			$ -
$ 893.520	$ 6.920	$ 495	$ 442.198.277			$ -
$ 893.520	$ 6.290	$ 510	$ 455.464.226			$ -
$ 893.520	$ 5.719	$ 525	$ 469.128.152			$ -
$ 893.520	$ 5.199	$ 541	$ 483.201.997			$ -
$ 893.520	$ 4.726	$ 557	$ 497.698.057			$ -
$ 893.520	$ 4.296	$ 574	$ 512.628.999			$ -
$ 893.520	$ 3.906	$ 591	$ 528.007.868			$ -
$ 893.520	$ 3.551	$ 609	$ 543.848.105			$ -
$ 893.520	$ 3.228	$ 627	$ 560.163.548			$ -
$ 893.520	$ 2.935	$ 646	$ 576.968.454			$ -
$ 893.520	$ 2.668	$ 665	$ 594.277.508			$ -
$ -	$ -	$ 685	$ -			$ -
$ 53.611.200	$ 8.096.231					

Cash Flow Calculation

CASH FLOWS											
EBITDA	D&A		EBIT	Dept payment	Interest	EBT	TAX	NET INCOME	OCF	FCF	Discounted FCF
	D&A profile	D&A									
$ -12.380.002	$ -	$ -	$ -12.380.002	$ 8.487.839	$ 679.027	$ -13.059.029	$ -4.962.431	$ -8.096.598	$ -8.096.598	$ -322.146.655	$ -322.146.655
$ -11.350.340	0,00%	$ -	$ -11.350.340	$ 8.487.839	$ 699.398	$ -12.049.738	$ -4.578.901	$ -7.470.838	$ -7.470.838	$ -219.666.823	$ -199.697.111
$ 93.488.244	3,33%	$ 16.975.679	$ 76.512.565	$ 8.487.839	$ 720.380	$ 75.792.185	$ 28.801.030	$ 46.991.155	$ 63.966.833	$ 55.478.994	$ 45.850.408
$ 97.470.496	3,33%	$ 16.975.679	$ 80.494.817	$ 8.487.839	$ 741.991	$ 79.752.826	$ 30.306.074	$ 49.446.752	$ 66.422.431	$ 57.934.591	$ 43.527.116
$ 101.474.239	3,33%	$ 16.975.679	$ 84.498.560	$ 8.487.839	$ 764.251	$ 83.734.309	$ 31.819.037	$ 51.915.272	$ 68.890.950	$ 60.403.111	$ 41.256.138
$ 105.508.275	3,33%	$ 16.975.679	$ 88.532.596	$ 8.487.839	$ 787.179	$ 87.745.417	$ 33.343.259	$ 54.402.159	$ 71.377.837	$ 62.889.998	$ 39.049.741
$ 109.580.989	3,33%	$ 16.975.679	$ 92.605.310	$ 8.487.839	$ 810.794	$ 91.794.516	$ 34.881.916	$ 56.912.600	$ 73.888.279	$ 65.400.439	$ 36.916.843
$ 113.700.396	3,33%	$ 16.975.679	$ 96.724.717	$ 8.487.839	$ 835.118	$ 95.889.599	$ 36.438.048	$ 59.451.552	$ 76.427.230	$ 67.939.391	$ 34.863.650
$ 117.874.181	3,33%	$ 16.975.679	$ 100.898.502	$ 8.487.839	$ 860.171	$ 100.038.331	$ 38.014.566	$ 62.023.765	$ 78.999.444	$ 70.511.604	$ 32.894.184
$ 122.109.735	3,33%	$ 16.975.679	$ 105.134.056	$ 8.487.839	$ 885.976	$ 104.248.079	$ 39.614.270	$ 64.633.809	$ 81.609.488	$ 73.121.649	$ 31.010.717
$ 126.414.191	3,33%	$ 16.975.679	$ 109.438.512	$ 8.487.839	$ 912.556	$ 108.525.957	$ 41.239.863	$ 67.286.093	$ 84.261.772	$ 75.773.932	$ 29.214.131
