



energy

Department:
Energy
REPUBLIC OF SOUTH AFRICA



STUDY OF THE COST OF NUCLEAR POWER

Submitted by :



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In Association with



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1. Executive Summary – Main conclusions

1.1 *Scope of the study*

The Department of Energy assigned Ingerop/NucAdvisor (ISA) to perform a four-week study aiming at updating the cost of nuclear power, based on available public information, and private information known from the Consultant (all data are clearly referenced to sources).

Previous estimates were done by the Electric Power Research Institute study in 2010 on a worldwide basis, including Eastern and Western technologies, and updated in 2012¹. EPRI also performed in 2012 a specific study about South Africa², comparing Levelised Costs of Electricity (LCOEs) of various sources of energies (four coal technologies, three gas technologies, nuclear, wind, solar concentration (CSP) and solar Photovoltaic (PV)).

The main data (Capital costs and LCOE) were statistically analysed to arrive at a range of costs, expressed in 2013 USD, in a similar way as performed in a paper published in April 2013 by Nuclear Engineering International.

Finally, levelised costs of electricity (LCOE) were compared with the statistical range of renewable (Wind, Solar PV, Solar CSP) and fossil fuel technologies (Gas, Coal) as contemplated in the Integrated Resource Plan 2010-2030.

The study included three main steps: data collection, data analysis and conclusions.

¹ *Program on Technology Innovation: Integrated Generation Technology Options 2012*. EPRI, Palo Alto, CA: 2013. 1026656.

² *Power Generation Technology Data for Integrated Resource Plan of South Africa*. EPRI, Palo Alto, CA: 2012.

1.2 Data collection

A large number of reports were collected, from many sources. All studies were provided to the Department of Energy (DOE) in an electronic format. Studies were divided in several categories as follow.

- **Generic studies**

A large number of generic studies (as opposed to vendor specific information) have been published in recent years, similar in details and content to the 2010 and 2012 EPRI studies referenced in the DOE Terms of Reference, which provide an overview of nuclear generation costs.

They are issued from different categories of organisations: intergovernmental or international (OCDE, NEA³, governments or state agencies, parliaments, accounting offices, professional organisations (nuclear industry, but also oil or wind industry, etc.), universities and academics, etc.). In total twenty one generic studies were reviewed, each study having generally assessed a large number of nuclear projects.

- **Utilities financial reports**

Because most large utilities committed to nuclear projects are listed, or issue publicly tradable bonds, they have disclosure obligations on their main projects, and long term provisions.

From eleven reports (US, European, Russian and Asian utilities), it was possible to extract accurate information on on-going projects and decommissioning accruals.

- **Consultant experience**

Consultant experience was used both for different technologies and countries where the Consultant had access to recent information about bids and contracts. This covered (in addition to other sources):

- o Technologies: EPR, ATMEA1, AP1000, VVER 92
- o Countries : China, Vietnam, Turkey, France

- **Specific information.**

Neither the generic studies nor utilities reports could provide all needed information on some specific items. *Specific information was* provided on *those items*:

- o Advanced Boling Water Reactor technology : Information was collected on three projects in the US, Europe and Asia
- o Preparatory works: A specific survey of Preparatory works was performed, which covered the nine projects in Russia, China, several European countries, and USA
- o Decommissioning costs: Decommissioning costs were evaluated both from the accounts of listed Utilities, which disclose their accruals related to decommissioning. But a direct literature survey was also done which provided information on seventeen commercial reactors and approximately twenty research reactors (Appendix 6).

In total, a large number of projects were reviewed and qualified according to the data accuracy and reliability. In general, most of the information was first-hand information from utilities or vendors, although the generic studies did not always quote their sources. But they were authored by reliable organisations, and can be trusted. Only very few information, when nothing else was available, was taken from press releases or media reports.

³ Glossary at the end of the report.

1.3 Data analysis

- **Normalization of the data**

All data were converted to 2013 US dollars, using a set of currency exchange rate, and an inflation table.

The following breakdown was issued for each individual data:

- o Preparatory works
- o Overnight costs (in US\$/kWe installed)
- o Fuel Costs (in US\$/kWh);
- o Long term Fuel Waste Management Costs (in US\$/kWh)
- o Operation and Maintenance Costs (in US\$/kWh)
- o Decommissioning and Dismantling Costs (US\$/ KWe decommissioned)

Furthermore, and in order to perform LCOEs calculations, the following additional information was recorded: Unit power and efficiency, Fuel burn-up, discount rates considered in the studies under review.

- **Modelisation and calculations**

After normalization, the different projects under review were grouped in four categories as follow.

Technologies in NDC	Technologies in SP	Generation III	Generation II
China Korea Viet Nam Turkey Jordan UAE UK	Finland France USA	ABWR AP 1000 APR 1400 ATMEA 1 EPR VVER – AES 2006	OPR 1000 CPR 1000

Table 1: Country and technology distribution through Technologies and types of nuclear programs

NDC: Countries having an on-going nuclear program, or having the intent to enter a multiple units program (“Nuclear developing countries”)

SP: Countries having nuclear projects with a single unit

Generation II: reactor is a design classification for a nuclear reactor, and refers to the class of commercial reactors built up to the end of the 1990s⁴.

Generation III: advanced generation III technologies, it refers to any development of the generation II nuclear reactor designs incorporating evolutionary design improvements developed during the lifetime of the generation II reactor designs. Improvements may concern fuel technology, superior thermal efficiency, passive safety systems, modular construction, consideration of severe accidents (with core melt) in the design.

Calculation of the leverage cost of electricity per kWh (LCOE) was done for these categories, including their breakdown into its main components (Capex/kWh (including capitalised preparatory works); Operation and Maintenance/kWh; Fuel/kWh; Decommissioning/kWh). For these calculations, a base case was done with a discount rate of 5% (used by EPRI in its generic report 2012) and a sensitivity analysis with a 10% discount rate. The calculation of the decommissioning costs in the LCOE was done in a very conservative manner, in order not to underestimate this component of the LCOE.

⁴ Prototypical generation II reactors include the PWR, CANDU, BWR, AGR, and VVER.

1.4 Main Conclusions

It is not possible to simplify the very large number of data and results provided in the course of this study to a limited number of results. However, some results can be highlighted through the following graphs.

- **Statistical distribution of LCOEs for the four groups**

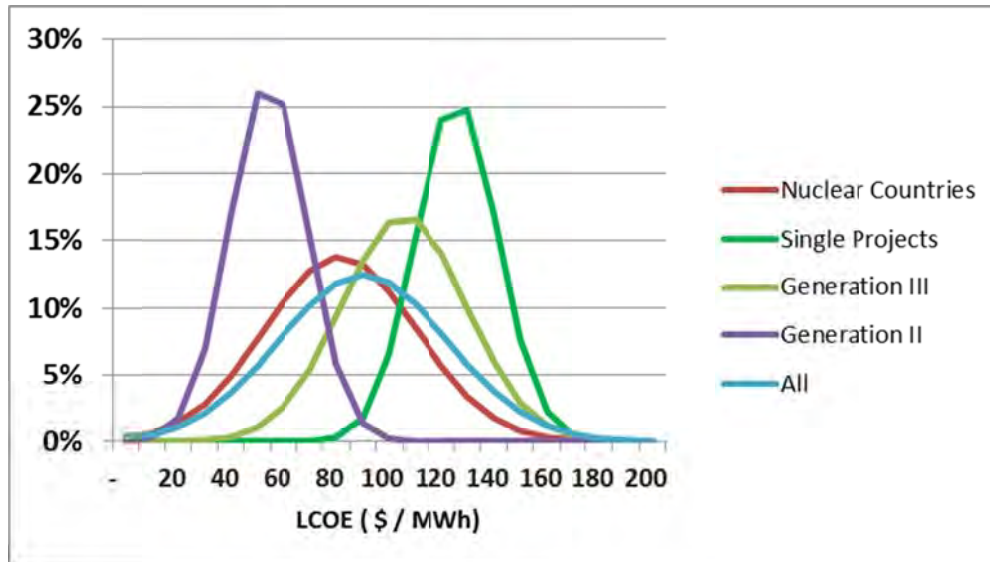


Figure 1 – Statistical Distribution of LCOE per category (Discount Rate 6.93%)

This graph illustrates the distribution of LCOEs per category. It clearly shows that Gen II reactors (no longer offered on the international market) could generate electricity at a significantly lower cost than Gen III.

- **Impact of the size of the program, and serial effect**

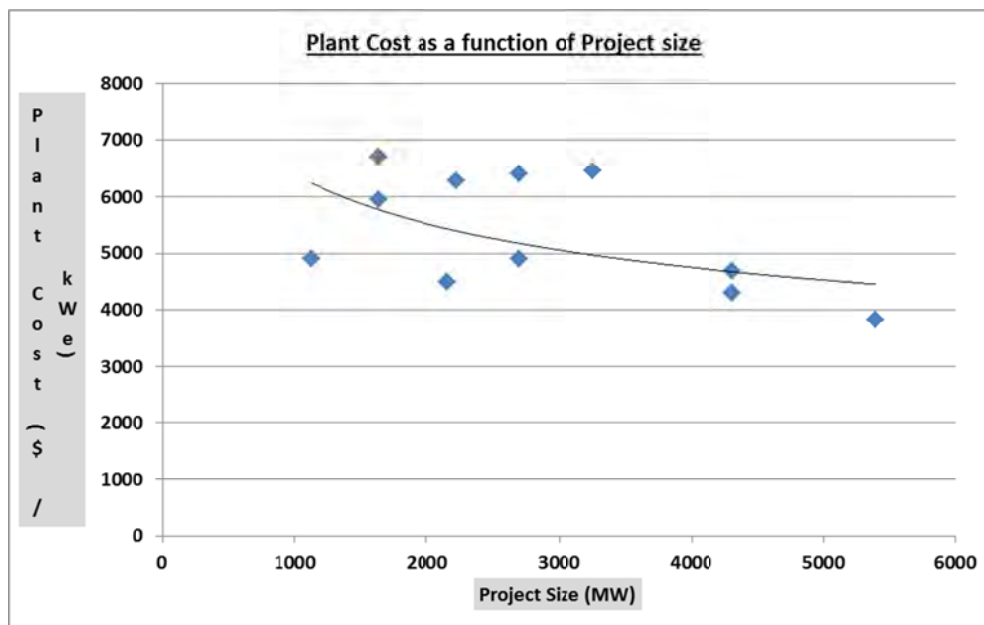


Figure 2 – Plant cost as a function of Project Size

It also illustrates the benefit of multiple programs against single units.

This graph illustrates the fact that the size of a project has a significant influence on its cost, multiple unit projects being 15% to 25% cheaper than single projects. Some papers found in the literature provide a direct evaluation of a series effect, and tend to conclude to a higher series effect than shown in Figure 2.

It is likely that Figure 2 underestimates the series effect as it mixes plants from different technologies, built in different countries. Further works should be performed, based on the basis of literature data and analytical studies to better substantiate the serial effect.

- ***Distribution of CAPEX***

The distribution of plant costs is illustrated in the next graph.

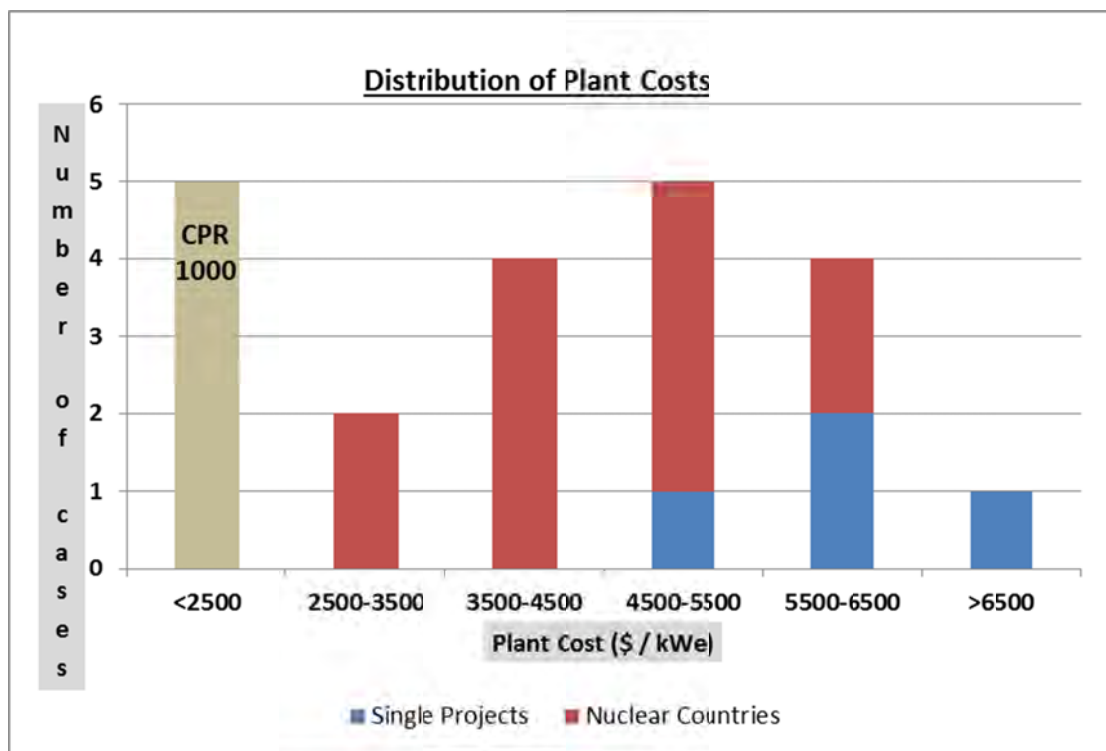


Figure 3 - Distribution of plant costs

It confirms the great competitiveness of Chinese CPR 1000 reactors (Gen II), and the lower Capex achieved in countries aiming at a continuing program, as opposed to single units.

The following chart provides the distribution of Capital Cost from the literature and utilities.

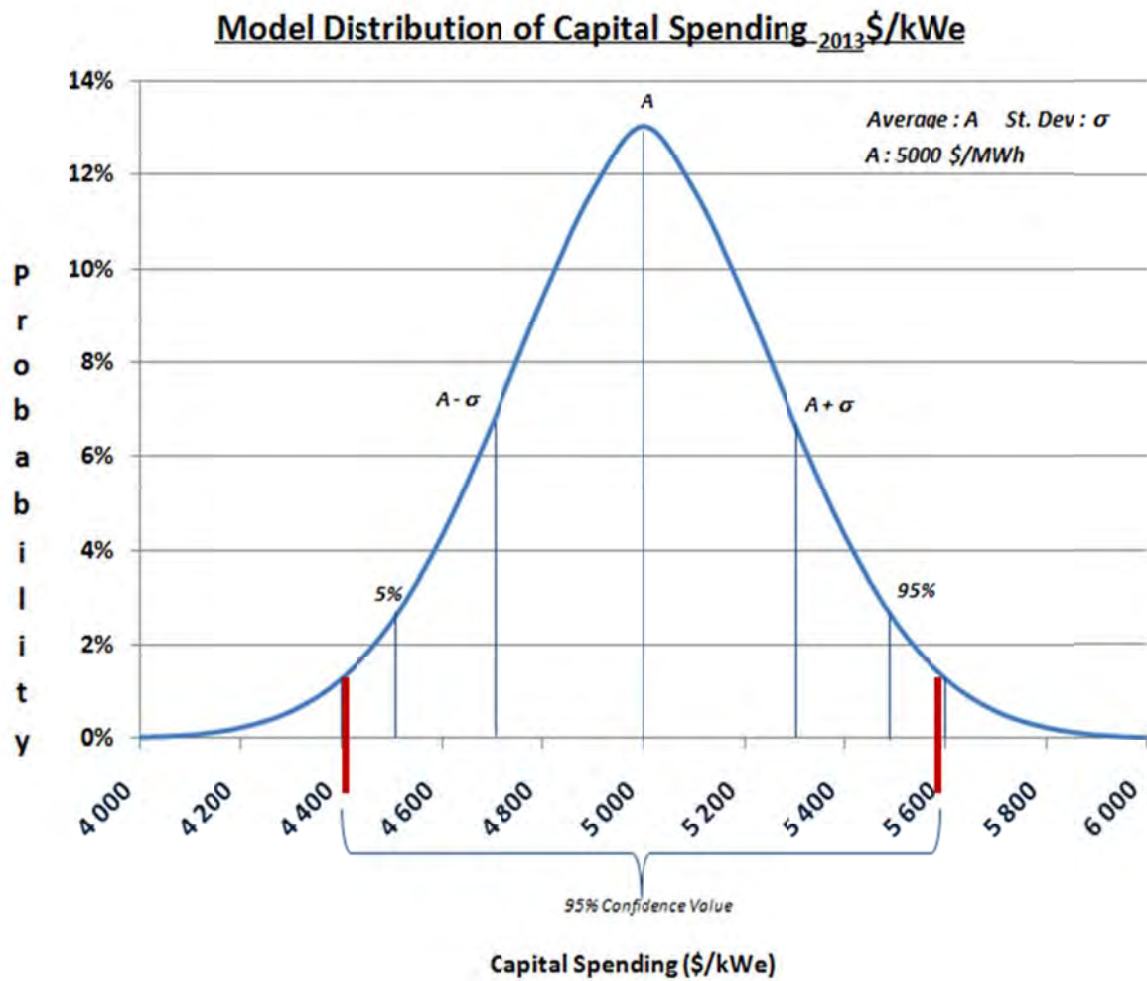


Figure 4 - Literature survey distribution of Capital Cost

Average value is ~5,000 \$/kWe. The Standard deviation is rather high, due to the fact that different technologies have been considered. More accurate results would be found, should the study be done per technology.

The next charts (which exclude Chinese CPR 1000) provide the distribution of the Capital Cost for projects all over the world calculated by the Consultant with a Discount Rate of 6.93%, the same used in the EPRI study specifically done for South Africa.

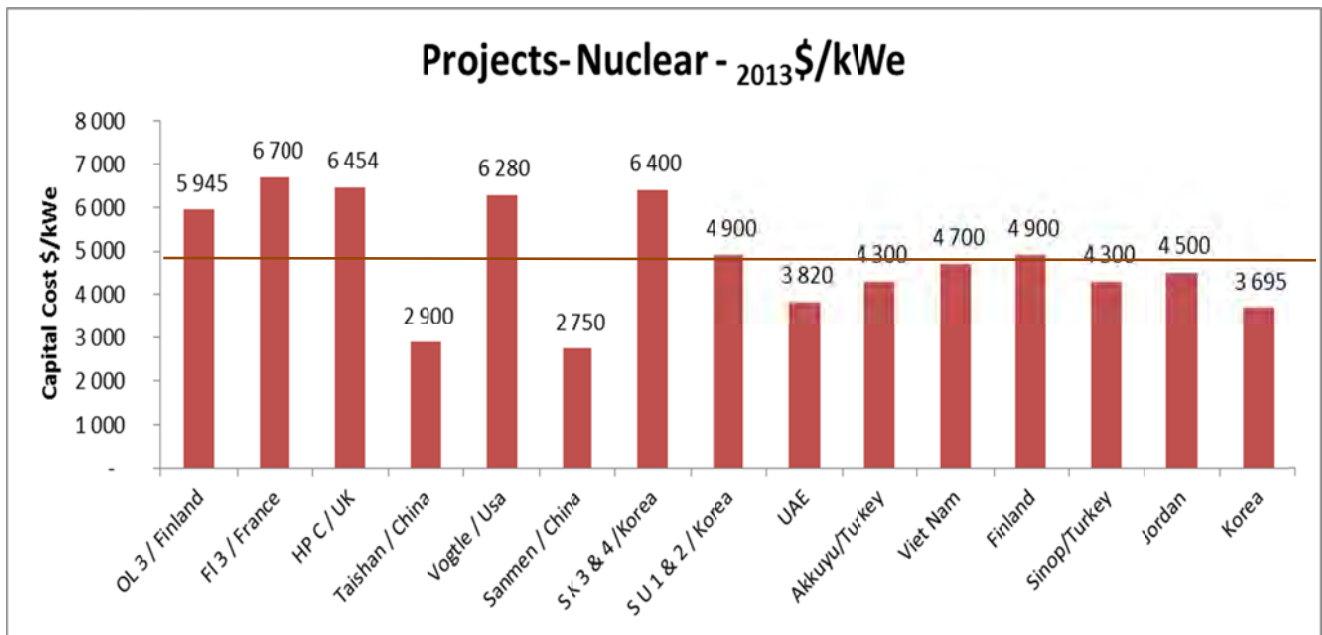


Figure 5 - Utilities reports - Capital costs of specific projects – Average 4 836 \$/kWe

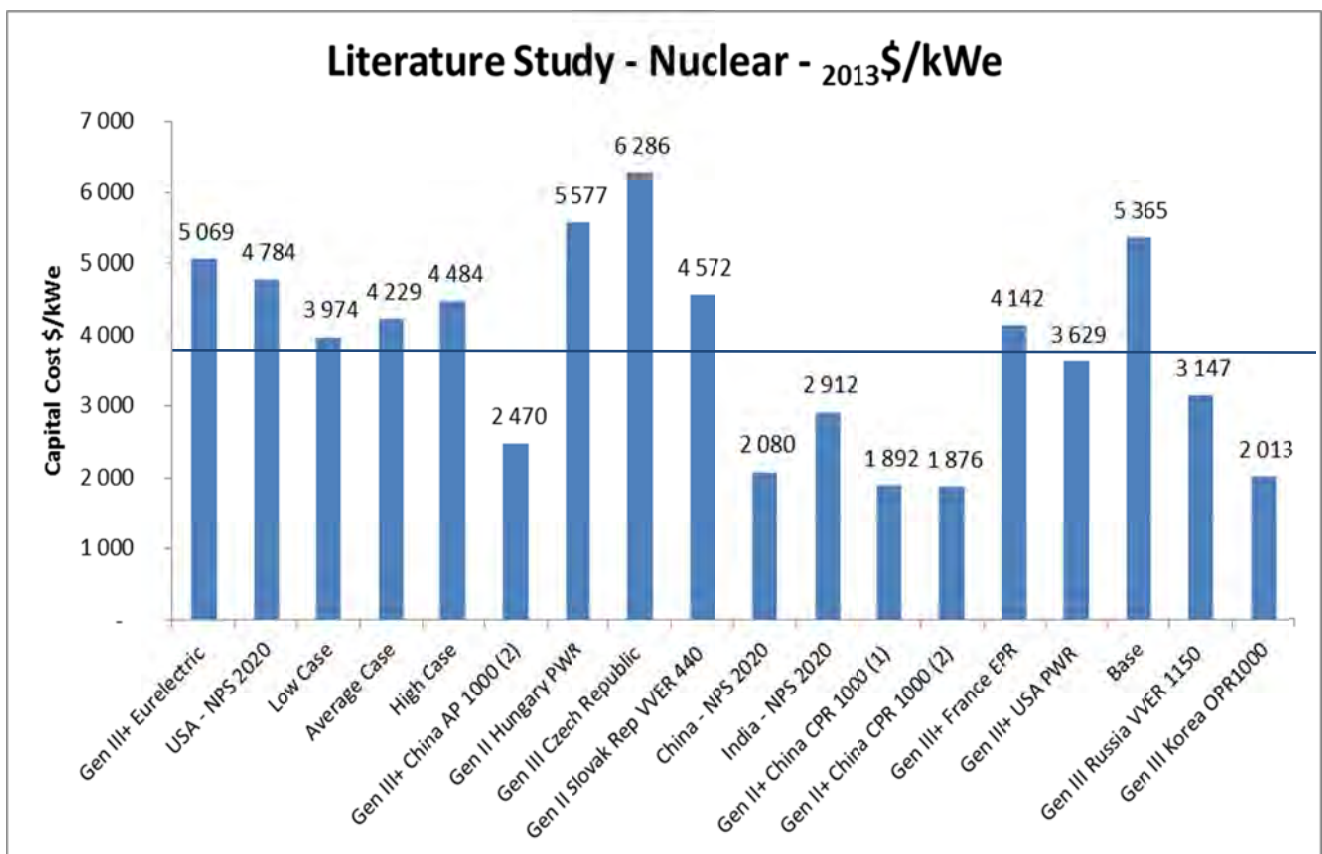


Figure 6 – Literature Study - Capital costs of specific projects – Average 3 806 \$/kWe

Projects costs derived from literature surveys, which include Chinese projects, are significantly below costs found in utilities reports. Apart from the low cost of Chinese projects, it is quite possible that literature surveys underestimate Owners costs.

- **Distribution of LCOEs**

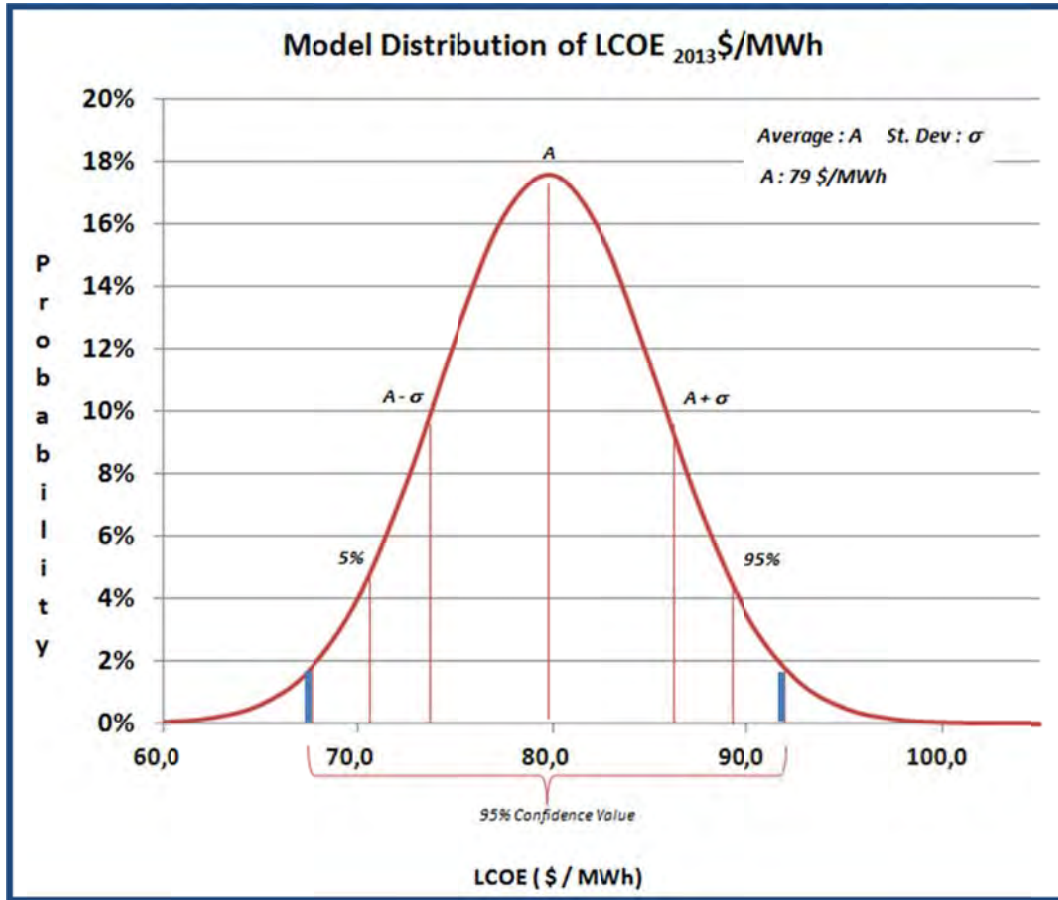


Figure 7 - Distribution of LCOEs – All data included

The overall review of all information which was covered tends to conclude that the mean value of present nuclear projects could be in the range of 5,000 \$/kW, and their LCOE would be in the range of 80\$/MWh assuming a very conservative calculation of the decommissioning component of this cost.

These figures represent a distribution of values taken from current or recent projects. It has to be acknowledged that they do not directly represent the cost of a nuclear project in South Africa, which should be strongly influenced by local conditions. While a first and single project could be in the high range of the evaluation, localisation and the benefit of a series of projects would greatly reduce their costs. It will be the main challenge for the owner(s) of the future projects to capture the benefit of these effects.

Further studies should be done, including Requests for Proposals from vendors, to consolidate these conclusions.

The next table provides a comparison to EPRI 2012 studies, but since it is not sure that both studies used the same methodology (especially for the decommissioning costs which are very conservatively estimated in the present study) a direct comparison to EPRI results cannot be made.

This table is similar to the table presented by EPRI in their 2012 specific to South Africa handed over by the DOE during the course of the assignment, including “average nuclear” (*Power Generation Technology Data for Integrated Resource Plan of South Africa. EPRI, Palo Alto, CA: 2012*).

Indeed the Consultant is not aware of the assumptions made by EPRI, especially with the discount of decommissioning costs, and it is very likely that EPRI approach is far less conservative than the approach presented in this report. Therefore we thought it would be inappropriate to make a direct comparison between the two results and did not attempt to present it.

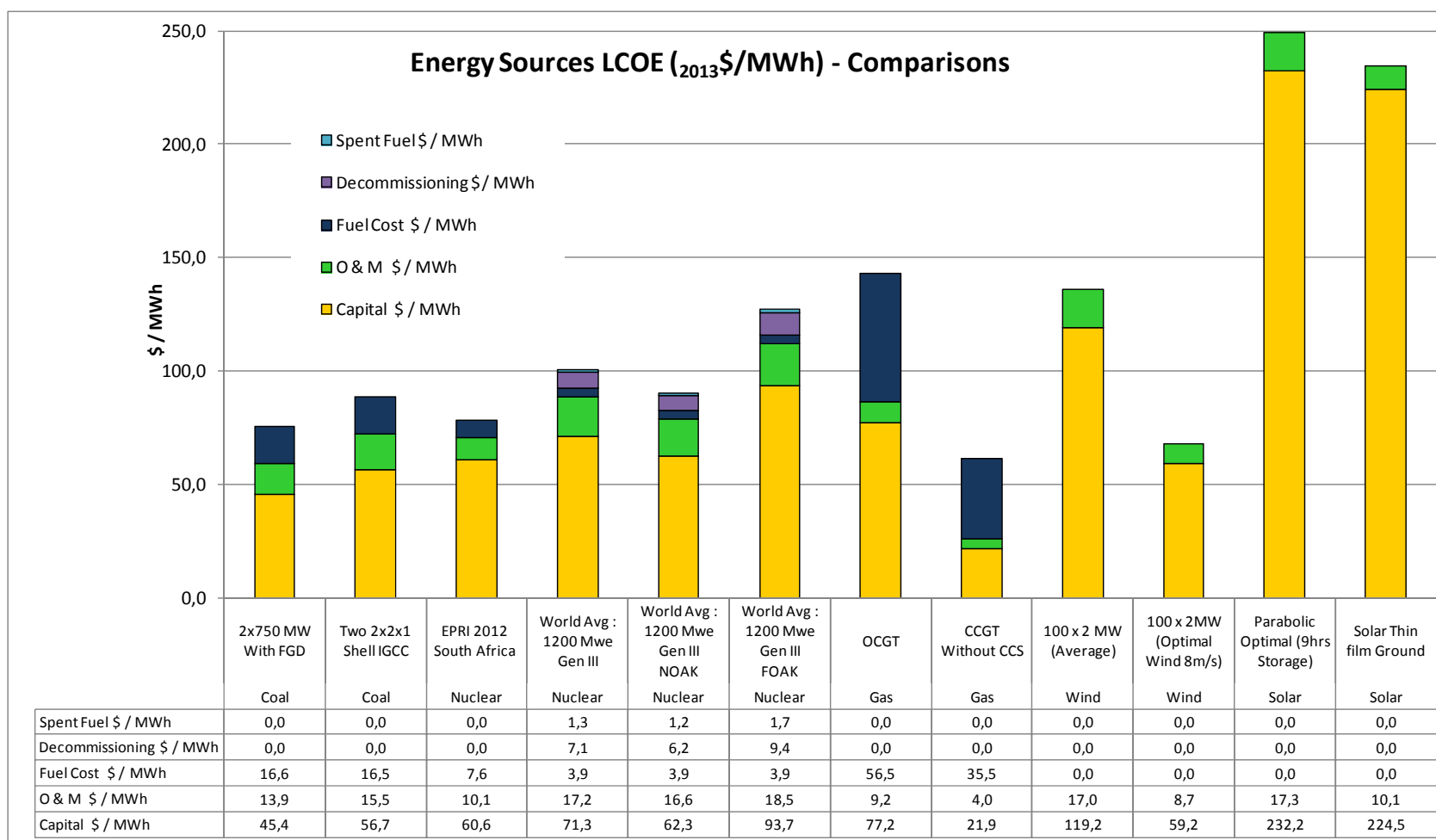


Figure 8 - Comparison to EPRI 2012 study

Main findings

The scope of the study was essentially a literature survey; and its main conclusions lay in the vast amount of data, harmonised and presented in Excel spread sheets transferred to the DOE.

During the short period of the assignment (four weeks), the consultant could establish the following:

- There is a significant reduction of Capex between countries having or planning a large nuclear program, and countries building single projects. Should South Africa confirm its nuclear ambitions, this point should be reflected in the procurement strategy.
- For the same reasons, Asian technology is cheaper than Western technology.
- The Terms of Reference did not request the evaluation by the consultant of the cost of the different technologies in South African conditions; only the cost in countries where active construction is taking place was requested. Although such study (evaluating the cost of respective technologies in SA conditions) would not be easy to perform, it would be advisable to do it before committing to large expenses for the finalisation of a nuclear program. Based on its experience, however, the Consultant believes that the impact of localisation would be proportional to the costs reported in this study, and would have a limited impact on the ranking of various energy sources.
- Only an open Call for bids would allow sorting these uncertainties.
- In order to compare nuclear energy to other energy resources, the Consultant used the LCOE methodology. It was shown and discussed in the full report that this methodology may have its shortcomings:
 - In the selection of a discount rate, which is a very controversial issue, when building an energy strategy
 - In the validity of the methodology for very long term projects having high uncertainties :
 - For nuclear energy, the long term costs of decommissioning
 - For fossil fuels, the long term costs of fuel, and their uncertainties.
- In order not to favour nuclear energy, the Consultant selected a very conservative approach to discount decommissioning costs; it is suggested to further discuss this issue, and make sensitivity analysis on this subject.

2. Introduction and Scope of Work

2.1. Summary

INGEROP South Africa (ISA) has been awarded a study, further to the Invitation to Tender DOE/001/2013/14 closed on May 14 2013. INGEROP South Africa will work together with INGEROP's subsidiary called NUCADVISOR and benefit from its technical support and in-depth knowledge of the nuclear energy projects. INGEROP South Africa will be the Lead Contact for the Department of Energy. INGEROP and NUCADVISOR are named "the Consultant" in this report.

The purpose of the study is to provide the DOE with an update on cost of nuclear power, based on available public information and private information known from the Consultant provided that all data are clearly referenced to source.

The previous official estimate received by the DOE was the Electric Power Research Institute study of 2010, which has recently been updated by the 2012 report.

Data should be statistically analyzed to arrive at a range of costs, expressed in 2013 USD, in a similar way as performed in a paper published in April 2013 by Nuclear Engineering International.

Finally, the levelized cost of electricity (LCOE) should be compared with the statistical range of renewable (Wind, Solar PV, Solar CSP) and fossil fuel technologies (Gas, Coal) as contemplated in the Integrated Resource Plan 2010-2030.

2.2. Purpose

The purpose of this Chapter is to make sure that the Consultant and the Department of Energy (DOE), the Client, maintain a common understanding of the way the assignment shall be conducted and evolve. While it mirrors the Terms of Reference in the aspects such as objectives and activities, it goes much further in others like data collection tools and methodology.

The preface is an elaborated version of the Terms of Reference (ToR) and of the approach presented into ISA's proposal. It should provide DOE's Project Manager with a clear indication of how the Consultant views his tasks and plan to achieve the objectives.

Even as some sections are repetitive of the ToR and the Consultant's proposal, they still serve to show that the Consultant is in accordance with the proposed. In case there would be any difference between the Preface and the Terms of Reference (ToR), the latter would prevail.

2.3. Consultant Understanding of the Department of Energy Request

2.3.1. International Context

The DOE initiated in 2010 a new plan for the energy sector development in South Africa for the next decades. This strategy has been reviewed through a public participation process that led to a better understanding of the future needs.

The document, adopted at the Cabinet level defines the Energy Strategy from 2010 to 2030, by selecting different scenarios according to objectives like CO₂ emission, demand and energy prices... The chosen option is based on a least-cost diversified generation plan for new builds, in alignment with the country's economic development. The outlines of the plan are the followings:

- The introduction of 18 GWe of renewable (Solar PV, CSP and wind)
- Renewables will be supported by the increase on Nuclear Electricity Generation (additional capacity of 9.6 GWe), which will offset the cost and dispatch uncertainties for Renewables.
- Nuclear Electricity will represent 20% of the production in 2030. Moreover, nuclear energy will enable the security of supply, by assuring a base load electricity production.
- The respect of the carbon dioxide emission constraint which limits the emission to 275 million tons of CO₂ per year will be mainly achieved by a decrease of coal in the energy mix, and the increase/introduction of New Nuclear Power Plants and Renewables.
- The increase of electricity import (hydro from Mozambique and Zambia, Coal from Mozambique and Botswana) is considered?

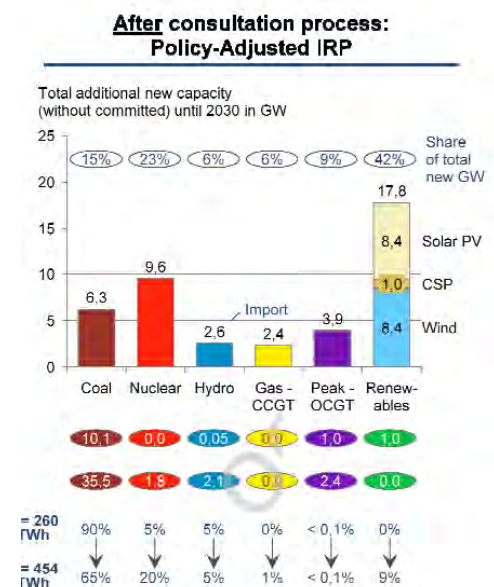


Figure 9: Policy Adjusted IRP for South Africa

The plan represents a major change for the South African energy mix, with significant economic and financial consequences. One challenge will be to design and execute the plan so that the significant upfront costs can be funded without economic disruption, and efficiently amortized at the lowest possible cost over the life of the assets.

The impact on the price of electricity is of utmost importance, since it is very likely to increase in the next decades (certain observers estimate that it will double by 2015 from current levels, which are very low by comparison to international standards). Vendors, investors and lenders will ultimately judge the efficiency and riskiness of the plan by assessing such aspects as how well the legislative choices protect the value of the assets, and how risk is shared across each project in the new energy mix. Finance ability and cost recovery – whether via increased tariff levels or other mechanisms – are essential for the feasibility of such a project.

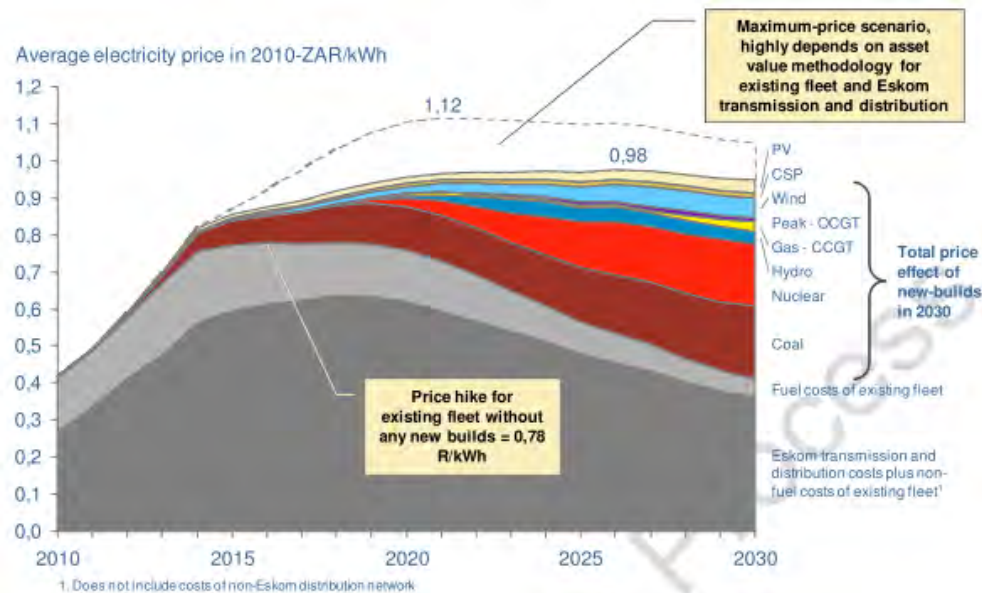


Figure 10: Electricity Price Projection in South Africa in the IRP

2.3.2. Our Understanding of the assignment

Before starting the South African procurement process of the nuclear units which are planned in the IRP, and in order to optimize this process, the Department of Energy wishes to update its information about the cost of nuclear energy, and its comparison to other sources considered in the IRP, primarily Renewables.

Through engagement with the client, the following Scope of works and depth of detail is understood to be required:

1. Preparatory costs
2. Overnight costs
3. Fuel costs
4. Long term fuel waste management costs
5. Operation and maintenance costs
6. Decommissioning and dismantling costs
7. Any other costs considered to make up more than 5% of the total.

As per the clients request the project will consist of a study of worldwide norms in terms of cost for nuclear new build programs rather than a firm bankable cost study. This will be conducted by using information available in the public domain, or known by the consultant from its past experience.

Results will be evaluated, and LCOEs will be derived and statistically analyzed; and then compared to data considered in the IRP for alternate sources of generation.

The study shall be made in a four-week time frame.

2.4. Methodology

This section presents our methodology and approach to the successful delivery of the stated objectives and scope of work as defined by the ToR.

It includes four steps:

1. Data collection
2. Data review and analysis
3. Nuclear plant LCOE and Cost modelling
4. LCOE Comparison of Nuclear to other Energy Sources.

2.4.1. Data Collection

0.4.1.1. Collection of generic figures (not vendor nor specific) on nuclear costs

A large number of reports have been published in recent years, similar in details and content to the 2011 EPRI study referenced in the DOE Terms of Reference, which provide an overview of nuclear generation costs. The latest version EPRI report is edition 2012, published on 19-Feb-2013, which provides the following updated summary.

Representative Cost and Performance of Power Generation Technologies (2015)

All Costs in Constant Dec. 2011\$	Nominal Plant Capacity, MW	Capacity Factor ¹ , %	Book Life, Years	Net HHV Heat Rate, Btu/kWh	CO ₂ Emissions ² , Metric Tons/MWh	Total Plant Cost, \$/kW	Total Capital Required ³ , \$/kW	FOM, \$/kW-yr	VOM, \$/MWh	Fuel Price, \$/MMBtu	LCOE ⁴ , \$/MWh
Pulverized Coal ⁵	750	80%	30	8,750	0.84	2,000-2,400	2,400-2,875	60	2.5	2-3	62-77
IGCC ⁵	800	80%	30	8,900	0.85	2,800-3,100	3,375-3,750	110	2	2-3	82-96
NGCC	550	80%	30	7,000	0.37	900-1,150	1,025-1,325	15	2.4	2-6	33-65
Nuclear	1400	90%	30	10,000	-	4,000-4,500	5,375-6,025	110	1.7	0.4-0.8	85-97
Biomass	100	80%	30	12,900	0 ⁶	3,600-4,500	4,150-5,250	66	5	2-6	90-156
Geothermal	15-50	80%	30	N/A	-	4,850-8,400	5,350-9,275	70-81	9.6	-	84-129
Onshore Wind ⁷	50-200	28-40%	20	N/A	-	1,750-2,400	1,825-2,500	36	-	-	62-117
Offshore Wind ⁷	200	40-45%	20	N/A	-	3,100-5,000	3,250-5,225	105	-	-	109-180
Concentrating Solar Thermal Power (CSP) ⁷	100-250	25-40%	30	N/A	-	3,300-6,100	4,050-7,550	64-88	-	-	159-180
Solar Photovoltaic (PV) ⁷	10	14-26%	20	N/A	-	2,000-2,300	2,200-2,525	20-25	-	-	107-203

Figure 11: Summary of the EPRI 2012 reports for Cost and Performance of Power Generation Technologies in 2015

However most of these reports, like the EPRI reports, do not systematically provide details on their sources, nor a breakdown of the costs in the categories contemplated by the DOE. Therefore the consultant will analyze not only synthetic information as the one provided by EPRI, but analytical information available from different sources.

A list of **generic sources** is provided in the next table. This list has been expanded and is more comprehensive than the initial list included in the offer. In general, those generic sources **do not provide technology specific data**.

Governmental and intergovernmental studies

UK –House of Commons –Energy prices – March 2013	A prospective comparison of energy prices by technology
UK – National Audit Office – Briefing for the House of Commons Climate Change and Energy Select Committee - The nuclear energy landscape in Great Britain –March 2012	An important report which supported the decision to continue negotiations with investors, including EdF, on the construction of new NPPs in the UK
Australian Government –Australian Electricity Generation – Technology costs – Reference Case 2010 and its updates.	Based on EPRI sources, but worth to compare, although Australia is not a nuclear country, their report includes references to nuclear costs
French Accounting Office - Les coûts de la filière électro nucléaire- The costs of the French Nuclear chain – January 2012	A very comprehensive study, which includes detailed information on new build, but also fuel cycle and decommissioning
International Energy Agency – Nuclear Energy Agency – OECD 2010	This very comprehensive report compares all energy types. Although dating 2010, and not updated, it deserves to be reviewed.
US Energy Information Administration - 2013	Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants

Non governmental studies

Electric Power Research Institute report - 2012	Integrated Generation Technology Options 2012
Electric Power Research Institute report - 2012	Parametric study of Front-End Nuclear fuel Cycle
Nuclear Engineering International (2013)	Future of shale gas. This article provides a detailed approach to nuclear energy and natural gas.
European Wind Energy Association (2012)	Model for comparing and projecting the levelized cost of electricity generated by new gas, coal, nuclear power stations and wind energy
World Nuclear Association	Power Generation in the new policies and the 450 scenarios (includes and Excel spreadsheet)
World Nuclear Association	The economics of Nuclear Power (March 2013)
Energy International Agency	Electricity Market Module/ Assumptions to the Annual Energy Outlook 2012
EXXON MOBIL	Energy Outlook 2013
BP	World Energy Outlook 2013

All data from these reports will be presented according to a standardized format, allowing an easy comparison and focus on the key factors impacting cost of nuclear. Financial data will be converted to 2013 USD, taking into account the average inflation rate of the country where data are sourced from, and the 2013 exchange rate between this country and the US.

The tables summarizing the original data findings will be structured as follows (if data are not available Not Available will be mentioned):

			<u>EPRI 2011</u>	<u>EPRI 2012</u>	<u>NEI 2013</u>	<u>EIA 2013</u>
Valuation Year			2010	2011	2011	2011
Nuclear Plant Start Operations			2015	2015	2015	2018
Nominal Plant Capacity	MW		1 400	1 400	1 400	N/A
Capacity Factor	%		90%	90%	90%	90%
Construction Duration	Months		84	84	54	N/A
Plant Cost (Overnight)	Low	\$/Kw	\$ 3 900	\$ 4 000	\$ 4 500	N/A
	High	\$/Kw	\$ 4 400	\$ 4 500	\$ 5 000	N/A
	Average	\$/Kw	\$ 4 150	\$ 4 250	\$ 4 750	N/A
Capital required	Low	\$/Kw	\$ 5 250	\$ 5 375	\$ 5 300	N/A
	High	\$/Kw	\$ 5 900	\$ 6 025	\$ 5 800	N/A
	Average	\$/Kw	\$ 5 575	\$ 5 700	\$ 5 550	N/A
Owner Cost + Interest	Average	%	34%	34%	17%	N/A
Capital Commitment	Average	Billions \$	7,8	8,0	7,8	N/A
Annual Output	Average	GWh	11 038	11 038	11 038	N/A

Total O & M		\$/MWh	\$ 21,2	\$ 21,2	\$ 9,5	N/A
Total O & M/plant cost		%	4,0%	3,9%	1,6%	N/A
Fuel	Mid-Point	\$/MWh	\$ 6,0	\$ 6,0	\$ 7,5	N/A
LCOE	Low	\$/MWh	\$ 76,0	\$ 85,0	\$ 86,0	\$ 104,4
	High	\$/MWh	\$ 87,0	\$ 97,0	\$ 93,0	\$ 115,3
	Average	\$/MWh	\$ 81,5	\$ 91,0	\$ 89,5	\$ 108,4
Production Cost		\$/MWh	\$ 27,2	\$ 27,2	\$ 17,0	\$ 25,0
CAPEX COST		\$/MWh	\$ 54,3	\$ 63,8	\$ 72,5	\$ 83,4

Debt Structure	%	50%	50%	50%	N/A
Nominal Return on Equity	%	11,0%	11,0%	12,0%	N/A
Nominal Debt Cost	%	7,0%	7,0%	6,0%	N/A
Nominal WACC Pretax	%	9,0%	9,0%	9,0%	N/A
Discount Rate After Tax	%	5,0%	5,0%	5,0%	N/A

Table 2: Form used for data collection

Fuel costs, and spent fuel management costs are technology specific to a very limited extent, Input data per ton, or per UTS for Uranium, conversion, enrichment, fabrication and disposal are essentially identical for all technologies, contemplated in the study (ie Light Water Reactors). They will be collected from generic reports or data provided by nuclear utilities and compared to the actual market data. For each technology considered, fuel costs per MWh will be calculated from these data, using the model presented hereafter.

Dismantling costs data are country specific, with huge variations depending on the specific regulations on the disposal of the rubbles, and used equipment. However, for any given country, they are essentially proportional to the size of the reactor and therefore to the value of the invested capital. Based on international data found in the survey, the Consultant shall establish the ratio “Dismantling & Decommissioning Costs to Capex” and use it for all technologies.

0.4.1.2. Technology specific Capex

CAPEX and construction times are the key drivers of the LCOE of nuclear facilities. They have to be evaluated for each technology, and it is expected that generic reports from governments, utilities or academics will provide limited information on this key element. Therefore, a vendor specific analysis shall be made.

The consultant shall review the following technologies which lead the market. The first five technologies are Generation III reactors.

- Westinghouse – AP 1000 -two projects under construction: US, and China,
- Areva – EPR - Projects under construction in Finland, China, France and considered in the UK,
- APR – 1400 – Under construction in Korea and the UAE,
- Rosatom VVER – 1200 (also named NPP-2006 or AES-2006) – Project under construction in Leningrad, and considered for Akkuyu – Turkey, and Vietnam,
- ATMEA 1- from ATMEA, a Joint Venture between Mitsubishi Heavy Industry and Areva which was recently selected in Turkey,
- CPR 1000 from China, which is a GEN II technology, but the workhorse of nuclear development in China; as far as data are available, the Consultant will try to derive the cost of the ACPR-1000, which is a technology upgrade of CPR-1000, to be qualified as generation III.
- ABWR from Japan is a 1350 MWe Gen III reactor. Four units were built and are operating in Japan. Two units are under construction in Taiwan with much delay. Other recent projects have been cancelled (South Texas 3 and 4, USA), or are progressing at very low speed (Visaginas, Lithuania). However Hitachi recently invested to take over the Horizon joint venture in the UK, with the prospect of building BWRs in this country (ABWR or a more advanced technology). Therefore and on DOE's request, cost information on this technology will be collected and evaluated, acknowledging that it will not be very reliable.

Origin of the data

There is very few and limited information directly issued by the nuclear vendor. However, there are indirect ways to get vendor specific data. The Consultant will use the following sources:

- Operators and investors information. As most operators and investors are listed, publicly traded companies, they have to publish information on their current investments and project commitments; the Consultant will systematically review all public Annual reports and Filings as appropriate,
- The Consultant has had access to total overnight costs for several technologies considered in recent projects (Turkey, Vietnam...) and will provide the results, however without providing a reference to the source of information.

Breakdown of technology-specific data

Breakdown of data will be established as follows:

- Overnight cost will be taken from public or private sources, when available, and documented.
- All type of sources will be considered (studies from the industry, academic studies, governmental studies, reports from utilities, media reports). Their reliability will be mentioned.
- The consultant will also use its own information gathered from previous studies or contacts with the industry, which will be qualified as "Consultant information", and not further documented.
- Reactor specific O&M costs are generally not published. Based on the results of the generic studies, the Consultant will provide its estimate of technology specific O & M costs, based on a qualitative and simplified analysis of the technologies, and their impact on O&M; essentially, the Consultant will calculate the rate of O&M to CAPEX, and its statistical dispersion.
- Fuel costs per kWh are essentially not technology specific; they will be directly calculated on the basis of international prices of Uranium, Conversion, Enrichment, and fuel fabrication (the latter being to some extent vendor specific, but due to competition, Fuel fabrication costs per ton of fuel is roughly the same for all vendors). The main variable factor of fuel costs is therefore the

achievable burn up, the efficiency and to a lesser extent the load factor of the nuclear power plant. The consultant will therefore use this direct approach to calculate fuel costs.

- Dismantling costs will be assessed through different dismantling projects achieved in the past..

The reactor specific information will be presented under a similar format as the generic data.

2.4.2. Data Analysis

The Consultant will rank the data collected, according to their accuracy and reliability. The Consultant will calculate LCOEs, considering uncertainties, and make an analysis using Excel formulas (average, standard deviation, and upper extreme (95% confidence) in a similar ways as considered in the paper recently published by Nuclear Engineering International (April 2013).

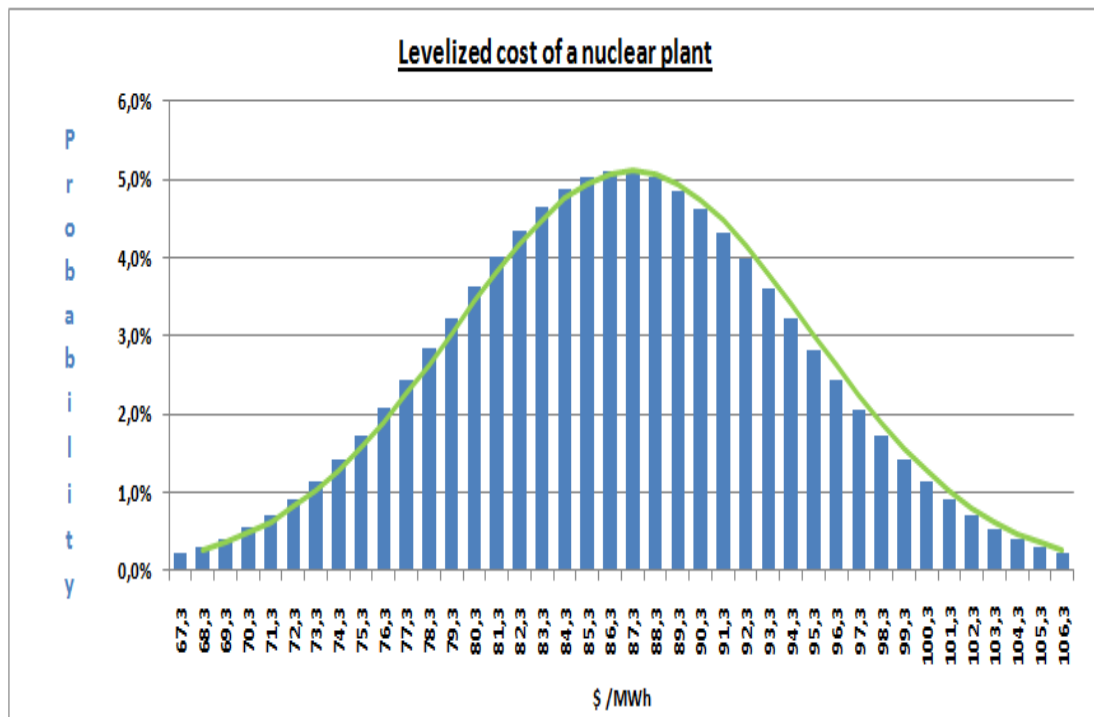


Figure 12: Typical format of data presentation, whenever possible

2.4.3. Nuclear Plant Modeling

The Consultant will perform a detailed modelling approach taking into considerations the inputs from the technology review.

An Excel model will be run with averaged cost data, and extreme cost data, as will be provided by the initial step of the study. Specific set of data will be agreed upon with the DOE for the various input level of the model (capital spending costs, maintenance and operation costs, etc)

This economic model:

- provide a quick overview of profitability of various energy sources to produce electricity
- provide comparisons for various nuclear reactors profitability
- calculate Levelized Cost of Energy for a given Discount Rate or,
- calculate Discount Rate for a given L.C.O.E
- adjust to any type of nuclear reactors, and may be extended to wind mills and gas turbines.
- provides scenarios and optimization of production mix

In terms of fuel validation, our Economic Model Calculation for fuel costs takes into consideration all necessary information:

- Thermal efficiency
- Pricing
- Validated by public data as illustrated (NEI source for the USA)

2.4.4. Comparison to other Energy Sources

The results of the model (essentially LCOE of nuclear generation) will be compared to the statistical range of renewable (Wind, Solar PV, Solar CSP) and fossil fuel technologies (Gas, Coal) as contemplated in the Integrated Resource Plan 2010-2030 and updated to latest cost values.

A comparison of results to the input data included in Table 28 of IRP 2010 will be done (Technology costs input w/o learning rates).

More detailed analysis will be done if the DOE provides the consultant with its underlying assumptions on learning rates.

Parametric studies, on **assumptions to be agreed with DOE** will be made; adjusting the discounting factor of new nuclear, its construction time and overnight cost, to better assess the sensitivity of nuclear price per kWh to these key parameters.

2.5. Work plan

Week	1	2	3	4
WP1 Data collection				
WP2 Modification and Data analysis				
WP 3 Comparison to other energy sources				
WP 4 Conclusions				

The following documents will be delivered:

Title	Content	Date
Inception report	Inception report	09/13/2013
Literature survey	Reference of all surveyed documents, and rough data taken from these documents	09/26/2013
Analysis : draft document and presentation	Normalized data (2013 USD ; identical scopes , and preliminary data analysis)	10/02/2013
Draft comparison, conclusions document and presentation	Statistical analysis, and comparison to other energy sources	10/09/2013
Final consolidated document and presentation	Conclusions	10/16/2013

* Date of final meeting changed at no cost to 10/23/2013 at the request of the DOE

3. Generic Reports

The following tables give the complete list of the studies and report used:

Nota Bene: The list is broader than contemplated in the Introduction report.

Nota Bene 2: The reliability (Low, Medium or High) is only applied for reports where cost data are detailed enough to be used is the consultant analysis. The reliability only concerns the figures, and not the Author or the method

Governmental and Intergovernmental Reports

Author		Year	Document Name	Data Reliability
	National Audit Office United Kingdom	April 2012	The nuclear energy landscape in Great Britain	/
	Australian Government Department of Resources, Energy and Tourism	Feb. 2010	Australian Electricity Generation Technology Costs – Reference Case 2010	High
	French Accounting Office	Jan. 2012	The costs of the French Nuclear sector	High
	International Energy Agency – Nuclear Energy Agency – OECD	2010	Projected Costs of Generating Electricity	Reliability Depending on figures
	The European Wind Energy Association (EWEA)	2010	Model for comparing and projecting the levelized cost of electricity generated by new gas, coal, nuclear power stations and wind energy	Low
	Nuclear Engineering International (NEI)	Apr. 2013	Evaluating the shale gas challenge	Medium

 NUCLEAR ENERGY INSTITUTE	Nuclear Engineering Institute (NEI)	Feb. 2013	White paper, the cost of New generating Capacity in Perspective	/
 World Nuclear Association	(WNA)		Power Generation in the new policies and the 450 scenarios (Excel spreadsheet also)	High
 World Nuclear Association	(WNA)	Mar. 2013	The economics of Nuclear Power	High
 eia	(EIA)	2012	Electricity Market Module/ Assumptions to the Annual Energy Outlook 2012	/
	House of Commons United Kingdom	March 2013	Energy Prices, Profits and Poverty	/

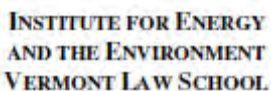
Non Governmental Organization

	BELLONA Foundation	2011	The Economics of the Russian Nuclear Power Industry	/
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Utility Groups Reports

Author		Year	Document Name	
	(EPRI)	Jan. 2010	Parametric study of Front-End Nuclear fuel Cycle	High
	(EPRI)	2010 2011 2012	Program on Technology Innovation: Integrated Generation Technology Options	High
	EXXON MOBIL	2013	Energy Outlook 2013	/
	BP	Jun. 2013	World Energy Outlook 2013	/
	VGB POWERTECH	Sept. 2012	Generation Portfolio	Low

Academic Studies

Author		Year	Document Name	
	University of California	Sept. 2012	What does it cost to build a nuclear power plant?	/
	Massachusetts Institute of Technology	2009	Future of Nuclear Power (update of the 2003 study)	Low
	Institute for Energy and the Environment Vermont Law School	2009	Mark Cooper – Policy challenges of nuclear reactor construction, cost escalation costs, and crowding out alternatives	/
	National Bureau of Economic Research	2012	Lucas W. Davis, 2012. "Prospects for Nuclear Power," Journal of Economic Perspectives, American Economic Association, vol. 26(1), pages 49-66, Winter.	/

<i>Abstract</i>	This report provides an overview of nuclear energy in Great Britain, covering the nuclear industry, Government policy, the regulatory regime and arrangements for dealing with the legacy from previous nuclear generation. It has been prepared by the National Audit Office for the Energy and Climate Change
<i>Author</i>	The National Audit Office (NAO) scrutinizes public spending on behalf of UK Parliament.
<i>Content</i>	The UK launched a few years ago a wide debate about the construction of New Nuclear Power Plants, as part of the UK Energy Market Reform This report evaluates the potential of Nuclear Energy for UK, through several indicators (Costs, Legal Framework, Regulatory, Time lines...) An overview of Nuclear Energy Situation in the UK is provided, based on existing production capacity taking into account the installations to be decommissioned; it also indicates the cost associated (Dismantling, Waste Storage) and the current national/international regulatory and legal framework on the subject. It provides eventually a wide vision of all the necessary steps to address for UK (Timeline, Planning, Design Assessment Process, NPP Financing, Decommissioning and Waste disposal financing...). The report analyzes costs of different energy sources of electricity that will allow the UK to meet the objective to deliver secure, low carbon and affordable energy. According to this report, Nuclear Cost of a First of a Kind NPP would be the cheapest energy source compared to Combined Cycle Gas Turbine (CCGT) or renewable energy. Estimated value is slightly less than £ 80/MWh or \$ 120/MWh. United Kingdom estimates that it will cost Nuclear Operator around £ 50 billion (or \$ 75 billion) to build 16 GWe of Nuclear Capacity over the next 20 years.

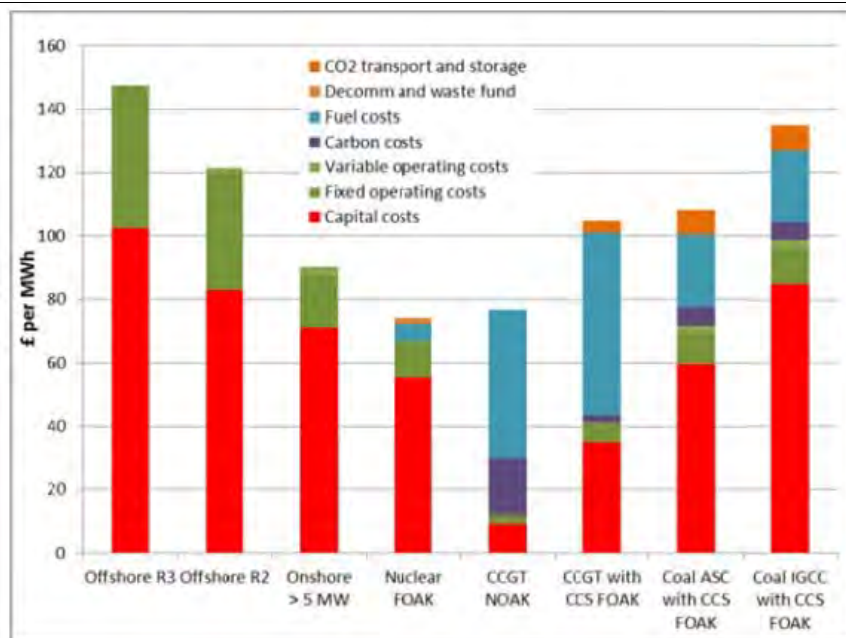


Figure 13: LCOE per technology - National Audit Office - United Kingdom – The nuclear energy landscape in Great Britain – April 2012

The report evaluates the spending program taking into account the cost of the EPR reactors in Finland (Olkiluoto) and France (Flamanville); the cost of these reactors have been significantly revised upwards since the publication of the reports

Finally the study deals with Decommissioning and its associated challenges (Waste disposal...). UK has several nuclear installations, so a decommissioning structure already exists. All the provisions are presented and enable to calculate the cost spent by UK for the management of its nuclear wastes, and the expected amounts provisioned to manage decommissioning of existing NPP.

The Nuclear Liabilities Fund is responsible for meeting the estimated £4 billion cost of decommissioning the eight operational nuclear power stations that are owned by EDF Energy

UK expects an amount of £420 thousands per MWe for decommissioning existing EDF Energy NPP (all but one are AGR reactors)

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity Cost (LCOE)
	Yes (for UK program and EPR)	Partial	Yes (For Nuclear and Others Energies)
Source	http://www.nao.org.uk/report/nao-briefing-the-nuclear-energy-landscape-in-great-britain/		

3.2. Department of Resources, Energy and Tourism - Australian Electricity Generation Technology Costs

<i>Abstract</i>	The objective of the report was to establish an up-to-date cost and performance database agreed by Australian stakeholders as supportable in the Australian context. The study is based on EPRI's report "Costs and Diffusion Barriers to the Deployment of Low-Emission Technologies". The report also provides a levelised cost analysis of a basket of technologies (Gas, Coal, Renewable, Nuclear...) in 2015 and 2030 (this provides an agreed basis for comparing globally available power generation technologies and costs).
<i>Author</i>	The Department of Resources, Energy and Tourism provides advice and policy support to the Australian Government regarding Australia's resources, energy and tourism sectors. The Department develops and delivers policies to increase Australia's international competitiveness, consistent with the principles of environmental responsibility and sustainable development. The report being based on EPRI work please refers to section related to EPRI studies for more details.
<i>Content</i>	The report provides two separate but related outputs – the 2015 and 2030 cost and performance data for selected technologies (including a discussion on the status and attributes of each), and an analysis of the levelised costs of each technology using a common methodology and set of assumptions. The technologies studied in the report are: Nuclear, Wind, Combined Cycle Gas Turbine (CCGT), Tidal/Wave, Open Cycle Gas Turbine (OCGT), Geothermal, Solar Thermal, Hydroelectric, Pulverised Coal (PC), Biomass, Solar Photovoltaic, Integrated Gasification Combined Cycle (IGCC)... Each technology follows a specific methodology to calculate LCOE, based on Australian resources and requirements, and detailed analysis of each technology. For each technology is given a full description of costs (Plant capital costs, O&M costs, Fuel Costs...). Results are presented in tables for each technology, and sensibility studies are done. The following chart gives an example of LCOE range for selected technologies:

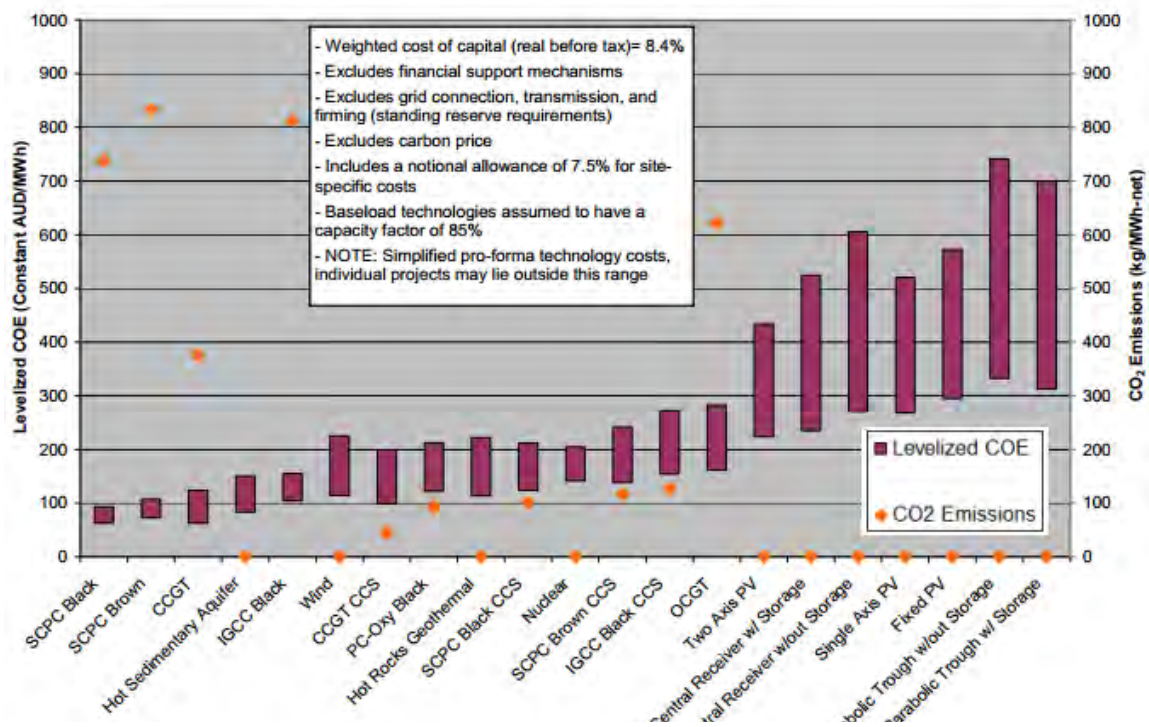


Figure 14: LCOE per technology - Australia AUD/MWh

Multi-dimensional sensitivity analysis was also conducted on 2015 technology levelised costs of electricity. These sensitivity analyses are presented as 'Tornado' graphs (see example below) showing the effect of different assumptions on the levelised cost of electricity results (Capital Cost, Plant life, Resource, Total O&M Cost...).

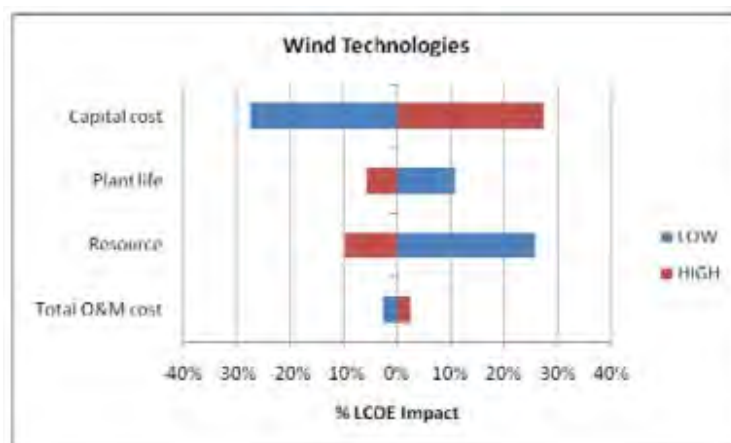


Figure 15: Wind Technology in Australia - High and Low assumptions

However, there is significant uncertainty in predicting future costs via learning curves, particularly where technologies are evolving rapidly opening up the possibility of unforeseen step changes in cost or performance.

In addition 'learning curve' based cost reductions are sensitive to the rate of assumed technology deployment which for low emission technologies will be driven by a global policy framework that is difficult to predict.

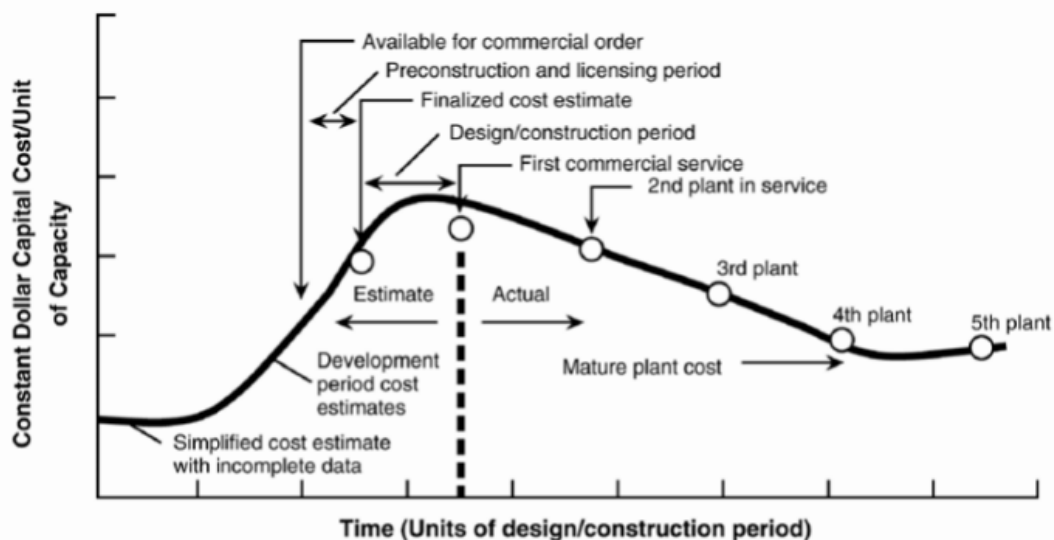


Figure 16: Capital Cost in Australia - Impact of series effect

Consequently, estimated costs for 2030 must be considered with caution.

However, the study is dedicated to Australia, for this reason some technological constraint have been taken. For example, due to shortages of water availability throughout Australia, each of the technologies evaluated were configured with air cooling of the condensers and auxiliary equipment to minimize water consumption.

Technology Description	IGCC WITH BLACK COAL WITHOUT CCS	IGCC WITH BLACK COAL WITH CCS (88.5% Capture)
Capital	93	141
O&M	23	34
Fuel	14	19
CO ₂ T&S	0	20
LCOE (Constant 2009 AUD/MWh)	130	213

Technology Description	CCGT WITHOUT CCS	CCGT WITH CCS	CCGT WITHOUT CCS
Capital	27	58	117
O&M	4	9	13
Fuel	65	79	98
CO ₂ T&S	0	8	0
LCOE (Constant 2009 AUD/MWh)	97	153	227

Technology Description	NUCLEAR GENERATION III/III+
Capital	137
O&M	26
Fuel	10
LCOE (Constant 2009 AUD/MWh)	173

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity Cost (LCOE)
	Yes	Yes	Yes
Source	http://www.ret.gov.au/energy/Documents/AEGTC%202010.pdf		

3.3. French Accounting Office – The cost of the Nuclear Power Sector - Jan. 2012

Abstract	The report concentrates on identifying and assessing the various costs associated with producing nuclear power in France and explaining the calculation methods and hypotheses adopted for each.														
Author	The Court of Auditors is a quasi-judicial body of the French government charged with conducting financial and legislative audits of most public institutions and some private institutions. The Court's three duties are to conduct financial audits of accounts, conduct good governance audits, and provide information and advice to the French Parliament and Administration.														
Content	The study from the French Accounting Office lists all the different costs related to the French Nuclear Industry, starting from the Research Costs associated to the early development of Nuclear Research, the construction costs, operating costs, dismantling costs... <i>NB: The report being extremely detailed and referenced; only the conclusion and some general figures will be detailed here.</i> Figures shows that the French Nuclear Program represented a very high initial investment (Research), with a construction cost that increased over time <i>From €1.07 million₂₀₁₀/MW in 1978 (Fessenheim) to €2.06 million₂₀₁₀ in 2000 (Chooz 1 and 2) or €1.37 million₂₀₁₀ in 2002 (at Civaux), with an average of €1.25 million₂₀₁₀ for the 58 reactors.</i> <i>For EPR in Flamanville the estimated cost per MW is €3.7million</i> This increase was notably due to changes in the safety baselines over time. The Operating expenses for the French Nuclear Fleet reached €8.9 billion₂₀₁₀ for 407.9 TWh power output in 2010 (i.e. €22/MWh) <table> <tr> <th>Operating Expenses in current €</th><th>In €million 2010</th></tr> <tr> <td>Nuclear Fuel</td><td>2135</td></tr> <tr> <td>Staff Costs</td><td>2676</td></tr> <tr> <td>External charges</td><td>2095</td></tr> <tr> <td>Taxes and duties</td><td>1176</td></tr> <tr> <td>Central functions</td><td>872</td></tr> <tr> <td>TOTAL OPERATING EXPENSES</td><td>8954</td></tr> </table> <i>Table 3: Operating expenses for the French Nuclear Fleet</i> Maintenance investments program for the period 2011-2025 represents an average of €3.3 billion per year (in 2010 the investment was €1.7 billion, i.e. €4.2/MWh in 2010). The figure takes into account all the design and safety improvements to meet French Safety Authority Requirements following the Fukushima Disaster. The report calculates nuclear electricity generating costs, using different approaches. Each method takes into account past, present and future costs (ie. Dismantling, Spent Fuel, Waste Management...).	Operating Expenses in current €	In €million 2010	Nuclear Fuel	2135	Staff Costs	2676	External charges	2095	Taxes and duties	1176	Central functions	872	TOTAL OPERATING EXPENSES	8954
Operating Expenses in current €	In €million 2010														
Nuclear Fuel	2135														
Staff Costs	2676														
External charges	2095														
Taxes and duties	1176														
Central functions	872														
TOTAL OPERATING EXPENSES	8954														

	It gives the following results for year 2010:		
	Results of the various calculations of generating cost per MWh according to objective		In €2 ₀₁₀
	Cost using the full cost accounting method, which takes into account the depreciation of the fleet but not the return on capital		€33.4/MWh
	Cost using the Champsaur commission approach, which takes into account the depreciation of the fleet and return on the capital that is not amortized (with the objective of calculating a tariff)		€33.1/MWh
	Current economic cost (CEC), which does not take into account fleet depreciation and which pays the capital originally invested, allowing for inflation (with the objective of calculating an average generating cost with no historical reference).		€49.5/MWh
Table 4: French LCOE results with various calculations methods			
For Flamanville EPR, the report estimates a generating cost in the range of €70 to €90/MWh.			
Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	http://www.ccomptes.fr/Publications/Publications/Les-couts-de-la-filiere-electro-nucleaire		



3.4. International Energy Agency – Nuclear Energy Agency Organisation for Economic Co-operation and Development (OECD) – Projected Costs of Generating Electricity - 2010

<i>Abstract</i>	This joint report by the International Energy Agency (IEA) and the OECD Nuclear Energy Agency (NEA) presents the latest data available for a wide variety of fuels and technologies, including coal and gas (with and without carbon capture), nuclear, hydro, onshore and offshore wind, biomass, solar, wave and tidal as well as combined heat and power (CHP). It provides levelised costs of electricity (LCOE) per MWh for almost 200 plants, based on data covering 21 countries (including four major non-OECD countries), and several industrial companies and organisations. The report also contains an extensive sensitivity analysis of the impact of variations in key parameters such as discount rates, fuel prices and carbon costs on LCOE. Additional issues affecting power generation choices are also examined.
<i>Author</i>	The International Energy Agency (IEA), an autonomous agency, has two objectives: to promote energy security amongst its member countries through collective response to physical disruptions in oil supply and to advise member countries on sound energy policy. The OECD Nuclear Energy Agency (NEA) has two main missions: – to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes – to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.
<i>Content</i>	<i>NB: Results of the reports and calculations methods will not be discussed in details.</i> The calculations are based on the simple levelised average (unit) lifetime cost approach adopted in previous studies, using the discounted cash flow (DCF) method. The calculations use generic assumptions for the main technical and economic parameters as agreed upon by the adhoc Expert Group. The most important assumptions concern the real discount rates, 5% and 10%, also keeping with tradition, fuel prices and, for the first time, a carbon price of USD 30 per ton of CO₂. The following table is an example of Overnight Costs for OECD Members of Nuclear, Coal Gas & Onshore wind. Others Energy sources like offshore wind, hydro, solar PV or CHP are also given in the report.

Table 3.1a: Overnight costs* of electricity generating technologies (USD/kWe) – Mainstream technologies**									
Country	Nuclear	USD/kWe	Coal	USD/kWe	Gas	USD/kWe	Onshore wind	USD/kWe	
Belgium	EPR-1600	5 383	Bk SC	2 539	Single Shaft CCGT	1 249	3x2MW	2 615	
			Bk SC	2 534	CCGT	1 099	1x2MW	2 461	
Canada					CCGT	1 069			
					CCGT	1 245			
Denmark	PWR	5 858	Br PCC	3 485	CCGT	1 573	33x3MW	2 745	
			Br FBC	3 485	CCGT w/CC(S)	2 611	5x3MW	3 280	
Finland			Br IGCC	4 671					
			Br FBC w/ BioM	3 690					
France			Br PCC w/CC(S)	5 812					
			Br FBC w/CC(S)	6 076					
Germany			Br IGCC w/CC(S)	6 268					
			Br FBC w/BioM and CC(S)	6 076					
Hungary	EPR	3 860					15x3MW	1 912	
	PWR	4 102	Bk PCC	1 904	CCGT	1 025	1x3MW	1 934	
Italy			Bk PCC w/CC(S)	3 223	Gas Turbine	520			
			Br PCC	2 197					
Japan			Br PCC w/CC(S)	3 516					
	PWR	5 198			CCGT		26x2MW	2 637	
Korea	ABWR	3 009	Bk	2 719	CCGT	1 549			
	OPR-1000	1 876	Bk PCC	895	LNG CCGT	643			
Mexico	APR-1400	1 556	Bk PCC	807	LNG CCGT	635			
			Bk PCC	1 961	CCGT	982			
Netherlands	PWR	5 105	Bk USC PCC	2 171	CCGT	1 025	3MW	2 076	
Slovak Republic	VVER	4 261	Br SC FBC	2 762					
	PWR	5 863			CCGT	1 622	3x2MW	3 716	
Switzerland	PWR	4 043							
	Adv Gen III+	3 362	Bk PCC	2 108	CCGT	969	100x1.5MW	1 973	
United States			Bk IGCC	2 433	AGT	649			
			Bk IGCC w/CC(S)	3 569	CCGT w/CC(S)	1 928			

Figure 17: Overnight costs of electricity generating technologies (USD/kWe)

The study also gives detailed data per technology of LCOE, below is the table for Nuclear Energy of projects all over the world:

Table 3.7a: Nuclear power plants: Levelised costs of electricity in US dollars per MWh												
Country	Technology	Net capacity MWe	Overnight costs ¹ USD/kWe	Investment costs ²		Decommissioning costs ³		Fuel Cycle costs USD/MWh	O&M costs ⁴ USD/MWh	LCOE		
				5%	10%	5%	10%			5%	10%	
			USD/kWe	USD/kWe	USD/MWh	USD/MWh	USD/MWh	USD/MWh	USD/MWh	USD/MWh	USD/MWh	
Belgium	EPR-1600	1 600	5 383	6 185	7 117	0.23	0.02	9.33	7.20	61.06	109.14	
Greek Rep.	PWR	1 150	5 858	6 392	6 971	0.22	0.02	9.33	14.74	69.74	115.06	
France*	EPR	1 630	3 860	4 483	5 219	0.05	0.005	9.33	16.00	56.42	92.38	
Germany	PWR	1 600	4 102	4 599	5 022	0.00	0.00	9.33	8.80	49.97	82.64	
Hungary	PWR	1 120	5 198	5 632	6 113	1.77	2.18	8.77	20.79/20.84	81.65	121.62	
Japan	ABWR	1 330	3 009	3 430	3 940	0.13	0.01	9.33	16.50	49.71	76.46	
Korea	OPR-1000	954	1 876	2 098	2 340	0.09	0.01	7.90	10.42	32.93	48.38	
	APR-1400	1 343	1 556	1 751	1 964	0.07	0.01	7.90	8.95	29.05	42.09	
Netherlands	PWR	1 650	5 105	5 709	6 383	0.20	0.02	9.33	13.71	62.76	105.06	
Slovak Rep.	VER 440/ V213	954	4 261	4 874	5 580	0.16	0.02	9.33	19.35/16.89	62.69	97.92	
	PWR	1 600	5 863	6 988	8 334	0.29	0.03	9.33	19.84	78.24	136.50	
Switzerland	PWR	1 530	4 043	4 758	5 612	0.16	0.01	9.33	15.40	57.83	96.84	
United States	Advanced Gen III+	1 350	3 382	3 814	4 296	0.13	0.01	9.33	12.87	48.73	77.39	
NON-OECD MEMBERS												
Brazil	PWR	1 405	3 798	4 703	5 813	0.84	0.84	11.64	15.54	65.29	105.29	
	CPR-1000	1 000	1 763	1 946	2 145	0.08	0.01	9.33	7.10	29.99	44.00	
China	CPR-1000	1 000	1 748	1 931	2 128	0.08	0.01	9.33	7.04	29.82	43.72	
	AP-1000	1 250	2 302	2 542	2 802	0.10	0.01	9.33	9.28	36.31	64.61	
Russia	VER-1150	1 070	2 933	3 238	3 574	0.00	0.00	4.00	16.74/16.94	43.49	68.16	
INDUSTRY CONTRIBUTION												
EPRI	APWR, ABWR	1 400	2 070	3 319	3 714	0.12	0.01	9.33	15.80	48.23	72.87	
Euroelectric	EPR-1600	1 600	4 724	5 575	6 592	0.19	0.02	9.33	11.80	59.93	105.84	

* The cost estimate refers to the EPR in Ramanville (EDF data) and is site-specific.

1. Overnight costs include pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).

2. Investment costs include overnight costs as well as the implied interest during construction (IDC).

3. In cases where two numbers are listed under O&M costs, numbers reflect 5% and 10% discount rates. The numbers differ due to country-specific cost allocation schedules.

* The cost estimate refers to the EPR in Flamanville (EDF data) and is site-specific.

1. Overnight costs include pre-construction (owner's), construction (engineering, procurement and construction) and contingency costs, but not interest during construction (IDC).
2. Investment costs include overnight costs as well as the implied interest during construction (IDC).
3. In cases where two numbers are listed under O&M costs, numbers reflect 5% and 10% discount rates. The numbers differ due to country-specific cost allocation schedules.

Figure 18: Nuclear power plants: LCOE in USD/MWh

Sensitivity analyses are performed, using tornado chart. Each parameters follows a +/- 50% variation its value.

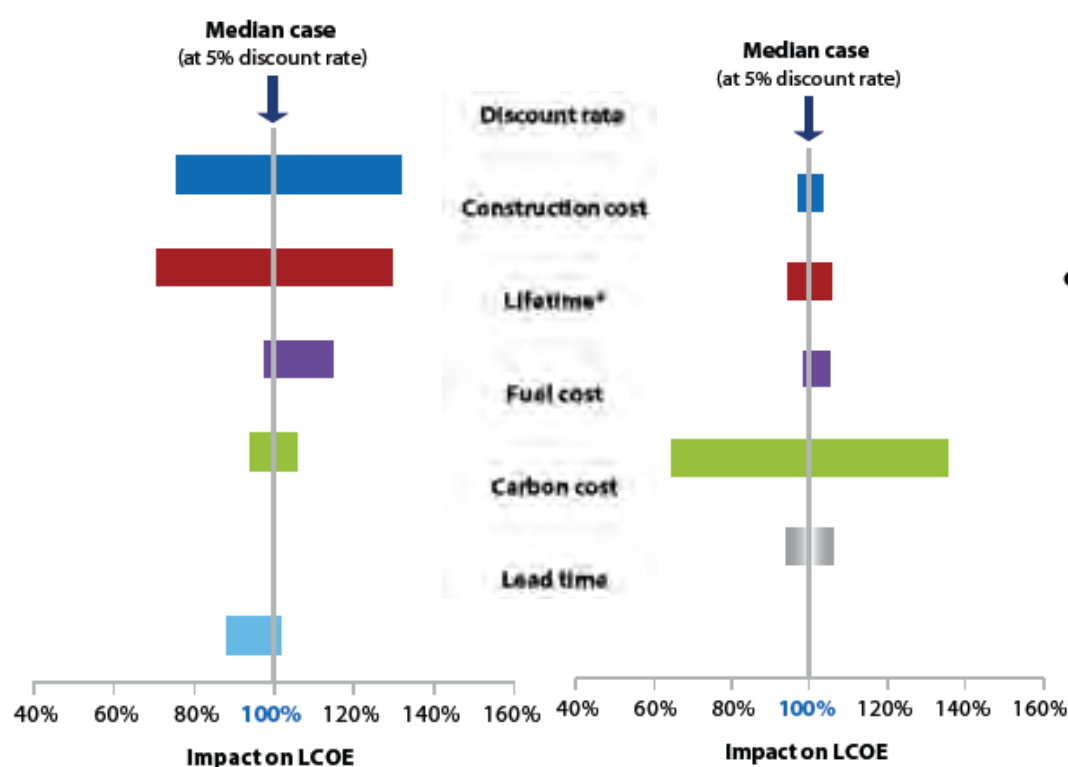
The cost structure of different Energy Sources is the following:

Table 6.2: Total generation cost structure												
	at 5%						at 10%					
	Nuclear	Coal	Coal w/CCS	Gas	Wind	Solar	Nuclear	Coal	Coal w/CCS	Gas	Wind	Solar
Total Investment cost	58.6%	25.9%	51.6%	11.1%	76.5%	91.7%	75.6%	39.8%	66.8%	17.3%	83.8%	94.9%
O&M	25.2%	9.2%	21.9%	5.2%	22.7%	7.3%	14.9%	7.5%	15.1%	4.9%	16.0%	4.9%
Fuel costs*	16.0%	27.9%	21.0%	71.3%	0.0%	0.0%	9.5%	22.8%	14.5%	66.4%	0.0%	0.0%
CO₂ costs	0.0%	36.8%	5.2%	12.3%	0.0%	0.0%	0.0%	29.9%	3.6%	11.4%	0.0%	0.0%
Decommissioning	0.3%	0.1%	0.2%	0.1%	0.8%	1.0%	0.0%	0.0%	0.0%	0.0%	0.2%	0.3%

*Fuel costs for nuclear comprise the costs of the full nuclear fuel cycle including spent fuel reprocessing or disposal.

Figure 19: Total generation cost structure

Results are the following for Nuclear (on the Left) and Gas (on the right) with the assumption of 5% Discount Rate:



The economics of nuclear energy are largely dependent on total investment costs, which are determined by both construction cost and the discount rate. At a 5% discount rate, the key driver of the LCOE of nuclear power is construction costs. Given the small share of fuel cost in total cost, variations on nuclear fuel prices and services have the least impact on total LCOE.

For gas, the picture is reversed. At any discount rate, the fuel cost is by far the single most important cost parameter affecting the LCOE of gas-fired plants. At a 5% discount rate, the carbon cost is the second most important cost determinant, closely followed by construction costs, while variations in the discount rate have the least impact of all parameters on total costs.

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	http://www.oecd-nea.org/pub/egc/		

3.5. The European Wind Association (EWEA) – Model for comparing and projecting the levelized cost of electricity - 2010

Abstract	The paper presents the methodology used for calculating and projecting the levelised cost of electricity generated from new fossil fuel, nuclear power stations and wind energy both on- and offshore. The specificity of the study is that it takes into consideration the risk of the cost associated to the fuel and carbon price volatility.																																				
Author	EWEA is a lobbying group for the wind industry, actively promoting wind power in Europe and worldwide. It has over 700 members from almost 60 countries, including wind turbine manufacturers with a leading share of the world wind power market, plus component suppliers, research institutes, national wind and renewables associations, developers, contractors, electricity providers, finance and insurance companies, and consultants. EWEA coordinates international policy, communications, research and analysis and provides various services to support members' requirements. EWEA analyses, formulates and establishes policy positions for the wind industry on key issues, cooperating with industry and research institutions on a number of market development and technology research projects.																																				
Content	EWEA provides a detailed analysis of the various factors needed for the determination of the LCOE of different energy sources (wind, nuclear, gas and coal). In addition, a simulator can be used on-line to measure impact of changes of different assumptions. One of the key assumptions of the EWEA model is the experience impact factor on the capital cost of various sources; such tool tends to favor wind energy as the model assumes in general a significant downward trend on the capital spending cost of renewable energy. Some of the different hypothesis used by the model are: <table><tr><th>NUCLEAR</th><th>Assumption</th><th>Range of References [8,25,27,34,29]</th></tr><tr><td>Total Plant Capacity (MW)</td><td>1000</td><td>1000</td></tr><tr><td>Load Factor (%)</td><td>85%</td><td>75%-90%</td></tr><tr><td>Nominal discount rate (%)</td><td>7.5%</td><td>-</td></tr><tr><td>Inflation rate(%)</td><td>2%</td><td>-</td></tr><tr><td>Discount rate used (%)</td><td>5.61%</td><td>7.9%-14.5%</td></tr><tr><td>Lifetime (y)</td><td>40</td><td>20-50</td></tr><tr><td>Overnight cost (€/kW)</td><td>3,000.00</td><td>2,000-5,000</td></tr><tr><td>Total Capital Cost (€/kW)</td><td>6,000.00</td><td>4,500-7,500</td></tr><tr><td>Total Fixed Annual Cost (€/kW)</td><td>15.00</td><td>9.00-90.00</td></tr><tr><td>Total O&M Annual Cost (€/kWh)</td><td>0.02</td><td>0.0035-0.02</td></tr><tr><td>Insurance Cost (€/kWh)</td><td>0.00019</td><td>-</td></tr></table>	NUCLEAR	Assumption	Range of References [8,25,27,34,29]	Total Plant Capacity (MW)	1000	1000	Load Factor (%)	85%	75%-90%	Nominal discount rate (%)	7.5%	-	Inflation rate(%)	2%	-	Discount rate used (%)	5.61%	7.9%-14.5%	Lifetime (y)	40	20-50	Overnight cost (€/kW)	3,000.00	2,000-5,000	Total Capital Cost (€/kW)	6,000.00	4,500-7,500	Total Fixed Annual Cost (€/kW)	15.00	9.00-90.00	Total O&M Annual Cost (€/kWh)	0.02	0.0035-0.02	Insurance Cost (€/kWh)	0.00019	-
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Insurance Cost (€/kWh)	0.00019	-																																			

Assumptions	GAS	Range of References [10,14,29,40]	COAL	Range of References [10,33,29,40]
Total Plant Capacity (MW)	1000	500-1000	1000	1000
Load Factor (%)	80%	65%-85%	80.00%	60%-80%
Nominal discount rate (%)	7.50%	-	7.50%	-
Inflation rate(%)	2%	-	2%	-
Discount rate used (%)	5.61%	6%-10%	5.61%	6%-7.8%
Lifetime (y)	30	20-40	40	40
Capital, Investment Cost (€/kW)	600	530-650	1600	1300-1700
Total Fixed Annual Cost (€/kW)	12	12-25	40	35-45
Total O&M Annual Cost (€/kWh)	0.0023	0.002-0.005	0.001	0.0003-0.0023
CO2 emissions factor	0.35	0.35-0.42	0.85	0.75-0.89

Table 5: Hypothesis used by EWEA model

The first part of this analysis presents the outcomes when volatility risk associated with fossil fuel and carbon price is not considered, with capital cost reduction for wind over the next 20 years

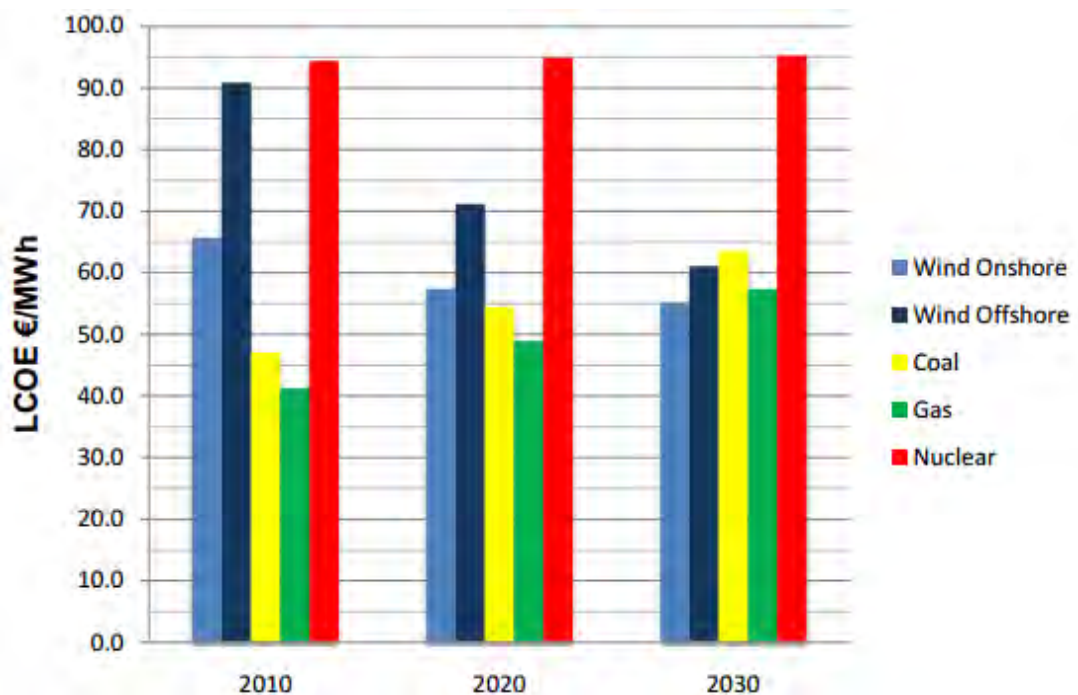


Figure 20: LCOE results with the EWEA model

Resulting graph is self explanatory.

In the second part of the report the effect of including the volatility risk is discussed.

Conclusion remains that wind energy is the most beneficial energy source, whereas nuclear LCOE closes the gap with fossil fuel energy sources.

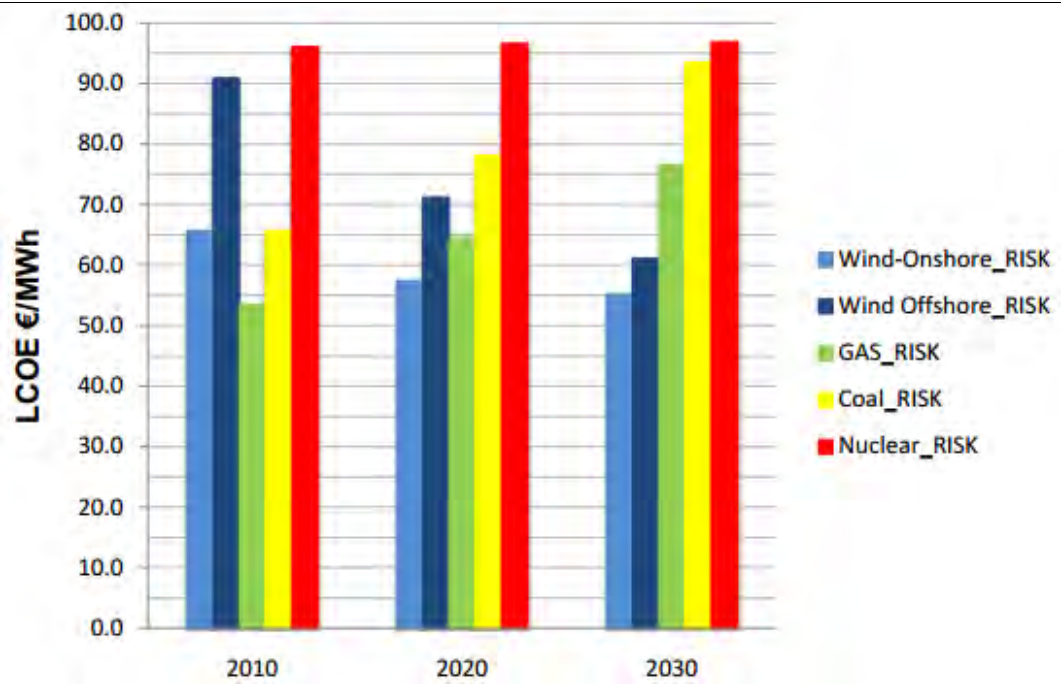


Figure 21: LCOE results with the EWEA model, with assumptions on the volatility of the supply

Before including the volatility risk, the fossil fuel technologies appear to be an appealing investment, experiencing low levelised cost.

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	http://proceedings.ewea.org/ewec2010/allfiles2/333_EWEC2010presentation.pdf		

Abstract	The study gives a probabilistic comparison of the investment risks of nuclear power and natural gas-based electricity generating plants (using a total-lifecycle power plant model). Although the cost of the gas plant (with carbon tax) is found to be slightly cheaper, that choice of fuel carries a far greater cost uncertainty (the cost of natural gas is a significant component of natural gas generating costs, and because the cost of natural gas is volatile) , suggesting a greater long-term investment risk than nuclear power.																																												
Author	Nuclear Engineering International, is a monthly print magazine including news, feature articles and technical articles of merit on the civil nuclear power industry, from front end fuel cycle to operations benchmarking (quarterly load factors league tables) to decommissioning & decontamination.																																												
Content	EnergyPath Corporation – a small consulting firm -developed a model that calculates according to several parameters the total cost for Construction, Operation and Decommissioning of an electric generating plant. The following study presents the results for Nuclear and Natural Gas Power Plants, based on the following assumptions: <table><tr><td></td><td></td><td>Nuclear</td><td>Natural gas (CCGT)</td></tr><tr><td>Capital costs</td><td>\$/kWe</td><td>\$5000</td><td>Unit 1: \$1107</td></tr><tr><td></td><td></td><td></td><td>Unit 2: \$2045</td></tr><tr><td>O&M</td><td>\$/kWe/yr</td><td>\$75</td><td>\$30</td></tr><tr><td>Capital improvements</td><td>\$/kWe</td><td>\$20 per fuel reloading</td><td>\$10 per year</td></tr><tr><td>Fuel costs (2012)</td><td></td><td>Uranium: \$48/lb U3O8</td><td>Natural Gas: \$4.35/MMBtu</td></tr><tr><td></td><td></td><td>Conversion: \$11/kgU</td><td></td></tr><tr><td></td><td></td><td>Enrichment: \$132/SWU</td><td></td></tr><tr><td></td><td></td><td>Fabrication: \$336/kgU</td><td></td></tr><tr><td>Heat rate</td><td>BTU/kWeh</td><td>10,4</td><td>6700</td></tr><tr><td>Carbon tax</td><td>\$/Ton CO2</td><td></td><td>\$25</td></tr></table> Table 6: Assumptions taken by EnergyPath Corporation There is investment risk inherent in both technologies, but from different sources. The key risk of nuclear power resides in uncertain capital costs, mostly during construction time. For natural gas, the risks are from the uncertain forward cost of natural gas –over several decades- and the potential for environmental compliance costs, primarily from the emissions of greenhouse gases (principally CO2). This model uses an original and proprietary risk-adjusted approach, based on probabilistic and theoretical assumptions of various parameters... It does not reflect actual or quoted costs of existing nuclear projects. These following figures show the probable range of costs for both technologies:			Nuclear	Natural gas (CCGT)	Capital costs	\$/kWe	\$5000	Unit 1: \$1107				Unit 2: \$2045	O&M	\$/kWe/yr	\$75	\$30	Capital improvements	\$/kWe	\$20 per fuel reloading	\$10 per year	Fuel costs (2012)		Uranium: \$48/lb U3O8	Natural Gas: \$4.35/MMBtu			Conversion: \$11/kgU				Enrichment: \$132/SWU				Fabrication: \$336/kgU		Heat rate	BTU/kWeh	10,4	6700	Carbon tax	\$/Ton CO2		\$25
		Nuclear	Natural gas (CCGT)																																										
Capital costs	\$/kWe	\$5000	Unit 1: \$1107																																										
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Carbon tax	\$/Ton CO2		\$25																																										

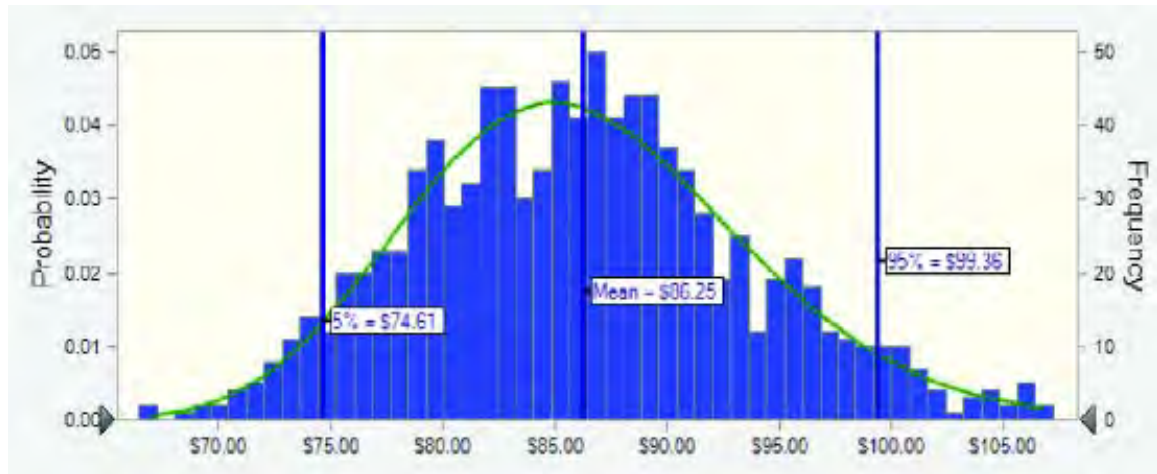


Figure 22: LCOE of Nuclear Power Plant (\$/MWh) (\$2012)



Figure 23: LCOE of a natural gas-fired electricity plant with carbon tax (\$/MWh) (\$2012)

Figure 22 shows that the expected levelized generating cost of nuclear power over its 60-year lifetime to be about \$87/MWh (all figures are in 2012 dollars). There is a 5% probability that the actual realized generating cost will exceed \$99/MWh and a 5% probability that the realized generating costs will be below about \$77/MWh.

In other words, there is 90% probability that the realized generating cost will be between \$77/MWh and \$99/MWh -- a range of \$22/MWh.

Figure 23 shows the same result, but for Natural Gas: **there is a 90% probability that the generating cost will be between \$65/MWh and \$103/MWh – a range of \$38/MWh, nearly twice the range of Nuclear Power Plant.**

All the risk occur after the build decision is made. Thus, natural gas plant investors are in the position of having to manage fuel (which represents 60% of LCOE) and potential environmental compliance costs for 60 years after the plant is constructed.

However risk is less important for Nuclear after the build decision because it is only related to fuel uncertainties, and fuel only represent about 2-3% of LCOE.

The following table illustrates typical results obtained using only the static (non-simulated) LCOE. This chart clearly shows the tradeoff between capital costs and variable costs (fuel and environmental compliance) between nuclear and natural gas plants.

But more important, it illustrates the risks of relying on static LCOE results.

Cost component	Nuclear	Natural gas	Natural gas
(\$/MWh)		(No environmental cost)	(With \$25/ton CO ₂)
Capital	\$ 57.78	\$ 12.72	\$ 12.72
O&M	\$ 10.03	\$ 3.46	\$ 3.46
Fuel	\$ 5.55	\$ 46.99	\$ 46.99
Taxes (sales and income)	\$ 9.79	\$ 10.39	\$ 10.39
Decommissioning	\$ 1.46	-	-
Waste disposal	\$ 1.00	-	-
Environmental compliance	-	-	\$ 9.80
TOTAL	\$ 85.61	\$ 73.55	\$ 82.35

Table 7: Cost Comparison between Nuclear and Natural Gas

The last part of the study gives details about the gas prices forecasts assumptions made previously.

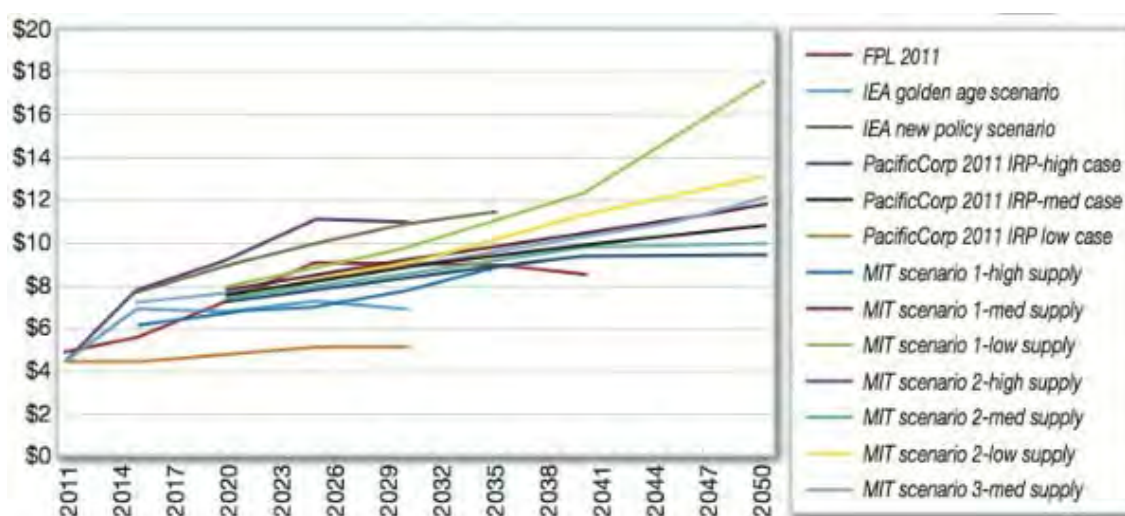


Figure 24: Natural gas forecast from reputable source 2011-2050 \$/MMBtu (\$2012)

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	http://www.neimagazine.com/features/featureevaluating-the-shale-gas-challenge		

3.7. Nuclear Energy Institute (NEI) – (White Paper) The Cost of New Generating Capacity in Perspective

Abstract	The report from NEI tries to take the debate on Nuclear Cost up, by not only having in mind the capital cost of Nuclear Power Plants. Like all new generating capacity, there is uncertainty about the capital cost of new nuclear power plants. Estimates range from \$4 billion in today's dollars for the engineering, procurement, and construction (EPC) cost of a single plant to \$22.5 billion in 2022 for an entire two-unit project (including transmission lines and other services). Although new nuclear power plants are capital-intensive, it is important to recognize that capital costs are only the starting point for any analysis of new generating capacity. The only accurate measure of economic competitiveness, and the one that is most important to regulators and consumers, is the cost of electricity produced by a particular project compared to alternative sources of electricity and to the market price of electricity when the power plant starts commercial operation. Analysis by generating companies, the academic community, government agencies, and others shows that even at capital costs in the \$4,000/kWe to \$6,000/kWe range, the electricity generated from nuclear power can be competitive with other new sources of baseload power (even without including CO2 cost impact). The key for Nuclear Energy is to have new financing structure and support from States.																				
Author	The Nuclear Energy Institute (NEI) is a nuclear industry lobbying group in the United States. NEI's mission is to foster the beneficial uses of nuclear technology before Congress, the White House and executive branch agencies, federal regulators, and state policy forums; proactively communicate accurate and timely information; and provide a unified industry voice on the global importance of nuclear energy and nuclear technology. NEI's objective is to ensure the formation of policies that promote the beneficial uses of nuclear energy and technologies in the United States and around the world.																				
Content	In order to have an updated vision on Nuclear Energy EPC Costs, the study takes examples on recent projects (although none has been initiated yet) 1. the two new units for South Carolina Electric & Gas (SCE&G), 2. new units at Turkey Point Site for Florida Power and Light Company (FP&L) 3. the two new units for Progress Energy Florida. <table><tr><th colspan="4">Nuclear Cost Estimates from Recent Public Service Commission Filings</th></tr><tr><th>Company</th><th>Plant Capacity (MWe)</th><th>Overnight Capital Cost (\$/kWe)</th><th>Total Project Cost (Billion \$)</th></tr><tr><td>SCE&G/Santee Cooper</td><td>2,200</td><td>3,719</td><td>9.8</td></tr><tr><td>FP&L</td><td>2,200</td><td>3,483 – 5,063</td><td>12.1 – 18.0</td></tr><tr><td>Progress</td><td>2,200</td><td>4,260⁶</td><td>17.2 – 22.5</td></tr></table> Figure 25: Nuclear Cost Estimates	Nuclear Cost Estimates from Recent Public Service Commission Filings				Company	Plant Capacity (MWe)	Overnight Capital Cost (\$/kWe)	Total Project Cost (Billion \$)	SCE&G/Santee Cooper	2,200	3,719	9.8	FP&L	2,200	3,483 – 5,063	12.1 – 18.0	Progress	2,200	4,260 ⁶	17.2 – 22.5
Nuclear Cost Estimates from Recent Public Service Commission Filings																					
Company	Plant Capacity (MWe)	Overnight Capital Cost (\$/kWe)	Total Project Cost (Billion \$)																		
SCE&G/Santee Cooper	2,200	3,719	9.8																		
FP&L	2,200	3,483 – 5,063	12.1 – 18.0																		
Progress	2,200	4,260 ⁶	17.2 – 22.5																		

Cost Estimation of each project is given in the previous table. When comparing figures to other sources of energy; in each case, Nuclear appeared to be the most viable generation alternative to natural gas.