$ 130.794.457	3,33%	$ 16.975.679	$ 113.818.779	$ 8.487.839	$ 939.932	$ 112.878.846	$ 42.893.962	$ 69.984.885	$ 86.960.563	$ 78.472.724	$ 27.504.211
$ 135.257.246	3,33%	$ 16.975.679	$ 118.281.567	$ 8.487.839	$ 968.130	$ 117.313.437	$ 44.579.106	$ 72.734.331	$ 89.710.010	$ 81.222.170	$ 25.879.886
$ 139.809.100	3,33%	$ 16.975.679	$ 122.833.421	$ 8.487.839	$ 997.174	$ 121.836.247	$ 46.297.774	$ 75.538.473	$ 92.514.152	$ 84.026.312	$ 24.339.430
$ 144.456.421	3,33%	$ 16.975.679	$ 127.480.742	$ 8.487.839	$ 1.027.089	$ 126.453.652	$ 48.052.388	$ 78.401.265	$ 95.376.943	$ 86.889.104	$ 22.880.617
$ 149.205.491	3,33%	$ 16.975.679	$ 132.229.812	$ 8.487.839	$ 1.057.902	$ 131.171.910	$ 49.845.326	$ 81.326.584	$ 98.302.263	$ 89.814.424	$ 21.500.859
$ 154.062.498	3,33%	$ 16.975.679	$ 137.086.819	$ 8.487.839	$ 1.089.639	$ 135.997.180	$ 51.678.928	$ 84.318.251	$ 101.293.930	$ 92.806.091	$ 20.197.309
$ 159.033.552	3,33%	$ 16.975.679	$ 142.057.873	$ 8.487.839	$ 1.122.328	$ 140.935.545	$ 53.555.507	$ 87.380.038	$ 104.355.717	$ 95.867.877	$ 18.966.948
$ 164.124.709	3,33%	$ 16.975.679	$ 147.149.030	$ 8.487.839	$ 1.155.998	$ 145.993.032	$ 55.477.352	$ 90.515.680	$ 107.491.359	$ 99.003.519	$ 17.806.653
$ 169.341.987	3,33%	$ 16.975.679	$ 152.366.308	$ 8.487.839	$ 1.190.678	$ 151.175.630	$ 57.446.739	$ 93.728.891	$ 110.704.569	$ 102.216.730	$ 16.713.252
$ 174.691.383	3,33%	$ 16.975.679	$ 157.715.704	$ 8.487.839	$ 1.226.399	$ 156.489.306	$ 59.465.936	$ 97.023.370	$ 113.999.048	$ 105.511.209	$ 15.683.569
$ 180.178.890	3,33%	$ 16.975.679	$ 163.203.211	$ 8.487.839	$ 1.263.191	$ 161.940.021	$ 61.537.208	$ 100.402.813	$ 117.378.492	$ 108.890.652	$ 14.714.456
$ 185.810.513	3,33%	$ 16.975.679	$ 168.834.834	$ 8.487.839	$ 1.301.086	$ 167.533.748	$ 63.662.824	$ 103.870.924	$ 120.846.602	$ 112.358.763	$ 13.802.822
$ 191.592.279	3,33%	$ 16.975.679	$ 174.616.601	$ 8.487.839	$ 1.340.119	$ 173.276.482	$ 65.845.063	$ 107.431.419	$ 124.407.098	$ 115.919.258	$ 12.945.649
$ 197.530.259	3,33%	$ 16.975.679	$ 180.554.580	$ 8.487.839	$ 1.380.322	$ 179.174.258	$ 68.086.218	$ 111.088.040	$ 128.063.718	$ 119.575.879	$ 12.140.013
$ 203.630.570	3,33%	$ 16.975.679	$ 186.654.892	$ 8.487.839	$ 1.421.732	$ 185.233.160	$ 70.388.601	$ 114.844.559	$ 131.820.238	$ 123.332.398	$ 11.383.087
$ 209.899.399	3,33%	$ 16.975.679	$ 192.923.720	$ 8.487.839	$ 1.464.384	$ 191.459.336	$ 72.754.548	$ 118.704.788	$ 135.680.467	$ 127.192.628	$ 10.672.155