Several academic institutions, research organizations and government agencies have conducted analyses of the cost of electricity from various generating options. Although the findings, may differ from analysis to analysis), all these analyses point in the same direction: **new nuclear plants can be competitive with other options** when they are placed in service and are likely to be comfortably competitive in a carbon-constrained world.

The study quotes several other Reports, from EPRI (Integrated Generation Technology Options, June 2011) or IEA (Annual Energy Outlook 2013) that give LCOE for many technologies in the USA.

Although nuclear project costs are undeniably large, total project cost does not measure a project's economic viability. The relevant metric is the cost of the electricity produced by the nuclear project relative to alternative sources of electricity and relative to the market price of electricity at the time the nuclear plant comes into service.

New nuclear power plants can be competitive, even with total project costs exceeding \$6,000/kWe, including EPC and owners' costs and financing costs.

NEI's modeling shows that a merchant nuclear plant with an 80 percent debt/20 percent equity capital structure, supported by a federal loan guarantee, will produce electricity in the range of \$84/MWh to \$91/MWh. (The range reflects EPC costs from \$4,500/kWe to \$5,000/kWe.)

Table 1. Cost of Electricity from Various Generating Technologies (in 2011 Dollars) ¹					
Technology	Nuclear		Coal (SCPC)	Gas (Combined Cycle)	
Project Structure	Project Finance with Loan Guarantee	Rate Base with CWIP ²	Rate Base with CWIP	Project Finance	
	80% Debt 20% Equity	50% Debt 50% Equity	50% Debt 50% Equity	50% Debt 50% Equity	
EPC Cost (\$/kWe)	\$4,500 - 5,000		\$3,200	\$1,000	
Total Cost ³ (\$/kWe)	\$6,000-\$6,600	\$5,300-\$5,800	\$3,500	\$1,200	\$1,200
Fuel Cost (nuclear - \$/MWh) (coal/gas - \$/mmBtu)	\$7.50		\$2.00	\$4.00	\$6.00
Capacity (MWe)	1,400		800	400	
First Year Busbar (\$/MWh)	\$84 - 91	\$115 - 126	\$99	\$56	\$70
Levelized Busbar (\$/MWh)	NA	\$86 - 93	\$75	NA	NA
Impact of CO ₂ Price at \$30/Ton (\$/MWh)	NA	NA	Add \$25.00	Add \$18.00	

Table 8: Cost of Electricity from various Generating Technologies

Nuclear energy is competitive with coal generation and offers fuel diversity and protection against future carbon costs or fossil fuel price spikes.

The results from NEI's model assume no restrictions on carbon dioxide emissions. If a carbon price of \$30/ton is incorporated, nuclear power becomes even more competitive.

NEI's modeling shows that, in the absence of a significant price for carbon, loan guarantees are an important tool to reduce the cost of electricity produced by commercial nuclear plants.

	With this support as a transition to a carbon-constrained world, the next nuclear plants can be competitive and economically viable.		
<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
<i>Source</i>	http://www.nei.org/CorporateSite/media/filefolder/WHITE-PAPER-Cost-of-New-Generating-Capacity-in-Perspective.pdf?ext=.pdf		

3.8. World Nuclear Association – Power Generation in the new policies and the 450 scenarios

Abstract	The World Energy Outlook forecasts are based on several scenarios: New Policies Scenario, 450 scenario, Efficient world scenario...																																																																																																																							
Author	The World Nuclear Association is the international organization that promotes nuclear energy and supports the many companies that comprise the global nuclear industry. Today WNA serves its membership, and the world nuclear industry as a whole, through actions to: - Provide a global forum for sharing knowledge and insight on evolving industry developments ; - Strengthen industry operational capabilities by advancing best-practice internationally ; - Speak authoritatively for the nuclear industry in key international forums that affect the policy and public environment in which the industry operates. All WNA activities focus on objectives outside the scope of national and regional associations, intergovernmental organizations and the industry's reactor safety organization, WANO.																																																																																																																							
Content	New Policies Scenario: A scenario that takes account broad policy commitments and plans that have been announced by countries, including national pledges to reduce greenhouse-gas emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be identified or announced. <table><tr><th colspan="10">NPS Scenario for Nuclear</th></tr><tr><th rowspan="2"></th><th colspan="3">Capital costs (\$2011 per kW)</th><th colspan="3">Yearly O&M Costs (\$2011 per kW)</th><th colspan="3">Efficiency (gross, LHV)</th></tr><tr><th>2011</th><th>2020</th><th>2035</th><th>2011</th><th>2020</th><th>2035</th><th>2011</th><th>2020</th><th>2035</th></tr><tr><td>Europe</td><td>4000</td><td>4000</td><td>4000</td><td>100</td><td>100</td><td>100</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>United States</td><td>4600</td><td>4600</td><td>4600</td><td>104</td><td>104</td><td>104</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>Japan</td><td>4200</td><td>4200</td><td>4200</td><td>116</td><td>116</td><td>116</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>Russia</td><td>3500</td><td>3500</td><td>3500</td><td>123</td><td>123</td><td>123</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>China</td><td>2000</td><td>2000</td><td>2000</td><td>70</td><td>70</td><td>70</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>India</td><td>2800</td><td>2800</td><td>2800</td><td>105</td><td>105</td><td>105</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>Middle East</td><td>3200</td><td>3200</td><td>3200</td><td>120</td><td>120</td><td>120</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>Africa</td><td>3600</td><td>3600</td><td>3600</td><td>120</td><td>120</td><td>120</td><td>33%</td><td>33%</td><td>33%</td></tr><tr><td>Brazil</td><td>3500</td><td>3500</td><td>3500</td><td>123</td><td>123</td><td>123</td><td>33%</td><td>33%</td><td>33%</td></tr></table> Table 9: New Policies Scenario - WNA	NPS Scenario for Nuclear											Capital costs (\$2011 per kW)			Yearly O&M Costs (\$2011 per kW)			Efficiency (gross, LHV)			2011	2020	2035	2011	2020	2035	2011	2020	2035	Europe	4000	4000	4000	100	100	100	33%	33%	33%	United States	4600	4600	4600	104	104	104	33%	33%	33%	Japan	4200	4200	4200	116	116	116	33%	33%	33%	Russia	3500	3500	3500	123	123	123	33%	33%	33%	China	2000	2000	2000	70	70	70	33%	33%	33%	India	2800	2800	2800	105	105	105	33%	33%	33%	Middle East	3200	3200	3200	120	120	120	33%	33%	33%	Africa	3600	3600	3600	120	120	120	33%	33%	33%	Brazil	3500	3500	3500	123	123	123	33%	33%	33%
NPS Scenario for Nuclear																																																																																																																								
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	2011	2020	2035	2011	2020	2035	2011	2020	2035																																																																																																															
Europe	4000	4000	4000	100	100	100	33%	33%	33%																																																																																																															
United States	4600	4600	4600	104	104	104	33%	33%	33%																																																																																																															
Japan	4200	4200	4200	116	116	116	33%	33%	33%																																																																																																															
Russia	3500	3500	3500	123	123	123	33%	33%	33%																																																																																																															
China	2000	2000	2000	70	70	70	33%	33%	33%																																																																																																															
India	2800	2800	2800	105	105	105	33%	33%	33%																																																																																																															
Middle East	3200	3200	3200	120	120	120	33%	33%	33%																																																																																																															
Africa	3600	3600	3600	120	120	120	33%	33%	33%																																																																																																															
Brazil	3500	3500	3500	123	123	123	33%	33%	33%																																																																																																															

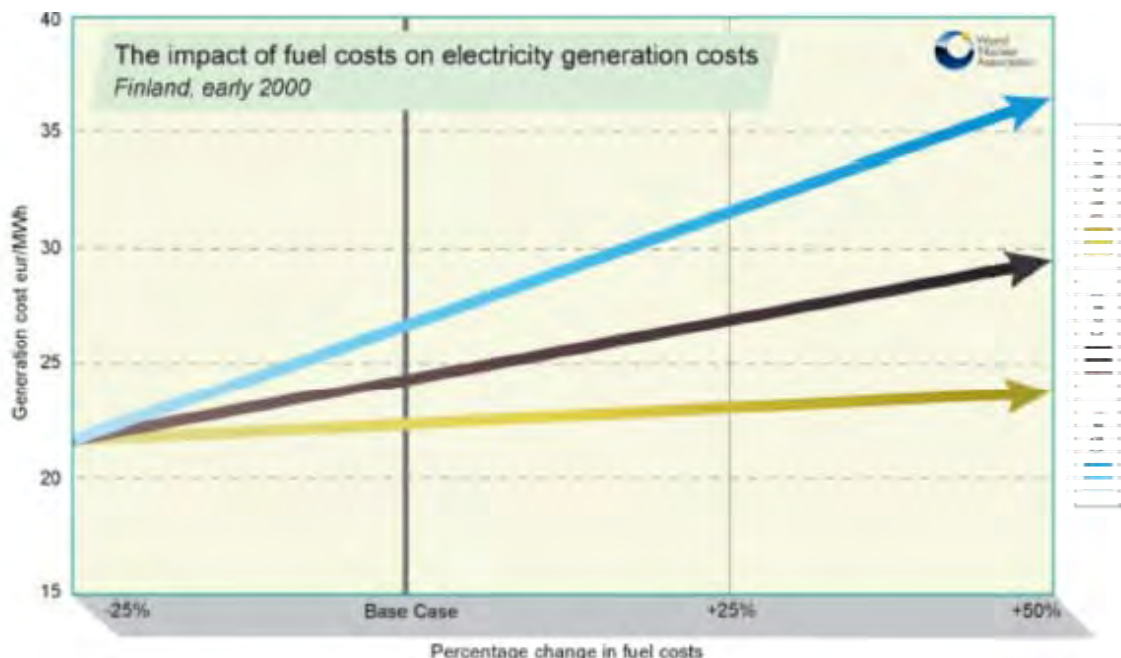
450 Scenario: A scenario that sets out an energy pathway consistent with the goal of limiting the global increase in temperature to 2°C by limiting concentration of greenhouse gases in the atmosphere to around 450 parts per million of CO₂.

450 Scenario (for Nuclear)						
	Capital costs (\$2011 per kW)		Yearly O&M Costs (\$2011 per kW)		Efficiency (gross, LHV)	
	2020	2035	2020	2035	2020	2035
Europe	4000	4000	100	100	33%	33%
United States	4600	4600	104	104	33%	33%
Japan	4200	4200	116	116	33%	33%
Russia	3500	3500	123	123	33%	33%
China	2000	2000	70	70	33%	33%
India	2800	2800	105	105	33%	33%
Middle East	3200	3200	120	120	33%	33%
Africa	3600	3600	120	120	33%	33%
Brazil	3500	3500	123	123	33%	33%

Table 10: 405 Scenario - WNA

The data base provided by WNA, also includes data parameters for other energy sources in the various regions. It is presented in an EXCEL format.

<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	No
<i>Source</i>	http://www.worldenergyoutlook.org/weomodel/		

Abstract	The “Economics” section of the World Nuclear Association gives a detailed breakdown of Nuclear Power Costs, and support the idea that Nuclear Power is cost competitive with other forms of electricity generation, despite relatively high capitals costs. However this competitiveness is not guaranteed where there is direct access to low-cost fossil fuels.																				
Author	The World Nuclear Association is the international organization that promotes nuclear energy and supports the many companies that comprise the global nuclear industry. Today WNA serves its membership, and the world nuclear industry as a whole, through actions to: - Provide a global forum for sharing knowledge and insight on evolving industry developments ; - Strengthen industry operational capabilities by advancing best-practice internationally ; - Speak authoritatively for the nuclear industry in key international forums that affect the policy and public environment in which the industry operates. All WNA activities focus on objectives outside the scope of national and regional associations, intergovernmental organizations and the industry's reactor safety organization, WANO.																				
Content	One of the benefit of Nuclear Energy is its fuel: the total fuel costs of a nuclear power plant are typically about a third of those for a coal-fired plant a between a quarter and a fifth of those for a gas combined-cycle plant. Moreover the fuel’s contribution to the overall cost of the electricity produced is relatively small, so even a large fuel price escalation will have relatively little effect. <table><caption>Data for Figure 26: The Impact of fuel costs on generation costs</caption><thead><tr><th>Percentage change in fuel costs</th><th>Gas (eur/MWh)</th><th>Coal (eur/MWh)</th><th>Nuclear (eur/MWh)</th></tr></thead><tbody><tr><td>-25%</td><td>~20</td><td>~20</td><td>~20</td></tr><tr><td>Base Case</td><td>~22</td><td>~22</td><td>~22</td></tr><tr><td>+25%</td><td>~26</td><td>~25</td><td>~23</td></tr><tr><td>+50%</td><td>~36</td><td>~29</td><td>~24</td></tr></tbody></table> Figure 26: The Impact of fuel costs on generation costs These show that a doubling of fuel prices would result in the electricity cost for nuclear rising about 9%, for coal rising 31% and for gas 66%. The WNA section of NPP economics gives several costs from different sources:	Percentage change in fuel costs	Gas (eur/MWh)	Coal (eur/MWh)	Nuclear (eur/MWh)	-25%	~20	~20	~20	Base Case	~22	~22	~22	+25%	~26	~25	~23	+50%	~36	~29	~24
Percentage change in fuel costs	Gas (eur/MWh)	Coal (eur/MWh)	Nuclear (eur/MWh)																		
-25%	~20	~20	~20																		
Base Case	~22	~22	~22																		
+25%	~26	~25	~23																		
+50%	~36	~29	~24																		

technology	region or country	At 10% discount rate	At 5% discount rate
Nuclear	OECD Europe	8.3-13.7	5.0-8.2
	China	4.4-5.5	3.0-3.6
Black coal with CCS	OECD Europe	11.0	8.5
Brown coal with CCS	OECD Europe	9.5-14.3	6.8-9.3
CCGT with CCS	OECD Europe	11.8	9.8
Large hydro-electric	OECD Europe	14.0-45.9	7.4-23.1
	China: 3 Gorges	5.2	2.9
	China: other	2.3-3.3	1.2-1.7
Onshore wind	OECD Europe	12.2-23.0	9.0-14.6
	China	7.2-12.6	5.1-8.9
Offshore wind	OECD Europe	18.7-26.1	13.8-18.8
Solar photovoltaic	OECD Europe	38.8-61.6	28.7-41.0
	China	18.7-28.3	12.3-18.6

Figure 27: OECD study Projected Costs of generating Electricity 2010 (in c\$/kWh at 5% and 10% discount rate)

	EPC cost	capacity	Electricity cost
Gas combined cycle, gas @ \$3.70/GJ	\$1000/kW	90%	\$44.00/MWh
Gas combined cycle, gas @ \$5.28/GJ	\$1000/kW	90%	\$54.70/MWh
Gas combined cycle, gas @ \$6.70/GJ	\$1000/kW	90%	\$61.70/MWh
Gas combined cycle, gas @ \$6.70/GJ, 50-50 debt-equity	\$1000/kW	90%	c \$70/MWh
Supercritical pulverised coal, 1300 MWe	\$3000/kW	85%	\$75.70/MWh
Integrated gasification combined cycle coal, 1200 MWe	\$3800/kW	85%	\$94.30/MWh
Nuclear, 1400 MWe (EIA's EPC figure)	\$5500/kW	90%	\$121.90/MWh
Nuclear, 1400 MWe (NEI suggested EPC figure)	\$4500-5000/kW	90%	\$85-90/MWh
Wind farm, 100 MWe	\$1000/kW	30%	112.90/MWh

Figure 28: NEI 2013 Financial Modelling

Nuclear plant: projected electricity costs (c/kWh)

Overnight capital cost \$/kW		1200	1500	1800
First unit	7 yr build, 40 yr life	5.3	6.2	7.1
	5 yr build, 60 yr life	4.3	5.0	5.8
4th unit	7 yr build, 40 yr life	4.5	4.5	5.3
	5 yr build, 60 yr life *	3.7	3.7	4.3
8th unit	7 yr build, 40 yr life	4.2	4.2	4.9
	5 yr build, 60 yr life *	3.4	3.4	4.0

Figure 29: University of Chicago Study (2004)

One important factor is shown through this study: the cost decrease (learning curves). Others studies are also quoted to demonstrate the recent Nuclear Price Escalation on capital costs (2009 MIT Study, US Energy Administration EIA 2010 Report, French Energy & Climate Directorate...).

	Finally the study also provides EPC Costs for recent projects: EdF Flamanville EPR: EUR 4 billion/\$5.6 billion, so EUR 2434/kW or \$3400/kW Bruce Power Alberta 2x1100 MWe ACR, \$6.2 billion, so \$2800/kW CGNPC Hongyanhe 4x1080 CPR-1000 \$6.6 billion, so \$1530/kW AEO Novovroznezh 6&7 2136 MWe net for \$5 billion, so \$2340/kW AEP Volgodonsk 3 & 4, 2 x 1200 MWe VVER \$4.8 billion, so \$2000/kW KHNP Shin Kori 3&4 1350 MWe APR-1400 for \$5 billion, so \$1850/kW FPL Turkey Point 2 x 1100 MWe AP1000 \$2444 to \$3582/kW Progress Energy Levy county 2 x 1105 MWe AP1000 \$3462/kW NRG South Texas 2 x 1350 MWe ABWR \$8 billion, so \$2900/kW ENEC for UAE from Kepco, 4 x 1400 MWe APR-1400 \$20.4 billion, so \$3643/kW The World Energy Association gives a global panorama of nuclear energy costs, showing that even with the recent cost escalation, and the competition with other Energy Sources: Nuclear remains a competitive Energy that can (under some conditions) be cheaper than Coal, Gas or Renewable.		
<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	No	Yes
<i>Source</i>	http://world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/		

<i>Abstract</i>	The National Energy Modeling System (NEMS) is a computer-based, energy-economy modeling system of U.S. through 2030. NEMS projects the production, imports, conversion, consumption, and prices of energy... Among several modules included in this system, one is dedicated to the Electricity market: The Electricity Market Module (EMM) EMM represents the capacity planning, dispatching, and pricing of electricity. Based on fuel prices and electricity demands provided by the other modules of the The National Energy Modeling System (NEMS), the EMM determines the most economical way to supply electricity, within environmental and operational constraints. There are assumptions about the operations of the electricity sector and the costs of various options in each of the EMM submodules. One of the sub-modules of EMM is dedicated to cost calculations, and provide cost estimates for new plants, fuel prices, unit operating levels, plant decommissioning costs, plant phase-in costs, and purchased power costs...
<i>Author</i>	The U.S. Energy Information Administration (EIA) is the statistical and analytical agency within the U.S. Department of Energy. EIA collects, analyzes, and disseminates independent and impartial energy information to promote sound policymaking, efficient markets, and public understanding of energy and its interaction with the economy and the environment. EIA is the nation's premier source of energy information and, by law, its data, analyses, and forecasts are independent of approval by any other officer or employee of the U.S. Government. EIA conducts a comprehensive data collection program that covers the full spectrum of energy sources, end uses, and energy flows. EIA also prepares informative energy analyses, monthly short-term forecasts of energy market trends, and long-term U.S. and international energy outlooks. EIA disseminates its data, analyses, and other products primarily through its website and customer contact center.
<i>Content</i>	An important number of technology are currently modeled by the EMM tool:

Fossil Fuel Fired	Nuclear
Existing Coal without FGD	Conventional nuclear
Existing Coal with FGD	Advanced nuclear
New pulverized coal with FGD	
Advanced clean coal technology	
Advanced clean coal technology with sequestration	
Gas/oil steam	
Conventional gas/oil combined cycle	
Advanced combined cycle	
Advanced combined cycle with sequestration	
Conventional combustion turbine	
Advanced combustion turbine	
Fuel cells	
Distributed generation	
(FGD = flue gas desulfurization)	
	Renewables
	Conventional hydropower
	Geothermal
	Solar-thermal
	Solar-photovoltaic
	Wind
	Wood
	Municipal solid waste

The study gives for each technology the Base & Total Overnight Cost, Variable O&M, Fixed O&M...

For projections in the future, the model use "Learning Rate" parameters, defined for each technology.

The model is also able to calculate when proceed to Fossil-fired steam plant retirements and nuclear retirements. Plants are assumed to retire when it is no longer economical to continue running them. Each year, the model determines whether the market price of electricity is sufficient to support the continued operation of existing plants.

The model is extremely complex, and takes into account a huge list of parameters (Legislation, CO2 Cost, Wastes Cost, Fuel Prices assumptions...).

Summary results is as follows:

Technology	Online Year ¹	Size (mW)	Lead time (years)	Base			Contingency Factors		Total Overnight Cost in 2010 ⁴ (2010 \$/kW)	Variable O&M ⁵ (2010 \$/mWh)	Fixed O&M (2010 \$/kW)	Heatrate ⁶ in 2011 (Btu/kWh)	nth-of-a-kind Heatrate (Btu/kWh)
				Cost in 2010 (2010 \$/kW)	Project Contin- gency Factor ²	Tecno- logical Optimism Factor ³							
Scrubbed Coal New ⁷	2016	1300	4	2,808	1.07	1.00			2,844	4.20	29.87	8,800	8,740
Integrated Coal- Gasification Comb Cycle (IGCC) ⁷	2016	1200	4	3,010	1.07	1.00			3,220	6.87	48.90	8,700	7,450
IGCC with carbon sequestration	2017	520	4	4,852	1.07	1.03			5,348	8.04	69.30	10,700	8,307
Conv Gas/Oil Comb Cycle	2014	540	3	931	1.06	1.00			977	3.43	14.39	7,000	6,800
Adv Gas/Oil Comb Cycle (CC)	2014	400	3	929	1.06	1.00			1,003	3.11	14.62	6,430	6,333
Adv CC with carbon sequestration	2017	340	3	1,834	1.08	1.04			2,080	6.45	30.25	7,325	7,493
Conv Comb Turbine ⁸	2013	85	2	927	1.06	1.00			974	14.70	6.98	10,745	10,450
Adv Comb Turbine	2013	210	2	634	1.06	1.00			666	8.87	6.70	9,750	8,850
Fuel Cells	2014	10	3	5,818	1.06	1.10			6,536	0.00	350.00	9,000	6,960
Adv Nuclear	2017	2236	6	4,619	1.10	1.05			5,335	2.04	88.75	10,460	10,460
Distributed Generation - base	2014	2	3	1,366	1.06	1.00			1,434	7.46	16.78	9,060	8,900
Distributed Generation - peak	2013	1	2	1,640	1.06	1.00			1,722	7.46	16.78	10,068	9,880
Biomass	2016	60	4	3,518	1.07	1.02			3,858	6.00	100.55	13,000	13,500
Geothermal ⁹	2011	50	4	2,393	1.06	1.00			2,513	9.64	108.52	9,760	8,760
MSW - Landfill Gas Conventional	2011	50	3	7,694	1.07	1.00			8,233	8.33	378.76	13,648	13,648
Hydropower ⁹	2016	500	4	2,134	1.10	1.00			2,347	2.59	14.27	9,760	9,760
Wind	2011	100	3	2,276	1.07	1.00			2,437	0.00	28.07	9,760	9,760
Wind Offshore	2016	400	4	4,345	1.10	1.25			5,974	0.00	53.33	9,760	9,760
Solar Thermal ¹⁰	2014	100	3	4,384	1.07	1.00			4,691	0.00	64.00	9,760	9,760
Photovoltaic ¹⁰	2013	150	2	4,528	1.06	1.00			4,755	0.00	16.70	9,760	9,760

Figure 30: EMM Model Results for different technologies

In addition, the report includes various assumptions of technology impact related to the cost of capital spending for nuclear:

Table 8.11: Cost characteristics for advanced nuclear technology: three cases

	Overnight Cost in 2012 (Reference) (2010\$/kW)	Total Overnight Cost ¹	
		Reference (2010\$/kW)	High Integrated Technology (2010\$/kW)
Advanced Nuclear	5335		
2015		5466	5638
2020		4733	5309
2025		4302	5002
2030		3850	4594
2035		3414	4181

¹Total overnight cost (including project contingency, technological optimism and learning factors, but excluding regional multipliers), for projects online in the given year.

Source: U.S. Energy Information Administration. AEO2012 National Energy Modeling System runs: REF2012.D020112C, LTRK1TEN.D031312A, HTRK1TEN.D032812A.

Table 11: Cost characteristics for advanced nuclear technology: three cases

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	http://www.eia.gov/oiaf/aeo/overview/index.html		



3.11. House of Commons – United Kingdom – Energy Prices, Profits and Poverty – March 2013

Abstract	This report focuses on trends in the United Kingdom domestic market, and more precisely, the costs of gas, electricity and other fuels used for heating and the impact on fuel poverty. It is part of a global commitment from the United Kingdom Government to study in details the reasons behind recent increases of Domestic Gas and Electricity prices that led to misunderstanding in the population. The House of Commons goal is to validate or not the relevance of these increases through a deep study of the cost structures.																																
Author	The House of Commons is composed of 650 Members of Parliaments (Mps), elected to represent the interests and concerns of United Kingdom public. MPs consider and propose new laws, and can scrutinize government policies by asking ministers questions about current issues either in the Commons Chamber or in Committees.																																
Content	The study does not provide a detailed cost for Nuclear Power Plants thus it is not relevant for the Cost Study as itself. However, it provides a breakdown of future UK price increases, mostly driven by the wholesale price increas UK Energy Price Increase (cf. Table below) from suppliers and the impact on the bills (particularly the understanding and acceptance) (Cf. full report). <table><tr><th></th><th>Gas</th><th>Electricity</th></tr><tr><td>Overall price increase</td><td>121%</td><td>79%</td></tr><tr><td>% of increase in unit costs due to:</td><td></td><td></td></tr><tr><td>Wholesale energy</td><td>66%</td><td>54%</td></tr><tr><td>Tranmission, distribution and metering</td><td>20%</td><td>13%</td></tr><tr><td>Carbon price</td><td>-</td><td>9%</td></tr><tr><td>Renewables</td><td>-</td><td>6%</td></tr><tr><td>Energy efficiency funding</td><td>7%</td><td>13%</td></tr><tr><td>VAT</td><td>5%</td><td>5%</td></tr><tr><td>Estimated increase in annual bill (2004 to 2010)</td><td>£295</td><td>£160</td></tr></table> Source: Household energy bills – impacts of meeting carbon budgets Committee on Climate Change, December 2011 Table 12: Overall electricity price increase in the UK				Gas	Electricity	Overall price increase	121%	79%	% of increase in unit costs due to:			Wholesale energy	66%	54%	Tranmission, distribution and metering	20%	13%	Carbon price	-	9%	Renewables	-	6%	Energy efficiency funding	7%	13%	VAT	5%	5%	Estimated increase in annual bill (2004 to 2010)	£295	£160
	Gas	Electricity																															
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Energy efficiency funding	7%	13%																															
VAT	5%	5%																															
Estimated increase in annual bill (2004 to 2010)	£295	£160																															
Cost Data	<table><tr><td>Plant Costs (Overnight)</td><td>Operational Expenditure (OPEX)</td><td>Electricity cost (LCOE)</td></tr><tr><td>No</td><td>No</td><td>No</td></tr></table>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)	No	No	No																										
Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)																															
No	No	No																															
Source	http://www.parliament.uk/briefing-papers/sn04153																																

Abstract	The report offers some estimates of the Russian nuclear industry costs. To achieve this, Bellona Foundation analyses an assumed project of a new nuclear power plant of Model Project NPP-20061 with reactors of the type VVER-12002 and VVER-1000 that Rosatom continues to build in Russia and abroad. Capital and operating costs will be estimated as they apply to this project.												
Author	The Bellona Foundation is an international environmental Non Governmental Organization. Founded in 1986 as a direct action protest group, Bellona has become a recognized technology and solution-oriented organization. Bellona endeavors to identify and implement sustainable solutions to the world's most pressing environmental problems. These include the fight against global climate change, the environmental impact of the oil and gas industry in Europe and Russia and the cleanup after the legacy of the Cold War in Russia.												
Content	<i>NB: The economy of the Russian nuclear energy industry is something extremely difficult to evaluate, because of the high opacity regarding the Russian State Atomic Energy Corporation Rosatom. Economic information is only made available in relative figures and general data whose accuracy it is impossible to verify.</i> On capital cost, the study takes the example of some projects: 1. Baltic NPP: \$2.811 billion per gigawatt of installed capacity. 2. New Belarus NPP (future estimated cost): \$3.9 billion per gigawatt of installed capacity The study then focuses on cost production increase overtime. Usually, as technologies develop and are better known and used more efficiently, production costs decrease, and this feedback effect holds for all other energy generation sectors – but not the nuclear energy industry, where the costs of producing power from nuclear reactors keep growing instead. Operating expenses are evaluated as the following: Concern Rosenergoatom's expenses in 2009 in US cents per one kilowatt-hour <table border="1"> <tr> <td>Material expenses</td><td>0.83</td></tr> <tr> <td>Payroll and remuneration of labour</td><td>0.33</td></tr> <tr> <td>Deductions for social benefits</td><td>0.06</td></tr> <tr> <td>Depreciation</td><td>0.22</td></tr> <tr> <td>Other expenses</td><td>0.53</td></tr> <tr> <td>Total</td><td>1.97</td></tr> </table> Table 13: Rosenergoatom operating expenses in 2009 The Nuclear Fuel Cycle Cost are included in the item “Material Expenses”, in this estimation the Fuel Cycle cost is claimed to be US 0.83 cents per kilowatt-hour The bank of Moscow made the same exercise and found the following figures:	Material expenses	0.83	Payroll and remuneration of labour	0.33	Deductions for social benefits	0.06	Depreciation	0.22	Other expenses	0.53	Total	1.97
Material expenses	0.83												
Payroll and remuneration of labour	0.33												
Deductions for social benefits	0.06												
Depreciation	0.22												
Other expenses	0.53												
Total	1.97												

Table 16. Bank of Moscow's estimates of costs of nuclear power production.

Cost item	Cost of production, in US cents per kilowatt-hour	Share in total NPP prime cost
Fuel	0.80	24 percent
Operation and engineering maintenance	1.93	58 percent
Capital costs, present value	0.60	18 percent
TOTAL	3.33	100 percent

Table 14: Bank of Moscow's estimates of costs of nuclear power production

Concerning fuel itself, so far, the Russian nuclear industry has satisfied its uranium demand by domestic production and has not been directly involved in the global uranium trading market – not, in any case, as a buyer. Using international cost structure of Fuel Cycle, the author evaluates the Russian Fuel Costs Cycle as the following:

Table 9. Nuclear fuel cycle costs (in thousand US dollars).

Cost category	Operating expenses	Future expenses on waste management	TOTAL
Natural uranium	29,528.7		29,528.7
Conversion	2,184.2		2,184.2
Enrichment	17,201.7	1,445.7	18,647.4
Fuel fabrication	13,125.9		13,125.9
Total costs of fresh fuel	62,040.4	1,445.7	63,486.2
SNF management		17,120.7	17,120.7
TOTAL	62,040.4	18,566.5	80,606.9

Table 15: Nuclear fuel cycle costs

The resulting fuel cost being US 0.92 cents per kilowatt-hour, including waste management of fuel, which accounts for 30% of fuel costs.

<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	No
<i>Source</i>	http://bellona.org/filearchive/fil_Economics-of-the-Russian-Nuclear-Power-Industry-English.pdf		

3.13. Electric Power Research Institute – Parametric Study on Front-End Nuclear Fuel Cycle – Jan. 2010

<i>Abstract</i>	The study is not an overall study on Nuclear Costs, but it focuses on Fuel Cycle and its associated costs. It will be used to evaluate in details all the costs related to fuel. The study evaluates front-end nuclear fuel cycle costs assuming that uranium recovered during the reprocessing of commercial light-water reactor (LWR) spent nuclear fuel is available to be recycled and used in the place of natural uranium. This report explores the relationship between the costs associated with using a natural uranium fuel cycle, in which reprocessed uranium (RepU) is not recycled, with those associated with using RepU. The main objective is to provide Electrical Utilities a clear analysis of the economical impact of developing a reprocessed uranium cycle, and its benefits in terms of overall fuel cost.
<i>Author</i>	The Electric Power Research Institute (EPRI) conducts research on issues related to the electric power industry in USA. EPRI is a nonprofit organization funded by the electric utility industry. EPRI is primarily a US-based organization, but receives international participation. EPRI's area covers different aspects of electric power generation, delivery and its use.
<i>Content</i>	As an academic approach, the study first details the Front-End of the Natural Uranium Nuclear Fuel Cycle and for Reprocessed Uranium. The PWR Fuel Cycle costs can be divided into Four main steps: 1. The cost of the initial resource (Uranium Ore or Reprocessed Uranium) 2. Conversion Services Costs 3. Enrichment Process Costs 4. Fuel Fabrication Costs Costs may range from simple to triple whether Natural Uranium of Reprocessed Uranium is selected. The following table gives the detailed differences, and regarding only to costs approach, reprocessed Uranium appears to be a cheaper choice.

Table 2-1

Reload Fuel Cycle Costs for Typical PWR Using Nominal Front-End Unit Costs, Assuming Natural Uranium Feed and Reprocessed Uranium Feed

Cost Component	Component Quantities	Nominal Unit Cost	Cost per Reload (Million \$)	Percent of Total	Fuel Cost (Mills/kWhe)
PWR Fuel Cycle Costs – NatU					
Uranium	787,997 lb U ₃ O ₈	\$48/lb U ₃ O ₈	\$37.8	45.2%	2.931
Conversion	301,591 kgU UF ₆	\$7/kgU	\$2.1	2.5%	0.164
Enrichment	224,687 SWU	\$165/SWU	\$37.1	44.4%	2.872
Fuel Fabrication	32,760 kg EUP	\$200/kgU	\$6.6	7.9%	0.508
Total			\$83.6		6.475
PWR Fuel Cycle Costs - RepU					
Uranium	1,160,183 lb U ₃ O ₈	\$0/lb U ₃ O ₈	\$0	0.0%	0.000
Conversion	444,038 kgU UF ₆	\$21/kgU	\$9.3	12.8%	0.722
Enrichment	295,879 SWU	\$190/SWU	\$56.2	77.3%	4.356
Fuel Fabrication	32,760 kg EUP	\$220/kgU	\$7.2	9.9%	0.558
Total			\$72.7		5.636

Table 16: Reload Fuel Cycle Costs for Typical PWR using nominal front-end unit costs

However the fuel itself is not the only parameter to take into account to determine to cost of switching from Natural Uranium to Reprocessed (and it is trivial to remember than Reprocessed Uranium needs a classic fuel cycle to produce Fuel Wastes).

However, these results are based on the hypothesis of a \$0 cost for Reprocessed Fuel, but there are costs associated to the storage of RepU etc...

The study then watch the impact of parameters:

1. Unit Cost of U₃O₈
2. Unit Cost of Enrichment Services
3. Unit Cost of Conversion Services
4. Unit Cost of Fabrication Services
5. Changes in the Enrichment Tails Assay
6. RepU Value
7. RepU Initial Enrichment
8. Unit Costs of Conversion Services & Enrichment Services
9. Unit Costs of Uranium Ore Concentrates and Enrichment Services

In both case, the parameters which has the major impact is the Enrichment Services (Almost 50% of the price for natural Uranium and 75% for Reprocessed Uranium).

With worldwide nuclear power plant capacity poised to expand, the use of RepU inventories to displace natural uranium feed may assist in reducing future gaps between uranium supply capacity and worldwide uranium requirements.

Decisions regarding whether to recycle RepU in the place of natural uranium ore concentrates in LWR fuel will depend upon economic factors, such as the unit cost of uranium ore

	concentrates, the need for higher enrichment assays to compensate for neutron absorbing isotopes in RepU... In addition, there are technical issues that must be addressed such as those associated with the licensing and use of RepU in reactor cores, and the need for additional worker protection measures during the processing and manufacture of RepU fuel. Clearly, if the cost premium associated with the processing of RepU can be minimized, possibly through dedicated facilities for conversion and enrichment, and if the unit price of NatU concentrates remains near or above its current value of approximately \$48/lb U3O8, there may be justification for expanding the now-limited recycle of RepU in LWRs.		
<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	No	Yes (Fuel Cost)	No
<i>Source</i>	http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001020659		

3.14. Electric Power Research Institute (EPRI) – Program on Technology Innovation: Integrated Generation Technology Options 2012 – Feb 2013

<i>Abstract</i>	The Integrated Generation Technology Options report provides an executive-level overview of near-term (2015) and longer term (2025) electricity generation technology costs and performance through an overview of each technology (Description of the technology, Current and projected technology performance and costs, fuel resources considerations, environmental concerns and considerations...).
<i>Author</i>	The Electric Power Research Institute (EPRI) conducts research on issues related to the electric power industry in USA. EPRI is a nonprofit organization funded by the electric utility industry. EPRI is primarily a US-based organization, but receives international participation. EPRI's area covers different aspects of electric power generation, delivery and its use.
<i>Content</i>	<i>NB: the report gives a detailed review of each Energy Source. We will only discuss here the sections related to LCOE and Capital Costs.</i> Estimates of the representative cost and performance of power generation options are presented in the two following tables (For 2015 then for 2025):

Representative Cost and Performance of Power Generation Technologies (2015)

All Costs in Constant Dec. 2011\$	Nominal Plant Capacity, MW	Capacity Factor ¹ , %	Book Life, Years	Net HHV Heat Rate, Btu/kWh	CO ₂ Emissions ² , Metric Tons/MWh	Total Plant Cost, \$/kW	Total Capital Required ³ , \$/kW	FOM, \$/kW-yr	VOM, \$/MWh	Fuel Price, \$/MMBtu	LCOE ⁴ , \$/MWh
Pulverized Coal ⁵	750	80%	30	8,750	0.84	2,000-2,400	2,400-2,875	60	2.5	2-3	62-77
IGCC ⁵	600	80%	30	8,900	0.85	2,800-3,100	3,375-3,750	110	2	2-3	82-96
NGCC	550	80%	30	7,000	0.37	900-1,150	1,025-1,325	15	2.4	2-6	33-65
Nuclear	1400	80%	30	10,000	-	4,000-4,500	5,375-6,025	110	1.7	0.4-0.8	85-97
Biomass	100	80%	30	12,900	0 ⁶	3,600-4,500	4,150-5,250	65	5	2-6	90-155
Geothermal	15-50	80%	30	N/A	-	4,850-8,400	5,350-9,275	70-81	9.6	-	84-129
Onshore Wind ⁷	50-200	28-40%	20	N/A	-	1,750-2,400	1,825-2,500	35	-	-	62-117
Offshore Wind ⁷	200	40-45%	20	N/A	-	3,100-5,000	3,250-5,225	105	-	-	109-180
Concentrating Solar Thermal Power (CSP) ⁷	100-250	25-49%	30	N/A	-	3,300-6,100	4,050-7,550	64-88	-	-	159-180
Solar Photovoltaic (PV) ⁷	10	14-28%	20	N/A	-	2,000-2,300	2,200-2,525	20-25	-	-	107-203

Table 17: Representative cost and performance of power generation technologies (2015)

Representative Cost and Performance of Power Generation Technologies (2025)

All Costs in Constant Dec. 2011\$	Nominal Plant Capacity, MW	Capacity Factor ¹ , %	Book Life, Years	Net HHV Heat Rate, Btu/kWh	CO ₂ Emissions ² , Metric Tons/MWh	Total Plant Cost, \$/kW	Total Capital Required ³ , \$/kW	FOM, \$/kW-yr	VOM, \$/MWh	Fuel Price, \$/MMBtu	LCOE ⁴ , \$/MWh
Pulverized Coal with Carbon Capture ^{5,6}	525	80%	30	9,840-12,450	0.09-0.12	3,300-4,200	3,850-5,050	100	5	2-3	102-137
IGCC with Carbon Capture ^{5,6}	500	80%	30	9,100-11,400	0.09-0.15	3,350-4,100	4,050-4,950	140	3.4	2-3	105-136
NGCC	550	80%	30	8,320	0.34	900-1,150	1,025-1,325	15	2.4	4-8	44-73
NGCC with Carbon Capture ⁵	485	80%	30	7,140-8,040	0.04	1,800-2,200	2,050-2,525	27	5	4-8	68-112
Nuclear	1400	90%	30	10,000	-	3,600-4,400	5,225-5,900	110	1.7	0.4-0.8	83-98
Biomass	100	80%	30	11,400	0 ⁶	3,500-4,400	4,025-5,125	85	5	2-8	86-145
Geothermal	15-50	80%	30	N/A	-	4,700-8,150	5,200-9,000	70-81	9.6	-	82-126
Onshore Wind ⁷	50-200	28-40%	20	N/A	-	1,450-2,000	1,525-2,100	35	-	-	53-100
Offshore Wind ⁷	200	40-45%	20	N/A	-	2,550-4,100	2,675-4,300	105	-	-	95-153
Concentrating Solar Thermal Power (CSP) ⁷	100 - 250	25-48%	30	N/A	-	3,000-5,500	3,675-6,750	64-88	-	-	144-167
Solar Photovoltaic (PV) ⁷	10	15-27%	20	N/A	-	1,500-1,700	1,650-1,850	20-25	-	-	81-151

Table 18: Representative cost and performance of power generation technologies (2025)

The reports also determine the impact of a CO₂ emission tax introduction on power generation costs.

The value of CO₂ cost per metric ton widely change the balance of Energy Sources costs, Nuclear becoming more and more competitive against Coal & Gas while the CO₂ cost is raising. (based on 2015 costs data).

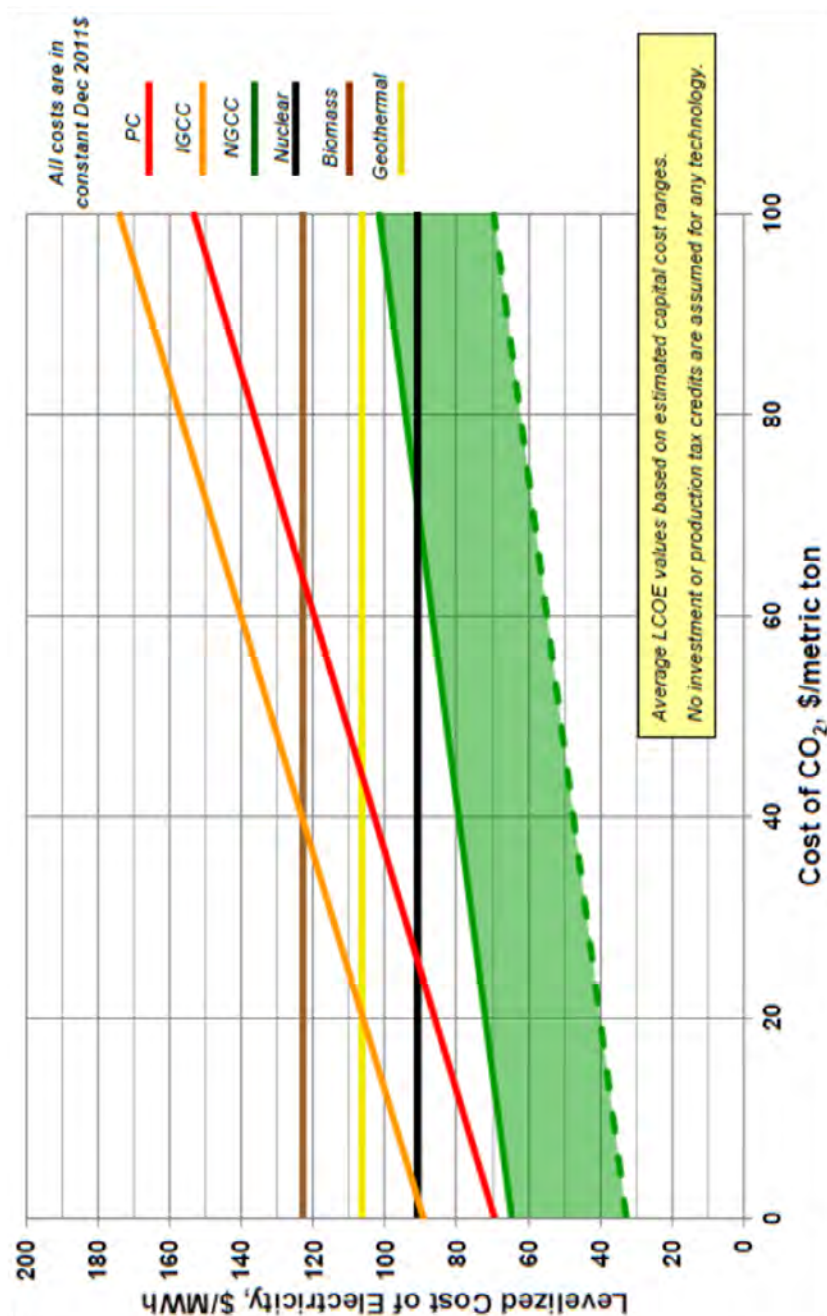
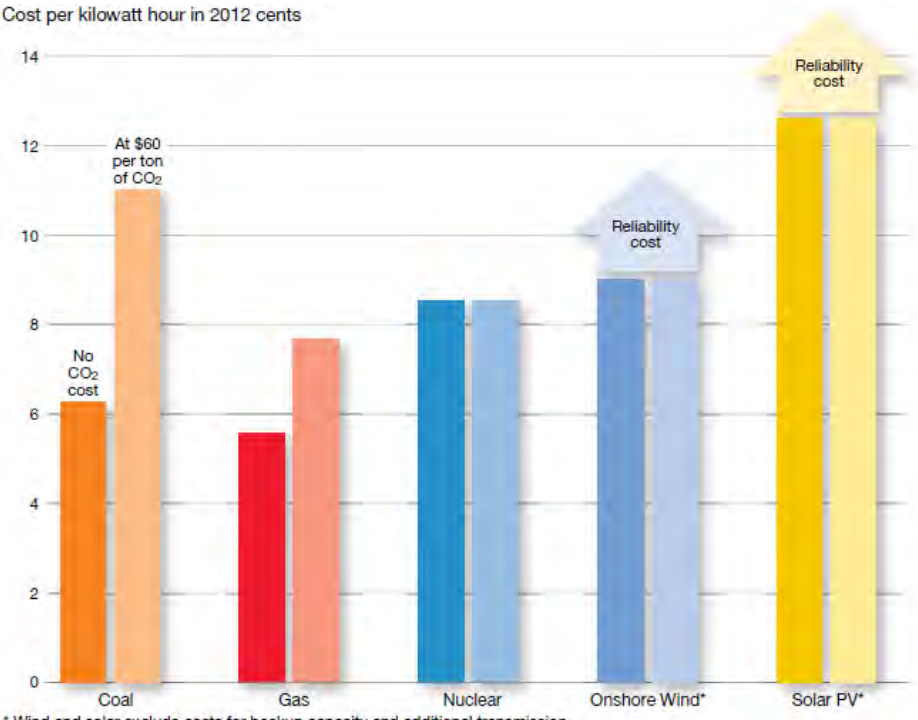


Figure 31: LCOE compared to cost of CO₂

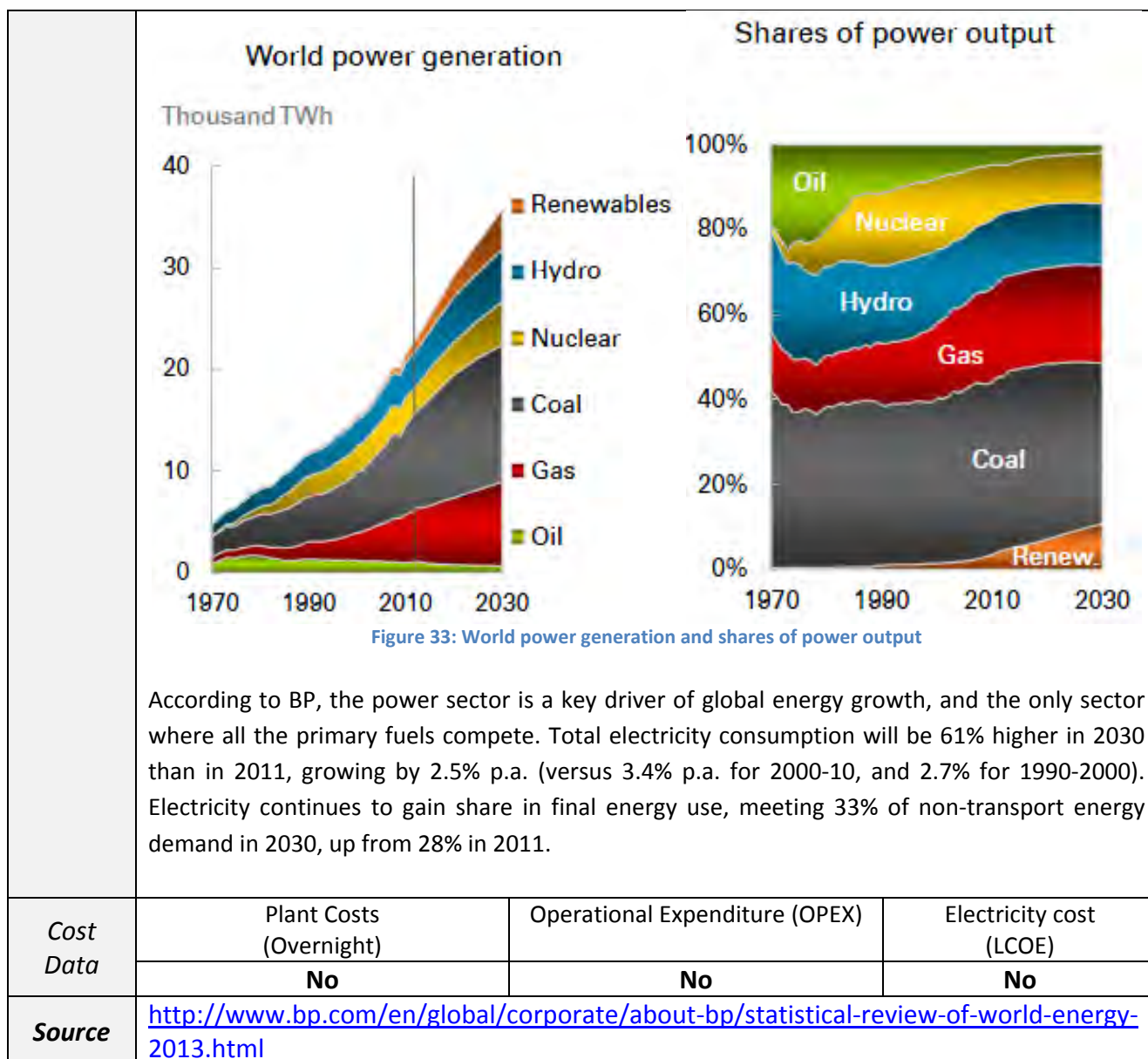
Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	http://www.epri.com/abstracts/Pages/ProductAbstract.aspx?ProductId=000000000001026656		

<i>Abstract</i>	The Outlook for Energy is ExxonMobil's long-term view of energy future. Exxon Mobile develop the Outlook annually to assess future trends in energy supply,demand and technology. The report deals with several aspects of Energy, from Industrial use of Energy to Electricity Generation, Emissions or Energy Supply.		
<i>Author</i>	Exxon Mobil Corporation is an American multinational oil and gas corporation. ExxonMobil is the world's third largest company by revenue and the second largest publicly traded company by market capitalization. Exxon Mobil's reserves were 72 billion oil-equivalent barrels at the end of 2007 and, with 37 oil refineries in 21 countries constituting a combined daily refining capacity of 6.3 million barrels (1,000,000 m3), Exxon Mobil is the largest refiner in the world, a title that was also associated with Standard Oil since its incorporation in 1870. ExxonMobil is the largest of the world's supermajors with daily production of 3.921 million BOE (barrels of oil equivalent). In 2008, this was approximately 3% of world production, which is less than several of the largest state-owned petroleum companies. When ranked by oil and gas reserves it is 14th in the world with less than 1% of the total.		
<i>Content</i>	Today, OECD and Non OECD countries consume approximately the same levels of electricity, but that relationship will change significantly as Non OECD electricity demand surges by 150 percent by 2040. Natural gas, nuclear and renewables grow to meet rising electricity demand, while coal and oil use declines. Cost per kilowatt hour in 2012 cents  * Wind and solar exclude costs for backup capacity and additional transmission. Figure 32: Average US cost of electricity generation in 2030 The study makes projection of the average electricity cost per technology in 2030 in the US (cf. previous figure).		
<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	No	No	Yes
<i>Source</i>	http://www.exxonmobil.com/Corporate/energy_outlook_view.aspx		



3.16. BP – World Energy Outlook 2013

<i>Abstract</i>	BP's annual Energy Outlook contains projections of future energy trends and factors that could affect them, based on BP views of likely economic and population growth and developments in policy and technology. However the report is mainly based on Forecast for Energy Consumption, with detailed situation for each source of Energy (Coal, Gas, Oil...), but it doesn't deal with Electricity Prices, or Installation Costs.
<i>Author</i>	BP (former name British Petroleum), is a British multinational oil and gas company. It is the fifth-largest energy company by market capitalization, fifth-largest company in the world measured by 2012 revenues, and the sixth largest oil and Gas Company measured by 2012 production. It is one of the six oil and gas "supermajors". BP is vertically integrated and operates in all areas of the oil and gas industry, including exploration and production, refining, distribution and marketing, petrochemicals, power generation and trading. It also has renewable energy activities in biofuels and wind power.
<i>Content</i>	Population and income growth are the key drivers behind growing demand for energy. By 2030 world population is projected to reach 8.3 billion, which means an additional 1.3 billion people will need energy; and world income in 2030 is expected to be roughly double the 2011 level in real terms. World primary energy consumption is projected to grow by 1.6% p.a. from 2011 to 2030, adding 36% to global consumption by 2030. The growth rate declines, from 2.5% p.a. for 2000-10, to 2.1% p.a. for 2010-20, and 1.3% p.a. from 2020 to 2030. The power sector diversifies its fuel mix, with more than half the growth coming from non-fossil fuels. Renewables contribute 27% of the growth, just ahead of coal (26%) and gas (21%). The Asia Pacific region, the largest regional energy producer, shows the most rapid growth rate (2.2% p.a.), due to large indigenous coal production, and accounts for 48% of global energy production growth. The region provides 35% of global energy production by 2030. The Middle East and North America contribute the next largest increments for supply growth; and North America remains the second largest regional energy producer. Energy production will grow in all regions but Europe. High prices are also supporting the expansion of supply, and not just from conventional sources – the development and deployment of new technologies across a range of energy sources is opening up new supply opportunities at scale. The “shale revolution”, first for gas and then for oil, is an example of this.



Abstract	The objective of this survey is to present ‘order of magnitude’ data – and thus not precise- that reveal the trends and the comparative cost advantages of technologies in a timeline up to 2030. This study covers the entire generation portfolio: renewables (RES) (on/off-shore wind, photo-voltaic and solar-thermal), hydropower (with pumped storage and run of-river), and thermal power plants (coal, lignite, gas and nuclear).																																																																				
Author	VGB PowerTech, is - as the European technical association for power and heat generation - a voluntary association of companies for which power and heat generation - i.e. power plant operation as well as the appropriate technique - is an important basis of their business. VGB POWERTECH is dealing with all questions regarding power and heat generation (renewable, fossil, nuclear) with their contiguous issues of environmental protection; in close co-operation with EURELECTRIC on European level and with BDEW on national level.																																																																				
Content	The study is based on data collected directly from Electricity Suppliers, the figures given for year 2011 are not the result of a VGB model/tool. However, the study uses assumptions on learning curve to estimate future costs, especially CAPEX. The study gives CAPEX and efficiency at three milestones: 2011, 2030 & 2050 (example below for the first milestone) Nuclear is only represented by an EPR reactor. <table><tr><th rowspan="2">Technology</th><th rowspan="2">Life time (years)</th><th rowspan="2">Typical Plant Size (MW)</th><th rowspan="2">Operation hours (h)¹⁾ (baseload)</th><th colspan="2">CAPE</th></tr><tr><th>2011 CAPEX</th><th>Efficiency</th></tr><tr><td colspan="6">Fossil Fuels</td></tr><tr><td>Gas open cycle</td><td>25</td><td>~ 250</td><td>6000</td><td>650</td><td>45</td></tr><tr><td>Gas CCGT</td><td>25</td><td>> 400</td><td>6000</td><td>800</td><td>60</td></tr><tr><td>Hard coal 600</td><td>35</td><td>~ 800</td><td>7500</td><td>1300</td><td>> 45</td></tr><tr><td>Lignite 600</td><td>35</td><td>~ 800</td><td>7500</td><td>1400</td><td>> 43</td></tr><tr><td>Hard coal / Lignite 700</td><td>35</td><td>~ 800</td><td>7500</td><td></td><td></td></tr><tr><td>Hard coal 700 + CCS</td><td>35</td><td>~ 800</td><td>7500</td><td></td><td></td></tr><tr><td>HC 600 + Biomass-co-firing</td><td>30</td><td>~800</td><td>7500</td><td>1390</td><td>>45</td></tr><tr><td colspan="6">Nuclear</td></tr><tr><td>EPR1600</td><td>40²⁾</td><td>1600</td><td>7900</td><td>3000³⁾</td><td>36</td></tr></table> Table 19: Capex per technology (VGB Powertech) Then LCOE for all the different types of technology studied. The LCOE breakdown is given, with Invest Costs, O&M Costs, Fuel Costs & CO2 Costs (Cf. figure below)	Technology	Life time (years)	Typical Plant Size (MW)	Operation hours (h) ¹⁾ (baseload)	CAPE		2011 CAPEX	Efficiency	Fossil Fuels						Gas open cycle	25	~ 250	6000	650	45	Gas CCGT	25	> 400	6000	800	60	Hard coal 600	35	~ 800	7500	1300	> 45	Lignite 600	35	~ 800	7500	1400	> 43	Hard coal / Lignite 700	35	~ 800	7500			Hard coal 700 + CCS	35	~ 800	7500			HC 600 + Biomass-co-firing	30	~800	7500	1390	>45	Nuclear						EPR1600	40 ²⁾	1600	7900	3000 ³⁾	36
Technology	Life time (years)					Typical Plant Size (MW)	Operation hours (h) ¹⁾ (baseload)	CAPE																																																													
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HC 600 + Biomass-co-firing	30	~800	7500	1390	>45																																																																
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EPR1600	40 ²⁾	1600	7900	3000 ³⁾	36																																																																

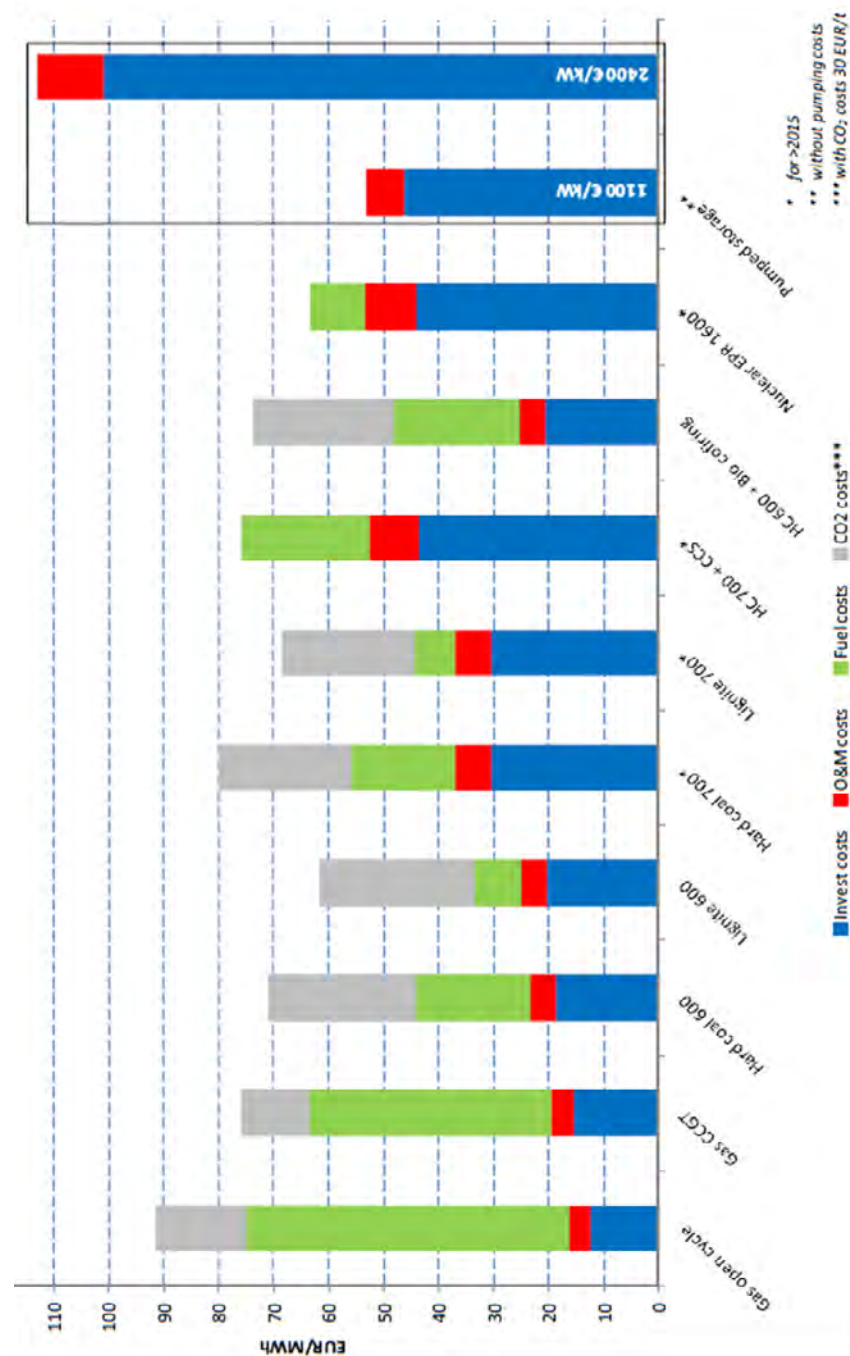


Figure 34: LCOE per technology (VBG Powertech)

Nuclear LCOE is estimated to be slightly higher than €60/MWh (\$ 81 /MWh) reflecting a \$3000/kW .

Cost Data	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
Source	https://www.vgb.org/vgbmultimedia/download/LCOE_Final_version_status_09_2012.pdf		

3.18. University of California (ILAR) – What does it cost to build a nuclear power plant ? – Sept. 2012

<i>Abstract</i>	The study is mainly focused on the question of capital costs for new nuclear power plants. ILAR goal was to analyze in details the pivotal assumptions currently used by the Energy modeling community to improve overall knowledge regarding several factors. Capital costs for new power plants are likely to vary worldwide to a much greater degree than widely assumed—largely because labor costs and various state-sponsored mechanisms for risk management vary so much. Labor saving innovations, such as in robotics and through international trade in preassembled components, may substantially lower costs even for plants that have long been thought immune to such improvements, such as large coal and nuclear facilities. The report offers an in-depth review of major studies on capital costs of building new power plants while exploring the major factors that determine these costs with an eye to how those driving forces might change in the future. In addition, it offers a brief case study on how those same factors affect capital costs in China.
<i>Author</i>	The Laboratory on International Law and Regulation (ILAR) is an international, interdisciplinary laboratory that explores when and why international laws actually work. The Laboratory is part of School of International Relations and Pacific Studies at University of California, San Diego. ILAR gratefully acknowledges anchor funding from the nonpartisan Electric Power Research Institute, BP, plc, the Norwegian Research Foundation and from UC San Diego's School of International Relations and Pacific Studies.
<i>Content</i>	The report provides critical information on construction costs of nuclear (and other energy sources). It is divided into three main sections: 1. Overview of literature on trends in the construction costs of new NPP with references to many other studies, some of which discussed in the current study, 2. NPP Cost breakdown analysis to identify the major driving forces of cost evolution and cost differences between regions, 3. China Case Study to explain the so-called cheap "Chinese Price" The recent cost studies show that across the advanced industrialized world (North America, Europe) capital costs have been rising rapidly for the last decade. Several factors are responsible for this increase such as: such as global commodity price, the demand for power generating equipment, shortages of construction services, and regulatory delays. According to the following chart, there is also a huge variation between countries.

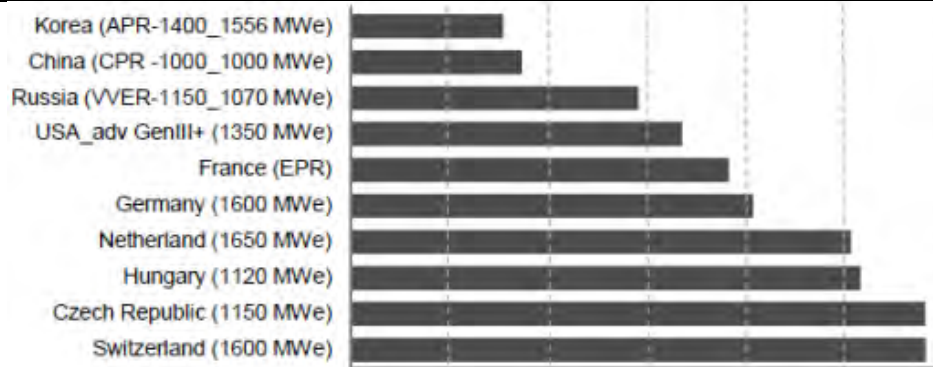


Figure 35: 2010 Overnight Capex for selected technologies (2010 USD/kWe)

Capital costs of building power plants can be defined at five levels: the Bare Erected Cost (BEC), the Engineering, Procurement and Construction Cost (EPCC), the Total Plant Cost (TPC), the Total Overnight Capital (TOC), and the Total As-Spent Capital (TASC). As illustrated in the following chart:

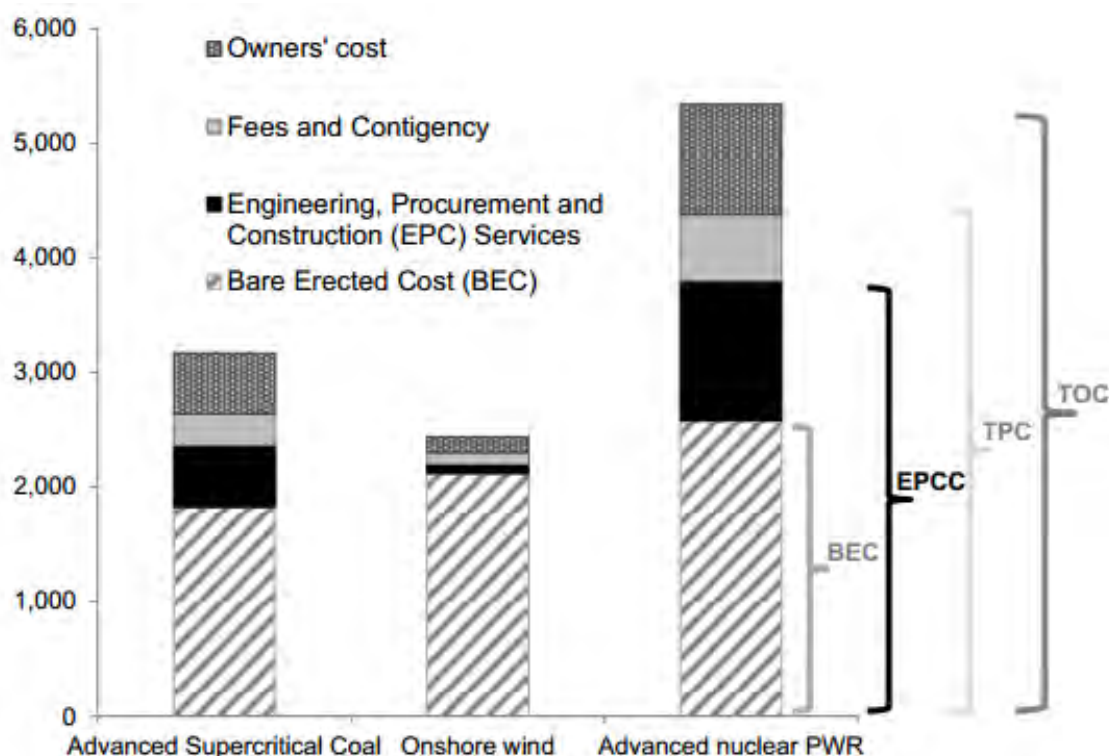


Figure 36: Base Plant site capital cost estimates for selected technologies (2010\$/kW)

The study then deals with 4 main components of the TOC:

1. Learning effects
2. The commodity market
3. The labor market
4. Regulation and Other Policy Interventions

Explanations for the very low capital costs in China are found in the study by looking deeply at all four of the factors examined earlier: learning, commodity prices, labor and policy.

The study does not provide indications of construction cost variations due to different nuclear

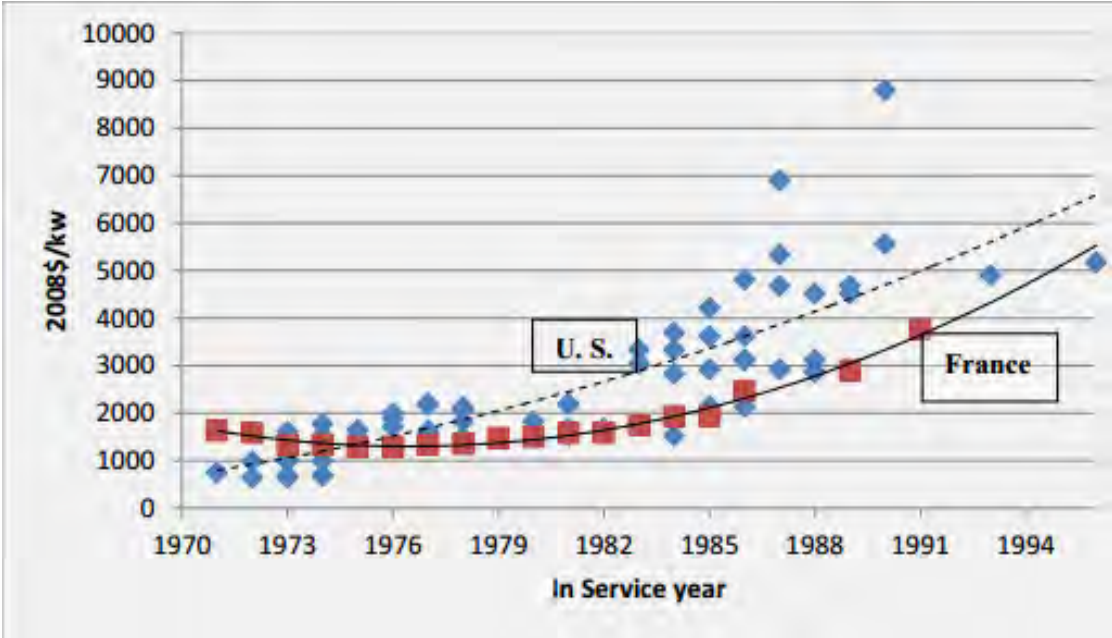
	technologies. It refers to a US DOE 2011 study indicating a cost per kilowatt installed of nuclear of \$ 5 000.		
<i>Cost Data</i>	Plant Costs (Overnight CAPEX)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	No	No
<i>Source</i>	http://ilar.ucsd.edu/assets/001/503883.pdf		

3.19. Massachusetts Institute of Technology – Future of Nuclear Power – Update of the 2003 Study

Abstract	The study addresses the steps needed in the near term to enable nuclear power to be a viable marketplace option at a time and at a scale that could materially mitigate climate change risks. In this context, the study explicitly assesses the challenges of a scenario in which nuclear power capacity expands in the United States. The important challenges examined are cost, safety, waste management, and proliferation risk. In addition, the report examines technology opportunities and needs, and offered recommendations for research, development, and demonstration.																																					
Author	The report is an initiative from different Directors and Professors of different department of the Massassuchets Institute of Technology.																																					
Content	Nota Bene: only the 2009 update of the 2003 study will be analyzed, though the report is based on the previous study conclusions. The study deals with the competitiveness of Nuclear Energy. MIT conclusion is that : “In deregulated markets, nuclear power is not now cost competitive with coal and natural gas. However, plausible reductions by industry in capital cost, operation and maintenance costs and construction time could reduce the gap. Carbon emission credits, if enacted by government, can give nuclear power a cost advantage.” The report shows that construction costs for all types of large-scale engineered projects have escalated dramatically within the last years. To give an idea of this increase, the following table shows the initial LCOE calculated in the 2003 study and its update: <table><tr><th colspan="2"></th><th>Overnight Cost</th><th>Fuel Cost</th><th>LCOE</th></tr><tr><th colspan="2"></th><th>\$/kW</th><th>\$/mmBtu</th><th>C\$/kWh</th></tr><tr><td rowspan="2">Nuclear</td><td>2003</td><td>2000</td><td>0.47</td><td>6.7</td></tr><tr><td>2009</td><td>4000</td><td>0.67</td><td>8.4</td></tr><tr><td rowspan="2">Coal</td><td>2003</td><td>1300</td><td>1.2</td><td>4.3</td></tr><tr><td>2009</td><td>2300</td><td>2.6</td><td>6.2</td></tr><tr><td rowspan="2">Gas</td><td>2003</td><td>500</td><td>3.5</td><td>4.1</td></tr><tr><td>2009</td><td>850</td><td>7</td><td>6.5</td></tr></table> Figure 37: Overnight Cost per technology The 2003 report founds that capital cost reductions and construction time reductions were plausible, but not yet proven – this judgment is unchanged in the report update. The challenge facing the nuclear industry lies in turning plausible reductions in capital costs and construction schedules into reality. The study then deals with several subject discussed in the previous report, such as: Government Incentives and regulations (the difference in financial assistance between Nuclear and Renewables for example), Safety, Waste Management, Fuel Cycle Issues, Non-Proliferation, technology opportunity and R&D needs. The conclusion of the report is quite similar from the previous one, the central premise of the			Overnight Cost	Fuel Cost	LCOE			\$/kW	\$/mmBtu	C\$/kWh	Nuclear	2003	2000	0.47	6.7	2009	4000	0.67	8.4	Coal	2003	1300	1.2	4.3	2009	2300	2.6	6.2	Gas	2003	500	3.5	4.1	2009	850	7	6.5
		Overnight Cost	Fuel Cost	LCOE																																		
		\$/kW	\$/mmBtu	C\$/kWh																																		
Nuclear	2003	2000	0.47	6.7																																		
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	2009	2300	2.6	6.2																																		
Gas	2003	500	3.5	4.1																																		
	2009	850	7	6.5																																		

	2003 MIT Study on the Future of Nuclear Power was that the importance of reducing greenhouse gas emissions, in order to mitigate global warming, justified reevaluating the role of nuclear power in the USA energy future. The 2003 study identified the challenges to greater deployment and argued that the key need was to design, build, and operate a few first-of-a-kind nuclear *plants with government assistance, to demonstrate to the public, political leaders, and investors the technical performance, cost, and environmental acceptability of the technology. The update insists that, no new plants are under construction (which is not true any longer as 2 AP 1000 are in construction) in the United States and insufficient progress has been made on waste management. The sober warning is that if more is not done, nuclear power will diminish as a practical and timely option for deployment at a scale that would constitute a material contribution to climate change risk mitigation.		
<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	Yes	Yes
<i>Source</i>	http://web.mit.edu/nuclearpower/pdf/nuclearpower-update2009.pdf		

3.20. Institute for Energy and the Environment Vermont law School – Mark Cooper – Policy Challenges of Nuclear Reactor Construction, cost escalation costs and crowding out alternatives 2009

Abstract	This study analyzes the two major challenges of nuclear reactor construction -- cost escalation and crowding out alternatives -- with new data in multiple analytic approaches.
Author	Mark Cooper is the senior fellow for economic analysis at the Institute for Energy and the Environment of the Vermont Law School. He is the author of "Nuclear Safety and Nuclear Economics" (2012) and "Policy Challenges of Nuclear Reactor Construction, Cost Escalation and Crowding Out Alternatives" (2009).
Content	The study is mainly focused on the history of Nuclear Energy in the US and France, with all the associated consequences linked to the decision taken a few decades ago to significantly develop Nuclear Energy. A brief analysis of PWR costs in the USA and France shows the cost escalation which Nuclear Industry must solve, as shown in the graph entitled “overnight costs of PWRs (\$2008). This graph shows the CAPEX of nuclear projects in the US and France from 1970 to 1994. According to the author, it supports its claim of a continuing increase, despite the learning curve. This phenomenon is linked to parameters like the increasing length of construction duration, the lack of learning curve, the increase of unit capacity...  Figure 38: Overnight costs of PWR (\$2008) [This curve is taken from report “NUCLEAR SAFETY AND NUCLEAR ECONOMICS, FUKUSHIMA REIGNITES THE NEVER-ENDING DEBATE: NUCLEAR SAFETY AT AN AFFORDABLE COST, CAN WE HAVE BOTH? IS NUCLEAR POWER NOT WORTH THE RISK AT ANY PRICE? The author provides no explanation to the two point over 7000 and 9000 \$/kW at the top of the chart].

	But on this subject, the report concludes that the claim that standardization, learning, or large increases in the number of reactors under construction will lower costs is not supported in the data. 1. The increasing complexity of nuclear reactors and the site-specific nature of deployment make standardization difficult, so cost reductions have not been achieved and are not likely in the future. 2. More recently, increasing complex technologies are more costly to build. 3. Building larger reactors to achieve economies of scale causes construction times to increase, offsetting the cost savings of larger reactors. In other words, longer production series of larger nuclear plants is not viewed as a reasonable solution. Broadly the paper shows that it is highly unlikely that the problems of the nuclear industry will be solved by an infusion of federal loans guarantees and other subsidies to get the first plants in a new building cycle completed. But if the Nuclear Industry is relaunched through massive subsidies it may delay the development of lower cost alternatives. However, Ingerop/NucAdvisor believes that this report has a strong anti-nuclear bias, and that some of its important findings such as absence of learning curve effect, or absence of benefit of standardization are not supported by evidence from other sources.		
<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	No	No
<i>Source</i>	http://www.vermontlaw.edu/Documents/IEE/20100909_cooperStudy.pdf		



3.21. National Bureau of Economic Research – “Prospects for Nuclear Power” Journal of Economic perspectives, American Economic Association - 2012

<i>Abstract</i>	With the US Natural Gas important decrease, the Fukushima Accident and the increasing construction cost for Nuclear Power Plant, the Nuclear Industry appears to be in a dead-end. The study tends to prove that there are certain factors that could make nuclear power a viable economic option (CO2 taxation, increase of fossil fuels energy...), but if these requirements are not achieved, a nuclear power renaissance seems unlikely.
<i>Author</i>	Lucas W. Davis is Assistant Professor at the Haas School of Business, University of California, Berkeley, California.
<i>Content</i>	The paper first deals with Nuclear Industry History and tends to compare the Nuclear Industry in the US with the one in the 70's. At this time, Nuclear Industry was a booming sector, but for several reasons, reactor orders fell precipitously after 1974. The author then analyses the evolution of construction cost for Nuclear Power Plant through history. Selected figures reveal a pronounced increase in construction costs, particularly for plants completed during the 1980s. There are several reasons behind this increase: Plants kept taking longer and longer to build; Regulation also contributed directly to construction costs. The Nuclear Regulatory Commission implemented revised safety codes and inspection requirements leading in several cases to extensive reactor redesigns. This has also financial consequences, the long period of time required for construction means that the cost of capital is a critical parameter for evaluating the viability of nuclear power: even for a low cost of capital, the extended construction period imposes financing costs that are a substantial part of total project costs. Another risk for Nuclear Energy is technology risk. Over the 40-plus year lifetime of a nuclear plant, the available sources of electricity generation could change considerably. An alternative, lower-cost technology could come along, or perhaps a technology that is known today such as wind or solar could quickly become more cost effective. An alternative technology for carbon abatement could become practical, like some form of carbon capture and storage, which would render moot one of the advantages of nuclear power. The study then tends to show that, Nuclear Energy is not competitive compared to Coal of Natural Gas.

Levelized Cost Comparison for Electricity Generation

<i>Source</i>	<i>Levelized cost in cents per kWh</i>		
	<i>Nuclear</i>	<i>Coal</i>	<i>Natural gas</i>
MIT (2009) baseline	8.7	6.5	6.7
Updated construction costs	10.4	7.0	6.9
Updated construction costs and fuel prices	10.5	7.4	5.2
With carbon tax of \$25 per ton CO ₂	10.5	9.6	6.2

Table 20: LCOE comparison for different technologies

However the author underlines that external costs are not always taken into account when comparing Nuclear to others Energy Sources, where for example Nuclear Wastes are integrated in LCOE, this is not the case for pollution resulting from Fossil Fuels Plants. More generally It appears that the consideration of external costs is not enough developed in cost studies.

The study then deals with the concept of “learning by doing”. If learning-by-doing could push construction costs down, this could change the equation considerably for nuclear power. A substantial literature in economics indicates that learning-by-doing matters in a variety of markets, and several studies have examined learning-by-doing in the construction of nuclear power plants.

<i>Cost Data</i>	Plant Costs (Overnight)	Operational Expenditure (OPEX)	Electricity cost (LCOE)
	Yes	No	Yes
Source	http://www.nber.org/papers/w17674		

4. Selected Nuclear Utilities Reports and Countries Studies

The various utilities performances, projects and issues related to nuclear are presented below in an alphabetical order and do not imply any ranking in terms of reliability of information or judgment on the data. Most of the data have been compiled from audited Financial Reports as presented to shareholders or regulators, and thus considered as reliable and updated sources of information.

Summary of the following data collection of the selected utilities is as follows:

	CEZ	EDF	EDF UK	ENEC
Current Fuel Cost \$/MWh	\$ 4.8	\$ 6.8	Not Applicable	Not Applicable
Current O&M Cost \$/MWh	\$ 32. (inc. SG& A)	\$ 37 (inc. SG& A) or \$ 22 without	\$ 28 (see detail)	Not Applicable
New Reactor Model	VVER	EPR	EPR	APR 1400
New Project Capex \$/kw	Not Available	\$ 6 700	\$ 6545	\$ 3 820

	EXELON	GEORGIA POWER	KEPCO	TVO
Current Fuel Cost \$/MWh	\$ 7.2	\$ 8.7	\$ 4.8	\$ 5.2
Current O&M Cost \$/MWh	\$ 12.3	Not Available (estimates = \$14 for AP 1000)	\$ 18.8	\$ 19.5
New Reactor Model	Not Applicable	AP 1000	APR 1400	EPR
New Project Capex \$/kw	Not Applicable	\$ 6280	\$ 4900 to 6400 (FOAK)	\$ 4525 to \$ 5945 (see detail)

Other projects, analyzed in this report relate to projects underway in China, Turkey, Finland, and Vietnam.

	China	China	China	Turkey	Turkey	Finland	Vietnam
Reactor Model	CPR 1000	AP 1000	EPR	VVER	ATMEA	VVER	VVER
New Project Capex/ kw	\$ 1 600 to 2100	\$ 2 750	\$ 2 730	\$ 4 165	\$ 5 000	\$ 4 300 to 6 000	\$ 5 000



4.1. CEZ

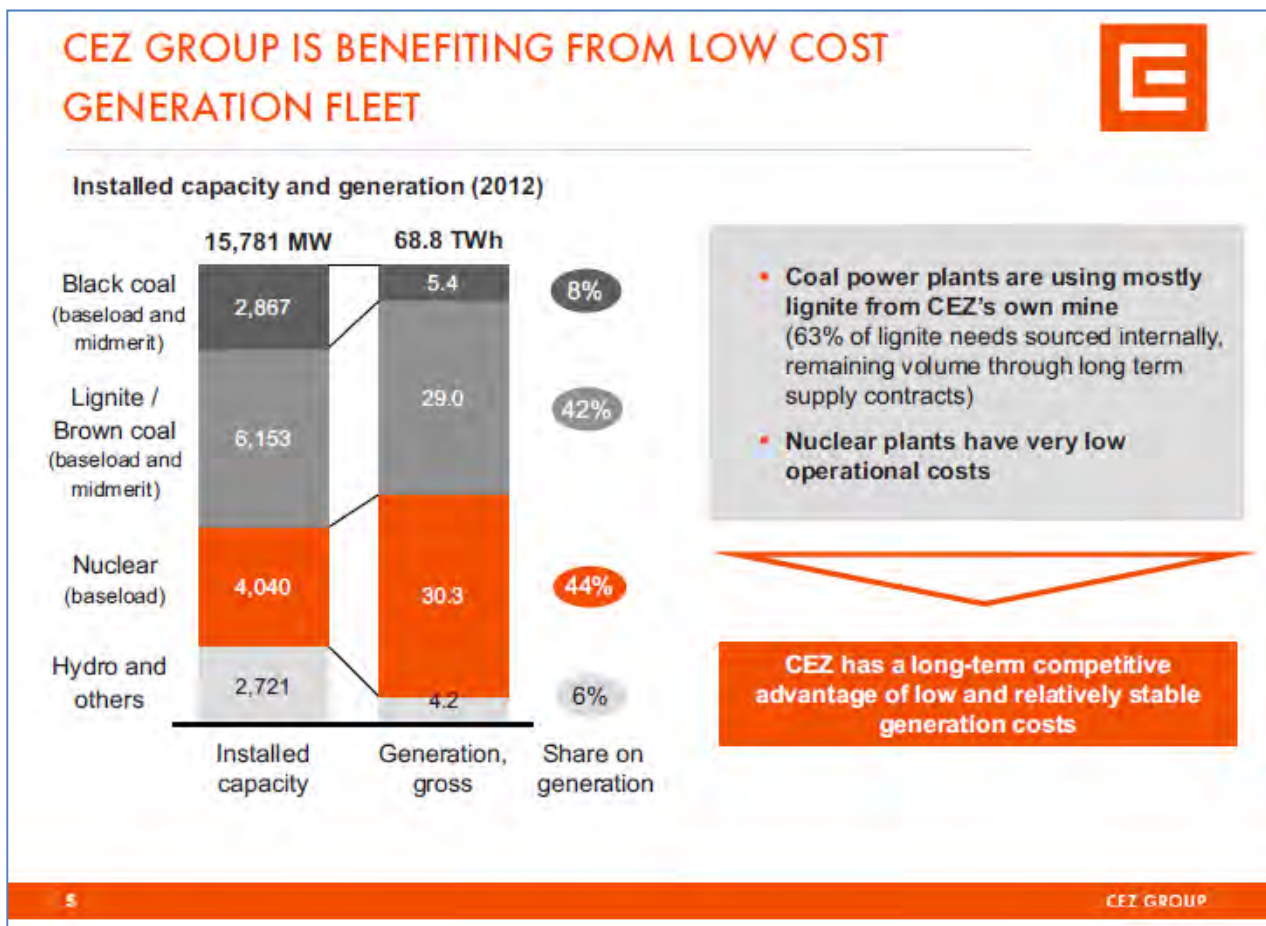
4.1.1. Main sources of information

- ✓ Annual Report 2012: www.cez.cz
- ✓ Shareholders presentation (May 2013)

4.1.2. CEZ Operations and costs

CEZ, the largest utility in the Czech Republic, operates 6 VVER type nuclear reactors of Russian origin (4X 510 MW units at Dukovany commissioned in the late 1980's and 2X 1000 MW units at Temelin commissioned in 2002-2003). The production output was 30 324 GWh in 2012 and 28 283 GWh in 2011 according to CEZ annual report.

CEZ is also very profitable – one of the most profitable in Europe- as explained below:



Specific information on nuclear is not detailed. However, the following tables indicate some important factors regarding profitability, fuel costs and operation costs. Expenses not related to fuel and power purchases do account for 32 % of the total operating expenses or slightly less than

20 % of revenues. The average O & M costs per MWh was € 24 in 2012 (\$ 32 / MWh) including plant not in operations yet and all Selling and Administrative expenses.

SELECTED HISTORICAL FINANCIALS OF CEZ GROUP EUR

Profit and loss

EUR m	2006	2007	2008	2009	2010	2011	2012
Revenues	5,931	6,943	7,316	7,811	7,909	8,343	8,555
Sales of electricity	5,898	6,472	6,575	6,901	6,971	7,230	7,429
Heat sales and other revenues	449	470	579	636	937	1,112	1,125
Operating Expenses	3,374	3,947	3,789	4,189	4,375	4,870	5,154
Purchased power and related services	1,710	1,843	1,657	1,917	2,162	2,620	2,850
Fuel	483	671	643	628	674	682	630
Salaries and wages	600	672	674	720	744	720	744
Other	601	760	814	923	785	849	930
EBITDA	2,558	2,996	3,528	3,622	3,534	3,473	3,401
<i>EBITDA margin</i>	<i>43%</i>	<i>43%</i>	<i>48%</i>	<i>46%</i>	<i>45%</i>	<i>42%</i>	<i>40%</i>
Depreciation	966	880	877	911	956	1,025	1,097
EBIT	1,592	2,116	2,651	2,711	2,577	2,448	2,304
<i>EBIT margin</i>	<i>27%</i>	<i>30%</i>	<i>36%</i>	<i>35%</i>	<i>33%</i>	<i>29%</i>	<i>27%</i>
Net Income	1,102	1,655	1,883	2,062	1,867	1,621	1,597

Balance sheet

EUR m	2006	2007	2008	2009	2010	2011	2012
Non current assets	12,011	12,452	13,771	16,504	17,829	18,586	19,683
Current assets	2,651	2,301	5,049	4,586	3,822	5,210	5,615
- out of that cash and cash equivalents	1,230	494	688	1,063	881	877	714
Total Assets	14,662	14,753	18,819	21,090	21,651	23,796	25,298
Shareholders equity (excl. minority int.)	7,752	6,815	6,891	7,969	8,807	9,021	9,952
Interest bearing debt	1,927	2,915	4,232	6,237	6,540	7,535	7,672
Other liabilities	4,984	5,023	7,697	6,884	6,304	7,240	7,674
Total liabilities	14,662	14,753	18,819	21,090	21,651	23,796	25,298

4.1.3. CEZ Nuclear Fuel Costs

Nuclear fuel costs, net of spent fuel disposal costs, were CZK 2 755 millions in 2012 and CZK 2 525 millions in 2011 (Annual Report 2012: page 228)

2.7. Fuel Costs

Fuel costs are expensed as fuel is consumed. Fuel expense includes the amortization of the cost of nuclear fuel. Amortization of nuclear fuel charged to fuel expense was CZK 2,787 million and CZK 3,225 million for the years ended December 31, 2012 and 2011, respectively. The amortization of nuclear fuel includes charges in respect of additions to the accumulated provision for interim storage of spent nuclear fuel to the extent they relate to the nuclear fuel consumed during the current accounting period (see Note 18). Such charges amounted to CZK 241 million and CZK 463 million in 2012 and 2011, respectively.

Such values would translate into a cost estimate of **\$ 4.8/MWh in 2012** and **\$ 4.5/MWh in 2011**, for VVER type fuel. This relatively low cost can be explained by the favorable long term purchasing agreement with Russian supplier (OAO-TVL).

4.1.4. CEZ Nuclear Decommissioning and Spent Fuel

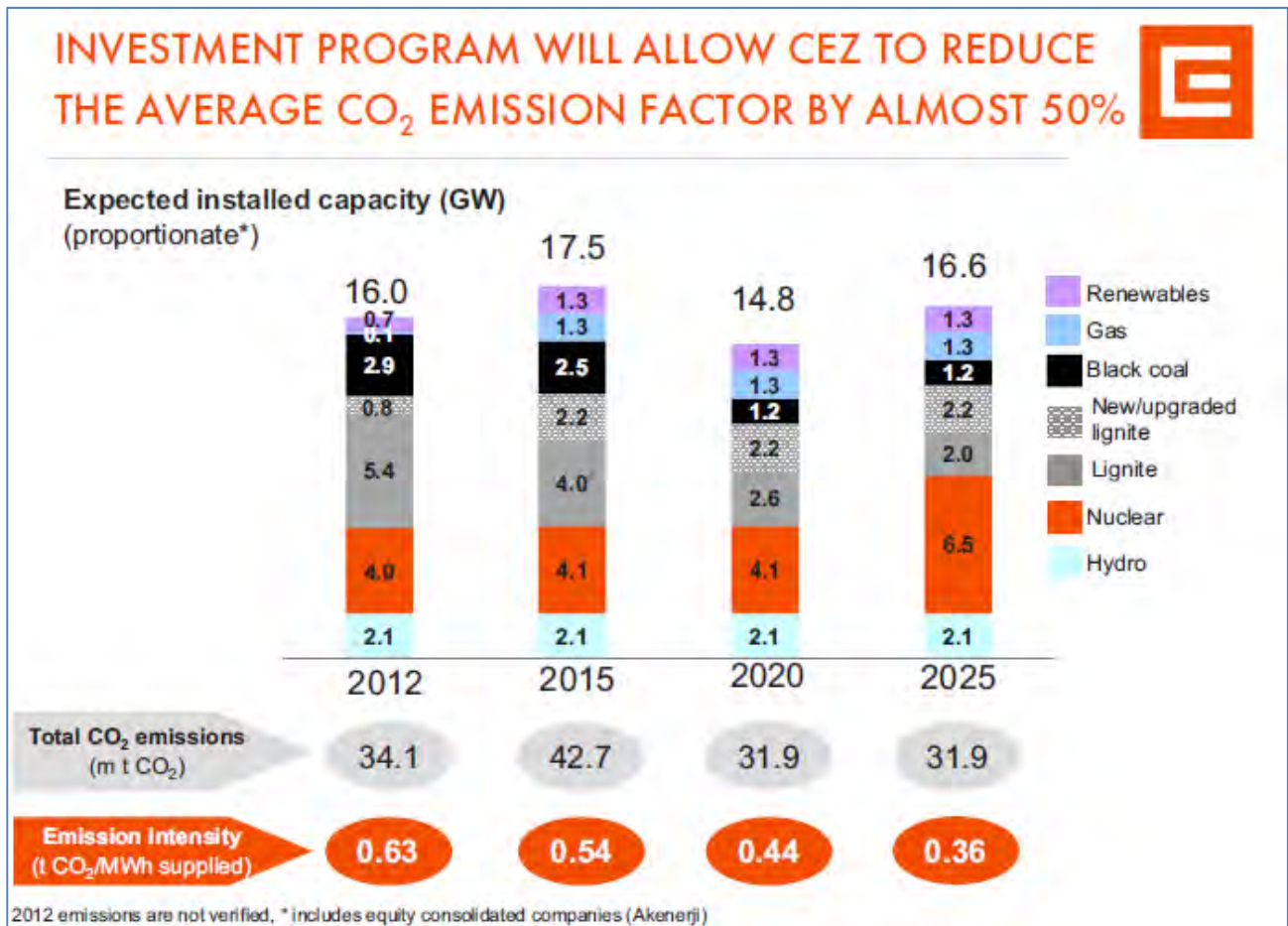
The Annual Report 2012 (page 261, footnote 18) provides two set of information:

- ✓ Actual estimate for the decommissioning of existing nuclear facilities of CZK 17.3 billion for Dukovany (circa: 2 000 MW) and CZK 14.6 billion for Temelin (circa 2000 MW). The current value of the decommissioning costs is estimated to be \$ 1 700 Millions translating into an average of **\$ 425 per installed kilowatt**.
- ✓ Variation to the provisions and funds on the balance sheet emphasizing the relative heavy weight of long-term spent fuel storage cost as compared to plant decommissioning

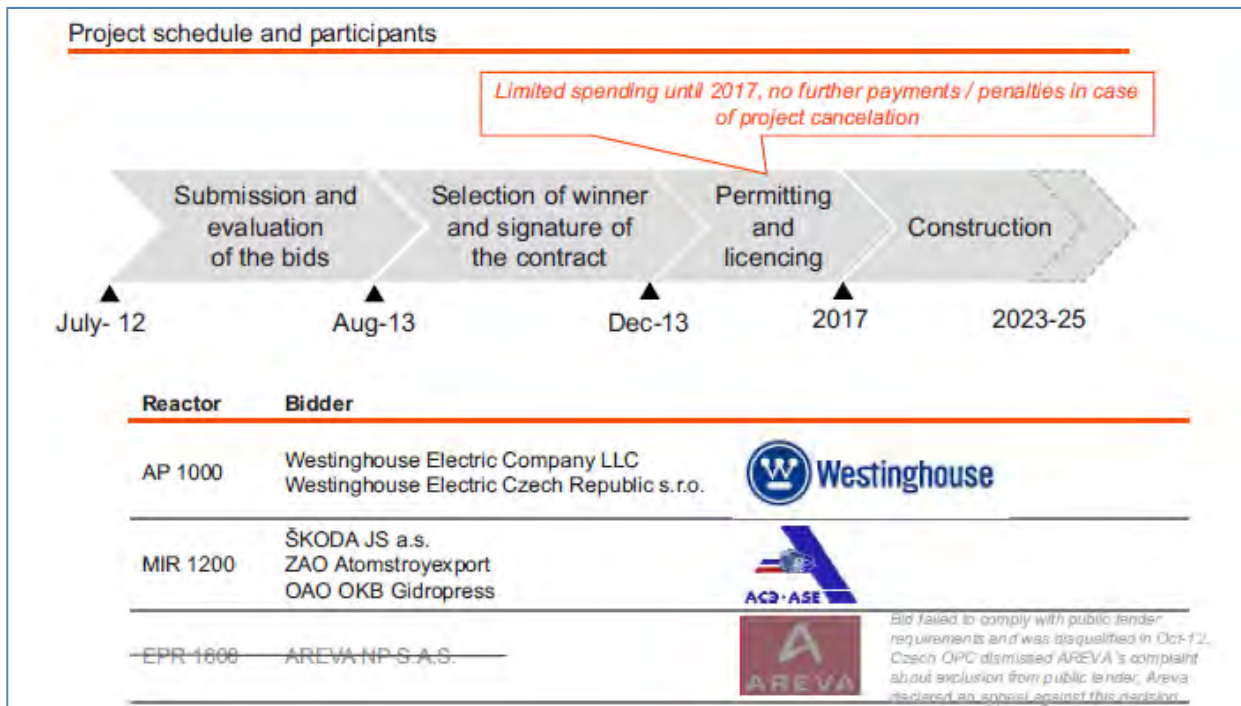
	Nuclear Decommissioning	Accumulated provisions		Total
		Spent fuel storage		
		Interim	Long-term	
Balance at December 31, 2010	8,793	5,998	22,057	36,848
Movements during 2011				
Discount accretion and effect of inflation	390	270	992	1,652
Provision charged to income statement	–	681	–	681
Effect of change in estimate charged to income statement	–	95	–	95
Effect of change in estimate added to fixed assets (Note 2.24)	–	–	37	37
Current cash expenditures	–	(614)	(1,414)	(2,028)
Balance at December 31, 2011	9,183	6,430	21,672	37,285
Movements during 2012				
Discount accretion and effect of inflation	414	289	976	1,679
Provision charged to income statement	12	453	–	465
Effect of change in estimate charged to income statement	–	364	–	364
Effect of change in estimate added to fixed assets (Note 2.24)	2,432	–	2,451	4,883
Current cash expenditures	(3)	(742)	(1,516)	(2,261)
Balance at December 31, 2012	12,038	6,794	23,583	42,415

4.1.5. CEZ Nuclear Projects

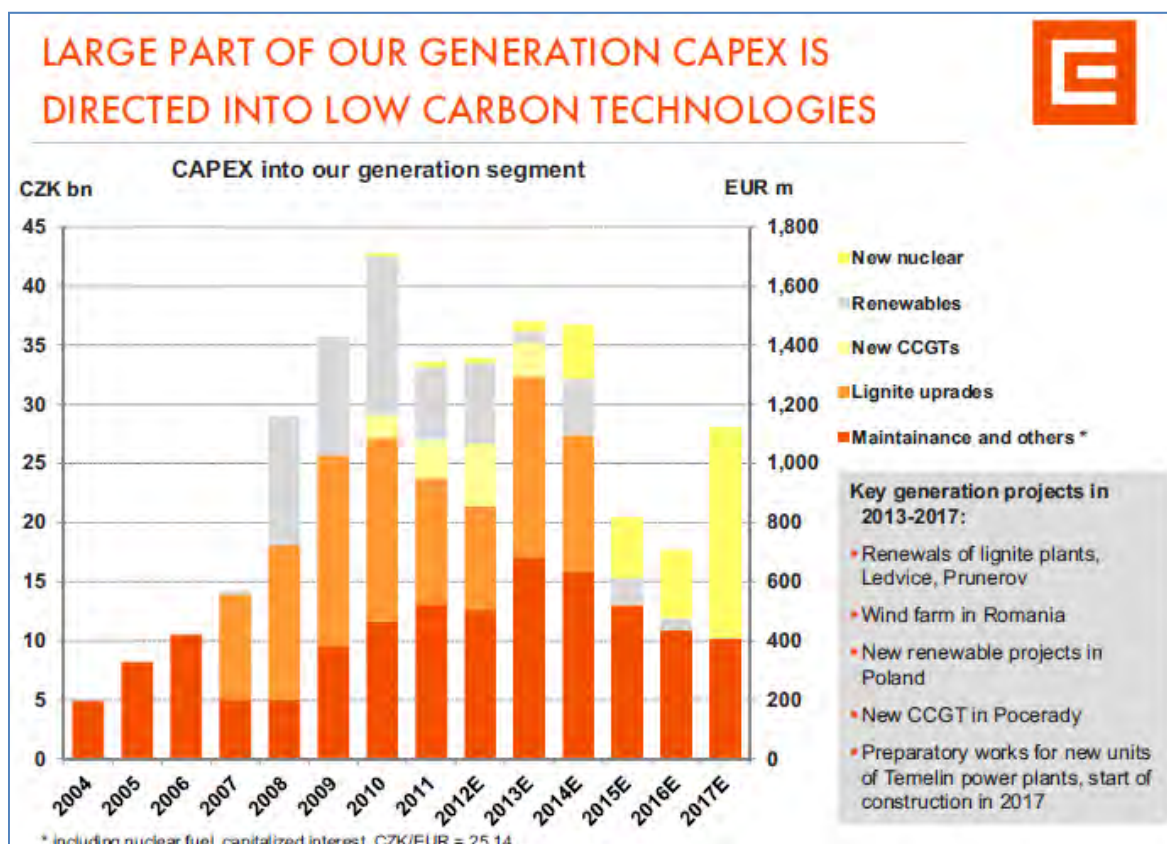
CEZ long term plan includes the construction of additional nuclear capacity (around 2 000 MW or a 50 % increase) as illustrated below:



Current status of the Project (Construction of new units at Temelin Nuclear Power Plant) is as follows:



Although no formal decision has taken place, the project impact on CEZ is estimated to represent an € 1.3 billion (\$ 1, 7 billion) of preparatory work expenses. No estimate of the overall project commitment has been provided.



4.2.1. Main sources of information

- ✓ Annual Report (2012): www.edf.com
- ✓ Presentation to shareholders
- ✓ French Accounting Office (2012): cost of the nuclear sector

4.2.2. EDF Operating costs

 Group installed capacity in 2012						
In MW ⁽¹⁾						
GROSS						
Reporting segment	Data					
	Total	Nuclear	Fossil-fired	Gas	Hydropower	Other Renewables
France	99 774	63 130	15 330	892	20 410	12
United-Kingdom	14 150	8 741	3 987	1 306	0	116
Italy	8 170	0	252	6 067	1 361	490
Other International	25 382	5 600	8 724	6 562	3 975	521
Other activities	8 881	0	52	4 558	81	4 190
Group total	156 357	77 471	28 346	19 385	25 827	5 328
NET						
Reporting segment	Data					
	Total	Nuclear	Fossil-fired	Gas	Hydropower	Other Renewables
France	99 774	63 130	15 330	892	20 410	12
United-Kingdom	14 150	8 741	3 987	1 306	0	116
Italy	8 170	0	252	6 067	1 361	490
Other International	10 764	2 862	3 660	3 930	81	231
Other activities	6 668	0	52	2 345	81	4 190
Group total	139 527	74 733	23 282	14 540	21 933	5 039
(1) In MW electric						

Total Production was in 2012:

 Group electricity generation						
In GWh						
2012						
Reporting segment	Data					
	Total	Nuclear	Fossil-fired	Gas	Hydropower	Other renewables
France	466 444	404 880	17 811	1 183	42 049	521
United-Kingdom	83 430	60 022	22 687	331	0	390
Italy	25 521	0	1 268	19 443	3 885	924
Other International	54 075	20 553	15 008	16 338	308	1 867
Other activities	13 130	0	118	4 278	78	8 656
Group total	642 601	485 455	56 892	41 574	46 321	12 359

Cost of electricity, in France, was in 2012 around **\$37/MWh** excluding fuel costs but including all other production costs, selling and administrative expenses;

In millions of euros

	Group total	France	International and Other activities	United Kingdom	Italy	Other International	Other activities
Sales	72 729	39 120	33 609	9 739	10 098	7 976	5 796
Fuel and energy purchases	(37 098)	(16 360)	(20 738)	(5 330)	(8 628)	(5 575)	(1 205)
Other external expenses	(10 087)	(5 860)	(4 227)	(1 215)	(577)	(681)	(1 754)
Personnel expenses	(11 624)	(8 676)	(2 948)	(1 128)	(261)	(504)	(1 055)
Taxes other than income taxes	(3 287)	(2 955)	(332)	(99)	(15)	(94)	(124)
Other operating income and expenses	5 451	4 661	790	87	402	(55)	356
EBITDA	16 084	9 930	6 154	2 054	1 019	1 067	2 014
Net changes in fair value on Energy & Commodity derivatives, excluding trading activities	(69)	(74)	5	50	(5)	(2)	(38)
Net depreciation and amortisation & increases in provisions for renewal (Impairment) / reversals	(7 013)	(4 358)	(2 655)	(888)	(644)	(590)	(533)
EBIT	8 245	5 566	2 679	972	265	86	1 356
MWh sold	642 601	466 444		83 430	25 521	54 075	13 130
% Nuclear	76%	87%		72%			
Sales / Mwh	113 €	84 €		117 €			
Costs / MWh excluding Fuel	30 €	28 €		28 €			

EDF does not provide a detailed cost of nuclear. However, the “Cour des Comptes” report of 2012 indicates a cost, excluding fuel, of \$ 22/MWh (for the year 2010).

The difference in values between \$ 37 and \$ 22 /MWh can be explained by the inflation differential from 2010 to 2012 (about 6 %) and by the significant weight of Selling & Administrative expenses of the EDF Group of which less than a billion € is allocated to nuclear.

Total operating costs for nuclear power generation in 2010 was 8.9 billion, or €22 per MWh. The total amount increased by 11 percent between 2008 and 2010 and by 14 percent relative to output.

Summary: operating costs

Types of charge	2008	2009	2010 adjusted €	Change 2010/2008
Fuel	€2 043 million €4.89	€2 093 million €5.37	€2 135 million €5.23	+ 5 percent + 7%
Personnel costs	€2 560 million €6.13	€2 606 million €6.69	€2 676 million €6.56	+ 5 percent + 7 percent
External costs	€1 768 million €4.23	€2 100 million €5.39	€2 095 million €5.14	+ 19 percent + 22 percent
Rates and taxes	€1 027 million €2.46	€1 091 million €2.80	€1 176 million €2.88	+ 15 percent + 17 percent
Central services	€669 million €1.60	€910 million €2.33	€872 million €2.14	+ 30 percent + 34 percent
Total	€8 067 million €19.3	€8 800 million €22.6	€8 954 million €22.0	11 percent 14 percent

Source: Cour des Comptes

4.2.3. Fuel Cost

EDF uses enriched uranium in all its reactors and also MOX (based on reprocessed fuel) in about 1/3 of its running fleet. EDF purchases annually around 1 100 Tons of nuclear fuel, making EDF the largest single buyer, so far, of nuclear fuel on a worldwide basis.

According to the report “The Costs of Nuclear Power” (January 2012), published by the French “Cour des Comptes”⁵, fuel cost per megawatt hour in France was around \$ 6.9 in 2010. Assuming an inflation of 3 % a year since 2010, the current cost of fuel could be estimated at around \$ 7.3 / MWh, in 2013.

Evolution of overall cost of nuclear fuel

Adjusted €	2008	2009	2010
Nuclear fuel costs in € millions (a)	1 485	1 504	1 503
Annual production in TWh	417.6	389.8	407.9
Cost of fuel used over year in € per MWh	3.56	3.86	3.68
Cost of keeping stock in € millions (b)	558	589	632
Total costs (a + b) in € millions	2 043	2 093	2 135
Annual production in TWh	417.6	389.8	407.9
Total fuel cost in € per MWh	4.89	5.37	5.23

Source: EDF

It should be noted that such cost includes the storage cost of fresh fuel prior to the loading into the reactors; such cost is worth around 40% of the value of the fuel itself.

Nuclear Reactors are mostly loaded with fresh fuel; they also include up to 10 % of MOX fuel increasing slightly year over year. The impact of the MOX usage on the overall fuel cost is not known.

Nuclear fuel consumption

Tonnes	Enriched Natural Uranium		Enriched Recycled Uranium		MOX	
Year	Loaded	Unloaded	Loaded	Unloaded	Loaded	Unloaded
2008	N/d	1049	18.5	16	82.5	93
2009	1004.7	995	51.6	21.0	92.6	79.6
2010	981.2	1030	71.9	28.6	112.5	86.4

Source: EDF

4.2.4. Decommissioning

EDF has a long experience in decommissioning as the first generation of gas reactors have been in the decommissioning mode for a long time.

The current provisions as of 12/31/2012 were:

⁵ Governmental body in charge of auditing and supervising all State owned entities and the French Treasury.

EDF nuclear provisions					
In millions of euros	31/12/2011 ⁽¹⁾	Net Allow.	Disc.	Other changes	31/12/2012
Provisions for back-end nuclear cycle					
Total	15 865	(1 006)	1 036	716	16 611
Provisions for management of spent fuel	9 143	(881)	550	686	9 498
Provisions for long-term management of radioactive waste	6 722	(125)	486	30	7 113
Provisions for nuclear dismantling and last cores					
Total	13 378	406	693	294	14 771
Provisions for dismantling power stations	11 366	405	592	215	12 578
Provisions for last cores	2 012	1	101	79	2 193
Total nuclear provisions	29 243	(600)	1 729	1 010	31 382

The gross costs of dismantling the existing power stations is estimated to be \$ 23,4 billion for 58 reactors reflecting an average cost of \$ 400 million per reactor (range from \$ 350 to \$ 400/kW).

Methodology to estimate the costs may vary from one country to the other, as explained in the previously described report of the French “Cour des Comptes”. One possible reason of the low evaluation by EDF is related to the standardization of its nuclear fleet.

Extrapolation of the cost of dismantling the current fleet: 11 international comparisons - € billion 2010 (1)							
Methods used by	EDF	Sweden	Belgium	Japan	USA 3 methods	UK	Germany 4 methods
Extrapolation for 58 reactors	18.1	20	24.4	38.9	27.3 33.4 34.2	46	25.8 34.6 44 62

Source: Cour des Comptes

4.2.5. Flamanville 3

EDF is currently building an EPR on the site (Flamanville) where 2 units of 1300 MW are in operations. According to the last quarterly financial release, the status of the project is:

Expected commissioning in 2016 (construction started in 2007)

95 % of civil works completed

46 % of electro-mechanical equipments construction achieved

Estimated cost of € 8, 5 billion or \$ 11, 0 billion (whether such cost includes capitalized interest is unclear and will be investigated)

AREVA, the main supplier of nuclear equipment, has publicly disclosed that the cost of the EPR in Flamanville does reflect the cost of a FOAK and is not representative of further EPR costs.

Such cost would translate into a capital cost of \$ 6 700 per kilowatt.