$ 216.343.005	3,33%	$ 16.975.679	$ 199.367.326	$ 8.487.839	$ 1.508.316	$ 197.859.011	$ 75.186.424	$ 122.672.587	$ 139.648.265	$ 131.160.426	$ 10.004.614
$ 222.967.736	3,33%	$ 16.975.679	$ 205.992.058	$ 8.487.839	$ 1.553.565	$ 204.438.493	$ 77.686.627	$ 126.751.865	$ 143.727.544	$ 135.239.705	$ 9.377.974
$ 229.780.040	3,33%	$ 16.975.679	$ 212.804.361	$ 8.487.839	$ 1.600.172	$ 211.204.189	$ 80.257.592	$ 130.946.597	$ 147.922.276	$ 139.434.437	$ 8.789.864
$ 236.786.471	3,33%	$ 16.975.679	$ 219.810.793	$ -	$ -	$ 219.810.793	$ 83.528.101	$ 136.282.691	$ 153.258.370	$ 153.258.370	$ 8.783.015
$ 243.993.706	3,33%	$ 16.975.679	$ 227.018.027	$ -	$ -	$ 227.018.027	$ 86.266.850	$ 140.751.177	$ 157.726.855	$ 157.726.855	$ 8.217.362
$ 251.408.548	0,00%	$ -	$ 251.408.548	$ -	$ -	$ 251.408.548	$ 95.535.248	$ 155.873.300	$ 155.873.300	$ 155.873.300	$ 7.382.540
$ 259.037.941	0,00%	$ -	$ 259.037.941	$ -	$ -	$ 259.037.941	$ 98.434.418	$ 160.603.524	$ 160.603.524	$ 160.603.524	$ 6.915.068
$ 266.888.979	0,00%	$ -	$ 266.888.979	$ -	$ -	$ 266.888.979	$ 101.417.812	$ 165.471.167	$ 165.471.167	$ 165.471.167	$ 6.476.957
$ 274.968.911	0,00%	$ -	$ 274.968.911	$ -	$ -	$ 274.968.911	$ 104.488.186	$ 170.480.725	$ 170.480.725	$ 170.480.725	$ 6.066.404
$ 283.285.157	0,00%	$ -	$ 283.285.157	$ -	$ -	$ 283.285.157	$ 107.648.360	$ 175.636.797	$ 175.636.797	$ 175.636.797	$ 5.681.707
$ 291.845.311	0,00%	$ -	$ 291.845.311	$ -	$ -	$ 291.845.311	$ 110.901.218	$ 180.944.093	$ 180.944.093	$ 180.944.093	$ 5.321.267
$ 300.657.155	0,00%	$ -	$ 300.657.155	$ -	$ -	$ 300.657.155	$ 114.249.719	$ 186.407.436	$ 186.407.436	$ 186.407.436	$ 4.983.577
$ 309.728.663	0,00%	$ -	$ 309.728.663	$ -	$ -	$ 309.728.663	$ 117.696.892	$ 192.031.771	$ 192.031.771	$ 192.031.771	$ 4.667.221
$ 319.068.016	0,00%	$ -	$ 319.068.016	$ -	$ -	$ 319.068.016	$ 121.245.846	$ 197.822.170	$ 197.822.170	$ 197.822.170	$ 4.370.867
$ 328.683.606	0,00%	$ -	$ 328.683.606	$ -	$ -	$ 328.683.606	$ 124.899.770	$ 203.783.836	$ 203.783.836	$ 203.783.836	$ 4.093.263
$ 338.584.048	0%	$ -	$ 338.584.048	$ -	$ -	$ 338.584.048	$ 128.661.938	$ 209.922.110	$ 209.922.110	$ 209.922.110	$ 3.833.235
$ 348.778.188	0%	$ -	$ 348.778.188	$ -	$ -	$ 348.778.188	$ 132.535.712	$ 216.242.477	$ 216.242.477	$ 216.242.477	$ 3.589.678