4.3. EDF Energy (Previously British Energy)

4.3.1. Main sources of information

- ✓ EDF Annual Report (2012): section “nuclear production”
- ✓ Presentation to shareholders 2013

4.3.2. EDF Energy current performance

EDF Energy operates 16 out of the 17 nuclear reactors in the UK. Only one of them is a PWR reactor, relatively recent. EDF-Energy, fully owned by EDF, currently plans a significant nuclear capacity extension and is well advanced in the preparation of construction of 2 EPR reactors.

The table below indicates that:

- ✓ Fuel cost was around \$ 13 / MWh (but fuel is predominantly AGR fuel)
- ✓ Operations costs were \$ 28 /MWh (but only Sizewell is a PWR)
- ✓ Nuclear EBITDA (\$ 2 362 Million in 2012) was very close to 50 % of Net Sales and would make nuclear projects affordable, especially during construction phase.

EDF Energy Segmental Analysis 2012							
	Unit	Generation		Electricity supply		Gas supply	
		Nuclear ⁽¹⁾	Non Nuclear ⁽²⁾	Domestic	Non-domestic	Domestic	Non-domestic
		2012	2012	2012	2012	2012	2012
Total revenue	£M	2,992	1,185	1,847	3,179	1,169	10
Revenue from sales of electricity and gas	£M	2,992	1,185	1,847	3,179	1,169	10
Other revenue	£M	6	60	10	8	3	0
Total operating costs	£M	507	633	898	2,007	700	5
Direct fuel costs	£M	507	633	898	2,007	700	5
Other direct costs	£M	167	198	650	995	304	1
Indirect costs	£M	842	172	334	172	205	1
EBITDA	£M	568	100	(25)	10	(37)	0
DA	£M	568	100	19	10	11	0
EBIT	£M	568	100	(44)	3	(48)	3
Volume ⁽³⁾	TWh, therms	59.5	24.5	14.8	36.8	1,054.3	6.6
WACO F/E/G ⁽⁴⁾	£/MWh, p/th	8.52	25.84	60.68	54.54	66.40	75.76

(1) Figures shown represent 100% of nuclear capacity, shared 50/50 by EDF Energy and Centrica

(2) Includes results of Sellafield, which is managed under Hold Separate Arrangements

(3) Volume measured net of losses i.e. National Balancing Point for Generation and Customers meter point for Supply

(4) WACO is calculated as the direct fuel cost per MWh. For Generation this reflects the delivered cost of fuel and for the Supply business, it covers the wholesale energy costs, the energy element of RBD costs as well as balancing and shaping costs.

4.3.3. EDF Energy current EPR projects

Several nuclear projects are contemplated in the UK as part of its National Market Reform. UK has very ambitious plans for nuclear in order to replace aging nuclear fleet (AGR technology for the most part)

The most advanced project so far is related to the construction of 2 EPR units on the site of EDF Energy (formerly British Energy) at Hinkley Point.

EDF Energy and its 100 % shareholder, EDF, have not decided yet to pursue the project, even though a substantial amount of money has been spent so far in preparatory work.

The main reason to the delay is related to the absence of agreement with the UK government on the fixation of the “strike price” for the purpose of setting Contract for differences (CfD) for the price of electricity produced.

As per the Financial Statements of EDF Energy Holdings, the accumulated spending on the projects in the UK were £ 2 517 million as of 12/31/2012, most of it related to Hinkley Point C project (and a CCGT project).

17. Property, plant and equipment								
	Land and buildings	Network assets	Generation assets	Nuclear power stations	Other plant and equipment	Equipment and fittings	Assets in the course of construction	Total
	£m	£m	£m	£m	£m	£m	£m	£m
Cost								
At 31 December 2010	334	17	1,726	8,232	381	197	1,214	12,101
Additions	-	-	-	28	63	-	919	1,010
Transfers	-	3	182	61	113	(8)	(361)	(10)
Decommissioning	-	-	10	-	-	-	-	10
Revaluation of final core provision	-	-	-	62	-	-	-	62
Disposals	-	-	(7)	-	(104)	(8)	(2)	(121)
At 31 December 2011	334	20	1,911	8,383	453	181	1,770	13,052
Additions	-	-	-	-	-	-	1,235	1,235
Transfers	-	1	106	167	198	(1)	(488)	(17)
Decommissioning	-	-	14	-	-	-	-	14
Revaluation of final core provision	-	-	-	(113)	-	-	-	(113)
Disposals	-	(3)	-	-	(65)	(1)	-	(69)
Transfer to assets held for sale	-	-	(320)	-	-	-	-	(320)
At 31 December 2012	334	18	1,711	8,437	586	179	2,517	13,782

In addition, the project itself is considered worth £ 14 billion or \$ 21 600 millions of which about 18 % already spent. It is unclear whether the amount includes capitalized interest or not. Commissioning is expected to occur in 2022, according to Press Reports, if construction effectively begins in 2014 (construction duration of 8 years)

On that basis, cost per kilowatt of the future UK EDF Energy EPR can be estimated at \$ 6,545/kW

4.4. ENEC (United Arab Emirates)



4.4.1. Main sources of information

- ✓ Kepco Filing on Form 20 F with the US SEC (page 61)

4.4.2. ENEC Nuclear Project

ENEC, a State Owned Utility in the United Arab Emirates, signed an agreement with KEPCO, KHNP and others to build 4 APR 1400 units on the coastal site of Barakah. Initial indications were that the project cost would be for a turn-key contract of 18, 6 billions \$ with the terms of the contract to last from Dec, 2009 to May, 2020 (construction duration of 11 years for 4 units)

The contracts include (a) the design and construction of 4 nuclear units with 1 400 MW of capacity each (b) the supply of fuel for 3 cycles including the initial loading and (c) technical support, training and education. Each unit is supposed to be built in 8 years (As disclosed in Kepco Form 20F filing April 2013).

The reported contract value does not include any capitalized interests and is currently estimated as of 12/31/2012 to be worth \$ 21 400 millions for a capacity of 5 600 MW.

<u>CONSTRUCTION CONTRACTS</u>				
(1) Changes in balance of construction contracts for the years ended December 31, 2012 and 2011 are as follows (KRW in millions):				
	2012			
	Jan. 1, 2012	Increase and decrease (*1)	Recognized revenue	Dec. 31, 2012
Nuclear power plant construction in UAE	₩22,689,640	₩(839,900)	₩(1,490,055)	₩20,359,685
Kazakhstan EPC and others	864,937	108,283	(365,990)	607,230
	<u>₩23,554,577</u>	<u>₩(731,617)</u>	<u>₩(1,856,045)</u>	<u>₩20,966,915</u>
(*1) The increased balance of contracts from new orders and others for the year ended December 31, 2012 is KRW 201,823 million and the decreased balance of contracts from changes in scale of construction for 2012 is KRW 933,440 million.				
	2011			
	Jan. 1, 2011	Increase and decrease (*1)	Recognized revenue	Dec. 31, 2011
Nuclear power plant construction in UAE	₩23,857,073	₩ —	₩(1,167,433)	₩22,689,640
Kazakhstan EPC and others	573,014	579,622	(287,699)	864,937
	<u>₩24,430,087</u>	<u>₩579,622</u>	<u>₩(1,455,132)</u>	<u>₩23,554,577</u>
(*1) The increased balance of contracts from new orders and others for the year ended December 31, 2011 is KRW 593,979 million and the decreased balance of contracts from changes in scale of construction and others for 2011 is KRW 14,357 million.				

Total cost per kilowatt of the APR 1400, outside of Korea, can be estimated at around \$ 3 820.

4.5.1. Exelon main sources of information

- ✓ EXELON Annual Report: www.exelon.com
- ✓ US Securities & Exchange Commission: 10 K Filing 2013

4.5.2. Exelon Nuclear Operations

Exelon operates 17 nuclear reactors, 5 of them being PWR with a total installed capacity of 17 000 MW (Annual report 2012: page 7).

Generating Resources	
At December 31, 2012, the generating resources of Generation consisted of the following:	
<u>Type of Capacity</u>	<u>MW</u>
Owned generation assets ^(a)	
Nuclear	17,202
Fossil	12,050
Renewable (including Hydroelectric) ^(b)	3,516
Owned generation assets	32,768
Long-term contracts ^(c)	9,296
Investment in CENG ^(d)	1,963
Total generating resources	44,027

(a) See "Fuel" for sources of fuels used in electric generation.
(b) Includes equity method investment in certain generating facilities.
(c) Excludes contracts with CENG. See Long-Term Contracts table in this section for additional information.
(d) Generation owns a 50.01% interest in CENG, a joint venture with EDF. See ITEM 2. PROPERTIES—Generation and Note 22—Related Party Transactions of the Combined Notes to Consolidated Financial Statements for additional information.

Its annual nuclear output is around 140 000 GWh (Annual Report 2012: page 12)

Fuel		
The following table shows sources of electric supply in GWh for 2012 and 2011:		
	<u>Source of Electric Supply ^(a)</u>	
	<u>2012</u>	<u>2011</u>
Nuclear	139,862	139,297
Purchases—non-trading portfolio ^(b)	91,994	18,908
Fossil	27,760	7,385
Renewable	4,079	4,253
Total supply	263,695	169,843

(a) Represents Generation's proportionate share of the output of its generating plants.
(b) Includes purchases in 2012 pursuant to Generation's PPA with CENG. See Note 22 of the Combined Notes to Consolidated Financial Statements for additional information.

Exelon purchases about \$ 1 000 million worth of nuclear fuel every year, thus at a cost of \$ 7.2 / MWh, consistent with the national average.

Capital Expenditures

Generation's business is capital intensive and requires significant investments in nuclear fuel and energy generation assets and in other internal infrastructure projects. Generation's estimated capital expenditures for 2013 are as follows:

(in millions)	
Nuclear fuel ^(a)	\$1,000
Production plant	1,000
Renewable energy projects ^(b)	575
Upgrades	225
Other	50
Total	<u>\$2,850</u>

(a) Includes Generation's share of the investment in nuclear fuel for the co-owned Salem plant.

(b) Primarily relates to expenditures for the completion of the Antelope Valley development project.

According to its most recent annual filing, the total production cost of the nuclear fleet was \$ **19.50/MWh** including nuclear fuel cost and operations cost (Annual report 2012: page 61)

	2012	2011	2010
Nuclear fleet capacity factor ^(a)	92.7%	93.3%	93.9%
Nuclear fleet production cost per MWh ^(a)	\$19.50	\$18.86	\$17.31

(a) Excludes Salem, which is operated by PSEG Nuclear, LLC, and CENG's nuclear facilities, which are operated by CENG. Reflects ownership percentage of stations operated by Exelon.

Excluding fuel, the cost of operations of Exelon was \$ **12.3/MWh** below the value provided by the US NEI historical data:

US Electricity Production Costs and Components

Year	Total Production Costs				Operations & Maintenance Costs				Fuel Costs			
	Coal	Gas	Nuclear	Petroleum	Coal	Gas	Nuclear	Petroleum	Coal	Gas	Nuclear	Petroleum
1995	2,74	3,99	2,80	6,23	0,65	0,77	1,95	1,78	2,09	3,23	0,85	4,45
1996	2,58	4,87	2,57	6,36	0,57	0,75	1,80	1,46	2,01	4,12	0,77	4,89
1997	2,49	4,94	2,74	5,66	0,55	0,73	1,98	1,20	1,93	4,22	0,76	4,46
1998	2,44	4,31	2,57	4,01	0,59	0,65	1,82	0,77	1,85	3,65	0,75	3,24
1999	2,35	4,66	2,37	4,79	0,56	0,54	1,68	1,08	1,79	4,12	0,68	3,72
2000	2,30	7,77	2,27	6,94	0,55	0,62	1,63	0,86	1,75	7,15	0,64	6,08
2001	2,36	7,79	2,18	6,39	0,58	0,68	1,58	0,87	1,78	7,11	0,60	5,52
2002	2,33	4,96	2,14	6,13	0,59	0,66	1,58	0,99	1,74	4,30	0,56	5,14
2003	2,30	6,82	2,11	7,31	0,58	0,70	1,54	1,15	1,71	6,12	0,57	6,16
2004	2,39	6,83	2,06	6,93	0,61	0,58	1,50	1,02	1,78	6,25	0,56	5,91
2005	2,59	8,55	1,99	9,52	0,61	0,56	1,47	1,01	1,98	7,99	0,52	8,51
2006	2,69	7,38	2,02	10,91	0,63	0,58	1,50	1,44	2,06	6,80	0,52	9,47
2007	2,74	7,11	2,04	11,45	0,64	0,56	1,51	1,53	2,10	6,55	0,53	9,93
2008	3,00	8,38	2,08	18,66	0,65	0,60	1,55	2,04	2,35	7,78	0,53	16,62
2009	3,18	5,34	2,06	13,73	0,72	0,64	1,47	2,79	2,45	4,70	0,59	10,94
2010	3,26	5,19	2,19	17,46	0,74	0,62	1,52	2,62	2,52	4,57	0,66	14,84
2011	3,34	4,60	2,24	22,98	0,74	0,56	1,54	2,37	2,60	4,04	0,69	20,61
2012	3,27	3,40	2,40	22,48	0,73	0,47	1,65	2,11	2,55	2,93	0,75	20,37

Production Costs = Operations and Maintenance Costs + Fuel Costs. Production costs do not include indirect costs and are based on FERC Form 1 filings submitted by regulated utilities. Production costs are modeled for utilities that are not regulated.

Source: Ventyx Velocity Suite

Updated: 5/13

4.6.1. Georgia Power source of information

- ✓ Annual Report 2012: www.georgiapower.com
- ✓ US Securities & Exchange Commission Filing 2013

4.6.2. Georgia Power Operations

Georgia Power has an ownership interest in 3 nuclear reactors (45.7 % in Vogtle 1 & 2 and 50.1% in Harsh power stations), generating around 16 200 GWh per annum.

Little detail is provided on the running costs with the exception of fuel, as presented below. Fuel cost close to \$ 8.7 / MWh would place GP at the upper range of the fuel cost in the USA.

MANAGEMENT'S DISCUSSION AND ANALYSIS (continued)			
Georgia Power Company 2012 Annual Report			
Details of the Company's generation and purchased power were as follows:			
	2012	2011	2010
Total generation (<i>billions of KWHs</i>)	59.8	65.5	75.3
Total purchased power (<i>billions of KWHs</i>)	28.7	26.8	21.7
Sources of generation (<i>percent</i>) -			
Coal	39	62	67
Nuclear	27	23	21
Gas	33	13	10
Hydro	1	2	2
Cost of fuel, generated (<i>cents per net KWH</i>) -			
Coal	4.63	4.70	4.53
Nuclear	0.87	0.78	0.66
Gas	3.02	4.92	5.75
Average cost of fuel, generated (<i>cents per net KWH</i>)	3.07	3.80	3.82
Average cost of purchased power (<i>cents per net KWH</i>) *	4.24	5.38	5.64
* Average cost of purchased power includes fuel purchased by the Company for tolling agreements where power is generated by the provider.			

Decommissioning costs are provided in a greater detail and indicate the decommissioning cost of the actual plants as well as the accumulated accrual as of 12/31/2012. Estimate of decommissioning cost would be around \$ 700/kW.

Site study cost is the estimate to decommission a specific facility as of the site study year. The estimated costs of decommissioning are based on the most current study performed in 2012. The site study costs and external trust funds for decommissioning as of December 31, 2012 based on the Company's ownership interests were as follows:

	Plant Hatch	Plant Vogtle Units 1 and 2
Decommissioning periods:		
Beginning year	2034	2047
Completion year	2068	2072
	<i>(in millions)</i>	
Site study costs:		
Radiated structures	\$ 549	\$ 453
Spent fuel management	131	115
Non-radiated structures	51	76
Total site study costs	\$ 731	\$ 644
External trust funds	\$ 435	\$ 256

4.6.3. Georgia Power current project at Vogtle

GP and its associates decided to build the first 2 AP 1000 in the USA, under an agreement in 2008 with a consortium made of Stone & Webster and Westinghouse. Construction timing is very ambitious as the expected commissioning of first unit is supposed to occur 4 years after first concrete.

Fact sheet presented by GP indicate a project cost of \$ 14 billion for 2 X 1170 MW plants, on the existing site of Vogtle (GA).



Vogtle Units 3 & 4 Benefits

- Georgia Power is building two additional nuclear units at Plant Vogtle to meet customer needs.
- Vogtle Units 3 and 4 represent a \$14 billion capital investment in Georgia and will create approximately 5,000 on-site construction jobs and 800 high-paying permanent jobs.

Project Status

- Total amount invested through Dec. 31, 2012 – \$2.2 billion.
- Vogtle Units 3 and 4 are expected to be placed in service in 2017 and 2018, respectively.
- First nuclear concrete placement was completed on March 15, 2013.
- CR-10 module, or "cradle," was placed on April 11, 2013.
- Unit 3 containment vessel bottom head (pictured) was placed on June 1, 2013.
- Unit 3 turbine island lower foundation work complete, upper foundation work progressing as scheduled.
- Unit 3 cooling tower on schedule and over 40 percent complete.
- Engineering, procurement and construction of the Facility is approximately 50 percent complete based on completion of contractual milestones.



Additional breakdown of the capital spending cost can be found in the 2013 NEI report which points out a cost of \$ 12.3 billion, **excluding any interest expenses**, for an advanced reactor (AN), typically a Westinghouse AP-1000 reactor.

TABLE 12-1 – BASE PLANT SITE CAPITAL COST ESTIMATE FOR AN

Technology: AN	
Nominal Capacity (ISO): 2,234,000 kW	
Nominal Heat Rate (ISO): N/A Btu/kWh-HHV	
<u>Capital Cost Category</u>	<u>(000s) (October 1, 2012\$)</u>
Civil Structural Material and Installation	1,792,260
Mechanical Equipment Supply and Installation	3,519,000
Electrical / I&C Supply and Installation	652,050
Project Indirects ⁽¹⁾	2,817,788
EPC Cost before Contingency and Fee	8,781,458
Fee and Contingency	1,345,500
Total Project EPC	10,126,958
Owner Costs (excluding project finance)	2,227,931
Total Project Cost (excluding finance)	12,354,889
Total Project EPC / kW	4,533
Owner Costs 22% (excluding project finance) / kW	997
Total Project Cost (excluding project finance) / kW	5,530
(1) Includes engineering, distributable costs, scaffolding, construction management, and start-up.	

The same report provides an O & M cost for future AP – 1000 reactor of:

TABLE 12-3 – O&M EXPENSES FOR AN	
Technology:	AN
Fixed O&M Expense	\$93.28/kW-year
Variable O&M Expense	\$2.14/MWh

This set of information would place the AP-1000 cost at \$ 6 280 / Kw and its running cost (excluding fuel) at \$ 14 / MWh approximately (well below the national US average);

In effect, a summary of 2009 Federal Regulatory Energy Commission (USA), analyzed by the Consultant, would indicate the following cost per reactor technology in operations:

<u>2009</u>	Load Factor	Maintenance	Operations	Production	Supplier
Vogle	95%	2,89	8,24	13,52	W
McGuire	96%	5,12	9,98	17,71	W
NorthAnna	96%	3,20	9,52	15,14	W
Sequoyah	94%	3,44	10,72	16,55	W
Catawba	91%	7,33	12,14	16,82	W
Callaway	98%	4,15	10,90	17,06	W
Robinson-2	104%	3,80	12,06	17,49	W
Surry	93%	4,61	12,86	18,21	W
Farley	93%	5,70	13,27	18,90	W
Watts Bar	97%	4,05	13,18	20,26	W
Wolf Creek	86%	5,07	15,63	20,49	W
Shearon-Harris	94%	5,90	15,33	21,08	W
South Texas	91%	5,12	16,67	21,41	W
Summer	81%	6,99	17,56	22,46	W
Diablo Canyon	83%	7,99	17,96	23,46	W
Turkey Point	88%	9,10	20,83	27,90	W
Average W	92%	5,28	13,55	19,28	W
Std Dev W	6%	1,74	3,38	3,43	W
Browns Ferry	84%	4,50	11,41	17,65	GE
Grand Gulf	99%	2,88	11,37	17,82	GE
Brunswick	89%	6,33	13,61	19,20	GE
Waterford	89%	5,09	13,08	19,60	GE
Hatch	80%	6,28	14,27	20,06	GE
River Bend	93%	6,58	15,51	21,47	GE
Quad Cities	97%	5,98	16,45	21,73	GE
Fermi-2	78%	8,01	18,63	23,69	GE
Columbia	84%	8,91	21,22	26,52	GE
Monticello	82%	5,52	25,53	33,52	GE
Average GE	87%	6,01	16,11	22,13	GE
Std Dev GE	7%	1,70	4,53	4,83	GE
St-Lucie	89%	5,85	14,30	20,79	CE
Palo Verde	61%	9,05	31,07	41,13	CE
Oconee	94%	6,38	11,64	16,55	BW
Arkansas	95%	5,67	11,55	18,49	BW
Crystal-River3	72%	5,70	19,66	24,56	BW
Average ALL	89%	5,72	15,04	21,01	ALL
Std Dev ALL	9%	1,73	4,89	5,48	ALL



4.7. KEPCO

4.7.1. Main sources of information

- ✓ KEPCO: US SEC filing: Form 20F 2013
- ✓ KHNP website www.khnp.co

4.7.2. Kepco Overall Situation

Kepco is the dominant electric utility in Korea, with a diversified portfolio of energy sources. Nuclear does account for about 30 % of the total production and appears to be the cheapest source of electricity, as total current production cost of electricity is half the average global cost.

	Items	Volume (Gigawatt hours)	Percentage of Total Volume (%)	Sales to KEPCO (in billions of Won)	Percentage of Total Sales (%)	Unit Price (Won/kWh)
Generation Companies ...	KHNP	148,416	31.5	6,733	15.8	45.4
	KOSEP	60,098	12.7	4,533	10.6	75.4
	KOMIPO	50,005	10.6	5,413	12.7	108.2
	KOWEPO	54,094	11.5	5,936	13.9	109.7
	KOSPO	61,041	12.9	6,937	16.3	113.7
	EWP	54,857	11.6	5,836	13.7	106.4
	Others ⁽¹⁾	42,992	9.2	7,199	17.0	167.5
	Total	471,503	100.0	42,587	100.0	90.3
Energy Sources	Nuclear	143,453	30.4	5,682	13.3	39.6
	Bituminous coal	184,485	39.1	12,238	28.7	66.3
	Anthracite coal	8,015	1.7	833	2.0	103.9
	Oil	14,516	3.1	3,673	8.6	253.0
	LNG	3,763	0.8	791	1.9	210.1
	Combined-cycle	101,355	21.5	16,888	39.7	166.6
	Hydro	3,346	0.7	605	1.4	181.0
	Pumped-storage	3,631	0.8	809	1.9	222.9
	Others	8,939	1.9	1,068	2.5	119.4
	Total	471,503	100.0	42,587	100.0	90.3
Load	Base load	332,456	70.5	18,200	42.7	57.7
	Non-base load	139,047	29.5	24,387	57.3	175.4
	Total	471,503	100.0	42,587	100.0	90.3

Note:

- (1) Others represent independent power producers that trade electricity through the cost-based pool system of power trading (excluding independent power producers that supply electricity under power purchase agreements with us).

This production is achieved by different sources, of which nuclear is less than 1/3 of total capacity (with a high average load factor).

	Number of Units	Installed Capacity ⁽¹⁾ (Megawatts)	Average Capacity Factor ⁽²⁾ (Percent)
Nuclear	23	20,716	82.3
Thermal:			
Coal	51	24,534	91.7
Oil	16	3,950	38.9
LNG	4	888	40.2
Total thermal	71	29,372	83.1
Internal combustion	206	367	35.4
Combined-cycle	109	12,936	65.1
Hydro	69	5,330	10.4
Wind	31	70	20.1
Solar	50	51	12.4
Fuel cell	4	6	78.1
Total	563	68,848	72.4

Notes:

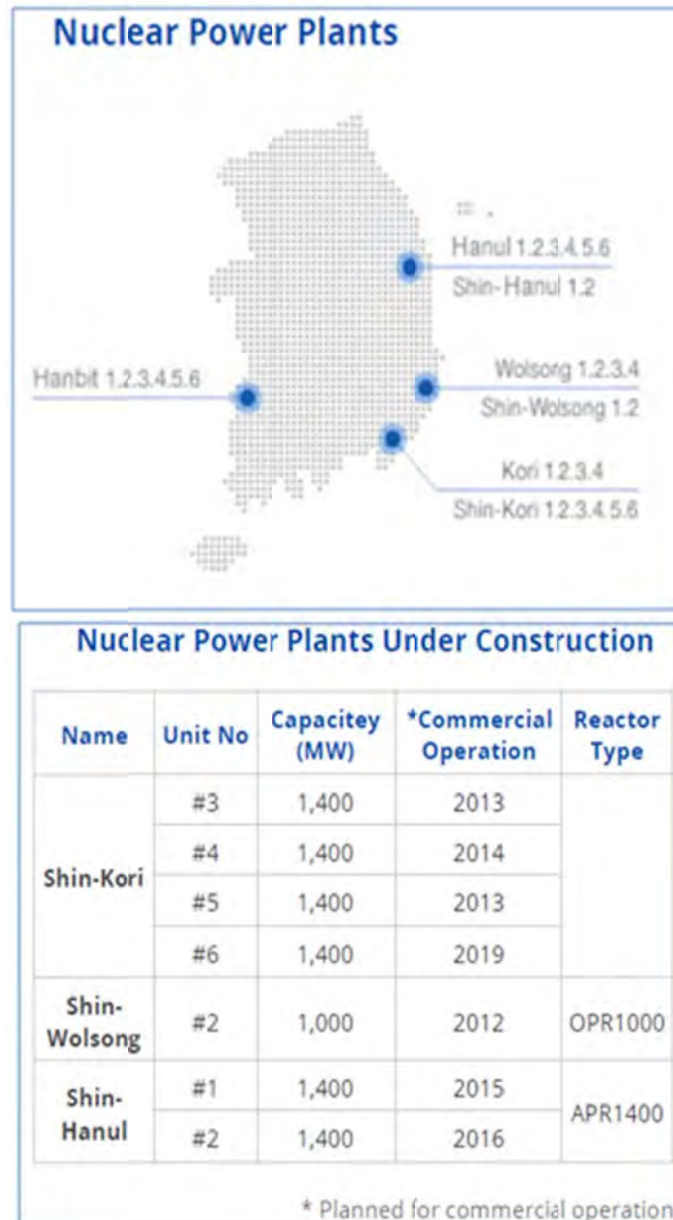
(1) Installed capacity represents the level of output that may be sustained continuously without significant risk of damage to plant and equipment.

(2) Average capacity factor represents the total number of kilowatt hours of electricity generated in the indicated period divided by the total number of kilowatt hours that would have been generated if the generation units were continuously operated at installed capacity, expressed as a percentage.

4.7.3. Kepeco Nuclear Operations

KOREA ELECTRIC POWER CO (KEPCO), the main electric generation company in Korea, operates all nuclear power plants in Korea with an installed capacity of 20 715 Megawatts, as of 12/31/2012. KEPCO current long term plan includes the construction of seven new reactors, one OPR 1000 reactor and up to 6 APR 1400 reactors.

KEPCO, KHNP and other affiliates are also the main contractor for the construction of 4 APR 1400 reactors in the United Arab Emirates (UAE).



KEPCO operates a wide range of reactor types from different origins, all PWR, with exception of 4 Candu reactors.

Unit	Reactor Type ⁽¹⁾ (Megawatts)	Reactor Design ⁽²⁾	Turbine and Generation ⁽³⁾	Commencement of Operations	Installed Capacity
Kori-1	PWR	W	GEC, Hitachi, D	1978	587
Kori-2	PWR	W	GEC	1983	650
Kori-3	PWR	W	GEC, Hitachi	1985	950
Kori-4	PWR	W	GEC, Hitachi	1986	950
Shin-Kori-1	PWR	D, KOPEC, W	D, GE	2011	1,000
Shin-Kori-2	PWR	D, KOPEC, W	D, GE	2012	1,000
Wolsong-1	PHWR	AECL	P	1983	679
Wolsong-2	PHWR	AECL, H, K	H, GE	1997	700
Wolsong-3	PHWR	AECL, H	H, GE	1998	700
Wolsong-4	PHWR	AECL, H	H, GE	1999	700
Shin-Wolsong-1	PWR	D, KOPEC, W	D, GE	2012	1,000
Yonggwang-1	PWR	W	W, D	1986	950
Yonggwang-2	PWR	W	W, D	1987	950
Yonggwang-3	PWR	H, CE, K	H, GE	1995	1,000
Yonggwang-4	PWR	H, CE, K	H, GE	1996	1,000
Yonggwang-5	PWR	D, CE, W, KOPEC	D, GE	2002	1,000
Yonggwang-6	PWR	D, CE, W, KOPEC	D, GE	2002	1,000
Ulchin-1	PWR	F	A	1988	950
Ulchin-2	PWR	F	A	1989	950
Ulchin-3	PWR	H, CE, K	H, GE	1998	1,000
Ulchin-4	PWR	H, CE, K	H, GE	1999	1,000
Ulchin-5	PWR	D, KOPEC, W	D, GE	2004	1,000
Ulchin-6	PWR	D, KOPEC, W	D, GE	2005	1,000
Total nuclear					<u>20,716</u>

Notes:

- (1) "PWR" means pressurized light water reactor; "PHWR" means pressurized heavy water reactor.
- (2) "W" means Westinghouse Electric Company (U.S.A.); "AECL" means Atomic Energy Canada Limited (Canada); "F" means Framatome (France); "H" means Hanjung; "CE" means Combustion Engineering (U.S.A.); "D" means Doosan Heavy Industries; "K" means Korea Atomic Energy Research Institute.
- (3) "GEC" means General Electric Company (UK); "P" means Parsons (Canada and UK); "W" means Westinghouse Electric Company (U.S.A.); "A" means Alstom (France); "H" means Hanjung; "GE" means General Electric (U.S.A.); "D" means Doosan Heavy Industries; "Hitachi" means Hitachi Ltd. (Japan).

4.7.4. Kepeco Fuel Costs

The average fuel cost of the various reactors were around **\$ 4.8/MWh** in 2012, excluding the cost of fuel of 4 “Candu” reactors that have an average cost 40 % higher than the other PWR reactors.

Fuel

Nuclear

Uranium, the principal fuel source for nuclear power, accounted for 34.1%, 34.9% and 33.6% of our fuel requirements for electricity generation in 2010, 2011 and 2012, respectively.

All uranium ore concentrates are imported from, and conversion and enrichment of such concentrates are provided by, sources outside Korea and are paid for with currencies other than Won, primarily in U.S. dollars.

In order to ensure stable supply, KHNP enters into long-term and medium-term contracts with various suppliers and supplements such supplies with purchases in spot markets. In 2012, KHNP purchased 100%, or approximately 4,432 tons, of its uranium concentrate requirement under long-term supply contracts with suppliers in Australia, Canada, France, Germany, Russia, Kazakhstan, the United States and Niger. Under the long-term supply contracts, the purchase prices of uranium concentrates are adjusted annually based on base prices and spot market prices prevailing at the time of actual delivery. The conversion and enrichment services of uranium concentrates are provided by suppliers in Canada, France, Germany, Japan, Russia, the United Kingdom and the United States. A Korean supplier typically provides fabrication of fuel assemblies. Except for certain fixed contract prices, contract prices for processing of uranium are adjusted annually in accordance with the general rate of inflation. KHNP intends to obtain its uranium requirements in the future, in part, through purchases under medium- to long-term contracts and, in part, through spot market purchases.

<u>Unit</u>	<u>Average Capacity Factor</u>	<u>Average Fuel Cost Per kWh</u>
	<u>(Percent)</u>	<u>(Won)</u>
Kori-1	51.0	5.8
Kori-2	84.5	5.5
Kori-3	78.1	5.1
Kori-4	100.1	5.0
Shin-Kori-1	81.2	5.3
Shin-Kori-2	98.5	7.2
Wolsong-1	81.0	7.7
Wolsong-2	94.4	7.5
Wolsong-3	90.7	7.8
Wolsong-4	100.2	7.7
Shin-Wolsong-1	95.7	5.9
Yonggwang-1	92.9	5.8
Yonggwang-2	101.7	4.3
Yonggwang-3	80.1	5.9
Yonggwang-4	88.8	4.6
Yonggwang-5	72.1	5.4
Yonggwang-6	83.1	4.8
Ulchin-1	80.1	5.2
Ulchin-2	98.7	5.0
Ulchin-3	69.4	5.5
Ulchin-4	0.0	0.0
Ulchin-5	100.4	5.0
Ulchin-6	88.2	4.8
Total nuclear	<u>82.3</u>	<u>5.6</u>

4.7.5. Kepeco Operation Costs

No detail of operation costs are directly provided by Kepeco. However, Kepeco details the profitability of the nuclear production activity as follows (Form 20 F: page F – 43)

	2012				
	Total segment revenue	Intersegment revenue	Revenue from external customer	Operating income (loss)	Depreciation and amortization
Electric power generation (Nuclear)	₩ 6,717,341	₩ 6,698,326	₩ 19,015	₩ 464,506	₩2,488,367
Electric power generation (Non-nuclear)	28,973,768	28,649,846	323,922	2,210,669	1,887,419
Transmission and distribution	49,033,869	1,121,920	47,911,949	(5,309,607)	2,562,128
Others	2,674,562	1,808,939	865,623	460,476	78,284
Adjustment	(38,279,031)	(38,279,031)	—	(126,367)	(19,488)
	<u>₩ 49,120,509</u>	<u>₩ —</u>	<u>₩49,120,509</u>	<u>₩(2,300,323)</u>	<u>₩6,996,710</u>

Total production costs, excluding depreciation of assets, can therefore be estimated in KRW 3 765 000 (\$ 3 389 Million), or **\$ 23.6 / MWh including the fuel cost** (on a production basis of 143 000 GWh)

Excluding Fuel Cost, the O & M cost of nuclear in Korea is estimated: **\$ 18.8 / MWh (in 2012)**.

4.7.6. Kepeco Decommissioning Costs

As indicated in footnote 27 of Kepeco Filing (page F-95), the provisions for decommissioning and dismantling were KRW 10 669 000 Million as 12/31/2012 (or \$ 9 600 Million).

	Dec. 31, 2012		Dec. 31, 2011	
	Current	Non-current	Current	Non-current
Litigation				
Litigation provision	₩ —	₩ 26,697	₩ —	₩ 44,409
Decommissioning cost				
Nuclear plants	—	9,462,723	—	5,061,265
Spent fuel	—	1,207,842	—	869,549

Such provisions are representative of the cumulated accruals as of 12/31/2012 and do not represent the overall value of decommissioning at the end of the life of the plants.

4.7.7. Kepco Nuclear Projects

KEPCO is in the process of:

- ✓ Completing the construction of an OPR 1000 unit (Shin Wolsong)
- ✓ Completing the construction of 2 APR 1400, soon to be commissioned (Shin Kori 3 & 4)
- ✓ Progressing in the construction of 2 APR 1400 to be commissioned in 2017/2018 (Shin Uljin 1 & 2)
- ✓ Planning construction of several additional APR 1400.

The current construction plan described on page 53 of the Kepco filing is:

Year	Number of Units	Type of Units	Total Installed Capacity (Megawatts)
2013	2	Nuclear power	2,400
	4	LNG-combined	2,175
2014	1	Nuclear power	1,400
	2	Coal-fired	1,540
	8	LNG-combined	6,066
2015	2	Coal-fired	2,020
	4	LNG-combined	3,132

From 2016 and 2027, our generation subsidiaries currently plan to complete eight nuclear units with an aggregate installed capacity of 11,400 megawatts (subject to any further plan to be announced by the Government in relation to the construction of additional nuclear generation capacity which was not included in the sixth Basic Plan), 23 coal-fired units with an aggregate installed capacity of 19,700 megawatts and 7 LNG-combined units with an aggregate installed capacity of 4,910 megawatts.

This plan reflects a capital commitment, including capitalized interest, of about \$ 21.6 billion for the nuclear program in the next 4 years:

The table below sets forth, for the years from 2013 to 2016, the budgeted amounts of capital expenditures (including capitalized interest) for the construction of generation, transmission and distribution facilities pursuant to our capital investment program. The budgeted amounts may vary from the actual amounts of capital expenditures for a variety of reasons, including, among others, the implementation of the sixth Basic Plan, changes in the number of units to be constructed, the actual timing of such construction, changes in rates of exchange between the Won and foreign currencies and changes in interest rates.

	2013	2014	2015	2016	Total
	(in billions of Korean won)				
Generation ⁽¹⁾ :					
Nuclear	5,432	5,526	6,272	6,843	24,073
Thermal	6,335	5,877	3,806	3,752	19,770
Sub-total	11,767	11,403	10,078	10,595	43,843
Transmission and Distribution:					
Transmission	2,222	2,840	2,550	1,595	9,207
Distribution	2,267	2,422	2,502	2,078	9,269
Sub-total	4,489	5,262	5,052	3,673	18,476
Others ⁽²⁾	3,458	3,711	3,521	2,864	13,554
Total	19,714	20,376	18,651	17,132	75,873

Note:

- (1) The budgeted amounts for our generation facilities are based on the fifth Basic Plan, as the corresponding budgeted amounts under the sixth Basic Plan are not yet available.
- (2) Principally consists of investments in renewable energy generation, among others.

More precisely, the capital commitments for the various reactors under construction are as follows:

47. COMMITMENTS FOR EXPENDITURE

- (1) The agreements for acquisition of property, plant and equipment as of December 31, 2012 and 2011 are as follows. (KRW in millions):

<u>Contracts</u>	<u>Dec. 31, 2012</u>		<u>Dec. 31, 2011</u>	
	<u>Amounts</u>	<u>Balance</u>	<u>Amounts</u>	<u>Balance</u>
Construction of New Uljin units	₩14,559,941	₩12,671,159	₩14,559,941	₩13,324,277
Construction of New Kori units	19,011,356	9,204,087	19,011,356	10,310,550
Construction of New Wolsong units	4,717,241	100,230	4,717,241	594,210

This would translate into the capital cost / KW estimated below:

Location	Model	Capital Budget (in local currency)	Capital Spending (in \$ Millions)	Actual Spending (in local currency)	Completion %	Estimated spending excluding interest	Capacity (MW)	Cost \$/Kw
Shin Wolsong	OPR 1000	4 717	4 434	4 617	98%	3 695	1 000	3 695
Shin Kori 1 & 2	APR 1400	19 011	17 870	9 807	52%	14 892	2 800	6 400
Shin Hanul 3 & 4	APR 1400	14 560	13 686	1 889	13%	11 405	2 800	4 900



4.8. TVO

4.8.1. TVO sources of information

- ✓ **TVO** Annual Report 2012
- ✓ **AREVA** annual report and reference document 2012
- ✓ **SIEMENS** filing with the US SEC 2013

4.8.2. TVO Operations

TVO operates 2 relatively old reactors with an average output of 14 850 GWh per year. Basically, TVO sells electricity to few customers which are its shareholders, at cost. Thus, TVO does not generate profits and is operated at the break-even point.

From the financial statements, the following costs can be estimated:

- ✓ Fuel costs of \$ 5.2 / MWh (average of the fuel purchase, net of inventory variation)
- ✓ Operations Costs of \$ 19.5 / MWh, excluding depreciation of fixed assets and fuel costs.

EUR 1 000	Note	1 Jan-31 Dec 2012	1 Jan-31 Dec 2011
Turnover	3	352 171	352 372
Work performed for own purpose	4	13 509	11 173
Other income	5	9 163	9 086
Materials and services	6	-125 095	-126 250
Personnel expenses	7	-61 668	-59 219
Depreciation and impairment charges	3,8	-56 497	-58 022
Other expenses	9	-93 463	-85 406
Operating profit/loss		38 120	43 734
Finance income	10	35 526	39 184
Finance expenses	10	-75 397	-77 265
Total finance income and expenses	3	-39 871	-38 081
Profit/loss before income tax		-1 751	5 653
Income taxes	11	1	-2
Profit/loss for the financial year		-1 750	5 651

6 MATERIALS AND SERVICES

EUR 1 000	2012	2011
Nuclear fuel	67 417	49 961
Coal	10 315	58 673
Materials and supplies	3 350	3 529
CO ₂ emission rights	933	6 732
Nuclear waste management services [®]	48 679	41 898
Increase (-) or decrease (+) in inventories	-16 513	-41 592
External services	10 914	7 049
Total	125 095	126 250

4.8.3. Olkiluoto 3

In 2005, TVO agreed with AREVA-SIEMENS to build the first EPR in Olkiluoto (#3) under a fixed price turn-key contract. Since then, construction has faced delays. Disputes between the suppliers and the utility have occurred. Completion and commissioning of this 1 650 MW reactor is now expected to take place in 2016, according to the most recent TVO filings.

Since the contract is a fixed price contract, the cost of the project is known with very good accuracy.

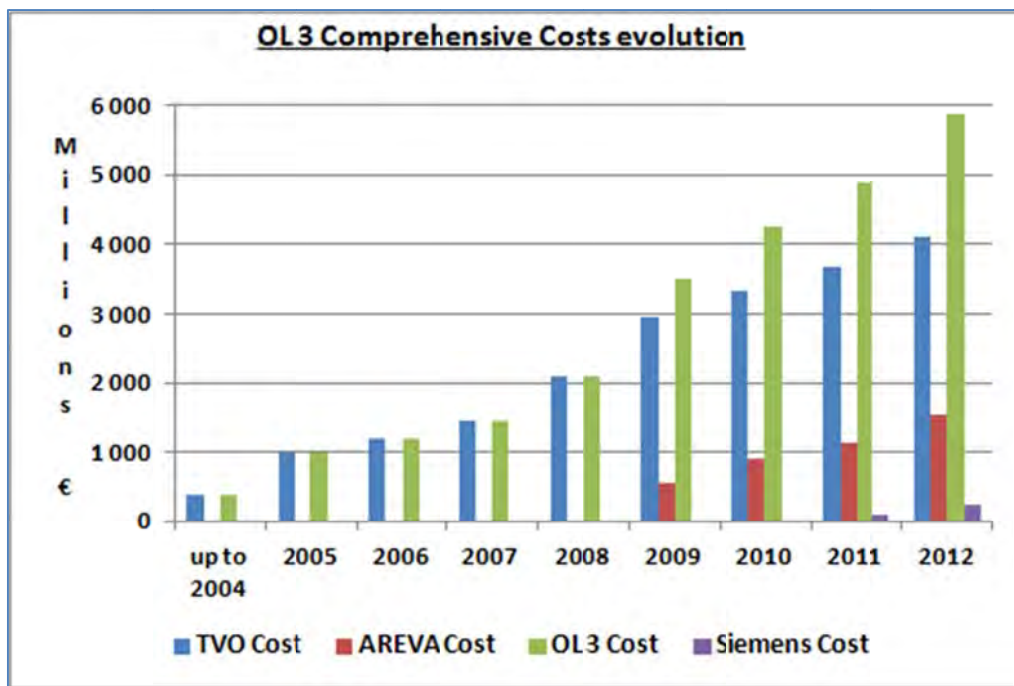
According to the TVO annual reports, the value of the construction in progress for the EPR at Olkiluoto 3, is € 3 445 millions or \$ 4 547 millions , **excluding capitalized interests**, which are reported separately on the balance sheet, as of 12/31/2012.

On that basis, the overall cost for TVO of the Olkiluoto 3 EPR would be close to \$ 5.7 billion at the end of completion. However, such figure does not provide a total value of the project cost, since both AREVA and SIEMENS incurred severe losses on their contracts.

AREVA has reported a cumulated loss to complete its part of the contract of € 1547 Million as of 12/31/2012. SIEMENS has reported a loss of € 239 Million.

12 PROPERTY, PLANT AND EQUIPMENT							
2012 EUR 1 000	Land and water areas	Buildings and construction	Machinery and equipment	Other property, plant and equipment	Construction in progress and advance payments	Decom- missioning	Total
Acquisition cost 1 Jan	11 421	284 520	1 303 904	51 065	3 163 098	148 839	4 962 847
Increase	88	1 491	19 609	2 508	312 887	0	336 583
Decrease	0	0	-20 874	0	-7 984	0	-28 858
Transfer between categories	0	0	22 041	0	-22 041	-100	-100
Acquisition cost 31 Dec	11 509	286 011	1 324 680	53 573	3 445 960	148 739	5 270 472
Accumulated depreciation and impairment charges according to plan 1 Jan	0	193 689	869 996	25 602	0	51 727	1 141 014
Decrease	0	0	-20 817	0	0	0	-20 817
Depreciation for the period	0	10 166	37 885	3 823	0	3 345	55 219
Accumulated depreciation and impairment charges according to plan 31 Dec	0	203 855	887 064	29 425	0	55 072	1 175 416
Book value 31 Dec 2012	11 509	82 156	437 616	24 148	3 445 960	93 667	4 095 056
Book value 1 Jan 2012	11 421	90 831	433 908	25 463	3 163 098	97 112	3 821 833

Based upon the actual reported figures, the cost of the Olkiluoto project has evolved as follows at the end of 2012:



By extrapolating the current figures, the cost of OL 3 per kilowatt can be estimated:

- ✓ **For TVO: around \$ 4 525/kW**
- ✓ **For the overall project, around \$ 5 945 /kW**
- ✓

4.9. China

Limited publicly disclosed information is available in China. Nuclear Power Plants are owned and operated by 3 different entities controlled by the State or local organizations:

- ✓ China National Nuclear Corp (CNNC) – historically the first nuclear owner in China
- ✓ China Guangdong Nuclear Power Group (CGNPG) - the owner of the first 900 MW units in Daya Bay.
- ✓ China Power Investment Corp (CPIC)- a smaller player in the industry

In addition to the plants currently operated, those entities participate in new projects alone or in association with other investors.

Current status of the new PWR projects based upon reliable sources of information (mostly the CGNPG web site and other presentations made by CGNPG representatives) is:

<u>Owner</u>	<u>Partner</u>	<u>Location</u>	<u>Province</u>	<u>Model</u>	<u>Size MW</u>	<u>#</u>	<u>First Unit Construction</u>	<u>Cost \$ / Kw</u>	<u>Local Content</u>
CGNPG	CPIC	Hongyanhe	Liaoning	CPR 1000	1119	4	2007	\$ 2 080	75 %
CGNPG	Datang	Ningde	Fujian	CPR 1000	1089	4	2008	\$ 2 080	80%
CGNPG	None	Yangjiang	Guangdong	CPR 1000	1086	4	2008	\$ 1 600	85 %
CGNPG	EDF	Taishan	Guangdong	EPR	1750	2	2009	\$ 2 730	50 %
CGNPG	None	Fangchenggang	Guangxi	CPR 1000	1080	2	2010	N/A	85 %
CPIC	N/A	Haiyang	Shandong	AP 1000	1250	2	2009	\$ 2750	N/A
CNNC	N/A	Fuguang	Fujian	M 310 +	1080	2	2008	\$ 1800	N/A
CNNC	N/A	Sanmen	Zhejiang	AP 1000	1250	2	2009	\$ 2750	N/A
CNNC	N/A	Fangjiaoshan	Zhejiang	CPR 1000	1080	2	2008	\$ 1600	N/A

Cost per kilowatt is not based on public information, but is considered as reliable; it does not include capitalized interest. However, CGNPG publicly discloses that on 12/31/2012, the value of its assets in operations or under construction were worth around \$ 42 billion, for an installed capacity of 8 800 MW (mostly Daya Bay and Ling Ao units) plus 16 000 MW under construction (about 60% complete). Rough calculation would indicate an average total cost per kilowatt of \$ 2.380, including capitalized interest on that basis.

In addition, construction duration of CPR 1000 reactors seems to be quite short. According to CGNPG, the Liaoning Hongyanhe NPP first unit construction started on 08/18/2007 and was commissioned on 06/06/2013 (69 months).

The EPR units in Taishan construction started in September, 2009. Commissioning remains officially scheduled for 2013, but more likely will take place later.

The first two AP 1000 (Sanmen -1 and Haiyang -2) will be connected to the grid in December 2014 (construction started respectively on April 2009 and December 2010) according to a September, 2013 announcement (WNA London symposium).

CGNPG indicates also that the Yangjiang NPP will be made of CPR 1000 and ACPR 1000 units, which is the latest Gen III development of the CPR 1000.

Recent press article in Nuclear Intelligence Weekly (09/06/2013) indicated that 2 additional CPR 1000 units might be built in Yangjiang and that the overall cost of the 6 units would be \$ 10.8 billion (around \$ 1 600 / kilowatt) much probably excluding owner costs and capitalized interest.

The National Development and Reform Commission, which regulates the electricity market in China, among other responsibilities, also issued in July, 2013 an uniform tariff for nuclear output throughout China of 0,43 Yuan /Kwh, or \$ 65 / MWh. It is widely believed that CPR 1000 is quite profitable at this price level.

4.10. Russia

Little detail is provided by Rosatom (a State Owned company) on the economics of its nuclear operations nor on the cost of the various projects.

In addition, latest financial publication available dates back to 2011. Nuclear operating costs can only be derived from those financial reports. They indicate that profitability is quite substantial for Rosatom.

3.4.1. MAIN FINANCIAL AND BUSINESS RESULTS IN 2011 ⁶			
MAIN FINANCIAL RESULTS, BLN RUB			
	2011	2010	2011/2010, %
Revenues	388.2 *	391.4	99.2
Cost of sales	(221.9)	(206.3)	107.6
Gross profit	166.3	185.1	89.8
Sales and administrative expenses	(69.7)	(60.3)	115.6
Other income and expenses, net	(10.6)	(9.9)	107.1
Financial income and expenses, net	(8.2)	8.6	(95.0)
Share in net profit/loss of companies, calculated by equity participation	2.7	(1.0)	(276.8)
Profit tax expenses	(19.7)	(29.6)	66.6
Profit for the year	60.8	92.9	65.5
Net operating profit after tax (NOPAT)	66.3	85.3	77.8

Electricity sales account for 52% approximately of the overall revenues for a total generation of 166 000 GWh per year on average (capacity factor around 82%).

STRUCTURE OF REVENUES FROM SALES TO EXTERNAL BUYERS, BLN RUB					
Operating segment	2011	% of total	2010	% of total	2011/2010, %
Electric power	202.3	52.1	208.3	53.2	97.1
Sales and trading	81.2	20.9	84.5	21.6	96.1
Fuel company	61.6	15.9	62.9	16.1	97.9
Machine-building	20.8	5.4	16.0	4.1	130.0
Mining	6.4	1.6	5.6	1.4	114.3
Other	15.9	4.1	14.1	3.6	112.8
TOTAL	388.2	100.0	391.4	100.0	99.2

Average selling price of electricity is therefore around \$ 48 / MWh, about half of the wholesale price in Europe. The structure of costs indicate that operation costs, including fuel but excluding depreciation account for 34 % of revenues, across all businesses of Rosatom.

STRUCTURE OF COSTS

Sales costs	2011	2010	2011/2010, %
Personnel expenses	73.4	58.8	124.9
Depreciation	60.8	54.9	110.8
Materials and fuel	35.4	35.1	100.8
Cost of purchased electric power, incl.:	20.3	15.1	134.6
cost of electric power for reselling and own needs of OJSC Rosenergoatom	11.9	9.5	125.3
Works and services by third-party contractors	22.6	19.1	118.0
Other costs	38.5	35.3	109.3
Change in finished product inventory and production in progress	(29.1)	(12.0)	242.4
TOTAL	221.9	206.3	107.6

This would indicate an average production cost of \$ 16, 6 / MWh, in line with international measures, excluding fuel costs and depreciation.

4.11. Other Projects

4.11.1. Fennovoima (Finland)

Fennovoima, another Finnish utility, announced in early September 2013, that it wanted to reach an agreement by year end 2013 with the Russian vendor Rosatom Overseas to build a 1200 MW reactor (VVER: AES 2006) for commissioning in 2024.

Cost of the project has been also confirmed as be in the range of \$ 5 200 and 7 900 millions, owner costs included. **The VVER cost per kilowatt in Hanhikivi should be in the range of \$ 4300 to 6 600 per kilowatt.**

4.11.2. Turkey

Turkey has announced 2 different projects: one based upon a Russian technology in Akkuyu and the most recent in Sinop based upon the Mitsubishi ATMEA technology/ AREVA.

Akkuyu Project

The project provides for construction of four nuclear power units (VVER-1200 reactors) of 1.2 GW capacity each (reference plant is Novovoronej NPP).

According to the agreement dated May 2010, the parties will cooperate in construction and operation of the nuclear power plant on "build-own-operate" terms.

The equity capital of the project company for NPP construction is shared as follows: Atomstroyexport JSC - 33.33%, INTER RAO UES OJSC - 33.33%, Rosenergoatom Concern OJSC - 31.34%, Atomenergoremont OJSC - 1%, and Atomtekhnenergo JSC - 1%. The agreement provides for a share of foreign investors in the equity capital of the Project Company could be up to 49%.

Rosatom has consistently indicated (Johannesburg, April 2012 and August 2013) that the construction of 4 X 1200 MW VVER units in Akkuyu, would cost \$ 20 billion (excluding interest expenses very likely).

The Turkish state-owned utility Tetas guarantees purchasing 70% of nuclear electricity from the project company commencing the start of commercial operation of the first and second power units of NPP and 30% of electricity produced by the third and fourth power units, at an average weighted price of 12.35 cents per kWh. The reminder of electricity will be sold in a free market.

Currently, the work is underway to prepare documents in support of applications for all required construction permits and licenses; the on-site work has been started. First concrete is planned for late 2013, with the first criticality of Unit 1 to be achieved in the second half of 2018. Further, the Project Company will consequently put on line Unit 2, Unit 3 and Unit 4 in yearly intervals after commencing of commercial operation of Unit 1.

This estimate would place the VVER reactor at a cost of **\$ 4 165 / kW**

Sinop Project

In May 2013, the Turkish government announced that a Japanese led consortium, including GDF-Suez, would build 4 ATMEA reactors of 1 100 MW each. The cost of the project is expected to be \$ 22 billion. The supply contract for the N.S.S part is expected to be in the range of \$ 5.2 to 6.5 billion, excluding any fuel supply. Signature of the final contractual arrangements is supposed to take place within 18 months. Very few details have been communicated by the parties involved in the project, so far.

Such announcement would place the cost per kilowatt of ATMEA units at \$ 5 000.

4.11.3. Vietnam

Russia and Vietnam have agreed in October 2010 to build 2 X 1 000 VVER reactors in Vietnam.

Rosatom has publicly indicated that the project cost (Johannesburg, April 2012) would be around \$ 10 billion.

Cost estimate would be \$ 5 000 / kW for a VVER unit.

5. Consultant experience

The Consultant used its experience based on its familiarity with different projects, to deliver the following information.

ATMEA1

Supplier: ATMEA

Efficiency: 35% to 37 % depending on cooling capacity; in Jordan: 35%

Thermal power: 3 150 MWth

Electrical power Jordan: 1 100 MWe (35% efficiency)

Electrical power Turkey (Sinop) : 1 120 MWe

Electrical power Viet Nam: 1 100 MWe (35% efficiency)

Capacity factor : > 90% - Fuel cycle: 18 months

Construction time: Jordan 101 months from Authorization to Proceed to Commercial operation

Turkey: 96 months

Overnight cost Jordan (not including site preparation and connection to the grid) : 4 900 \$/kW

Two units Jordan = 11 B\$ plus Owners cost (estimated at 3 B\$) and fuel

Two units Turkey: 4 300 \$/kW

Two units Viet Nam: 4 200 \$/kW

AES 92 (offered in Jordan)

Supplier: Rosatom

Efficiency: 30%

Thermal power: 3 012 MWth

Electrical power: 913 MWe (this figure is drastically below official figures)

Construction time: 94 months from Authorization to Proceed to Commercial operation AP1000 (offered in Viet Nam)

Efficiency: 32% in Vietnamese conditions – Max: 34 %

Initial Russian offer to Jordan : 5 500 €/kW (one unit) ; 4 700 €/kW (two units) ; a new offer is being processed, and a much lower price is expected by the Customer.

EPR

India : 3 000 \$/kW

RSA: 4 300 \$/kW

“Standard EPR”: 3 800 \$/kW

South African EPR (2008/9 offer)

12,129 B€ for two units, not including spare parts and training, nor fuel

First fuel load and three reloads: 0,903 B€

Guaranteed availability for the first two years: 91,2% (first unit) to 92,6% (second unit)

No quotation for subsequent units

Chinese EPR (Taishan) two units – Joint venture budget (investor and operator)

Electrical output: 1,660 MWe

Approved budget – **two units**: 49,85 Billions Renmimbi = 7,5 B\$ (**2 260\$/kW**)

Present budget (2009) **two units**: 62,15 Billions Renmimbi = 9,32 B\$ (**2 800 \$/kW**)

Although the budget of the Chinese EPR sharply increased, it remains well below the budget of the French or Finnish EPR (page 66).

6. DATA ANALYSIS

6.1. Data Analysis Executive Summary

The Study of Cost of Nuclear has the objective of updating the Department of Energy on the costs of nuclear power, by consolidating estimates of a broad range of studies, with a global view inclusive of eastern and western nuclear technologies.

For this Data Analysis phase, the various technologies under review have been classified in the following way:

- Technologies used by Countries that are developing a nuclear program or are committed to launch such a program (“Nuclear developing Countries” or “NDC”)
*This category refers, in particular, to countries having a large NPP Construction Program, being currently underway (China) or ready to be launched (UK).
Studies that do not identify specific countries (EPRI for instance) have been classified in this category. Those studies have been prepared at the time, where large nuclear programs were considered throughout the world in light of the “nuclear renaissance”, therefore data collected from these studies imply multiple units programs.*
- Technologies used by Countries not belonging to the previous category (“Single projects” or “SP”)
This category refers to countries that have the Nuclear Technology and Nuclear Power Plants in construction or in projects, but without having a large NPP Program Construction in the next decades. For example France with the EPR in Flamanville, which is the only NPP in construction and/or planned in this country.
- Generation III technologies (“Gen III”)
Generation III nuclear reactors represent the newest commercial generation of reactors that meet best internationally accepted standards in terms of safety of operations. In addition, those reactors benefit from, state-of-the-art design improvements on fuel technology, thermal efficiency, resilience to severe accidents with core melt and have a longer operational life (typically 60 years).
- Generation II technologies (“Gen II”)
Generation II refers to the previous class of commercial reactors that began operation in the 1970s and represent the bulk of the world’s Nuclear Power Plants. Designed for a typical operational lifetime of 40 years, Gen II reactors include pressurized water reactors (PWR), CANada Deuterium Uranium reactors (CANDU), boiling water reactors (BWR), advanced gas-cooled reactors (AGR) and VVER.. This generation of reactors is no longer proposed by many nuclear vendors and are not considered as safe as Gen III reactors by Safety Authorities.
- First of a Kind projects (FOAK)
First of a Kind reactor usually refers to the first nuclear unit in a series of multiple units using the same design and specifications. In general, FOAK becomes the reference plant for the other units and any improvement to the FOAK is reflected in the succeeding units. Engineering work and construction costs are typically higher for FOAK NPP than for the following NPPs as one-time costs are absorbed by the FOAK projects.

- Next of a Kind projects(NOAK)

NOAK refers to projects that are similar in design and specifications to previous NPPs and are therefore built a certain number of times. Typically, costs of NOAK are lower than the costs of the FOAK, as a result of the learning experience and of the impact of construction in larger volume on construction costs (one typical example, would be the sharing of site preparation costs on multiple units as opposed to a single unit)

In this report the classifications are as follows:

Technologies in NDC	Technologies in SP	Gen III	Gen II
China Korea Viet Nam Turkey Jordan UAE UK	Finland France USA	ABWR AP 1000 APR 1400 ATMEA 1 EPR VVER – AES 2006	OPR 1000 CPR 1000

Table 21: Literature Reports Classification of Countries (NDC/SP) and Technologies (GenII/GenIII)

In total, the Data Analysis covers 38 Data points of which 18 have been provided by the Literature Survey and 20 by observations coming from the Utilities data reviewed.

Literature surveys provide the minimum information required to make comparisons and analysis:

- Cost of capital invested per kilowatt,
- Levelized cost of energy (LCOE) broken down between Fuel, Operations Costs and Capital costs expressed in \$ / Megawatthours,
- Discount rate

Those studies refer to future projects.

Utilities data refer to actual costs of operating existing nuclear plants (fuel, O & M, decommissioning, etc). The selected utilities in the report reflect the effective costs of operations of close to 100 reactor units (around ¼ of the world fleet).

In addition, the report provides information on capital costs of current nuclear projects underway throughout the world and where reliable information is available.

As a result, in order to compare the analytical work based on the Literature Survey and the Utilities observations, a model has also been developed capable of computing the LCOE of the various existing projects using the input data provided for in the Data Collection process.

First output of the Data Analysis is the LCOE distribution of all the Data Points segregated in the main categories: Literature Survey, Own Observations associated with nuclear developing countries and single projects. Range of values is quite large; however most of the projects or studies LCOE are located in the \$60 to 75/MWh (for a 5 % discount rate).

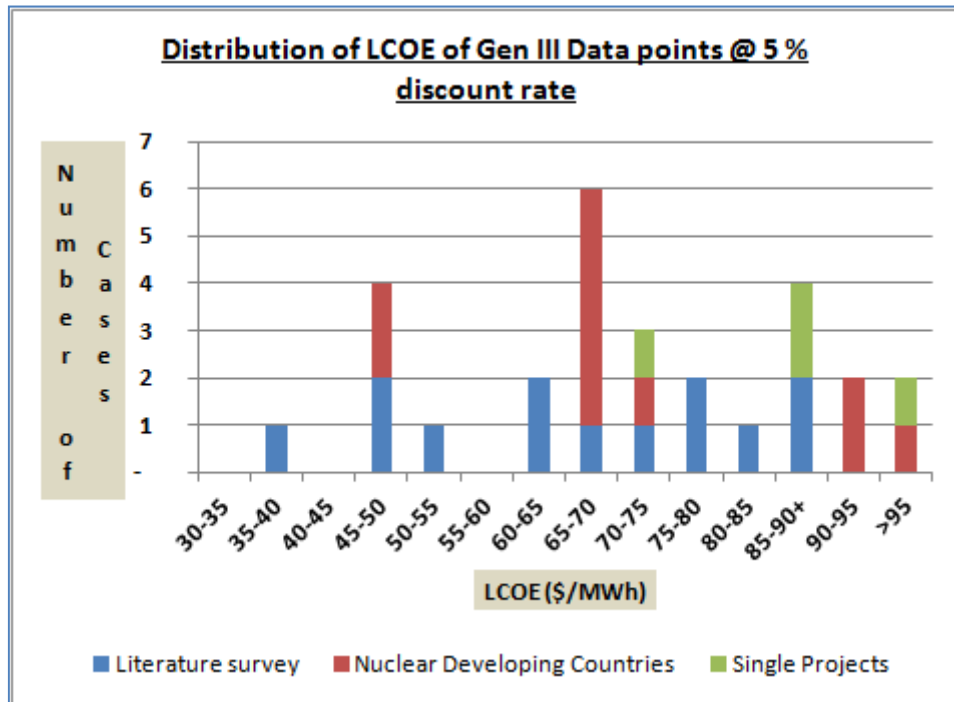


Figure 39: Distribution of LCOE of Gen III Data points @ 5% Discount Rate

The main focus of this Data Analysis section is therefore to put in evidence the various factors that would support those preliminary findings and define the parameters for a final conclusion on the cost of nuclear, based upon observations and subsequent calculations.

6.2. Data Analysis Introduction

DATA ANALYSIS objectives are:

- Consolidation of the **generic studies** results presented in the first report,
- Consolidation of the **selected utilities** survey presented in the previous report
- Consolidation of the **technology results**, using a uniform model structure, presented in this report,

Analysis focuses on the Levelized Cost of Energy (LCOE), which calculation methodology may vary from one study to the other or may not be known.

LCOE is the most commonly used indicator for comparing various energy sources or technologies to produce electricity. The LCOE can be described by the general formula:

$$\text{LCOE} = \frac{\text{Total Life Cycle Cost}}{\text{Total Life Cycle Energy Production}}$$

Life Cycle Cost includes the capital spending portion embedded in the LCOE, the fuel usage, the operations and maintenance costs as well as, in the specific case of nuclear energy, the decommissioning costs of the plant at the end of its life, and the used fuel waste management and/or storage. All these factors are discounted with an appropriate discount rate which basically represents the weighted average cost of the money invested, or a collective preference for present versus future revenues; refer to §5.5.3 “What Discount rate to select – sensitivity analysis” for further explanations.

The EPRI Report “Power Generation Technology Data for Integrated Resource Plan of South Africa” is based on 6.93% Discount Rate, details of this rate is given in the following table:

**Table 5-1
Economic Parameters**

Type of Security	% of Total	-- Current Dollars --		-- Constant Dollars --	
		Cost (%)	Return (%)	Cost (%)	Return (%)
Debt	60	10.0	6.0	7.3	4.4
Preferred Stock	N/A	N/A	0.0	N/A	0.0
Common Stock	40	12.2	4.9	9.4	3.8
Total Annual Return			10.9		8.2
Inflation Rate	2.5				
Federal and State Income Tax Rate	28				
Property Taxes, Insurance, and Other Taxes	2.0				
Discount Rate					
After Tax			9.19		6.93
Before Tax			10.87		8.16

Table 22 : EPRI Report - Economic Parameters & Discount Rate

Discount rate assumptions used in this report are developed in the Technology results section and in the Energy sources comparison section.

In this process, a judgment will be brought on the “reliability” of the information used (ranking High, Medium and Low) and statistical analysis based upon such ranking when possible.

Foreign currencies have been converted with the following exchange rates:

Average Currency Exchange Rate									
	US \$ / €	€ / US \$	ZAR / €	ZAR / US \$	£ / €	£ / US \$	Won / €	Won / US \$	Ruble / \$
2010	1,321	0,757	9,66	7,31	0,86	0,65	1 530	1 158 €	30,455
2011	1,400	0,714	10,14	7,25	0,87	0,62	1 546	1 104 €	29,313
2012	1,293	0,773	10,58	8,18	0,81	0,63	1 448	1 120 €	31,015
2013	1,314	0,761	12,56	9,56	0,86	0,65	1 461	1 111 €	31,703

Note: 2013 average calculated from January to August 2013 Source: European Central Bank

Table 23 : Average Currency Exchange Rate

In addition, all values have been converted into 2013 US \$, with the applicable exchange rates:⁶

\$ inflation to reach 2013												
2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
35,8%	32,1%	30,0%	27,1%	23,8%	19,8%	16,0%	12,8%	8,6%	9,0%	7,3%	4,0%	1,9%

Table 24 : US\$ Inflation to reach 2013

(This table shows the total inflation from any year later than 2000 to 2013).

⁶ The inflation rate is based on data from the latest US government CPI data published on Sept. 17, 2013
<http://www.usinflationcalculator.com/>

6.3. Generic Studies Consolidation

6.3.1. Summary of Data Collection

All studies presented in the Data Collection have been converted to a standard format, as presented in Annex 1.

Report's Data	Case	Capacity	CAPEX	O&M	Fuel	Others	LCOE	Overnight & Owner Cost	Discount Rate
			\$/MWh	\$/MWh	\$/MWh	\$/MWh	\$/MWh	\$/kWe	% / annum
IEA - OECD	Gen III+ Eurelectric	1600	41,43	12,66	10,01	0,20	64,30	5 069	5,0%
WNA	USA - NPS 2020		65,52	13,94	10,40	-	89,86	4 784	5,0%
EPRI	Low Case	1400	55,38	15,95	6,11	-	77,44	3 974	5,0%
EPRI	Average Case	1400	60,99	15,95	6,11	-	83,05	4 229	5,0%
EPRI	High Case	1400	66,59	15,95	6,11	-	88,65	4 484	5,0%
IEA - OECD	Gen III+ China AP 1000 (2)	1000	18,88	9,96	10,01	0,11	38,96	2 470	5,0%
IEA - OECD	Gen II Hungary PWR	1120	44,28	32,02	9,41	1,90	87,61	5 577	5,0%
IEA - OECD	Gen III Czech Republic	1150	45,45	15,82	10,01	0,24	74,83	6 286	5,0%
IEA - OECD	Gen II Slovak Rep VVER 440	954	38,85	18,12	10,01	0,17	67,16	4 572	5,0%
WNA	China - NPS 2020		25,58	10,40	10,40	-	46,38	2 080	5,0%
WNA	India - NPS 2020		39,31	15,60	10,40	-	65,31	2 912	5,0%
IEA - OECD	Gen II+ China CPR 1000 (1)	1000	14,46	7,62	10,01	0,09	32,18	1 892	5,0%
IEA - OECD	Gen II+ China CPR 1000 (2)	1000	14,35	7,55	10,01	0,09	32,00	1 876	5,0%
IEA - OECD	Gen III+ France EPR	1630	33,31	17,17	10,01	0,05	60,54	4 142	5,0%
IEA - OECD	Gen III+ USA PWR	1350	28,33	13,81	10,01	0,14	52,29	3 629	5,0%
NEI	Base	1400	58,88	10,22	5,66	2,51	77,26	5 365	5,0%
IEA - OECD	Gen III Russia VVER 1150	1150	24,20	18,18	4,29	-	46,66	3 147	5,0%
IEA - OECD	Gen III Korea OPR1000	954	15,58	11,18	8,48	0,10	35,33	2 013	5,0%
NAO UK 2012	FOAK/NOAK 2013		102,39	22,40	8,00	12,80	143,98	6 559	10,0%
NAO UK 2012	FOAK/NOAK 2019		89,59	20,80	8,00	11,20	127,99	6 559	10,0%
Australia	Base		121,41	23,04	8,86	-	153,31	5 088	10,0%
MIT	Base						91,56	4 360	
EWEA 2010	Base	1000	65,34	57,26	9,09	-	131,70	3 959	5,6%
VGB POWERTECH	Base		56,41	11,77	13,05	-	81,23		
IEA - OECD	Gen III+ Korea APR1400	1400	13,02	9,60	8,48	0,08	31,17	1 670	5,0%
IEA - OECD	Gen III Japan ABWR		25,48	17,70	10,01	0,14	53,34	3 229	5,0%
IEA - OECD	Gen III EPRI APWR ABWR	1400	24,66	16,95	10,01	0,13	51,75	3 187	5,0%

Table 25 : Data Collection Details on costs for LCOE and Overnight & Owner Costs

6.3.1. Reliability evaluation/ Classification

No evaluation is made on the methodology used by the various authors of the studies as most of the methods are not detailed.

The Consultant has however made its own judgment by discarding studies with information missing or where the input data were substantially outside a reasonable range of value, mostly for the Capital Spending information. In addition, studies using the same annual discount rate of 5 % have been retained.

Life duration of the nuclear plant is a very significant factor; unfortunately, such life duration is not always detailed in the studies, although the most recent consider a 60 years life for new generation of nuclear reactors. Older studies took values as low as 40 years even for same technologies.

Report's Data	Case	Capacity	CAPEX	O&M	Fuel	Others	LCOE	Overnight & Owner Cost	Discount Rate	Classification	Gen	Reliability	Observations
			\$/MWh	\$/MWh	\$/MWh	\$/MWh	\$/MWh	\$/kWe	% / annum				
IEA - OECD	Gen III+ Eurelectric	1600	41,43	12,66	10,01	0,20	64,30	5 069	5,0%	NDC	III	3	
WNA	USA - NPS 2020		65,52	13,94	10,40	-	89,86	4 784	5,0%	SP	III	3	
EPRI	Low Case	1400	55,38	15,95	6,11	-	77,44	3 974	5,0%	NDC	III	3	
EPRI	Average Case	1400	60,99	15,95	6,11	-	83,05	4 229	5,0%	NDC	III	3	
EPRI	High Case	1400	66,59	15,95	6,11	-	88,65	4 484	5,0%	NDC	III	3	
IEA - OECD	Gen III+ China AP 1000 (2)	1000	18,88	9,96	10,01	0,11	38,96	2 470	5,0%	NDC	III	3	
IEA - OECD	Gen II Hungary PWR	1120	44,28	32,02	9,41	1,90	87,61	5 577	5,0%	SP	II	3	
IEA - OECD	Gen III Czech Republic	1150	45,45	15,82	10,01	0,24	74,83	6 286	5,0%	SP	III	3	
IEA - OECD	Gen II Slovak Rep VVER 440	954	38,85	18,12	10,01	0,17	67,16	4 572	5,0%	SP	II	3	
WNA	China - NPS 2020		25,58	10,40	10,40	-	46,38	2 080	5,0%	NDC	III	3	
WNA	India - NPS 2020		39,31	15,60	10,40	-	65,31	2 912	5,0%	NDC	III	3	
IEA - OECD	Gen II+ China CPR 1000 (1)	1000	14,46	7,62	10,01	0,09	32,18	1 892	5,0%	NDC	II	3	
IEA - OECD	Gen II+ China CPR 1000 (2)	1000	14,35	7,55	10,01	0,09	32,00	1 876	5,0%	NDC	II	3	
IEA - OECD	Gen III+ France EPR	1630	33,31	17,17	10,01	0,05	60,54	4 142	5,0%	SP	III	2	Capex Low
IEA - OECD	Gen III+ USA PWR	1350	28,33	13,81	10,01	0,14	52,29	3 629	5,0%	SP	III	2	Capex low
NEI	Base	1400	58,88	10,22	5,66	2,51	77,26	5 365	5,0%	NDC	III	2	O & M low
IEA - OECD	Gen III Russia VVER 1150	1150	24,20	18,18	4,29	-	46,66	3 147	5,0%	NDC	III	2	Capex low
IEA - OECD	Gen III Korea OPR1000	954	15,58	11,18	8,48	0,10	35,33	2 013	5,0%	NDC	II	2	Capex low
NAO UK 2012	FOAK/NOAK 2013		102,39	22,40	8,00	12,80	143,98	6 559	10,0%	NDC	III	1	Discount rate 10 %
NAO UK 2012	FOAK/NOAK 2019		89,59	20,80	8,00	11,20	127,99	6 559	10,0%	NDC	III	1	Discount rate 10 %
Australia	Base		121,41	23,04	8,86	-	153,31	5 088	10,0%	NDC	III	1	Discount rate 10 %
MIT	Base						91,56	4 360		NDC	III	1	Not enough detail
EWEA 2010	Base	1000	65,34	57,26	9,09	-	131,70	3 959	5,6%	NDC	III	1	O & M Costs
VGB POWERTECH	Base		56,41	11,77	13,05	-	81,23			NDC	III	1	No Capex
IEA - OECD	Gen III+ Korea APR1400	1400	13,02	9,60	8,48	0,08	31,17	1 670	5,0%	NDC	III	1	Capex too low
IEA - OECD	Gen III Japan ABWR		25,48	17,70	10,01	0,14	53,34	3 229	5,0%	SP	III	1	Japan
IEA - OECD	Gen III EPRI APWR ABWR	1400	24,66	16,95	10,01	0,13	51,75	3 187	5,0%	SP	III	1	

Table 26: Summary of the data base - generic studies

6.3.2. Analysis

Generic studies Analysis has been conducted, as a result of the reliability judgment, on level 2 and 3 studies:

Generic surveys [Actual Numbers]				Generic surveys [%]			
#	SP	NDC	Total	#	SP	NDC	Total
Gen III	4	9	13	Gen III	22%	50%	72%
Gen II	-	5	5	Gen II	0%	28%	28%
All	4	14	18	All	22%	78%	100%

Table 27 : Generic Survey Details regarding Country Classification and Technology

The 18 Data Points cover a large spectrum of situations; it should be noted that countries without large nuclear program no longer develop Gen II technology. Such Gen II technology for new projects is mainly concentrated in China, as a consequence of decisions to build reactors of that technology prior to the Fukushima accident.

6.3.3. Synthesis

The following table summarizes the main results of the generic surveys:

LITERATURE SURVEY ANALYSIS		NDC	SP	Gen III	Gen II	All
Number of studies		14	4	13	5	18
Average						
Nuclear Plant Size	MW	1 230	1 241	1 348	1 006	1 234
Capital Spending	\$ / kWe	3 292	4 832	4 044	3 186	3 806
Average per kWh						
Capex	\$ / MWh	36,3	42,6	43,4	25,5	38,4
Fuel Cost	\$ / MWh	8,1	10,0	8,4	9,6	8,7
O & M	\$ / MWh	12,6	18,5	14,3	15,3	14,6
Others	\$ / MWh	0,3	0,4	0,2	0,5	0,3
LCOE	\$ / MWh	57,3	71,5	66,3	50,9	62,0

Table 28 : Literature Survey Analysis - Main Results (Quoted Costs)

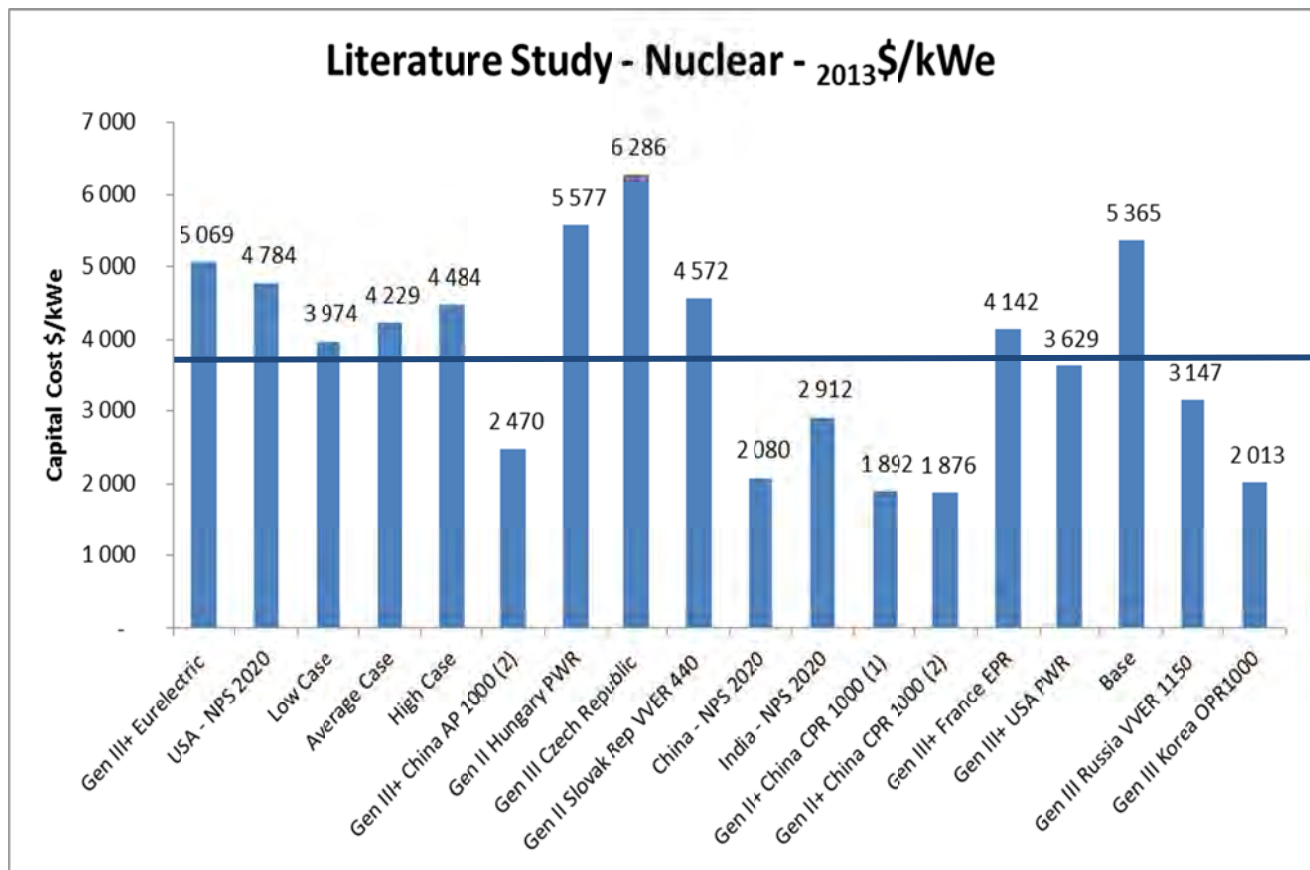


Figure 40: Literature study Nuclear - 2013\$/kWe – Average (including Chinese Gen II reactors : 3 806 £/kWe

The Literature survey tends to demonstrate that countries that have an on-going nuclear development program have a lower LCOE / kWh than countries that are developing single nuclear projects. The 20 % difference in LCOE is influenced by the Gen II projects that China is pursuing.

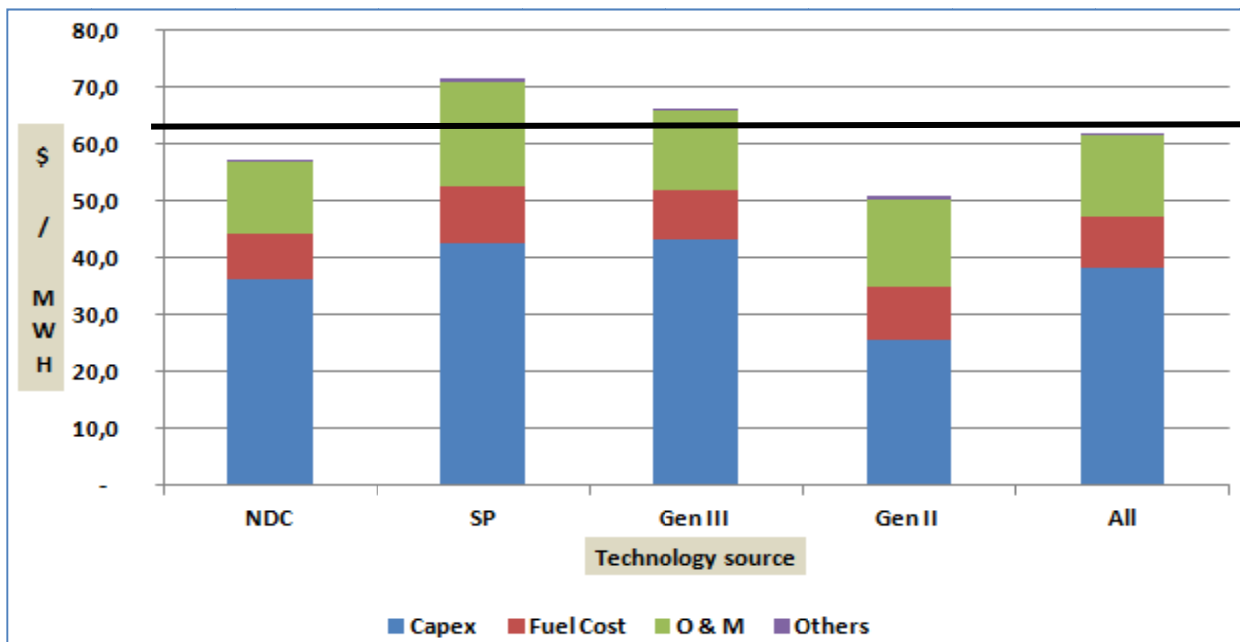


Figure 41 : LCOE Breakdown in Literature Survey by Technology Source – Average 62 \$/MWh (Quoted Costs)

The Analysis does confirm that the Fuel costs per MWh, which probably includes spent fuel management costs in the studies, ranges from \$ 8 to 10 /MWh.

Operations & Maintenance costs vary from one category to the other; however, the upper level found in the countries developing single projects is consistent with the fact that costs factors are relatively more expensive in those countries (labour, parts, etc). It is also widely expected that the higher the capital spending per kWe, the higher the LCOE. This rule of thumb is confirmed by the following graph, although it is somehow surprising to observe that LCOE moves up the ladder faster than the capital spending per kilowatt.

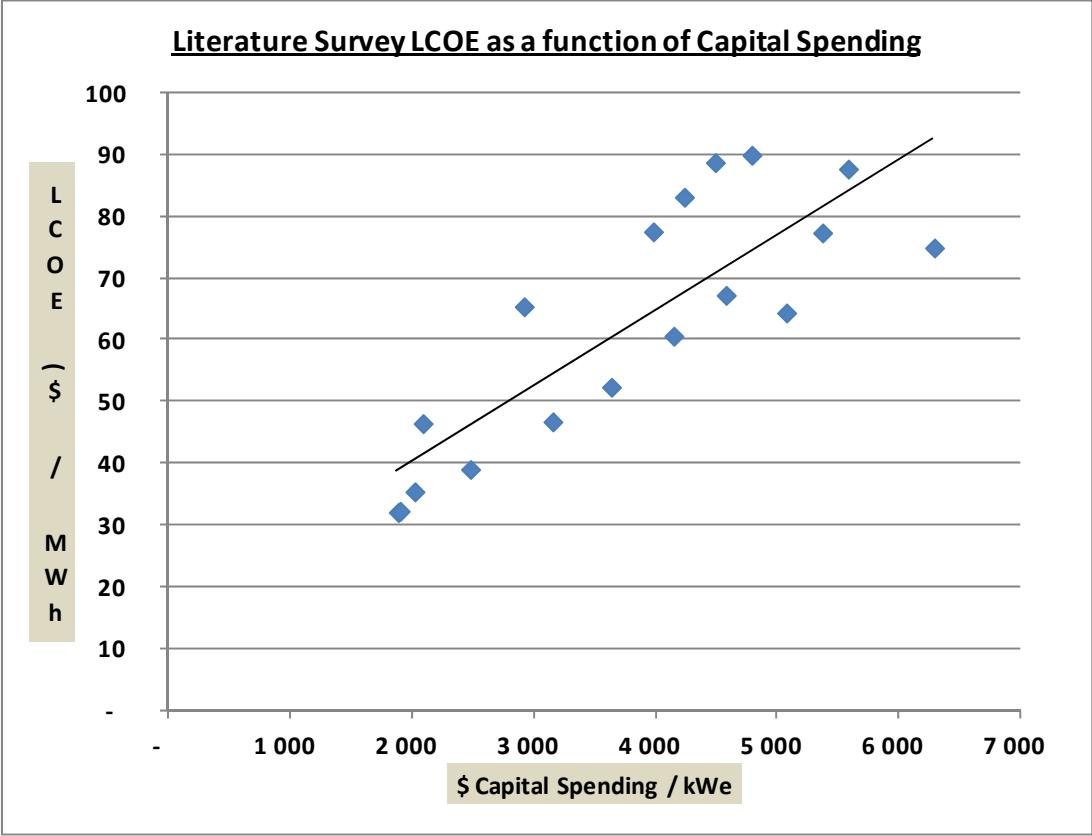


Figure 42: Literature Survey LCOE as a function of Capital Spending (Quoted Costs)

6.4. Utilities Reports

6.4.1. Data Collection Content

The Data Collection specific to the utilities provides 2 sets of information:

- o Data related to the nuclear production costs,
- o Capital spending of pending projects under realization or well advanced.

Such data collection does not provide directly any insight on LCOE, but gives a good and very reliable range of values for existing nuclear fleet costs. No Gen III reactors⁷ are yet in operation; thus the values do reflect only Gen II reactors.

The selected utilities reviewed can be classified as follows, based upon installed capacity and do reflect mostly Gen II technologies which represents today the bulk of the world nuclear fleet.

Utilities Surveyed [Nb]				Utilities Surveyed [%]			
GW installed	SP	NDC	Total	GW installed	SP	NDC	Total
Gen III	5	-	5	Gen III	5%	0%	5%
Gen II	89	21	110	Gen II	78%	18%	95%
All	95	21	115	All	82%	18%	100%

Table 29 : Utilities Surveyed Statistics in terms of Country Classification and Technologies

In detail, the utilities review includes:

UTILITIES REPORT			EDF	GEORGIA POWER	EXELON	TVO	CEZ	KEPCO	TEPCO
Reactor Model			PWR	PWR	BWR/PWR	BWR	PWR	PWR	ABWR
Main Vendor Origin			France	US	US	US	Russia	France, US, Korea	Japan
Global Output		TWh /year	405	20	140	14	30	150	-
Global Capacity		GW	63	3	17	2	4	21	5
Classification			SP	SP	SP	SP	SP	NDC	SP
Generation			II	II	II	II	II	II	III

Table 30 : Utilities Surveyed Details

⁷ Except four ABWRs in Japan, but which CAPEX and OPEX are quite uncertain..

6.4.2. Data Analysis

6.4.2.1 Fuel Costs

Fuel cost refers to the cost of fresh fuel loaded in a reactor and purchased by nuclear operators from fuel vendors. Such cost include the value of the Uranium (between 1/3 and 40% of the total cost), the cost of the various phases of transformation of the Uranium, in particular enrichment services (around 40 % of the total costs) and the fabrication of the fuel rods and assemblies. Sometimes, fuel costs reported by utilities include the spent fuel management costs; this is the case of US utilities reported fuel costs.

As a result, the Consultant has tentatively harmonized fuel costs calculations by separating the spent fuel costs from the costs of fresh fuel, as illustrated below:

FUEL COST DATA COLLECTION		EDF	GEORGIA POWER	EXELON	TVO	CEZ	KEPCO	TEPCO
Reactor Model		PWR	PWR	BWR/PWR	BWR	PWR	PWR	ABWR
Global Output	TWh /year	405	20	140	14	30	150	
Collected Fuel Cost	\$ / MWh	\$ 5,2	\$ 8,7	\$ 7,2	\$ 5,2	\$ 4,8	\$ 4,8	\$ 7,5
Notes on Collected Data:								
EDF Fuel Cost includes MOX fuel / Reactors of 900, 1300 and 1450 MW (excludes spent fuel management)								
KEPCO: ranges of reactors from various origin, excludes Candu reactors				TEPCO ABWR costs is an estimate (if plant in operations)				
Exelon & Georgia Power includes spent fuel								
CEZ: VVER models								
Spent Fuel Cost embedded	\$ / MWh	\$ -	\$ 0,7	\$ 0,4	\$ -	\$ -	\$ -	\$ -
Net Fuel Cost	\$ / MWh	\$ 5.2	\$ 8.0	\$ 6.8	\$ 5.2	\$ 4.8	\$ 4.8	\$ 7.5

Table 31 : Fuel Cost Data Collection (Actual Costs)

The fuel cost ranges is rather narrow; fuel costs differences can be explained by reactor technology performances that may vary from one to the other, but also by the differences in purchase prices of Uranium or other value added services. In addition, actual costs of fuel may reflect pricing decision taken several years ago, as nuclear operators usually buy a significant portion of their needs under long term agreements. Recent trend in the industry would indicate price reductions of Uranium Ore, for instance which accounts for 1/3 of the fuel costs loaded in a reactor.

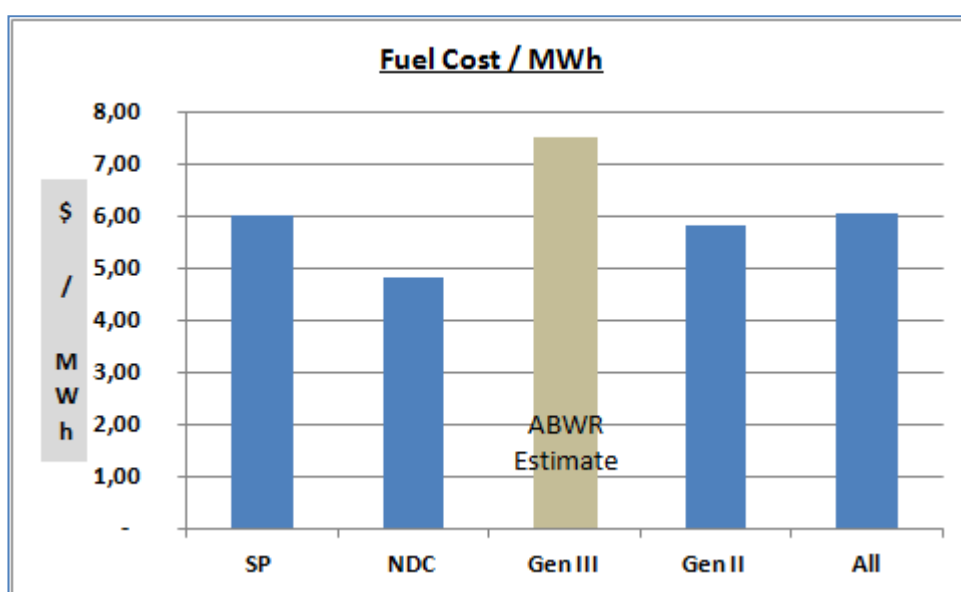


Figure 43: Fuel Cost Results per Category (Actual Costs)

6.4.2.2 Back End Costs

Back end costs represent the costs borne by the utilities to dispose of the used fuel, to treat or storage the nuclear waste and to decommission the nuclear plant at the end of its operating life. Utilities usually split those costs into 4 categories:

- **Management of spent fuel** (interim storage, long term storage),
- **Management of waste disposal** depending upon the industrial solutions adopted by the utilities,
- **Decommissioning** of the plants,
- **Dismantling of the last core** in reactors (only EDF provides such information as costs of the other utilities is very likely included in the plant decommissioning item)

Costs related to spent fuel or waste management are directly related to the volume of fuel consumed and to the quantity of waste produced by the reactors. Those costs are usually accrued annually by the utilities on the basis of their annual cash payments and/or the estimate of future payments.

Decommissioning costs take place several decades after the commencement of operations of nuclear reactors. In most countries, utilities are required to fund those future expenses by either paying fees to outside entities (Finland, for instance) or by setting aside money into dedicated funds managed by the utilities but restricted specifically for paying decommissioning activities. Such funds are subject to specific and local regulations that would indicate in what kind of financial instruments the money should be invested in (usually government bonds). The purpose of those rules and regulations is to make sure that money will be available to decommission nuclear plants no matter what happens to the utilities managing the reactors.

As a result, utilities provide systematically the value of the accruals on their balance sheet as required by the IFRS standards. Those accruals are usually computed with actuarial calculations taking into considerations at least 2 components:

- A discounting factor specific to each utility,
- A cost estimate as of the balance sheet measurement date (i.e.: the cost of decommissioning a plant as if such action were to take place at the measurement date),

Such estimate is rarely provided publicly (with one notable exception: EDF)

Reference to appendix.

EDF France	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million €	Million €	%			Million \$
Management of spent fuel	14 844	15 250	2,7%	404 880	GWh	20 000
Management of radioactive waste	23 801	24 562	3,2%	404 880	GWh	32 200
Dismantling power stations	21 108	22 174	5,1%	63 130	MW	29 000
Last core	3 888	3 887	0,0%	63 130	MW	5 100
TOTAL	63 641	65 873	3,5%	Report 1 page 72		86 300
EDF Energy (UK)	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million €	Million €	%			Million \$
Management of spent fuel	3 860	3 820	-1,0%	60 022	GWh	5 000
Management of radioactive waste	3 969	4 188	5,5%	60 022	GWh	5 500
Dismantling power stations	12 213	12 887	5,5%	8 741	MW	16 900
TOTAL	20 042	20 895	4,3%	Report 1 page 67		27 400
GEORGIA POWER	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million \$	Million \$	%			Million \$
Management of spent fuel		246		16 200	GWh	246
Dismantling power stations		1 002		3 000	MW	1 002
TOTAL	-	1 248		Report 1 page 80		1 248

Table 32: Gross Estimate of back end costs as of 12/31/2012 (Actual Costs)

No detail information is provided by the utility on how such cost estimate has been determined; in general, they are estimated based upon technical and economic studies reviewed on a periodic basis.

Cost Accruals are the amounts of costs set aside by the utilities to cover future costs related to spent fuel management, or waste treatment or decommissioning of the plants.

In order to calculate the accruals, utilities take into consideration at least:

- The gross estimate of the costs,
- The number of years already lapsed since the start of the nuclear plant operations,
- The number of years before using the funds,
- Probabilistic assumptions (generally never disclosed),
- Discounting and inflation factors,

Balance Sheet Provisions and Accruals						
EDF Group	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million €	Million €	%			Million \$
Management of spent fuel	9 143	9 498	3,9%	485 455	GWh	12 400
Management of radioactive waste	6 722	7 113	5,8%	485 455	GWh	9 300
Dismantling power stations	11 366	12 578	10,7%	77 471	MW	16 500
Last core	2 012	2 193	9,0%	77 471	MW	2 900
TOTAL	29 243	31 382	7,3%	Report 1 page 72		41 100
CEZ	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million CZk	Million €	%			Million \$
Management of spent fuel	28 102	30 377	8,1%	30 324	GWh	1 583
Dismantling power stations	9 183	12 038	31,1%	4 040	MW	627
TOTAL	37 285	42 415	13,8%	Report 1 page 67		2 210
EXELON	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million \$	Million \$	%			Million \$
Management of spent fuel	1 020	1 020	0,0%	139 862	GWh	1 020
Dismantling power stations	2 660	3 720	39,8%	17 202	MW	3 720
TOTAL	3 680	4 740	28,8%	Report 1 page 80		4 740
KEPCO	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million Won	Million Won	%			Million \$
Management of spent fuel	869	1 207	38,9%	143 453	GWh	1 086
Dismantling power stations	5 061	9 462	87,0%	20 716	MW	8 516
TOTAL	5 930	10 669	79,9%	Report 1 page 87		9 602
TVO	12/31/2011	12/31/2012	Variation	Key Reference Indicators		12/31/2012
	Million €	Million €	%			Million \$
Nuclear Waste Management	832	858	3,1%	14 850	GWh	1 124
TOTAL	832	858	3,1%	Report 1 page 87		1 124

Table 33: Balance Sheet Provisions and Accruals (Actual Costs)

The analysis of the data collected illustrates a wide variety of results, which can be explained, partially by the various discounting or inflating assumptions used.

In general, countries legislation requires nuclear utilities to set aside every year money into dedicated funds which will be used at a later date to pay for the back-end activities. Money should be invested in low risks instruments generally government bonds or similar.

Utilities compute the annual accruals by calculating the net present value of future payments with the following inflation and discounting factors. The higher the difference between discount rate and inflation, the lower the accruals.

		CEZ	EDF	KepCo	TVO
Annual Inflation	%	1,5%	1,9%	2,9%	
Discount Rate	%	2,5%	4,8%	4,5%	5,5%
Spread	%	1,0%	2,9%	1,6%	5,5%

Table 34: Details of Inflation and Discount Rate used by utilities

Utilities do not disclose the specific cost / MWh related to the back end costs whether related to fuel or to plant decommissioning. As a result, specific calculation has been made using two separate methods::

- o Based upon the gross estimate of the total costs,
- o Based upon year-end total accruals,

CALCULATION BASED ON PROJECTED COSTS	12/31/2012	Production	Project Life	Net Discount	NPV Energy	Cost
	Million \$	GWh	years	%	TWh	\$ / MWh
EDF France	52 200	404 880	50	2,9%	10 618	4,92
GEORGIA POWER	246	16 200	40	3%	374	0,66
CALCULATION BASED ON ACTUAL ACCRUALS	12/31/2012	Production	Past life	Net Discount	NPV Energy	Cost
	Million \$	GWh	years	%	TWh	\$ / MWh
EDF Group	21 700	485 455	25	2,9%	8 548	2,54
CEZ	1 583	30 324	25	1,0%	668	2,37
EXELON	1 020	139 862	25	3,0%	2 435	0,42
KEPCO	1 086	143 453	20	1,6%	2 439	0,45

Table 35 : Fuel Back End Costs (Actual Costs)

CALCULATION BASED ON PROJECTED COSTS	12/31/2012	Capacity				Cost
	Million \$	MW				\$ / kWe
EDF France	34 100	63 130				540
GEORGIA POWER	1 002	3 000				334
CALCULATION BASED ON ACTUAL ACCRUALS	12/31/2012	Capacity	Past life	Life to Go	Future Value	Cost
	Million \$	MW	years	years	Million \$	\$ / kWe
EDF Group	19 400	77 471	25	25	38 800	501
CEZ	627	4 040	25	25	1 255	311
EXELON	3 720	17 202	25	25	7 440	433
KEPCO	8 516	20 716	25	30	18 735	904

Table 36: Decommissioning Costs (Actual Costs)

BACK END COSTS		EDF	GEORGIA POWER	EXELON	TVO	CEZ	KEPCO	TEPCO
Reactor Model		PWR	PWR	BWR/PWR	BWR	PWR	PWR	ABWR
Global Output	TWh /year	405	20	140	14	30	150	-
Global Capacity	GW	63	3	17	2	4	21	5
Inflation Rate (IFRS 37)	%	1,9%	2,0%	2,0%	2,0%	1,5%	2,9%	
Discount Rate (IFRS 37 or NRC)	%	4,8%	5,0%	5,0%	5,0%	2,5%	4,5%	
Fuel & Waste	\$ / MWh	\$ 3,7	\$ 0,7	\$ 0,4	\$ 5,2	\$ 2,4	\$ 0,4	\$ -
Decommissioning	\$ / kWe	\$ 520	\$ 334	\$ 433	\$ -	\$ 311	\$ 904	\$ -
Decommissioning	\$ / MWh	\$ 4,61	\$ 2,88	\$ 3,05	\$ -	\$ 1,90	\$ 6,10	\$ -

Table 37: Back end cost summary (Actual Costs)

Back End costs may vary substantially from one utility to the other as assumptions vary the same way. EDF cost, at the upper end of the range, is probably influenced by the use of reprocessed fuel and by the waste treatment, as well as the technical solutions for long term storage (safety being the largest driver of the cost).

Kepco cost is also influenced by conservative assumptions for discounting the future costs.

It should be noted that few studies do provide analysis of the back end costs. The only exception is the World Nuclear Association / OECD study which indicates the discounted decommissioning costs. As a result, decommissioning costs discounted at a high discount rate tend to have no influence on the LCOE, especially as most of the expenses may occur very late (after 60 years for Gen III reactors).

6.4.2.3 Operations and Maintenance Cost

O & M costs include, in all cases:

- Operations costs during effective running of the NPP,
- Regular maintenance costs during operation or shutdown of the plant,
- Major repair costs recognizing that during major repair, some of the costs are capitalized and depreciated upon a certain number of years (Depreciation may not be reported by the utilities in the O & M line of their P & L)

However, some other cost, may or may not be included in the O & M costs:

- Accruals for the management of spent fuel (unload, storage in pools, transportation and dry or long term storage)
- Fuel waste management accruals,
- Decommissioning accruals (ultimate dismantling of the plant and intermediate decommissioning of some major components like steam generators replaced)

Preferably, O & M costs do not include any selling or administrative expenses, as most of the comparisons and calculations of the LCOE are done at the “bus bar” level (or wholesale price). Unfortunately, few utilities provide the O & M cost at the “bus bar” level.

The Consultant believes that most of the O & M costs are fixed (once the operating crew is set, the cost of it does not move) and a function of the capital invested in the reactor. This is confirmed by the breakdown of EDF production cost which indicates that 1/3 of the O & M cost is related to external costs (services provided by third party suppliers). It is also worth mentioning that taxes may have a very heavy weight on the O & M costs but those costs may differ substantially from one country to the other.

As most of the O & M costs are “fixed”, the impact on the cost per MWh is greatly influenced by the efficiency of the plant and by the cost of the plant itself.

The following table does provide a range of values of O & M costs of utilities surveyed; the base data are always expressed and provided in \$ / MWh and range from \$ 13 to a high \$ 24 / MWh. However, the table also converts the values in \$ / kWe installed, as O & M costs are also influenced by the size and the efficiency of the nuclear plants.

O & M COST SUMMARY			EDF	GEORGIA POWER	EXELON	TVO	CEZ	KEPCO	TEPCO
Reactor Model			PWR	PWR	BWR/PWR	BWR	PWR	PWR	ABWR
Global Output	TWh /year		405	20	140	14	30	150	-
Global Capacity	GW		62	3	17	2	4	21	5
O & M (Original Data)	\$ / MWh		\$ 24,0	N/A	\$ 13,3	\$ 19,5	\$ 16,0	\$ 18,8	\$ 22,0
O & M (Calculated)	\$ / kWe		\$ 156,8	N/A	\$ 109,5	\$ 136,5	\$ 120,0	\$ 134,3	N/A
Notes:									
EDF estimate provided by French Cour des Comptes adjusted for inflation									
Tepco ABWR O & M performances are unknown (likely 20 % higher than PWR)									
KEPCO provided by segment reporting includes Candu reactors									

Table 38: O&M Data Cost Summary (Actual Costs)

As O & M costs are mostly fixed costs, it should be noted that in the sample analyzed, the cost per kWe ranges from \$ 110 to 160. This cost / kWe is largely influenced by the following factors:

- Labor costs in the country
- Spare part costs which are closely related to the capital cost of the NPP
- Technology

6.4.2.4 Comparisons between production cost in the generic surveys and utilities reports.

Fuel Costs, including management of spent fuel, O & M costs, accruals for decommissioning costs can be aggregated a “Production costs”. As Literature survey and utilities do provide an indication of those costs, the following table compare the 2 sets of information, which reflect the data reported in the previous sections of the report (using the normalized classification):

UTILITIES SURVEYS	[Average]	SP	NDC	Gen III	Gen II	TOTAL
Fuel Cost	\$ / MWh	6,00	4,80	7,50	5,80	6,04
Spent Fuel Cost	\$ / MWh	2,47	0,45	N/A	2,14	2,14
O & M	\$ / MWh	18,20	18,80	21,96	18,32	18,32
Decommissioning	\$ / MWh	2,49	6,10	N/A	3,09	3,09
Production Costs	\$ / MWh	29,16	30,15	29,46	29,34	29,59
GENERIC SURVEYS	[Average]	SP	NDC	Gen III	Gen II	All
Fuel Cost	\$ / MWh	8,13	9,98	8,43	9,58	8,75
O & M	\$ / MWh	12,86	18,90	14,53	15,77	14,87
Production Costs	\$ / MWh	20,99	28,87	22,95	25,35	23,62

Table 39: Comparison of production costs (Average) between generic surveys and utilities reports

UTILITIES SURVEYS	Maximum	SP	NDC	Gen III	Gen II	TOTAL
Fuel Cost	\$ / MWh	8,00	4,80	7,50	8,00	8,00
Spent Fuel Cost	\$ / MWh	5,20	0,45		5,20	5,20
O & M	\$ / MWh	24,00	18,80	24,00	24,00	24,00
Decommissioning	\$ / MWh	4,61	6,10	-	6,10	6,10
Production Costs	\$ / MWh	41,81	30,15	31,50	43,30	43,30
GENERIC SURVEYS	Maximum	SP	NDC	Gen III	Gen II	All
Fuel Cost	\$ / MWh	10,40	10,40	10,40	10,01	10,40
O & M	\$ / MWh	32,02	18,18	18,18	32,02	32,02
Production Costs	\$ / MWh	42,42	28,58	28,58	42,03	42,42

Table 40: Comparison of production costs (Maximum) between generic surveys and utilities reports

Production costs (defined as Fuel + O & M + Back end) show an overall production cost 20 % higher in the utilities survey than in the generic surveys.

The main, if not the only, difference lies in the consideration for back end costs. Those costs may represent an accrual per MWh almost equal to the fuel cost line.

This is further evidenced by figures provided by TVO-which is the only utility reporting such figure- where nuclear waste management costs equal fuel costs (average of last 3 years).

TEOLLISUUDEN VOIMA OYJ (FAS)					
Parent company's financial statement has been prepared in accordance with the Finnish Accounting Standards (FAS)					
EUR million	2012	2011	2010	2009	2008
Turnover	347	347	355	296	245
Profit/loss before appropriations	1	8	7	-24	-37
Fuel costs	62	67	80	65	56
Nuclear waste management costs	77	68	65	66	56

Table 41: TVO - Nuclear waste management costs figures

As back end costs are usually spent at the end of the projects life, the way the future cost is discounted is very critical to the value of the overall LCOE. However, Capital costs remain the first critical factor in the determination of the LCOE.

6.4.2.5. Project capital costs

Plant Costs include all costs that are incurred and necessary for the completion of a nuclear power plant before effective production of electricity. Usually such plant costs are capitalized on the balance sheet of

the owner of the NPP; it includes, all the preparatory work expenses that are capitalized, the site preparation costs, the infrastructure of the NPP, all the engineering work, the first fuel core, etc. Scope may vary from one project to the other as many costs are specific to the countries or the site, in addition to the project scope itself (one unit or multiple units, etc)

Project costs do not include capitalized interest. The projects reviewed in the Utilities section, include Gen III projects as reflected in the following table:

UTILITIES SURVEY		EDF	EDF UK	TVO	KEPCO	KEPCO	UAE	GEORGIA POWER	General Survey
Reactor Model		EPR	EPR	EPR	APR 1400	APR 1400	APR 1400	AP 1000	see section 1
Location		Flamanville	Hinkley Point	Olkiluoto	Shin Kori	Shin Uljin	Barakah	Vogtle	
Serial Number		FOAK	NOAK	FOAK	FOAK	NOAK	NOAK	FOAK	
Unit size (MW)		1650	1650	1650	1400	1400	1400	1120	
Project size (MW)		1650	3300	1650	2800	2800	5600	2240	
Cost per kWe	\$ / kWe	6 700	6 545	5 945	6 400	4 900	3 820	6 280	4 528
UTILITIES SURVEY		JAEC	Turkey	Viet Nam	Viet Nam	Lituania	China	Average	Std.dev
Reactor Model		ATMEA	ATMEA	ATMEA	VVER - AES 92	ABWR	EPR	excluding China	excluding China
Location		Jordan	Sinop				Taishan		
Serial Number		NOAK	NOAK	NOAK	NOAK	NOAK	NOAK		
Unit size (MW)		1100	1120	1100	913	1050	1650	1 296	262
Project size (MW)		2200	2240	2200	1826	1050	3300	2 463	1 157
Cost per kWe (overnight)	\$ / kWe	4 900	4 300	4 200	4 700	4 800	2 900	5 291	1 019

Table 42: Details of the projects reviewed in the Utilities Survey (Actual Costs)

When excluding the Gen II projects under construction, the majority of the outstanding projects have a cost per kWe between \$ 4 500 and 5 500. Projects developed in countries having a nuclear program tend to have costs at or below this central value, whereas single projects tend to be in the upper range of the chart.

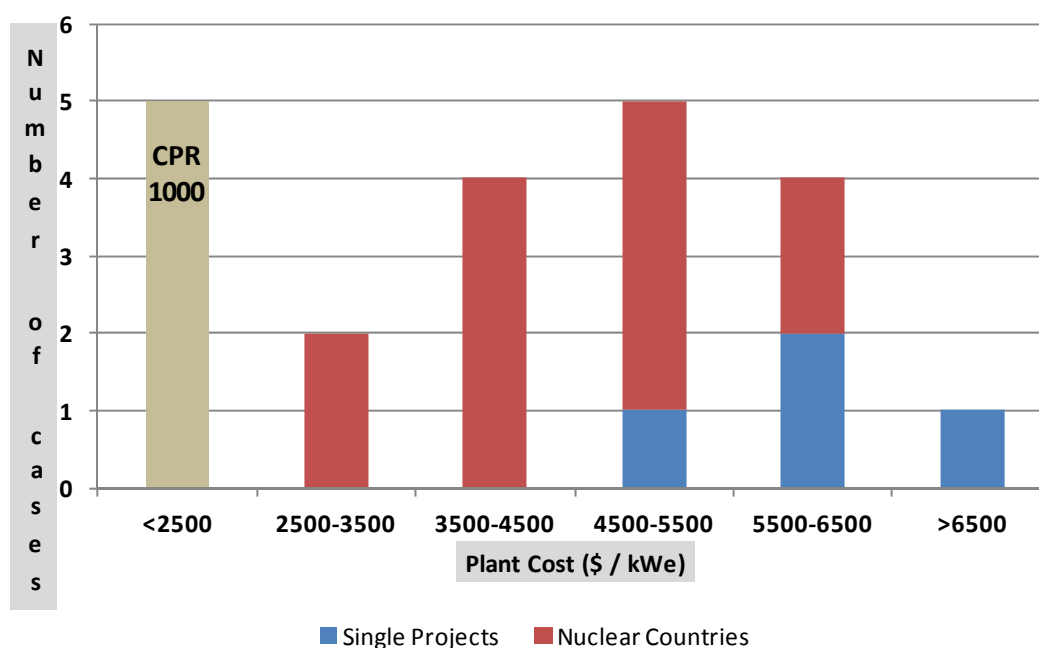


Figure 44: Distribution of Plant Costs for Gen III NPP

The factors that may explain the dispersion of the plant cost per kilowatt include:

- Nature of the reactor technology,
- Size of the nuclear fleet projected to be built,

- Local content proportion that may have a significant impact on the construction cost, depending upon the countries capabilities to produce locally and cheaper some parts of the projects⁸

The Analysis does not provide direct indication of how the countries industrial capabilities may impact project costs; however, the cost breakdown basis provided by a recent NEI study would indicate the areas of a construction project that may be impacted by localization programs (Civil works, engineering, etc.).