$ 359.275.113	0%	$ -	$ 359.275.113	$ -	$ -	$ 359.275.113	$ 136.524.543	$ 222.750.570	$ 222.750.570	$ 222.750.570	$ 3.361.559
$ 370.084.157	0%	$ -	$ 370.084.157	$ -	$ -	$ 370.084.157	$ 140.631.980	$ 229.452.178	$ 229.452.178	$ 229.452.178	$ 3.147.903
$ 381.214.917	0%	$ -	$ 381.214.917	$ -	$ -	$ 381.214.917	$ 144.861.669	$ 236.353.249	$ 236.353.249	$ 236.353.249	$ 2.947.800
$ 392.677.257	0%	$ -	$ 392.677.257	$ -	$ -	$ 392.677.257	$ 149.217.357	$ 243.459.899	$ 243.459.899	$ 243.459.899	$ 2.760.395
$ 404.481.317	0%	$ -	$ 404.481.317	$ -	$ -	$ 404.481.317	$ 153.702.900	$ 250.778.416	$ 250.778.416	$ 250.778.416	$ 2.584.885
$ 416.637.529	0%	$ -	$ 416.637.529	$ -	$ -	$ 416.637.529	$ 158.322.261	$ 258.315.268	$ 258.315.268	$ 258.315.268	$ 2.420.519
$ 429.156.620	0%	$ -	$ 429.156.620	$ -	$ -	$ 429.156.620	$ 163.079.515	$ 266.077.104	$ 266.077.104	$ 266.077.104	$ 2.266.591
$ 442.049.627	0%	$ -	$ 442.049.627	$ -	$ -	$ 442.049.627	$ 167.978.858	$ 274.070.769	$ 274.070.769	$ 274.070.769	$ 2.122.442
$ 455.327.905	0%	$ -	$ 455.327.905	$ -	$ -	$ 455.327.905	$ 173.024.604	$ 282.303.301	$ 282.303.301	$ 282.303.301	$ 1.987.451
$ 469.003.138	0%	$ -	$ 469.003.138	$ -	$ -	$ 469.003.138	$ 178.221.192	$ 290.781.945	$ 290.781.945	$ 290.781.945	$ 1.861.038
$ 483.087.350	0%	$ -	$ 483.087.350	$ -	$ -	$ 483.087.350	$ 183.573.193	$ 299.514.157	$ 299.514.157	$ 299.514.157	$ 1.742.659
$ 497.592.918	0%	$ -	$ 497.592.918	$ -	$ -	$ 497.592.918	$ 189.085.309	$ 308.507.609	$ 308.507.609	$ 308.507.609	$ 1.631.805
$ 512.532.579	0%	$ -	$ 512.532.579	$ -	$ -	$ 512.532.579	$ 194.762.380	$ 317.770.199	$ 317.770.199	$ 317.770.199	$ 1.527.998
$ 527.919.444	0%	$ -	$ 527.919.444	$ -	$ -	$ 527.919.444	$ 200.609.389	$ 327.310.055	$ 327.310.055	$ 327.310.055	$ 1.430.791
$ 543.767.012	0%	$ -	$ 543.767.012	$ -	$ -	$ 543.767.012	$ 206.631.465	$ 337.135.548	$ 337.135.548	$ 337.135.548	$ 1.339.766
$ 560.089.179	0%	$ -	$ 560.089.179	$ -	$ -	$ 560.089.179	$ 212.833.888	$ 347.255.291	$ 347.255.291	$ 347.255.291	$ 1.254.528
$ 576.900.251	0%	$ -	$ 576.900.251	$ -	$ -	$ 576.900.251	$ 219.222.096	$ 357.678.156	$ 357.678.156	$ 357.678.156	$ 1.174.712
$ 594.214.959	0%	$ -	$ 594.214.959	$ -	$ -	$ 594.214.959	$ 225.801.685	$ 368.413.275	$ 368.413.275	$ 368.413.275	$ 1.099.972
$ -57.363	0%	$ -	$ -57.363	$ -	$ -	$ -57.363	$ -21.798	$ -35.565	$ -35.565	$ -853.657.525	$ -2.317.060