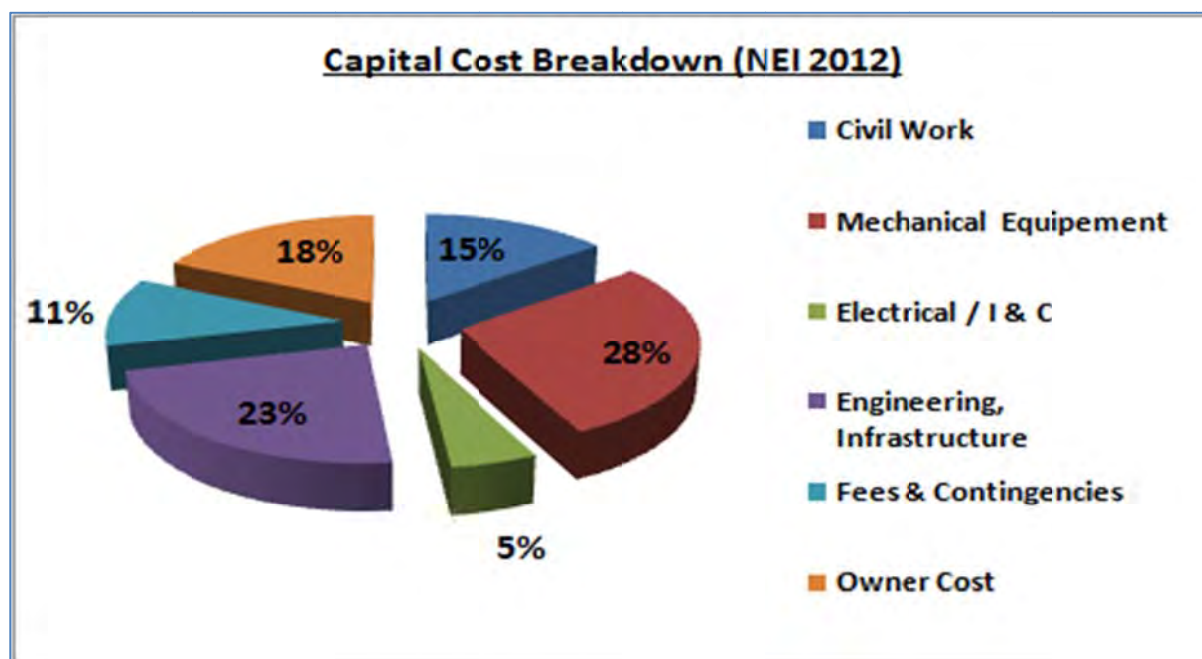


Figure 45 Capital Cost Breakdown (NEI Study 2012)

The breakdown presented in the chart giving information on the structure of the capital cost also enables to foresee the costs differences that will happen between two projects using the same technology, in two different areas of the world having for instance different labour costs. Civil work costs will be different in France and China, explaining the differences of costs for EPR construction for example.

The current report identifies the cost of the existing projects based upon the specificities of the countries where those projects will take place; further analysis will be required to estimate more precisely the capital costs in the south-African situation.

Multiple units and series effect

Projects with multiple units demonstrate a lower cost per kWe, as reflected in the analysing the utilities reports. When excluding Chinese Gen II projects from the sample, the analysis shows a cost reduction of 20 to 30 % when the project size is above 4 000 MW. This trend is confirmed by Consultant experience of recent quotations that would indicate cost savings for multiple unit orders.

⁸ NEI 2012 study provides cost breakdown of all energy projects.

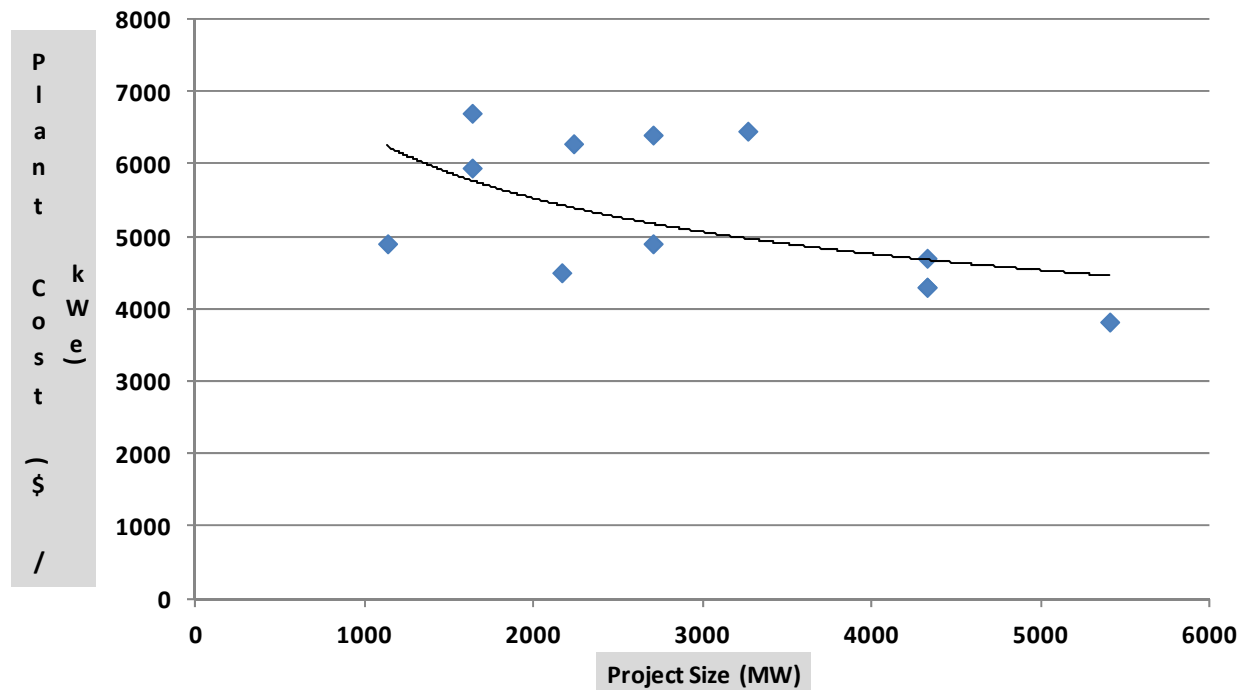


Figure 46: Plant cost as a function of project size

The increase of Project Size by building several units at the same site provides opportunities for capital cost reduction, in areas such as Siting, Licensing costs, Site labour, common facilities...

In addition to the sharing of the site land cost, site-licensing costs can also be shared among multiple units. During the construction phase, considerable efficiencies and associated savings can be gained from phased construction and rolling the various craft teams from one unit to the next. In addition, by construction repetition, there is craft labour learning that reduces the time to perform a given task and correspondingly reduces both construction labour cost and schedule.

Multiple-unit plants can obtain significant cost reduction by using common facilities such as: access roads, temporary work site buildings, administration and maintenance buildings, warehouses, auxiliary systems (demineralised water, auxiliary steam, compressed air, emergency power supply, gas storage, etc.), guardhouse, radwaste building and water structures. Nearly 90% of the world's nuclear power plants are constructed as multiple-unit plants.

The French utility EDF, which has a large experience of building multiple units at the same site (six identical units at Gravelines site), and of ordering large series of identical units, made an evaluation⁹, based on its experience, of the benefit of these factors. The main findings are shown in the subsequent figure.

⁹ EDF – The series effect: impact on capital costs of standardization of PWR plants – 15th annual conference of the International Association for Energy Economics – Tours, France, May 1992

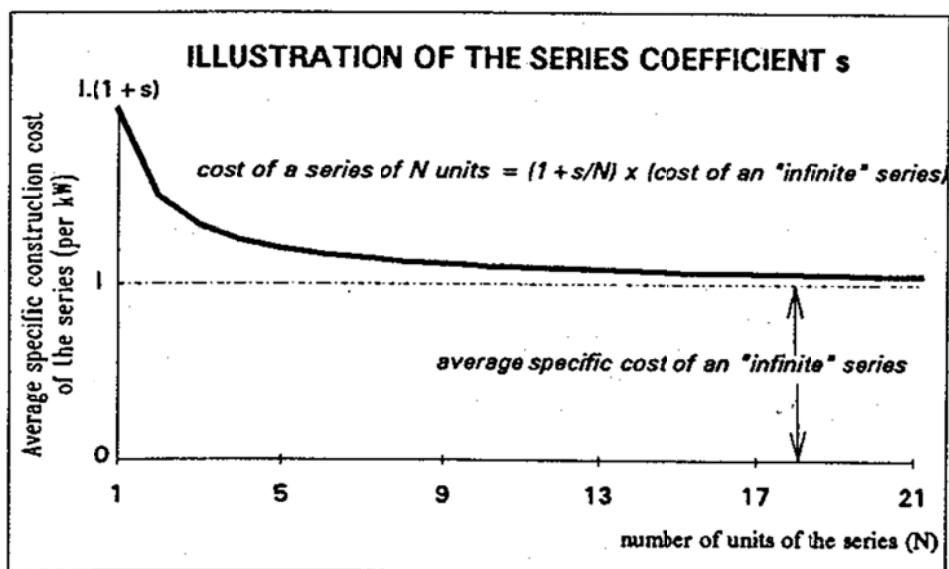


Figure 47: Impact of the series effect - EDF assessment

Another study¹⁰, made in the framework of the Nuclear Energy Agency (which is part of the OECD) provided more details on this subject, by trying to sort out the benefit of series by themselves (design and engineering costs assigned to several projects; better productivity and efficiency in workshops, due to repetition) from the site effect described above.

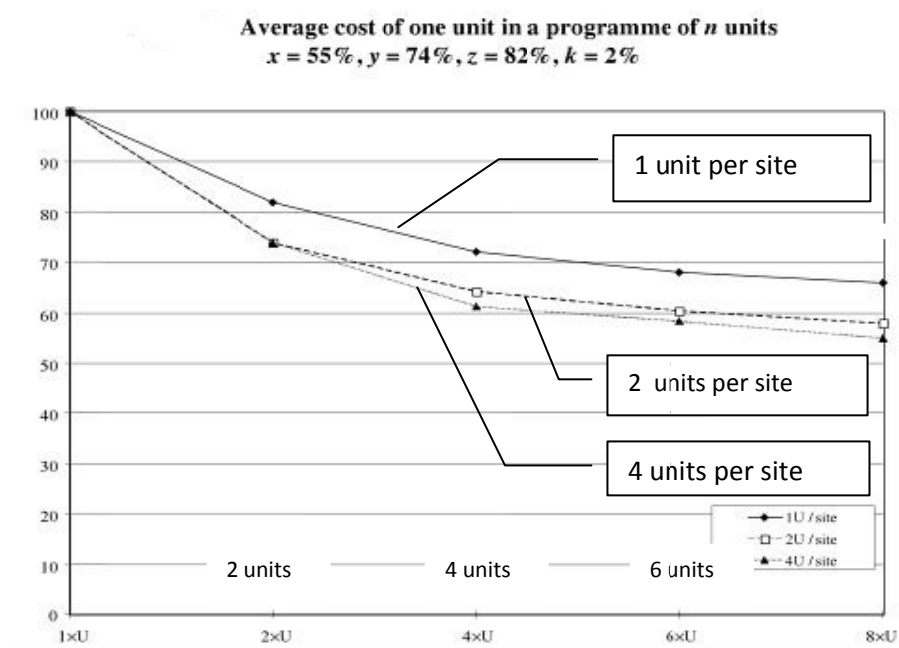


Figure 48: Multiple Units - Several units per site - NEA/OECD study

The study defines the following parameters:

- X: First of a Kind extra cost parameter
- Y: parameter related to the gain in building a pair of units
- Z: parameter related to the gain in building two pair of units at the same site
- K: industrial productivity coefficient

¹⁰ Reduction of capital costs of nuclear power plants – NEA/OECD – 2000 - http://books.google.fr/books?id=x-mIgek8kC&pg=PA56&lpg=PA56&dq=%22series+effect%22+productivity&source=bl&ots=8a4ZvHzQrI&sig=DGcfZluacdnpZckhWgtQPalv71E&hl=en&sa=X&ei=PcxoUpK1DOSp0QX4lYGgDg&redir_esc=y#v=onepage&q=%22series%20effect%22%20productivity&f=false

Based on Korean experience, the authors assessed the following values : $x=55\%$; $y=74\%$; $z=82\%$; $k=2\%$

The main findings and conclusions of these different studies are:

- Series effect is achieved when six standardised units are built. Beyond this figure, the benefit gets asymptotic,
- Optimal configuration is to have at least two and preferably four units at the same site.

6.5. Technology Results

6.5.1. Methodology

The purpose of this technology results section is to calculate the expected LCOE of all the current projects reviewed in the previous section and thus to provide a common methodology and tool to compare various technologies. As a result, technology analysis is mostly based upon:

- A standard model for calculating the LCOE and the cost breakdown in a similar manner,
- Data input specific to each technology and/or project, based upon the figures collected in the previous sections.

The Consultant believes that such representation of the various technologies would provide a good representation of the differences between generations, between first plant on line and its successive copies and between technologies themselves.

It does not reflect the performance of one specific reactor, but rather a group of similar nuclear plants.

The model and the basic formulas are described in detail in annex. It relies upon discounting at the appropriate discount rate a flow of costs (capital spending, fuel, etc) and energy production.

6.5.2. Model Validation

The Model can be validated by using the Literature Survey Input data:

- Power capacity
- Capital cost / kWe

LITERATURE SURVEY ANALYSIS		NDC	SP	Gen III	Gen II	All
Average						
Nuclear Plant Size	MW	1 230	1 241	1 348	1 006	1 234
Capital Spending	\$ / kWe	3 292	4 832	4 044	3 186	3 806
Average per kWh						
Capex	\$ / MWh	36,3	42,6	43,4	25,5	38,4
Fuel	\$ / MWh	8,1	10,0	8,4	9,6	8,7
O & M	\$ / MWh	12,6	18,5	14,3	15,3	14,6
Others	\$ / MWh	0,3	0,4	0,2	0,5	0,3
LCOE	\$ / MWh	57,3	71,5	66,3	50,9	62,0
TECHNOLOGY REVIEW @ 5 %		NDC	SP	Gen III	Gen II	All
Average						
Nuclear Plant Size	MW	1 230	1 241	1 348	1 006	1 234
Capital Spending	\$ / kWe	3 292	4 832	4 044	3 186	3 806
Average per kWh						
Capex	\$ / MWh	31,6	45,6	38,1	31,6	36,7
Fuel	\$ / MWh	4,1	3,8	3,8	4,8	4,1
O & M	\$ / MWh	18,8	24,5	20,5	18,2	20,5
Back End	\$ / MWh	5,0	6,2	5,5	5,3	5,5
LCOE	\$ / MWh	59,6	80,1	67,9	59,9	66,9

Table 43: Literature Survey Analysis summary for LCOE and Capital Spending

6.5.3. What discount rate to select – sensitivity analysis

Selection of the discount rate

Selecting a discount rate, when making energy policy studies, is generally a subject for hot discussions between experts, with very different conclusions whether pure financial perspective, or macroeconomic views are considered.

A standard definition of discount rate is: *“The interest rate at which an agent discounts future events in preferences in a multi-period model”*. Central questions to the implementation of this definition are to discuss who the “agent” is, and on which basis its preferences between future and present are optimised.

For a private agent, the answer is straightforward, and the discount rate equals the Weighted average cost of capital (WACC) which is the cost of resources which the agent can be mobilise.

When making energy policy studies, this would theoretically result in different discount rates for different technologies, insofar as the cost of capital (and to some extent the cost of debt) may be fairly different from one technology to the other (because of different risk factors). But the policy maker, in charge on optimising the future energy policy is not in the same position as the private investor deciding to invest in a single project. The policy maker is representing the view of all stakeholders, and reflects their preference for giving priority to present or future revenues, versus investment. As an “agent”, the policy maker is not optimizing any specific investment, but the economy as a whole.

Economists have introduced the concept of social discount rate, which is a measure used to guide choices about the value of assigning funds to social projects (in the sense of highways, schools, environmental protection, etc.). It is defined as *“the appropriate value of r to use in computing present discount value for social investments”*.

The social discount rate is a reflection of a society's relative valuation on today's well-being versus well-being in the future. The appropriate selection of a social discount rate is crucial for cost-benefit analysis, and has important implications for resource allocations. There is wide diversity in social discount rates, with developed nations typically adopting a lower rate, and developing nations a higher rate, as shown in the next chart¹¹. It reflects the fact that developing countries have immediate needs, and also a high systemic growth without need of much new investment (education and organization being the main growth factors); whereas the priority of developed countries is to transfer their legacy to future generations, which implies a lower preference for short term benefits.

While there is no consensus on the way to calculate a discount rate at a nation level, there is a wide consensus to the point that such rate should exist in any countries: should a nation invest in railways, or highways, or universities cannot be only a matter of “gut feeling”. It has to be part of a cost-benefit analysis, with a discount rate as an underlying factor; and this discount rate can only be the same for so different activities.

In the field of energy policies, it could be argued that it is essentially a matter of private investment, and should be left to the players which have their individual discount rates. However, it is widely recognized that any energy policy has long range impacts, and therefore that the government has the duty to offer a strategy based on a long term view, independent of investors' appetite; and which implies to make use of the same (and single) discount rate used for other policy decisions.

¹¹ Australian government – Productivity commission – 2010 Valuing the Future: the social discount rate in cost-benefit analysis (page 10). http://pc.gov.au/_data/assets/pdf_file/0012/96699/cost-benefit-discount.pdf

Because of hot discussions on discount rates, it is common practice to assess policies with two discount rates, in order to better figure out their consequences.

The selection of a South African discount rate would require a discussion *per se*, which would fall well beyond the scope of this report. Most of the studies reviewed in the frame of this report used one single discount rate (in the vast majority of studies: 5%). The generic EPRI reports (all countries) uses a 5% discount rate¹².

Table A-1
Financial Assumptions – Non technology-specific, investor-owned utility (IOU) financing rates

Inputs	Rate
Nominal Equity Rate (%)	11%
Nominal Debt Rate (%)	7%
Debt Ratio (%)	50%
Income Tax Rate (%)	39.3%
Inflation Rate (%)	2.5%
Property Tax/Insurance Rate (%)	1.3%
Calculated Values	
Nominal Before Tax Weighted Average Cost of Capital (WACC)	9.0%
Real After Tax WACC (Discount Rate)	5.0%

Figure 49 - EPRI Generic discount rate

The specific situation of South Africa, with its need to invest in infrastructure projects competing for the same capital resources would tend to give priority to projects having the highest “short term return”, and therefore to consider a higher discount rate; which was the case in the IRP 2010 study (8%). As agreed when processing the study, the Consultant considered two discount rates (5% and 10%), for the purpose of making sensitivity analysis.

EPRI in their 2012 report specific to South Africa¹³ adopted 6,93% as a discount rate, which under their claim represents a weighted average cost of capital (WACC); this report states that the discount rate is calculated as $(\% \text{ debt}) \times (\text{cost of debt}) + (\% \text{ equity}) \times (\text{cost of equity}) = \text{discount rate}$
 $60\% \times 7.3\%/\text{year} + 40\% \times 10.6\%/\text{year} = 8.6\%/\text{year}$ ¹⁴

However the report provides no explanation for the difference between this calculated figure (8,6%) and the adopted figure (6,93% after tax, and 8,16% before tax).

For the purpose of making comparisons between energy sources, the present report used this 6,93% discount rate, in order to be able to compare 2013 to 2012 results.

¹² *Program on Technology Innovation: Integrated Generation Technology Options 2012*. EPRI, Palo Alto, CA: 2013. 1026656.

¹³ *Power Generation Technology Data for Integrated Resource Plan of South Africa*. EPRI, Palo Alto, CA: 2012.

¹⁴ *EPRI Base report - Power Generation Technology Data for Integrated Resource Plan of South Africa – 2012* page 5-7

**Table 5-1
Economic Parameters**

Type of Security	% of Total	-- Current Dollars --		-- Constant Dollars --	
		Cost (%)	Return (%)	Cost (%)	Return (%)
Debt	60	10.0	6.0	7.3	4.4
Preferred Stock	N/A	N/A	0.0	N/A	0.0
Common Stock	40	12.2	4.9	9.4	3.8
Total Annual Return			10.9		8.2
Inflation Rate	2.5				
Federal and State Income Tax Rate	28				
Property Taxes, Insurance, and Other Taxes	2.0				
Discount Rate					
After Tax			9.19		6.93
Before Tax			10.87		8.16

Table 44 : EPRI Report - Economic Parameters & Discount Rate

As a provisional conclusion, and without having made a full assessment of a South African discount rate which is beyond the scope of this study, and in line with the trend for a decreasing discount rates as economies develop, the Consultant suggests that the Governable 23bissent revisits the 8% discount rate considered in IRP 2010, and expects that it will be kept at 8% or slightly reduced after further studies.

<i>Country</i>	<i>Agency</i>	<i>Discount rate (per cent)</i>
Philippines		15 ^a
India		12 ^a
Pakistan		12 ^a
International Multi-lateral Development Banks	World Bank	10–12 ^a
	Asia Development Bank	10–12 ^a
	Inter-American Development Bank	12 ^a
	European Bank for Reconstruction and Development	10 ^a
	African Development Bank	10–12 ^a
New Zealand	Treasury and Finance Ministry	8 ^g . From 1982 to 2008 it was 10 ^{abf}
Canada	Treasury Board	8 ^c . From 1976–2007 was 10 (and test 8–12 per cent) ^{ab}
China (People's Republic)		8 ^a
South Africa		8 (and test 3 and 12 per cent) ^d
United States	Office of Management and Budget	7 (and test 3 per cent). Used 10 per cent until 1992. ^a
European Union	European Commission	5 From 2001–2006 was 6 per cent ^a
Italy	Central Guidance to Regional Authorities	5 ^a
The Netherlands	Ministry of Finance	4 (risk free rate). ^e
France	Commissariat General du Plan	4. From 1985–2005 used 8 per cent ^{ab}
United Kingdom	HM Treasury	3.5 (declining to 1 per cent for costs and benefits received more than 300 years in the future) from 2003. ^a From 1969–78 used 10 per cent ^a
Norway		3.5. From 1978–98 used 7 per cent ^{ab}
Germany	Federal Finance Ministry	3. From 1999–2004 used 4 per cent ^{ab}
United States	Environmental Protection Agency	2–3 (and test 7 per cent) ^a

^a Zhuang et al. (2007, table 4, pp. 17–18, 20). ^b Spackman (2006, table A.1, p. 31). ^c Treasury Board of Canada (2007, p. 37, 1998, p. 45). ^d South African Department of Environmental Affairs and Tourism (2004, p. 8). ^e van Ewijk and Tang (2003, p. 1). ^f Use of the 10 per cent rate by New Zealand government departments is confirmed by Young (2002, p. 12); Abusah and de Bruyn (2007, p. 4). ^g New Zealand Treasury (2008) recommends a default rate of 8 per cent (after adjusting the market risk premium of 7 per cent for

Table 45: Current real discount rates in practice (reference in foot note of previous page)

6.5.4. Sensitivity to Discount Rate

Changing the discount rate to 10 %, would significantly change the LCOE and almost double it for the samples in the Literature survey:

TECHNOLOGY REVIEW @ 5 %		NDC	SP	Gen III	Gen II	All
Average						
Nuclear Plant Size	MW	1 230	1 241	1 348	1 006	1 234
Capital Spending	\$ / kWe	3 292	4 832	4 044	3 186	3 806
Average per kWh						
Capex	\$ / MWh	31,6	45,6	38,1	31,6	36,7
Fuel	\$ / MWh	4,1	3,8	3,8	4,8	4,1
O & M	\$ / MWh	18,8	24,5	20,5	18,2	20,5
Back End	\$ / MWh	5,0	6,2	5,5	5,3	5,5
LCOE	\$ / MWh	59,6	80,1	67,9	59,9	66,9
TECHNOLOGY REVIEW @ 10%		NDC	SP	Gen III	Gen II	All
Average						
Nuclear Plant Size	MW	1 230	1 241	1 348	1 006	1 234
Capital Spending	\$ / kWe	3 292	4 832	4 044	3 186	3 806
Average per kWh						
Capex	\$ / MWh	81,8	119,8	100,3	73,2	93,8
Fuel	\$ / MWh	4,1	3,8	3,8	4,8	4,1
O & M	\$ / MWh	18,8	24,5	20,5	18,2	20,5
Back End	\$ / MWh	10,0	13,7	11,7	9,5	11,2
LCOE	\$ / MWh	114,8	161,8	136,3	105,7	129,6

Table 46: Sensitivity to Discount Rates 5% Vs 10%

The next graph illustrates the impact of increasing the discount rate from 5% to 10%.

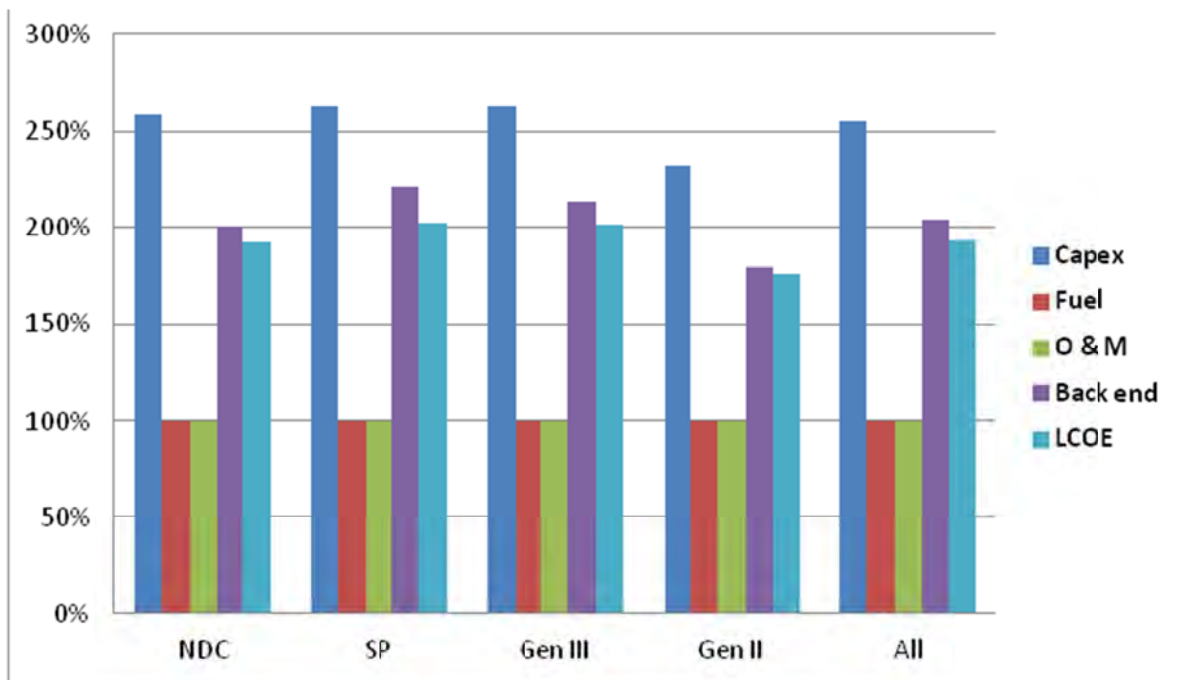


Figure 50 : Ratio of costs for 10% vs 5% Discount Rate (10%/5%)

As expected, the increase of the discount rate from 5% to 10% has the following impacts:

1. A strong increase of the Capex/kWh, which more than doubles (multiplication by 259%);
2. No impact on Fuel/kWh and O&M/kWh, as the change in discount rate impacts both the numerator and denominator of the calculation. The increase in discount rate reduces the discounted value of these items, but also the discounted amount of generated power;
3. A significant impact on the decommissioning component of the LCOE. In most assessments of nuclear competitiveness, an increase in Discount rate reduces the share of decommissioning costs in the LCOE, as it is assumed that these costs are to be faced at the end of life of the facility, and therefore heavily discounted ; and even more if the discount rate increases. However, the Consultant believes that this method of discounting the decommissioning costs is unduly favourable to the nuclear energy, and can be criticised on the basis of two main sets of arguments:
 - i. This method assumes that the cost of decommissioning is subject to the same inflation rate as any other costs, as is the case for all other components of the LCOE, when making calculations without consideration given to inflation. However, decommissioning requirements are not well established, and the review of decommissioning costs done in the first part of this study (data collection) tends to demonstrate that these costs increase over time faster than inflation;
 - ii. Regulators tend to require that decommissioning funds be accrued at the beginning of the projects, and provisions made in tangible assets having no long term risks; such assets provide an annual return which is much lower than the discount rate.

For these reasons, the Consultant calculated the decommissioning costs per kWh as a percentage of the CAPEX per kWh; as a consequence, these decommissioning costs increase with the discount rate. This methodology may be considered as overly conservative, but it was chosen to be very resilient to external critics.

6.5.5. Utilities Projects LCOE

The different on-going projects reviewed in this Analysis have different costs profile and efficiency profiles:

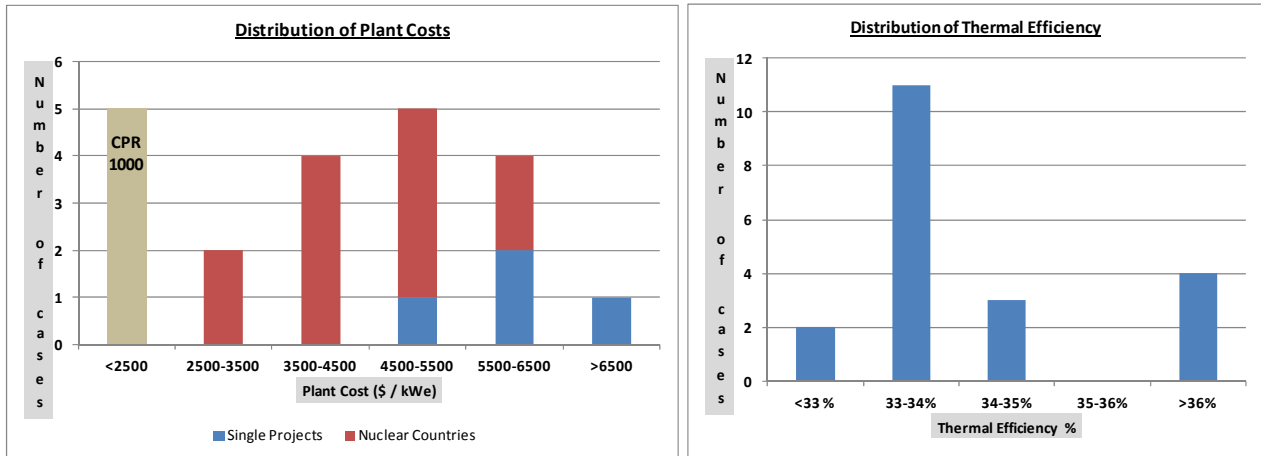


Figure 51 : Distribution of Plant Costs and Thermal Efficiency

As a result, the LCOE profiles (at a 5 % discount rate) are:

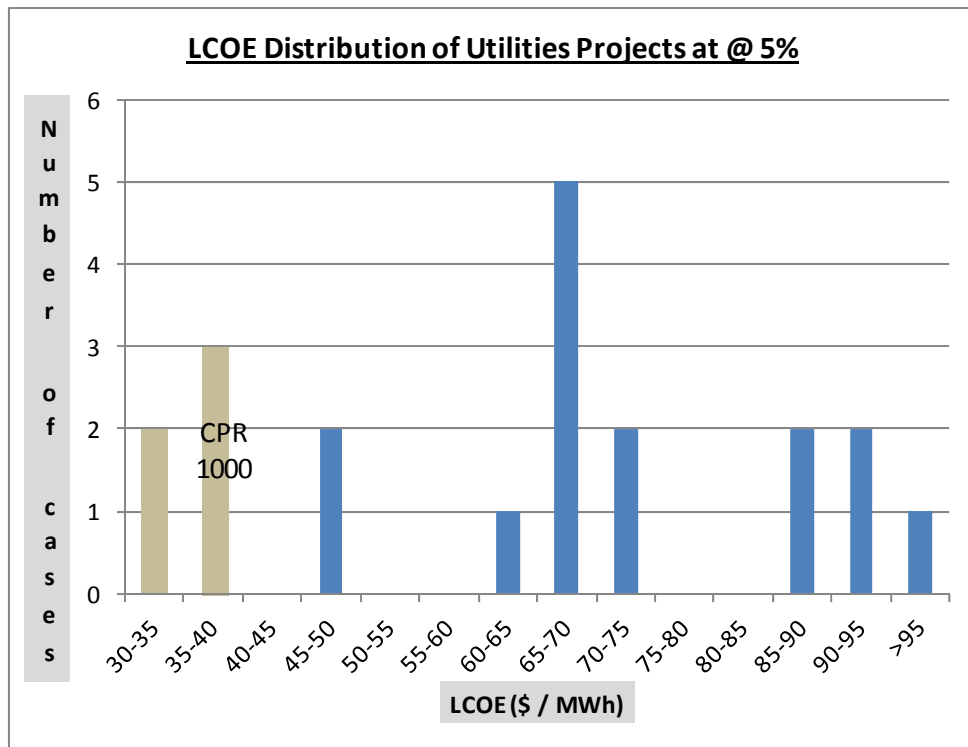


Figure 52 : LCOE Distribution of Utilities Projects at 5%

6.5.6. Technology Results Summary and comparisons to Literature Survey

Using the same discount rate, the summary of all findings would indicate the following:

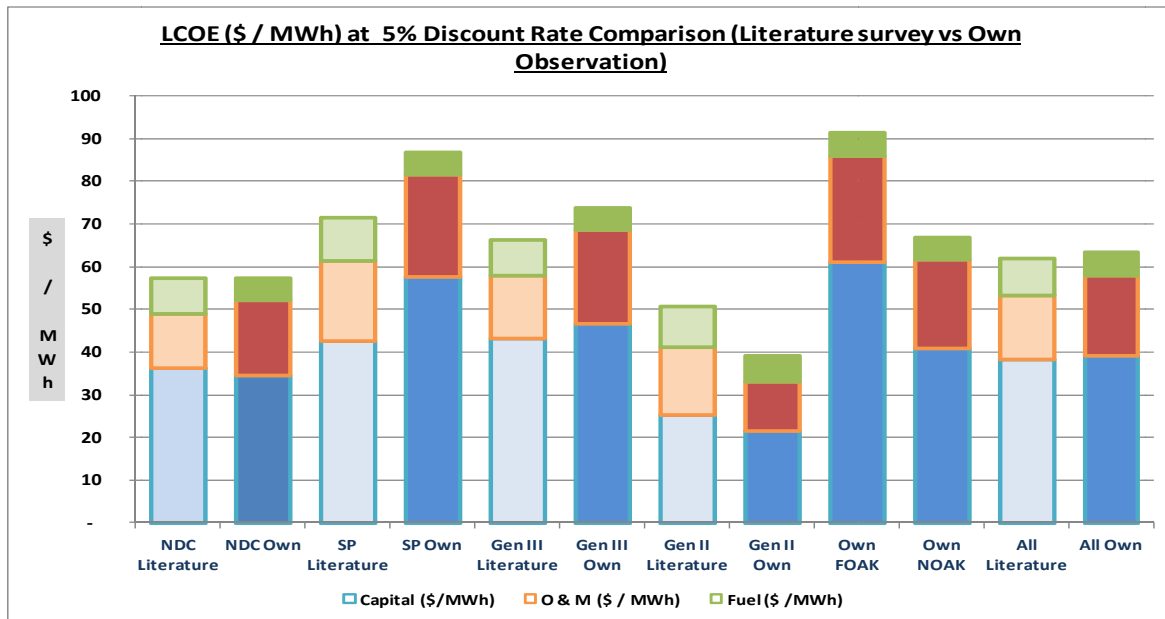


Figure 53: LCOE (\$/MWh) at 5% Discount Rate Comparison (Literature survey Vs Own Observation)

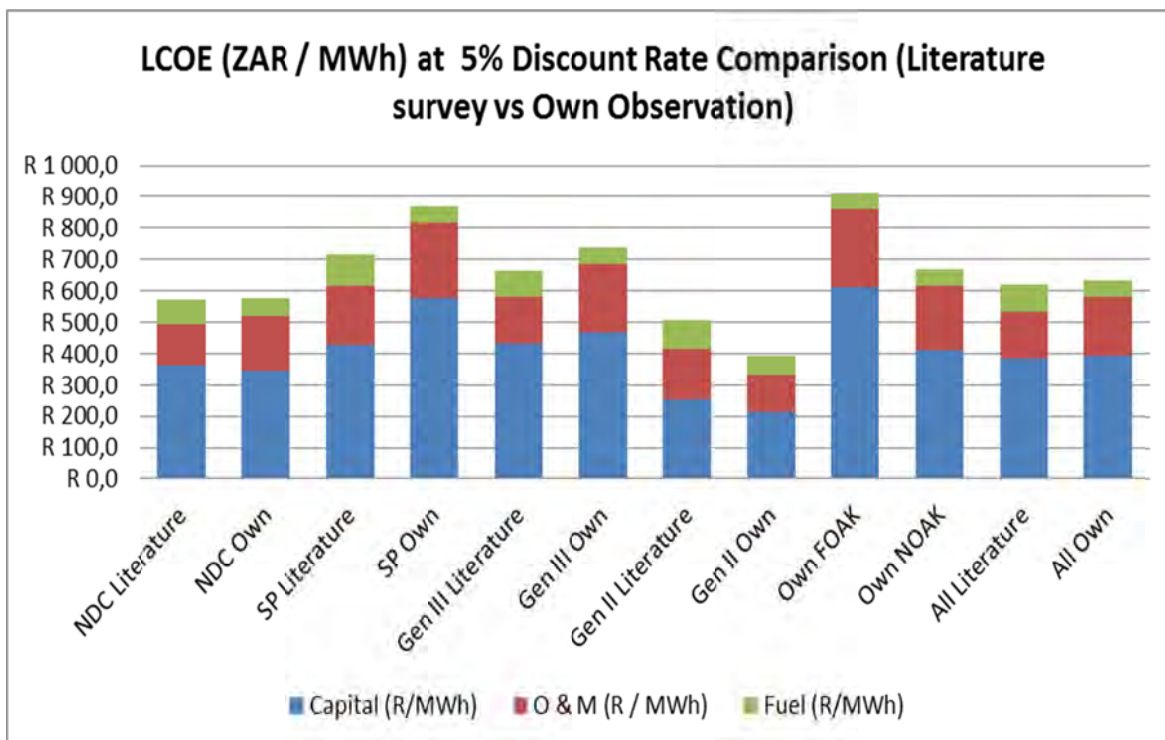


Figure 54: LCOE (ZAR/MWh) at 5% Discount Rate Comparison (Literature survey Vs Own Observation)

**Exchange rate: 10 ZAR per USD*

Results are pretty close between the literature study and the technology study, especially in the NDC Category. Some differences can be explained due to recent new estimates of some project (EPR Flamanville France, EPR Olkiluoto Finland...), literature study does not take into account these recent cost updates, leading to lowest prices in literature for SP (Single Projects) and Generation III.

But Discount rate influences the LCOE quite significantly as illustrated in the next page.

NB: the 6.93 % Discount Rate is the one used in the 2012 EPRI Report “Power Generation Technology Data for Integrated Resource Plan of South Africa”.

	5 % Discount Rate	10 % Discount Rate	6,96 % Discount Rate
All Projects			
LCOE (\$ / MWh)	\$ 63,4	\$ 132,4	\$ 85,3
Decommissioning (\$ / Mwh)	\$ 3,9	\$ 10,2	\$ 5,9
O & M (\$ / MWh)	\$ 14,9	\$ 14,9	\$ 14,9
Spent Fuel (\$ / MWh)	\$ 1,3	\$ 1,3	\$ 1,3
Fuel (\$ /MWh)	\$ 4,1	\$ 4,1	\$ 4,1
Capital (\$/MWh)	\$ 39,2	\$ 101,9	\$ 59,1
Capital (\$ / kWe)	\$ 4 095,2	\$ 4 095,2	\$ 4 095,2
Technologies in Nuclear Developping Countries			
LCOE (\$ / MWh)	\$ 57,6	\$ 116,9	\$ 76,4
Decommissioning (\$ / Mwh)	\$ 3,5	\$ 8,9	\$ 5,2
O & M (\$ / MWh)	\$ 14,1	\$ 14,1	\$ 14,1
Spent Fuel (\$ / MWh)	\$ 1,2	\$ 1,2	\$ 1,2
Fuel (\$ /MWh)	\$ 4,1	\$ 4,1	\$ 4,1
Capital (\$/MWh)	\$ 34,6	\$ 88,5	\$ 51,8
Capital (\$ / kWe)	\$ 3 629,9	\$ 3 629,9	\$ 3 629,9
Technologies in Single Projects			
LCOE (\$ / MWh)	\$ 87,0	\$ 194,7	\$ 120,7
Decommissioning (\$ / Mwh)	\$ 5,8	\$ 15,6	\$ 8,8
O & M (\$ / MWh)	\$ 18,1	\$ 18,1	\$ 18,1
Spent Fuel (\$ / MWh)	\$ 1,6	\$ 1,6	\$ 1,6
Fuel (\$ /MWh)	\$ 3,8	\$ 3,8	\$ 3,8
Capital (\$/MWh)	\$ 57,6	\$ 155,5	\$ 88,4
Capital (\$ / kWe)	\$ 5 956,3	\$ 5 956,3	\$ 5 956,3

	5 % Discount Rate	10 % Discount Rate	6,96 % Discount Rate		5 % Discount Rate	10 % Discount Rate	6,96 % Discount Rate
Gen III				Gen II			
LCOE (\$ / MWh)	\$ 73,8	\$ 159,0	\$ 100,7	LCOE (\$ / MWh)	\$ 39,2	\$ 70,5	\$ 49,2
Decommissioning (\$ /	\$ 4,7	\$ 12,4	\$ 7,1	Decommissioning (\$ /	\$ 2,2	\$ 5,0	\$ 3,1
O & M (\$ / MWh)	\$ 17,2	\$ 17,2	\$ 17,2	O & M (\$ / MWh)	\$ 9,6	\$ 9,6	\$ 9,6
Spent Fuel (\$ / MWh)	\$ 1,3	\$ 1,3	\$ 1,3	Spent Fuel (\$ / MWh)	\$ 1,3	\$ 1,3	\$ 1,3
Fuel (\$ /MWh)	\$ 3,9	\$ 3,9	\$ 3,9	Fuel (\$ /MWh)	\$ 4,5	\$ 4,5	\$ 4,5
Capital (\$/MWh)	\$ 46,8	\$ 124,2	\$ 71,3	Capital (\$/MWh)	\$ 21,6	\$ 50,0	\$ 30,7
Capital (\$ / kWe)	\$ 4 917,8	\$ 4 917,8	\$ 4 917,8	Capital (\$ / kWe)	\$ 2 175,8	\$ 2 175,8	\$ 2 175,8
NOAK (excluding China)				FOAK			
LCOE (\$ / MWh)	\$ 66,8	\$ 140,4	\$ 90,2	LCOE (\$ / MWh)	\$ 91,3	\$ 205,4	\$ 127,1
Decommissioning (\$ /	\$ 4,1	\$ 10,8	\$ 6,2	Decommissioning (\$ /	\$ 6,1	\$ 16,5	\$ 9,4
O & M (\$ / MWh)	\$ 16,6	\$ 16,6	\$ 16,6	O & M (\$ / MWh)	\$ 18,5	\$ 18,5	\$ 18,5
Spent Fuel (\$ / MWh)	\$ 1,2	\$ 1,2	\$ 1,2	Spent Fuel (\$ / MWh)	\$ 1,7	\$ 1,7	\$ 1,7
Fuel (\$ /MWh)	\$ 3,9	\$ 3,9	\$ 3,9	Fuel (\$ /MWh)	\$ 3,8	\$ 3,8	\$ 3,8
Capital (\$/MWh)	\$ 41,0	\$ 107,9	\$ 62,3	Capital (\$/MWh)	\$ 61,2	\$ 164,8	\$ 93,7
Capital (\$ / kWe)	\$ 4 352,4	\$ 4 352,4	\$ 4 352,4	Capital (\$ / kWe)	\$ 6 331,3	\$ 6 331,3	\$ 6 331,3

The following tables use a 6.93% Discount rate.

A- All projects of the utilities study (20 projects)

All Projects	Average	Std.dev	Max at 95% Confidence	Min at 95% Confidence
LCOE (\$ / MWh)	\$ 85,3	\$ 31,9	\$ 147,9	\$ 22,7
Decommissioning (\$ / Mwh)	\$ 5,9	\$ 2,6	\$ 10,9	\$ 0,9
O & M (\$ / MWh)	\$ 14,9	\$ 4,4	\$ 23,6	\$ 6,2
Spent Fuel (\$ / MWh)	\$ 1,3	\$ 0,3	\$ 1,9	\$ 0,7
Fuel (\$ /MWh)	\$ 4,1	\$ 0,4	\$ 4,8	\$ 3,4
Capital (\$/MWh)	\$ 59,1	\$ 25,7	\$ 109,4	\$ 8,8
Capital (\$ / kWe)	\$ 4 095	\$ 1 720	\$ 7 466,1	\$ 724,3

B- All Generation III projects (14 projects)

Gen III	Average	Std.dev	Max at 95% Confidence	Min at 95% Confidence
LCOE (\$ / MWh)	\$ 100,7	\$ 23,5	\$ 146,9	\$ 54,6
Decommissioning (\$ / Mwh)	\$ 7,1	\$ 2,0	\$ 11,0	\$ 3,3
O & M (\$ / MWh)	\$ 17,2	\$ 2,8	\$ 22,7	\$ 11,6
Spent Fuel (\$ / MWh)	\$ 1,3	\$ 0,4	\$ 2,0	\$ 0,6
Fuel (\$ /MWh)	\$ 3,9	\$ 0,2	\$ 4,3	\$ 3,5
Capital (\$/MWh)	\$ 71,3	\$ 19,6	\$ 109,7	\$ 32,8
Capital (\$ / kWe)	\$ 4 918	\$ 1 289	\$ 7 444,5	\$ 2 391,0

C- All FOAK projects (4 projects) – GEN III

FOAK	Average	Std.dev	Max at 95% Confidence	Min at 95% Confidence
LCOE (\$ / MWh)	\$ 127,1	\$ 7,5	\$ 141,8	\$ 112,5
Decommissioning (\$ / Mwh)	\$ 9,4	\$ 0,6	\$ 10,5	\$ 8,2
O & M (\$ / MWh)	\$ 18,5	\$ 1,9	\$ 22,2	\$ 14,9
Spent Fuel (\$ / MWh)	\$ 1,7	\$ 0,5	\$ 2,7	\$ 0,6
Fuel (\$ /MWh)	\$ 3,8	\$ 0,3	\$ 4,4	\$ 3,3
Capital (\$/MWh)	\$ 93,7	\$ 5,9	\$ 105,3	\$ 82,2
Capital (\$ / kWe)	\$ 6 331	\$ 312	\$ 6 943,3	\$ 5 719,2

D- All NOAK projects (10 projects) – GEN III

NOAK	Average	Std.dev	Max at 95% Confidence	Min at 95% Confidence
LCOE (\$ / MWh)	\$ 90,2	\$ 18,7	\$ 126,8	\$ 53,6
Decommissioning (\$ / Mwh)	\$ 6,2	\$ 1,5	\$ 9,2	\$ 3,3
O & M (\$ / MWh)	\$ 16,6	\$ 3,1	\$ 22,6	\$ 10,6
Spent Fuel (\$ / MWh)	\$ 1,2	\$ 0,1	\$ 1,3	\$ 1,0
Fuel (\$ /MWh)	\$ 3,9	\$ 0,2	\$ 4,3	\$ 3,5
Capital (\$/MWh)	\$ 62,3	\$ 15,2	\$ 92,0	\$ 32,5
Capital (\$ / kWe)	\$ 4 352	\$ 1 061	\$ 6 431,3	\$ 2 273,5

6.5.7. LCOE and Capex Range for Gen III technologies

By using the technology model, the range of values of the LCOE can be calculated by changing the values of the various input parameters (Capital Cost /kWe, fuel burnup, etc).

A normal distribution has been used on each parameter according to its average value and its standard deviation (defined by the user), to modify randomly each average value. It enabled to create twenty scenarios of Capital Cost and LCOE, then used to plot distribution of Capital Spending and LCOE.

Capital Cost

Capital Cost	Unit		Average	Std.dev
Discount Rate	%	DATA INPUT	5,0%	0,0%
Installed Capacity	Mwe		1 200	100
Load Factor	%		90%	3%
Life expectancy	Years		60	5
Construction Duration	Years		7,0	1,0
Overnight Cost / kwe	\$ / kWe		5 000	300

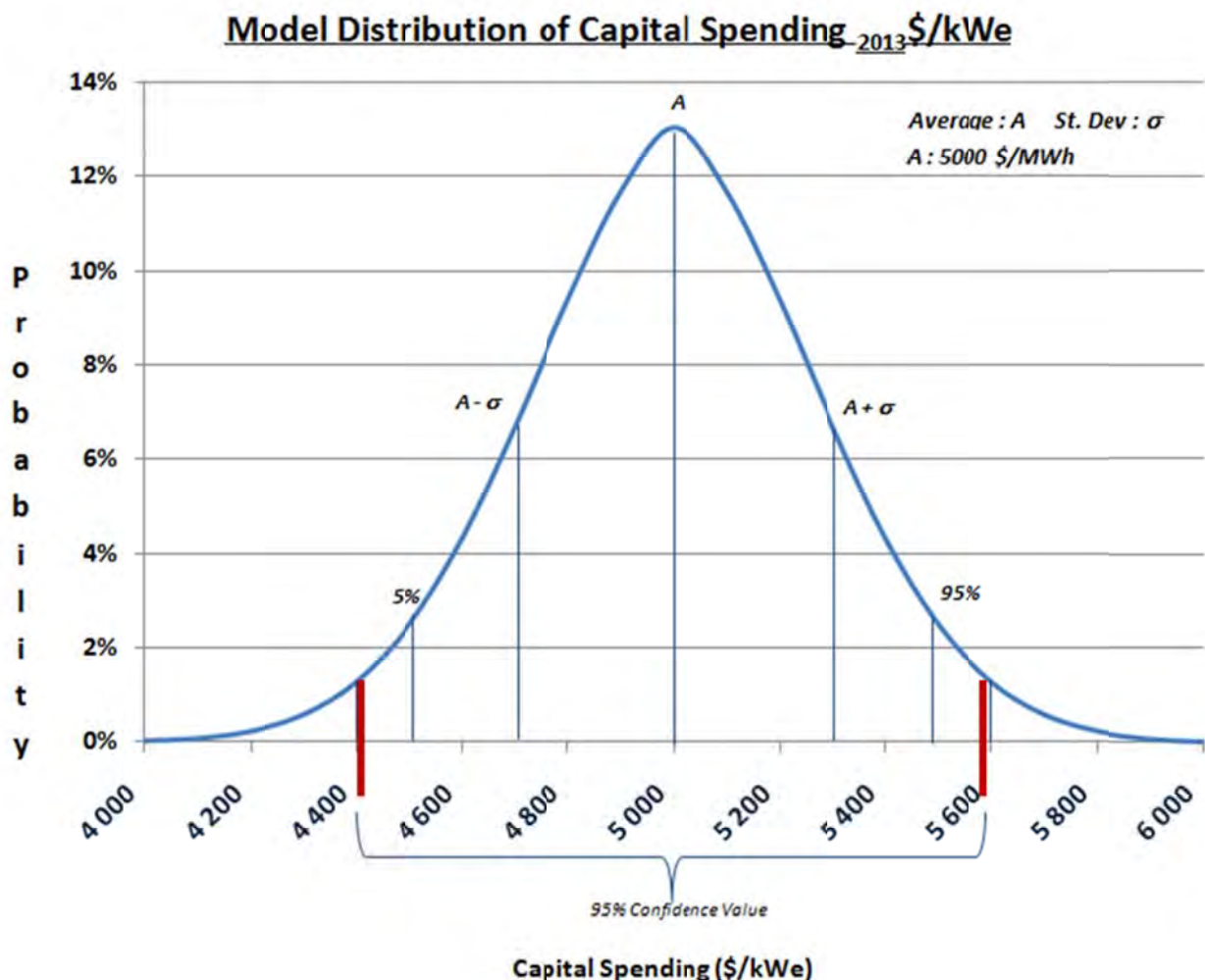


Figure 55: Model Distribution of Capital Spending / KWe

Fuel, Spent Fuel and O & M:

<u>Fuel Cost</u>	<u>Unit</u>		Average	Std.dev
Thermal Efficiency	%	DATA INPUT	35,0%	1,0%
Fuel Burnup	Mwdays/ton		55 000	5 000
Fuel Fabrication Price	\$ / kg UO ₂		250	10
Enrichment Price	\$ / SWU		110	10
Conversion Price	\$ / kg U		10	2
Uranium Ore Price	\$ / lb U ₃ O ₈		40	2
Enrichment (% to average)			1,00	0,00

<u>Spent Fuel</u>	<u>Unit</u>		Average	Std.dev
Nuclear Fuel Back End	% Value Added	INPUT	100%	20%

<u>O & M</u>	<u>Unit</u>		Average	Std.dev
O & M Cost per year	% Cost	INPUT	3,5%	0,5%
Decommissioning Cost	% Cost		8%	1%

LCOE Range:

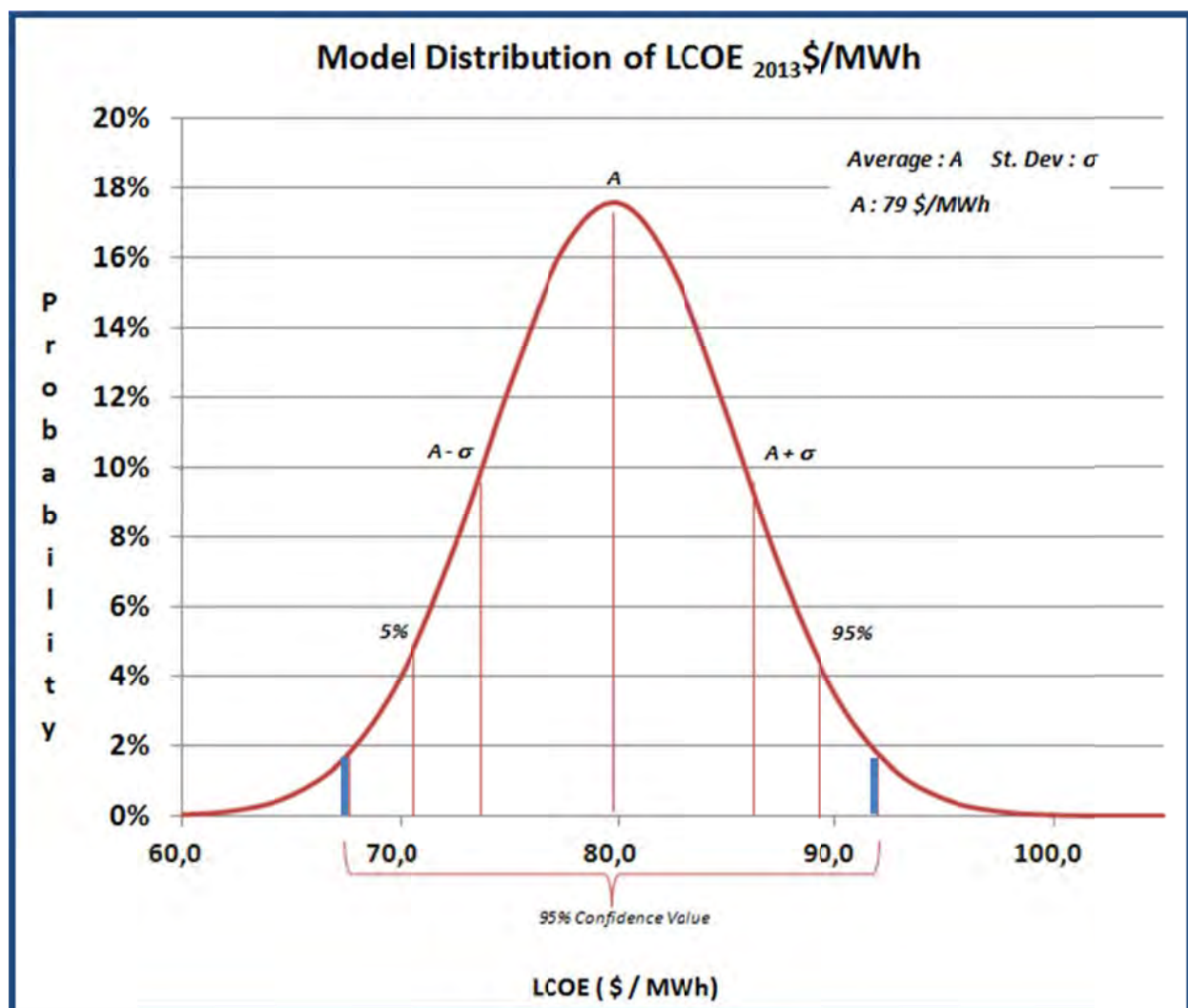


Figure 56: Model Distribution of LCOE

6.6. COMPARISONS TO OTHER ENERGY SOURCES

The Integrated Resource Plan provides a comparison of the cost of nuclear in the South-African context with other energy sources installed or to be installed in South-Africa.

The comparisons made in this report indicate (a) an update of the cost of nuclear based energy upon worldwide data collected and not specific to South-Africa and (b) an update of the cost of other energy sources based upon the last EPRI 2012 analysis (converted into Us \$ and in 2013 estimated values).

As a result, the underlying assumptions made for the other energy sources have been kept and no judgment has been made on the reliability or accuracy of those assumptions, with regard to the current economic environment. As an example, gas (LNG) price assumption is around \$ 4.4 / Mbtu in the EPRI study; this assumption has not been modified, no matter what the current gas market price could be in South-Africa.

Capacity factor being also a significant parameter impacting the LCOE; the assumptions used in the EPRI have not been modified. For Wind energy, where many solutions are presented in the EPRI report, only 2 have been presented in the following graph: average of a 100 X 2 MW farm and best optimal wind farm (with a more than 40 % capacity factor).

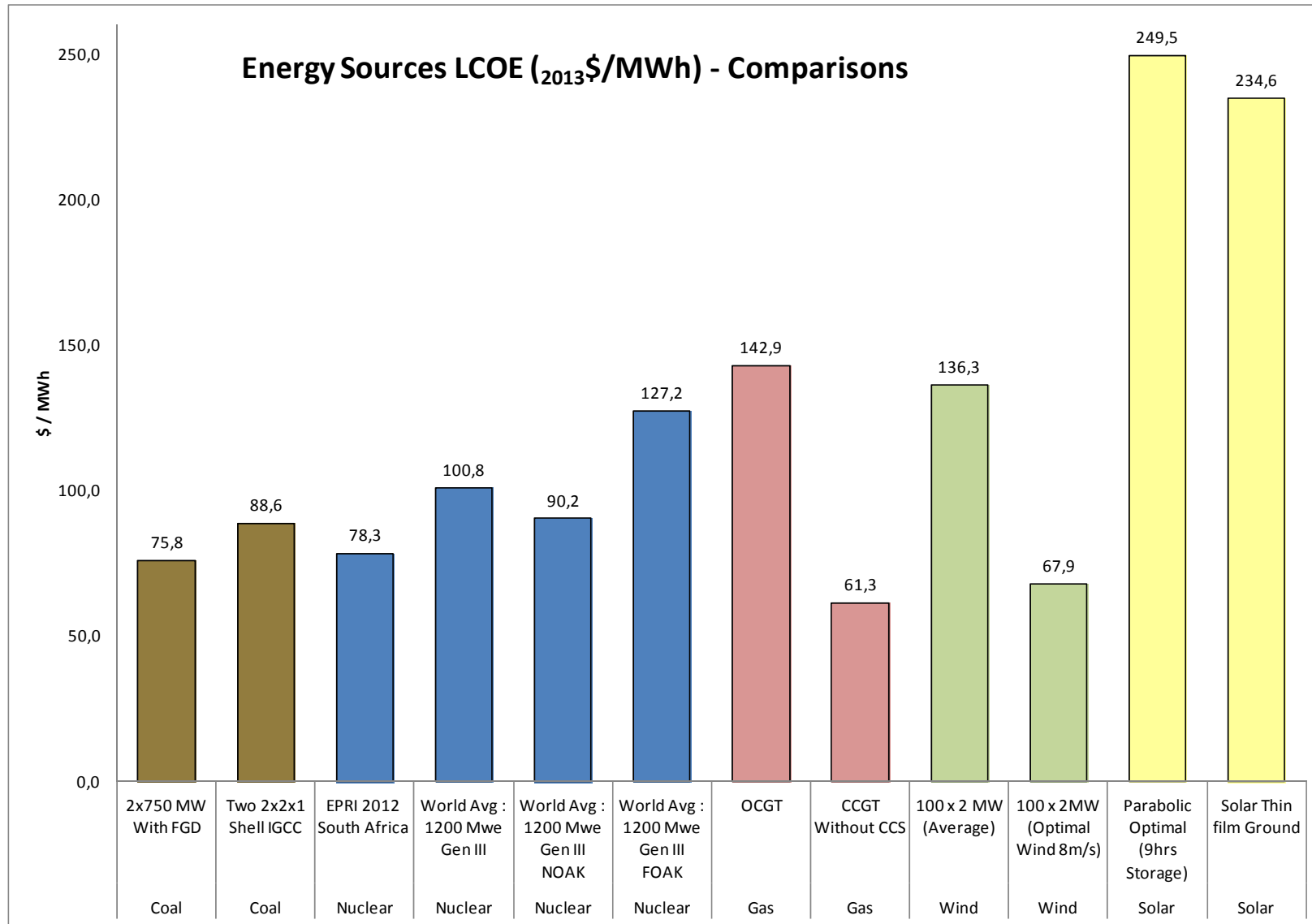


Figure 57: Energy sources LCOE (\$/MWh) Comparisons (for non-nuclear technologies, EPRI 2012 values adjusted for inflation)

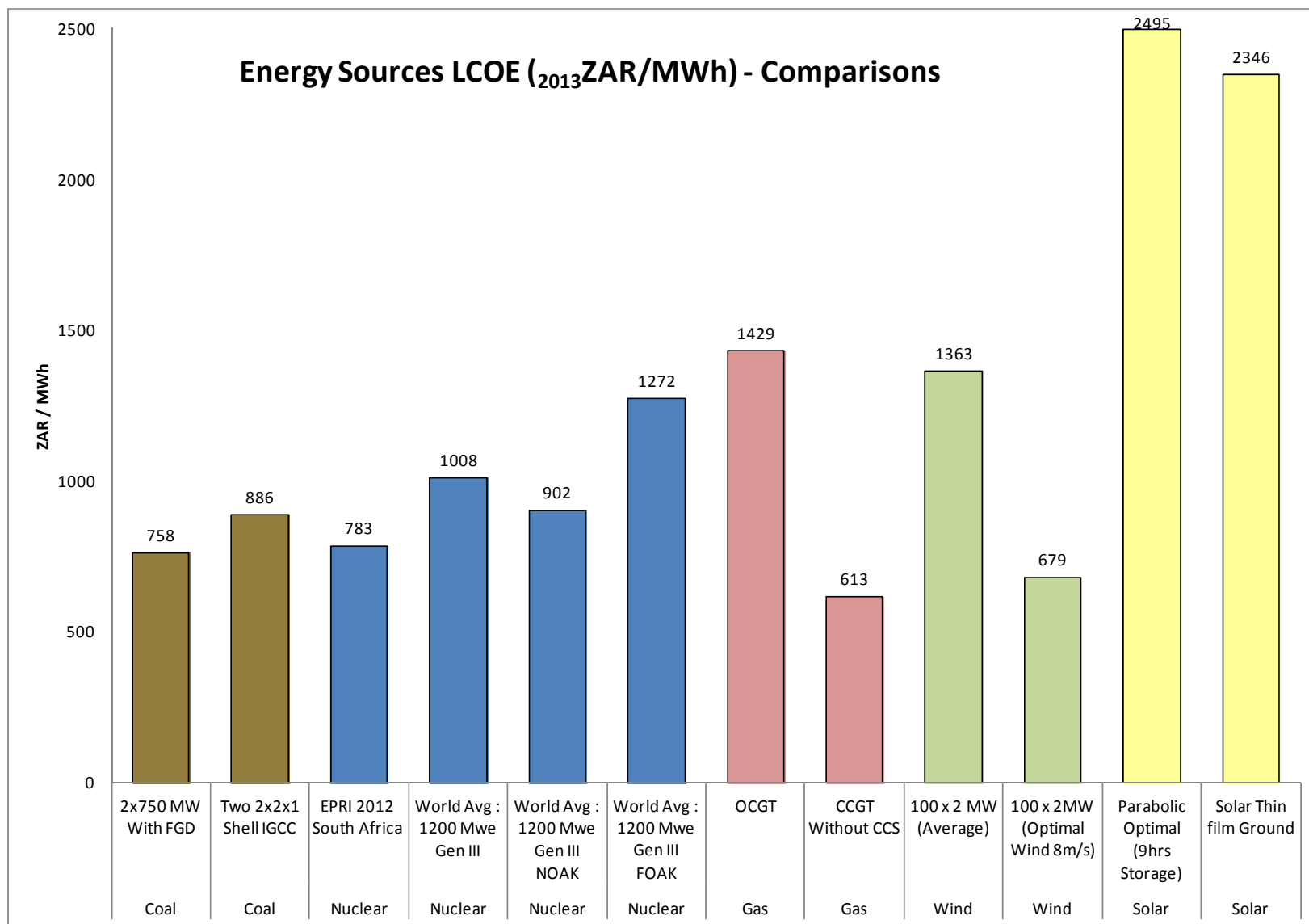


Figure 59: Energy sources LCOE (ZAR/MWh) Comparisons (for non-nuclear technologies, EPRI 2012 values adjusted for inflation) - Exchange rate: 10 ZAR per USD

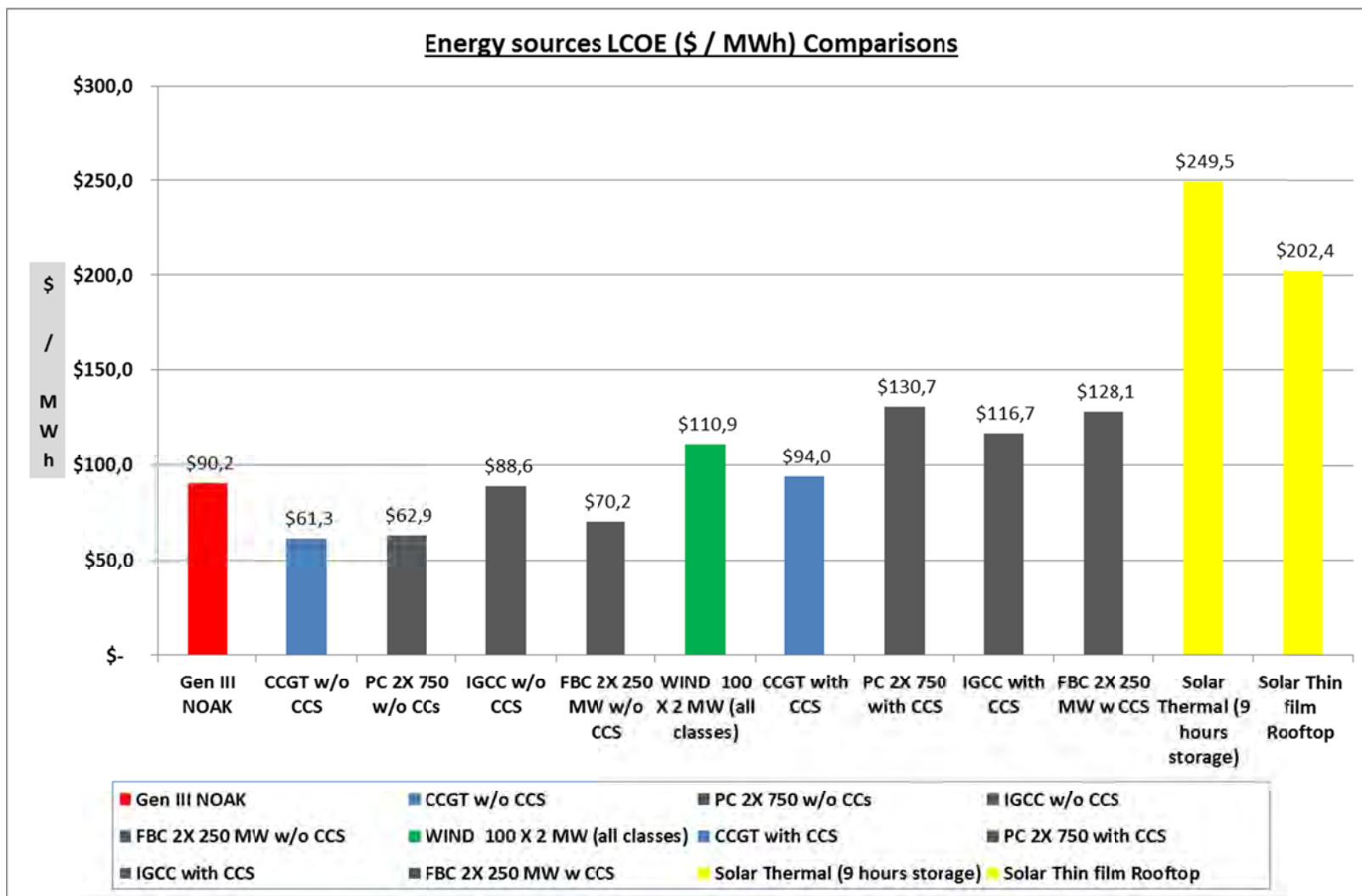


Figure 59: Energy sources LCOE (ZAR / MWh) Comparisons (for non-nuclear technologies, EPRI 2012 values adjusted for inflation) - Exchange rate: 10 ZAR per USD

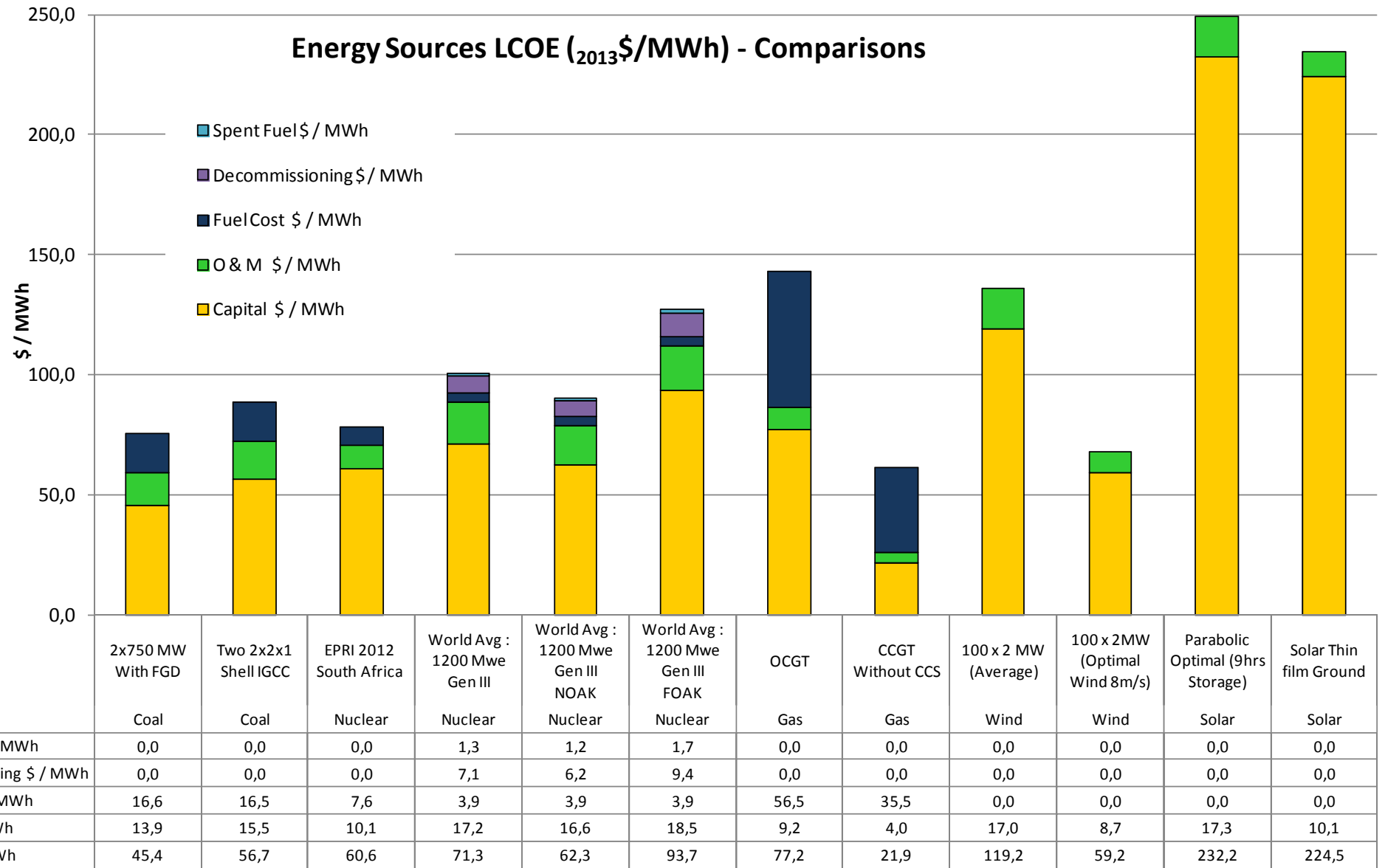


Figure 62: LCOE Comparisons (2013\$/MWh)

The comparison between energy sources can also be viewed in function of its capital intensity, as presented in the following graph, which is influenced not only by the capital cost / kWe but also by the capacity factor of the energy source.

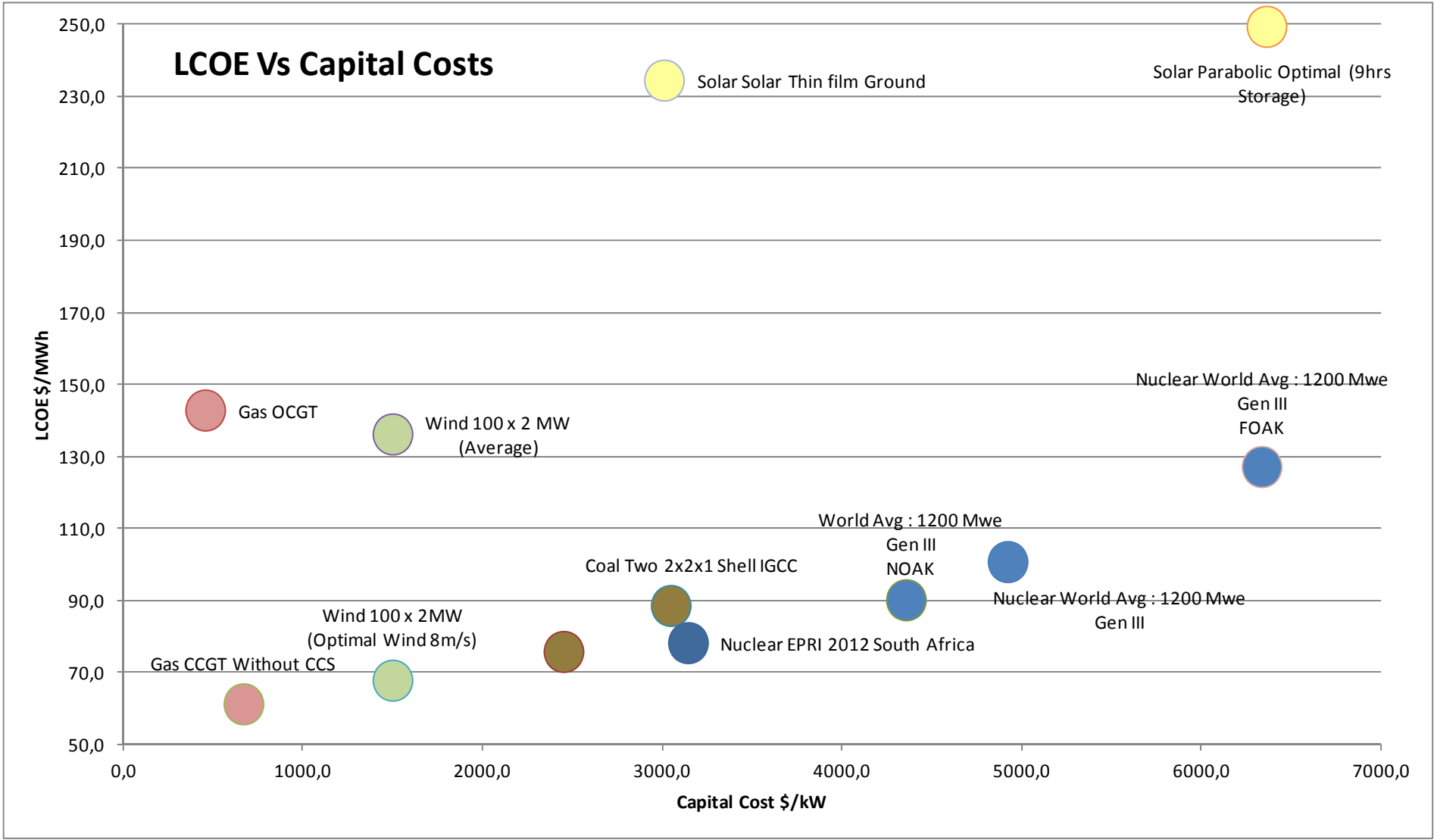


Figure 63: LCOE versus capital cost (\$2013)

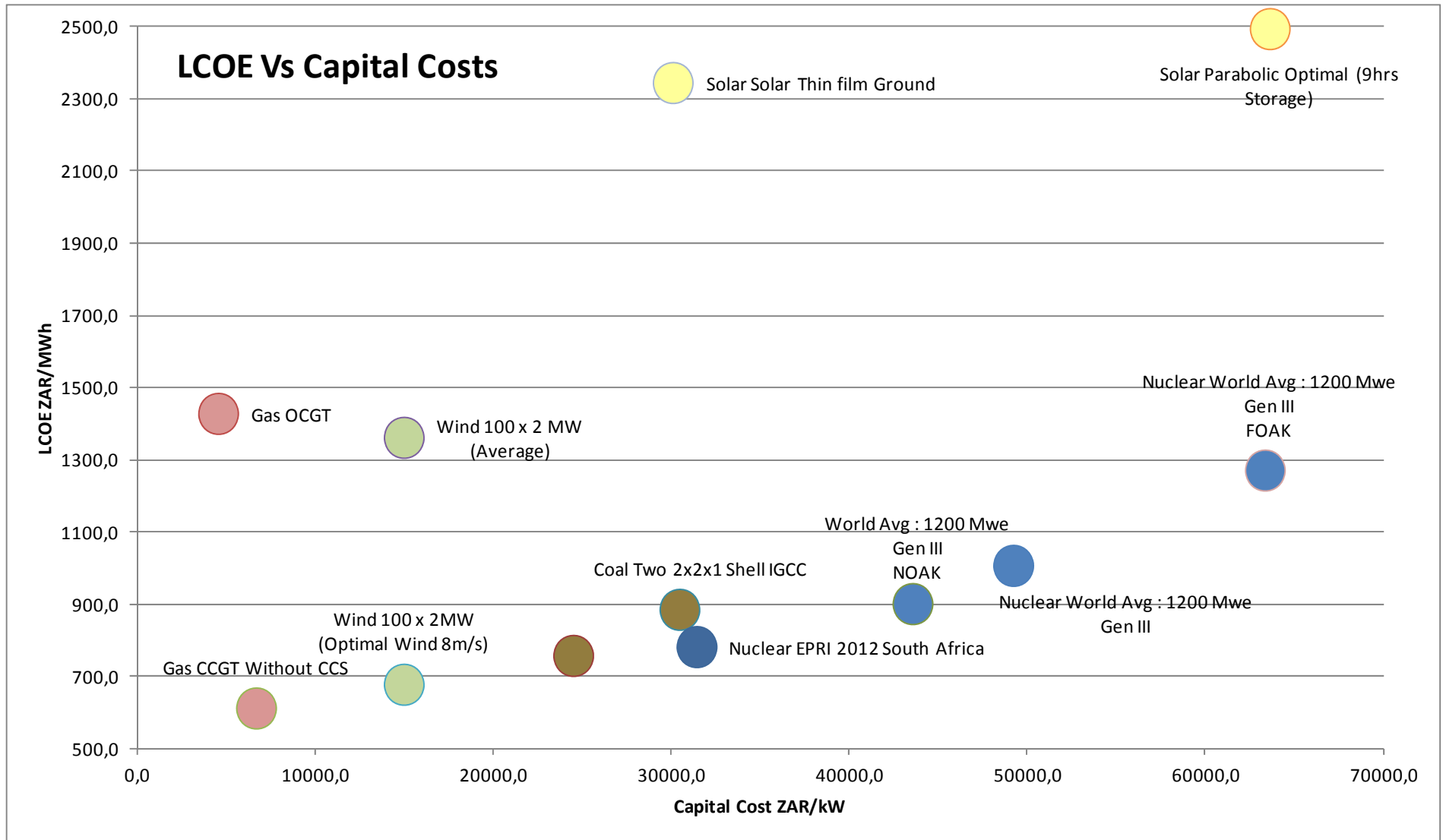


Figure 64: LCOE VS capital cost (ZAR 2013)

Recent publicly available presentation (February, 2013) of ALSTOM (a significant player in the energy sector) indicates a range of values for European new projects, where nuclear is positioned as very competitive to other fossil fuels or renewable energy sources. Absolute values are not provided.

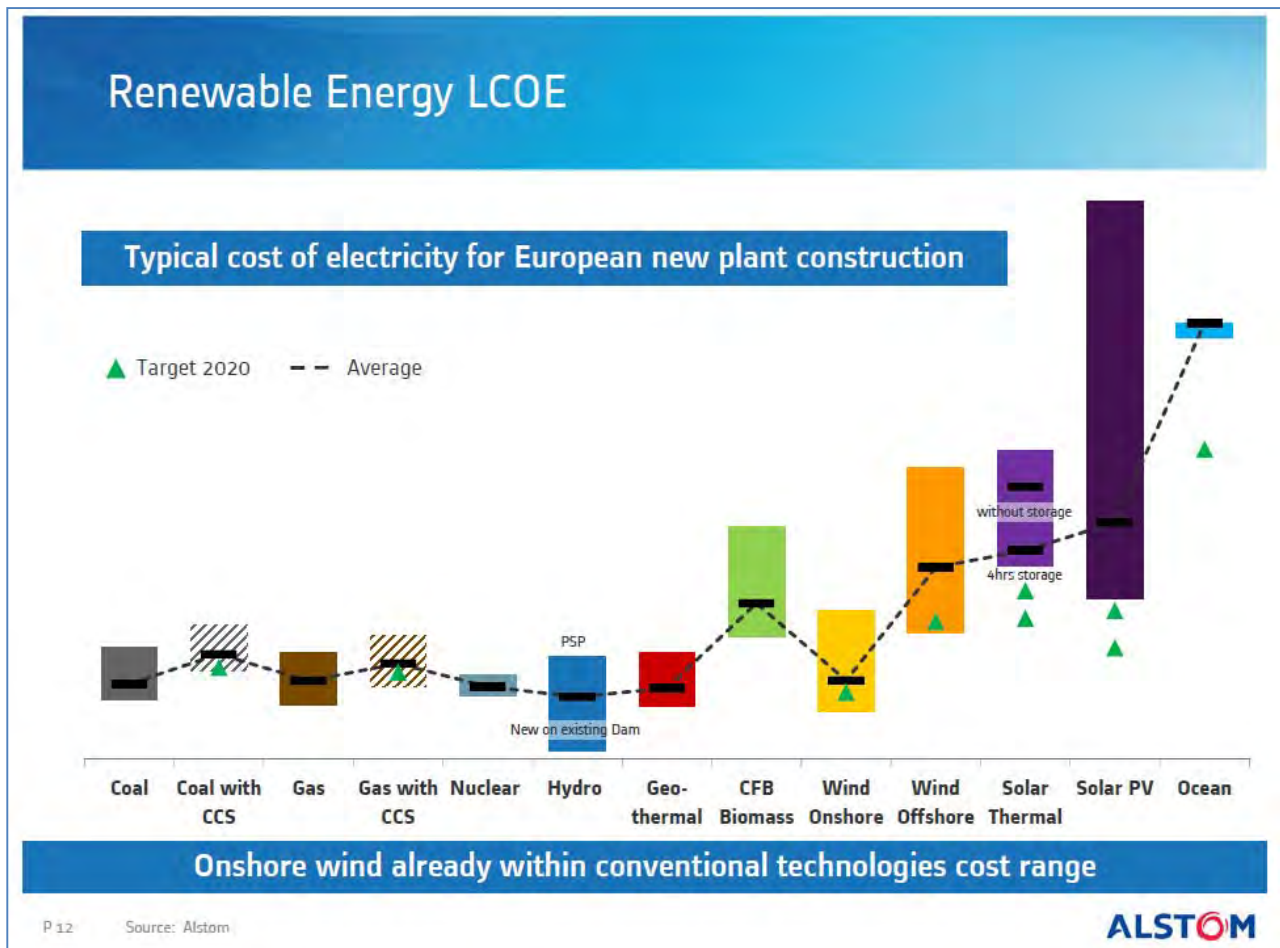


Figure 65 : LCOE Comparison - ALSTOM Presentation Feb 2013

Appendices

Appendix 1 – Literature Studies Summaries



(A) National Audit Office - United Kingdom – The nuclear energy landscape in Great Britain – April 2012

NB: the report does not directly gives the cost details, and refers to a DOE study: Department of Energy & Climate Change (DECC) - DECC Electricity Generation Costs 2013 - July 2013

Reference Year			Units	2013	2012	Comments
CAPEX	Nuclear Plant Start Operations		Year	2013		* For a FOAK/NOAK project Starting in 2013
	Nominal Plant Capacity		MWe	n.a.		
	Capacity Factor		%	n.a.		
	Construction Duration		Months	n.a.		
	Plant (Overnight) Cost	Low	\$/kW	5919	5809	* 3700€/kW
		Average		6559	6437	* 4100€/kW
		High		7359	7222	* 4600€/kW
	Capital Required	Low	\$/MWh	n.a.	n.a.	* 64€/MWh
		High		n.a.	n.a.	
		Average		102	100,48	
Owner Cost + Interest		%	n.a.			
Capital Commitment		Billions \$	n.a.	n.a.		
Annual Output		GWh	n.a.			
OPEX	Variable O&M		\$/MWh	5	4,71	* 3€/MWh
	Fixed O&M		\$/kW/Year	115	113,04	* 72000 £/MW/year
			\$/MWh	17,6	17,27	* 11€/MWh
	Total O&M		\$/MWh	22,4	21,98	
	Total O&M / Plant Cost		%	21,9%		
	Fuel	Mid-Point	\$/MWh	8,0	7,85	* 5€/MWh
Others	Pre-Development Costs		\$/MWh	10	9,42	* 6€/MWh
	Decommissioning & Waste Funds		\$/MWh	3	3,14	* 2€/MWh
TOTAL	LCOE	Low	\$/MWh	n.a.	n.a.	* 90€/MWh
		High		n.a.	n.a.	
		Average		144	141,3	
	Production Cost		\$/MWh	n.a.	n.a.	
Discount Rate After Tax			%	10%		* 10% Discount Rate
Summary	CAPEX		\$/MWh	102		
	O&M		\$/MWh	22,4		
	Fuel		\$/MWh	8,0		
	Other		\$/MWh	13		Pre-developing Costs, Decommissioning & Waste Funds
Conversion Rate			1 £ = 1.57 \$			



(2) National Audit Office - United Kingdom – The nuclear energy landscape in Great Britain – April 2012

NB: the report does not directly gives the cost details, and refers to a DOE study: Department of Energy & Climate Change (DECC) - DECC Electricity Generation Costs 2013 - July 2013

Reference Year			Units	2013	2012	Comments
CAPEX	Nuclear Plant Start Operations		Year	2013		* For a FOAK/NOAK project Starting in 2019
	Nominal Plant Capacity		MWe	n.a.		
	Capacity Factor		%	n.a.		
	Construction Duration		Months	n.a.		
	Plant (Overnight) Cost	Low	\$/kW	5919	5809	* 3700€/kW
		Average		6559	6437	* 4100€/kW
		High		7359	7222	* 4600€/kW
	Capital Required	Low	\$/MWh	n.a.	n.a.	* 56€/MWh
		High		n.a.	n.a.	
		Average		90	87,92	
	Owner Cost + Interest		%	n.a.		
Capital Commitment		Billions \$	n.a.	n.a.		
Annual Output		GWh	n.a.			

OPEX	Variable O&M		\$/MWh	5	4,71	* 3€/MWh
	Fixed O&M		\$/kW/Year	115	113,04	* 72000 £/MW/year
			\$/MWh	16,0	15,7	* 10€/MWh
	Total O&M		\$/MWh	20,8	20,41	
	Total O&M / Plant Cost		%	23,2%		
	Fuel	Mid-Point	\$/MWh	8,0	7,85	* 5€/MWh

Others	Pre-Development Costs		\$/MWh	8	7,85	* 5€/MWh
	Decommissioning & Waste Funds		\$/MWh	3	3,14	* 2€/MWh

TOTAL	LCOE	Low	\$/MWh	n.a.	n.a.	* 80€/MWh
		High		n.a.	n.a.	
		Average		128	125,6	
	Production Cost		\$/MWh	n.a.	n.a.	

Discount Rate After Tax		%	10%		* 10% Discount Rate
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Summary	CAPEX		\$/MWh	90	
	O&M		\$/MWh	20,8	
	Fuel		\$/MWh	8,0	
	Other		\$/MWh	11	Pre-developing Costs, Decommissioning & Waste Funds

Conversion Rate		1 £ = 1,57 \$	
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Department of Resources, Energy and Tourism - Australian Electricity Generation Technology Costs

Reference Year			Units	2013	2009	Comments
CAPEX	Nuclear Plant Start Operations		Year	n.a.		
	Nominal Plant Capacity		MWe	1117		

	Capacity Factor		%	n.a.		* 5,742 AU\$/kW * 137 AU\$/MWh * 6.413 Billion AU\$
	Construction Duration		Months	n.a.		
	Plant Cost (Overnight)	Average	\$/kW	5088	4668	
	Capital Required	Average	\$/MWh	121	111,4	
	Capital Commitment		Billions \$	6	5,21	
	Annual Output		GWh	n.a.		

OPEX	Variable O&M		\$/MWh	5	5,0	* 6,1 AU\$/MWh
	Fixed O&M		\$/kW/Year	130	119,4	* 146,9 AU\$/kW year
			\$/MWh	18	16,2	* 19,9 AU\$/MWh
	Total O&M		\$/MWh	23	21,1	* 26 AU\$/MWh
	Total O&M / Plant Cost		%	23,3%		* 10 AU\$/MWh
	Fuel	Mid-Point	\$/MWh	9	8,1	

TOTAL	LCOE	Average	\$/MWh	153	140,7	* 173 AU\$/MWh
	Production Cost		\$/MWh	n.a.		

Summary	CAPEX		\$/MWh	121	
	O&M		\$/MWh	23,0	
	Fuel		\$/MWh	8,9	
	Other		\$/MWh	0	

Conversion Rate	1 US \$ = 1,23 AU \$
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NB: the values for Investment costs, decommissioning and total LCOE are based on a 5% discount rate

Reference Year		Units	2013	2010	Comments
Belgium EPR 1600					
Summary	Net Capacity	MWe	1600		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	5776	5383	
	Investment Costs (5%)	\$/kW	6637	6185	
	LCOE (5%)	\$/MWh	65,52	61,06	
	CAPEX	\$/MWh	47,53	44,3	
	O&M	\$/MWh	7,73	7,2	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,25	0,23	
Czech Republic PWR					
Summary	Net Capacity	MWe	1150		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	6286	5858	
	Investment Costs (5%)	\$/kW	6859	6392	
	LCOE (5%)	\$/MWh	74,83	69,74	
	CAPEX	\$/MWh	48,77	45,45	
	O&M	\$/MWh	15,82	14,74	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,24	0,22	
France EPR					
Summary	Net Capacity	MWe	1630		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	4142	3860	
	Investment Costs (5%)	\$/kW	4810	4483	
	LCOE (5%)	\$/MWh	60,54	56,42	
	CAPEX	\$/MWh	33,31	31,04	
	O&M	\$/MWh	17,17	16	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,05	0,05	
Germany PWR					
Summary	Net Capacity	MWe	1600		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	4401	4102	
	Investment Costs (5%)	\$/kW	4935	4599	
	LCOE (5%)	\$/MWh	53,62	49,97	
	CAPEX	\$/MWh	34,16	31,84	
	O&M	\$/MWh	9,44	8,8	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,00	0	
Hungary PWR					
Summary	Net Capacity	MWe	1120		
	Overnight Costs	\$/kW	5577	5198	
	Investment Costs (5%)	\$/kW	6043	5632	

	LCOE (5%)	\$/MWh	87,61	81,65	Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	CAPEX	\$/MWh	44,28	41,27	
	O&M	\$/MWh	32,02	29,84	
	Fuel	\$/MWh	9,41	8,77	
	Other	\$/MWh	1,90	1,77	

Japan ABWR					
Summary	Net Capacity	MWe	1330		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	3229	3009	
	Investment Costs (5%)	\$/kW	3680	3430	
	LCOE (5%)	\$/MWh	53,34	49,71	
	CAPEX	\$/MWh	25,48	23,75	
	O&M	\$/MWh	17,70	16,5	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,14	0,13	

Korea OPR-1000					
Summary	Net Capacity	MWe	954		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	2013	1876	
	Investment Costs (5%)	\$/kW	2251	2098	
	LCOE (5%)	\$/MWh	35,33	32,93	
	CAPEX	\$/MWh	15,58	14,52	
	O&M	\$/MWh	11,18	10,42	
	Fuel	\$/MWh	8,48	7,9	
	Other	\$/MWh	0,10	0,09	

Korea APR-1400					
Summary	Net Capacity	MWe	1343		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	1670	1556	
	Investment Costs (5%)	\$/kW	1879	1751	
	LCOE (5%)	\$/MWh	31,17	29,05	
	CAPEX	\$/MWh	13,02	12,13	
	O&M	\$/MWh	9,60	8,95	
	Fuel	\$/MWh	8,48	7,9	
	Other	\$/MWh	0,08	0,07	

Netherlands PWR					
Summary	Net Capacity	MWe	1650		Include front-end costs and back-end costs
	Overnight Costs	\$/kW	5478	5105	
	Investment Costs (5%)	\$/kW	6126	5709	
	LCOE (5%)	\$/MWh	67,34	62,76	
	CAPEX	\$/MWh	42,40	39,52	
	O&M	\$/MWh	14,71	13,71	

	Fuel	\$/MWh	10,01	9,33	* associated with waste management
	Other	\$/MWh	0,21	0,2	* Decommissioning Costs (5%)

Slovak Republic VVER 440/V213					
Summary	Net Capacity	MWe	954		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	4572	4261	
	Investment Costs (5%)	\$/kW	5230	4874	
	LCOE (5%)	\$/MWh	67,16	62,59	
	CAPEX	\$/MWh	38,85	36,21	
	O&M	\$/MWh	18,12	16,89	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,17	0,16	

Switzerland PWR1					
Summary	Net Capacity	MWe	1600		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	6291	5863	
	Investment Costs (5%)	\$/kW	7498	6988	
	LCOE (5%)	\$/MWh	83,95	78,24	
	CAPEX	\$/MWh	52,34	48,78	
	O&M	\$/MWh	21,29	19,84	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,31	0,29	

Switzerland PWR2					
Summary	Net Capacity	MWe	1530		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	4338	4043	
	Investment Costs (5%)	\$/kW	5105	4758	
	LCOE (5%)	\$/MWh	62,05	57,83	
	CAPEX	\$/MWh	35,34	32,94	
	O&M	\$/MWh	16,52	15,4	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,17	0,16	

USA PWR Gen III+					
Summary	Net Capacity	MWe	1350		Include front-end costs and back-end costs * associated with waste management * Decommissioning Costs (5%)
	Overnight Costs	\$/kW	3629	3382	
	Investment Costs (5%)	\$/kW	4092	3814	
	LCOE (5%)	\$/MWh	52,29	48,73	
	CAPEX	\$/MWh	28,33	26,4	
	O&M	\$/MWh	13,81	12,87	
	Fuel	\$/MWh	10,01	9,33	
	Other	\$/MWh	0,14	0,13	

Brazil PWR				
Summary	Net Capacity	MWe	1405	
	Overnight Costs	\$/kW	4075	3798
	Investment Costs (5%)	\$/kW	5046	4703
	LCOE (5%)	\$/MWh	70,06	65,29
	CAPEX	\$/MWh	39,99	37,27
	O&M	\$/MWh	16,67	15,54
	Fuel	\$/MWh	12,49	11,64
	Other	\$/MWh	0,90	0,84

Include front-end costs and back-end costs
* associated with waste management
* Decommissioning Costs (5%)

China CPR 1000 (1)				
Summary	Net Capacity	MWe	1000	
	Overnight Costs	\$/kW	1892	1763
	Investment Costs (5%)	\$/kW	2088	1946
	LCOE (5%)	\$/MWh	32,18	29,99
	CAPEX	\$/MWh	14,46	13,48
	O&M	\$/MWh	7,62	7,1
	Fuel	\$/MWh	10,01	9,33
	Other	\$/MWh	0,09	0,08

Include front-end costs and back-end costs
* associated with waste management
* Decommissioning Costs (5%)

China CPR 1000 (2)				
Summary	Net Capacity	MWe	1000	
	Overnight Costs	\$/kW	1876	1748
	Investment Costs (5%)	\$/kW	2072	1931
	LCOE (5%)	\$/MWh	32,00	29,82
	CAPEX	\$/MWh	14,35	13,37
	O&M	\$/MWh	7,55	7,04
	Fuel	\$/MWh	10,01	9,33
	Other	\$/MWh	0,09	0,08

Include front-end costs and back-end costs
* associated with waste management
* Decommissioning Costs (5%)

China AP 1000				
Summary	Net Capacity	MWe	1250	
	Overnight Costs	\$/kW	2470	2302
	Investment Costs (5%)	\$/kW	2728	2542
	LCOE (5%)	\$/MWh	38,96	36,31
	CAPEX	\$/MWh	18,88	17,6
	O&M	\$/MWh	9,96	9,28
	Fuel	\$/MWh	10,01	9,33
	Other	\$/MWh	0,11	0,1

Include front-end costs and back-end costs
* associated with waste management
* Decommissioning Costs (5%)

Russia VVER 1150				
Summary	Net Capacity	MWe	1070	

	Overnight Costs	\$/kW	3147	2933	
	Investment Costs (5%)	\$/kW	3474	3238	
	LCOE (5%)	\$/MWh	46,66	43,49	
	CAPEX	\$/MWh	24,20	22,55	
	O&M	\$/MWh	18,18	16,94	Include front-end costs and back-end costs
	Fuel	\$/MWh	4,29	4	* associated with waste management
	Other	\$/MWh	0,00	0	* Decommissioning Costs (5%)

EPRI APWR ABWR					
Summary	Net Capacity	MWe	1400		
	Overnight Costs	\$/kW	3187	2970	
	Investment Costs (5%)	\$/kW	3561	3319	
	LCOE (5%)	\$/MWh	51,75	48,23	
	CAPEX	\$/MWh	24,66	22,98	
	O&M	\$/MWh	16,95	15,8	Include front-end costs and back-end costs
	Fuel	\$/MWh	10,01	9,33	* associated with waste management
	Other	\$/MWh	0,13	0,12	* Decommissioning Costs (5%)

Eurelectric EPR 1600					
Summary	Net Capacity	MWe	1600		
	Overnight Costs	\$/kW	5069	4724	
	Investment Costs (5%)	\$/kW	5982	5575	
	LCOE (5%)	\$/MWh	64,30	59,93	
	CAPEX	\$/MWh	41,43	38,61	
	O&M	\$/MWh	12,66	11,8	Include front-end costs and back-end costs
	Fuel	\$/MWh	10,01	9,33	* associated with waste management
	Other	\$/MWh	0,20	0,19	* Decommissioning Costs (5%)

The European Wind Association (EWEA) – Model for comparing and projecting the levelized cost of electricity - 2010

Reference Year			Units	2013	2010	Comments
CAPEX	Nuclear Plant Start Operations		Year	n.a.		* 3000 €/kW * 6000 €/kW
	Nominal Plant Capacity		MWe	1000		
	Capacity Factor		%	85		
	Construction Duration		Months	n.a.		
	Plant (Overnight)	Cost Average	\$/kW	3959	3690	
	Capital Required	Average	\$/MWh	65	n.a.	
	Owner Cost + Interest		%	n.a.		
	Capital Commitment		Billions \$	n.a.	n.a.	
	Annual Output		GWh	7446		
OPEX	Variable O&M		\$/MWh	n.a.	n.a.	* 0,02 €/kWh/year
	Fixed O&M		\$/kW/Year	n.a.	n.a.	* 15 €/kW/Year
			\$/MWh	n.a.	n.a.	
	Total O&M		\$/MWh	57,26	53,4	
	Total O&M / Plant Cost		%	43,5%		
	Fuel	Mid-Point	\$/MWh	9,1	8,5	* 0,005 €/kWh
Others	Pre-Development Costs		\$/MWh	n.a.	n.a.	
	Decommissioning & Waste Funds		\$/MWh	n.a.	n.a.	
TOTAL	LCOE	Average	\$/MWh	132	123	* 99,79 €/kWh
	Production Cost		\$/MWh	n.a.	n.a.	
Nominal Discount Rate			%	7,5%		
Inflation Rate			%	2%		
Discount Rate used			%	5,61%		
Summary	CAPEX		\$/MWh	65,34		
	O&M		\$/MWh	57,26		
	Fuel		\$/MWh	9,09		* Risk Included
	Other		\$/MWh	0		
Conversion Rate			1 € = 1,23 \$			

NB: the values for Investment costs, decommissioning and total LCOE are based on a 5% discount rate

Reference Year	Units	2013	2012	Comments
Summary	Net Capacity	MWe	n.a.	
	Overnight Costs	\$/kW	5365	5000
	LCOE (5%)	\$/MWh	77,26	75,82
	CAPEX	\$/MWh	58,88	57,78
	O&M	\$/MWh	10,22	10,03
	Fuel	\$/MWh	5,66	5,55
	Other	\$/MWh	2,51	2,46

*Decommissioning, waste disposal

NB: the present study do not give LCOE details, consequently **data presented below will not be used**

Project Structure : Project Finance with Loan Guarantee 80% Debt / 20% Equity

Reference Year			Units	2013	2011	Comments
Summary	EPC Cost	Low	\$/kWe	4680	4500	
		High	\$/kWe	5200	5000	
	Total Cost	Low	\$/kWe	6240	6000	
		High	\$/kWe	6864	6600	
	Fuel Cost		\$/MWh	8	7,5	
	Capacity		Mwe	1400		
	First Year Busbar	Low	\$/MWh	87	84	
		High	\$/MWh	95	91	
	Levelized Busbar	Low	\$/MWh	n.a.	n.a.	
		High	\$/MWh	n.a.	n.a.	

Project Structure : Rate Base with CWIP 50% Debt / 50% Equity

Reference Year			Units	2013	2011	Comments
Summary	EPC Cost	Low	\$/kWe	4680	4500	
		High	\$/kWe	5200	5000	
	Total Cost	Low	\$/kWe	5512	5300	
		High	\$/kWe	6032	5800	
	Fuel Cost		\$/MWh	8	7,5	
	Capacity		Mwe	1400		
	First Year Busbar	Low	\$/MWh	120	115	
		High	\$/MWh	131	126	

	Levelized Busbar	Low	\$/MWh	89	86	
		High	\$/MWh	97	93	

2.8. World Nuclear Association – Power Generation in the new policies and the 450 scenarios

NB: the LCOE data comes from the World Energy Outlook 2011

Reference Year	Units	2013	2011	Comments
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2.8. (A) USA - LCOE in the New Policies Scenario 2020

Summary	Overnight Costs	\$/kW	4784	4600	
	LCOE	\$/MWh	89,86	86,4	
	CAPEX	\$/MWh	65,52	63	
	O&M	\$/MWh	13,94	13,4	
	Fuel	\$/MWh	10,40	10	
	Other	\$/MWh	0,00	0	

2.8. (B) China - LCOE in the New Policies Scenario 2020

Summary	Overnight Costs	\$/kW	2080	2000	
	LCOE	\$/MWh	46	44,6	
	CAPEX	\$/MWh	25,58	24,6	
	O&M	\$/MWh	10,40	10	
	Fuel	\$/MWh	10,40	10	
	Other	\$/MWh	0,00	0	

2.8. (C) India - LCOE in the New Policies Scenario 2020

Summary	Overnight Costs	\$/kW	2912	2800	
	LCOE	\$/MWh	65	62,8	
	CAPEX	\$/MWh	39,31	37,8	
	O&M	\$/MWh	15,60	15	
	Fuel	\$/MWh	10,40	10	
	Other	\$/MWh	0,00	0	

World Nuclear Association – The Economics of Nuclear Power – March 2013

NB: the report does not provide detailed LCOE for nuclear



EIA –Electricity Market Module – Assumptions to the Annual Energy outlook 2012

NB: the report does not provide detailed LCOE for nuclear, only Overnight Costs and O&M

Reference Year		Units	2013	2010	Comments
Summary	Online Year	Year	2017		
	Size	Mwe	2236		
	Lead Time	Years	4		
	Base Overnight Cost	\$/kW	4956	4619	
	Project Contingency Factor		1,10		
	Technological Optimism Factor		1,05		
	Total Overnight Cost	\$/kW	5724	5335	
	Variable O&M	\$/MWh	2,19	2,04	
	Fixed O&M	\$/kW	95,23	88,75	



House of Commons – United Kingdom – Energy Prices, Profits and Poverty – March 2013

NB: the report does not provide detailed LCOE for nuclear



House of Commons – United Kingdom – Energy Prices, Profits and Poverty – March 2013

NB: the report does not provide detailed LCOE for nuclear

NB: the report does not provide detailed LCOE for nuclear, only Data for Fuel Costs

Reference Year			Units	2013	2012	Comments
CAPEX	Nuclear Plant Start Operations		Year	2015		
	Nominal Plant Capacity		MWe	1400		
	Capacity Factor		%	90%		
	Construction Duration		Months	84		
	Plant (Overnight) Cost	Low	\$/kW	3974	3900	
		Average		4229	4150	
		High		4484	4400	
	Capital Required	Low	\$/MWh	5350	5250	
		Average		5681	5575	
		High		6012	5900	
Owner Cost + Interest		%	34%			
Capital Commitment		Billions \$	8	7,8		
Annual Output		GWh	11038			
OPEX	Variable O&M		\$/MWh	2	1,7	
	Fixed O&M		\$/kW/Year	112	110	
			\$/MWh	20	19,5	
	Total O&M		\$/MWh	22	21,2	
	Total O&M / Plant Cost		%	4,0%		
	Fuel	Mid-Point	\$/MWh	6	6	
TOTAL	LCOE	Low	\$/MWh	77	76	
		Average		83	81,5	
		High		89	87	
	Production Cost		\$/MWh	28	27,2	
	CAPEX Cost (Average)		\$/MWh	55	54,3	

Debt Structure	%	50,0%	
Nominal Return on Equity	%	11,0%	
Nominal Debt Cost	%	7,0%	
Nominal WACC Pretax	%	9,0%	
Discount Rate after Tax	%	5,0%	

(A) EPRI 2011 - Low Case			
mm ann	Overnight Costs	\$/kW	3974

	LCOE	\$/MWh	77,44
	CAPEX	\$/MWh	49,73
	O&M	\$/MWh	21,60
	Fuel	\$/MWh	6,11
	Other	\$/MWh	0,00

(B) EPRI 2011 - Average Case				
Summary	Overnight Costs	\$/kW	4229	
	LCOE	\$/MWh	83,05	
	CAPEX	\$/MWh	55,33	
	O&M	\$/MWh	21,60	
	Fuel	\$/MWh	6,11	
	Other	\$/MWh	0,00	

(C) EPRI 2011 - High Case				
Summary	Overnight Costs	\$/kW	4484	
	LCOE	\$/MWh	88,65	
	CAPEX	\$/MWh	60,94	
	O&M	\$/MWh	21,60	
	Fuel	\$/MWh	6,11	
	Other	\$/MWh	0,00	



2.15. Exxon Mobil – World Energy Outlook 2013

NB: the report does not provide detailed LCOE for nuclear



2.16. BP – World Energy Outlook 2013

NB: the report does not provide detailed LCOE for nuclear



VGB POWERTECH – Generation portfolio - Sept 2012

Reference Year		Units	2013	2011	Comments
Nuclear Power Plant EPR 1600 - 2011					
Summary	Overnight Costs	\$/kW			
	LCOE	\$/MWh	81,23	78,11	
	CAPEX	\$/MWh	56,41	54,24	

O&M	\$/MWh	11,77	11,32
Fuel	\$/MWh	13,05	12,55
Other	\$/MWh	0,00	0,00

Conversion Rate	1 € = 1,23 \$
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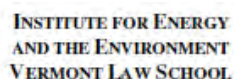
University of California (ILAR) – What does it cost to build a nuclear power plant ? – Sept. 2012

NB: the report does not provide detailed LCOE for nuclear



Massachusetts Institute of Technology – Future of Nuclear Power – Update of the 2003 Study

Reference Year	Units	2013	2009	Comments
Nuclear Power Plant EPR 1600 - 2011				
Overnight Costs	\$/kW	4360	4000	
LCOE	\$/MWh	91,56	84,00	



Institute for Energy and the Environment Vermont law School – Mark Cooper – Policy Challenges of Nuclear Reactor Construction, cost escalation costs and crowding out alternatives 2009

NB: the report does not provide detailed LCOE for nuclear



**2.21. National Bureau of Economic Research – “Prospects for Nuclear Power”
Journal of Economic perspectives, American Economic Association - 2012**

NB: the report does not provide detailed LCOE for nuclear

Appendix 2 – Formulas

General equation

$$LCOE = \frac{\text{Total Life Cycle Cost}}{\text{Total Lifetime Energy Production}}$$

LCOE for Nuclear/ Fossil Fuels

$$LCOE = \frac{\sum_{t=1}^n \frac{I_t + F_t + M_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} \quad \text{Or} \quad LCOE = \frac{\sum_{t=1}^n \frac{I_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} + \frac{\sum_{t=1}^n \frac{F_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} + \frac{\sum_{t=1}^n \frac{M_t}{(1+r)^t}}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}}$$

- **LCOE** = Levelized Cost of Energy
- I_t = Capital Spending in year t (I = Net Present Value of Project Spending)
- F_t = Fuel Spending in year t
- M_t = Maintenance & Operations Spending in year t
- E_t = Electricity Generation in year t
- r = Discount Rate net of inflation
- R = Discount Rate before inflation
- i = Inflation Rate

If F_t , M_t , E_t , are constant whatever the value of t , then LCOE can be simplified to:

$$LCOE = \frac{I}{\sum_{t=1}^n \frac{E_t}{(1+r)^t}} + \frac{F_t}{E_t} + \frac{M_t}{E_t}$$

Provided also that $\frac{R-i}{1-i} = r$

LCOE formula used in the Model

LCOE (in \$ per Mwh)

$$= \frac{\text{Present Value of Capital Spent}}{\text{Present Value of Energy Produced}} + [\text{Fuel Cost} + \text{O \& M Costs}] (\text{in \$ per Mwh})$$

Appendix 3 – Model

Model description

The model structure is based upon the calculation of the following cost factors:

- Capital spending cost,
- Fuel cost,
- Spent fuel and waste cost,
- O & M cost,
- Decommissioning cost,

Each cost factor requires some input parameters specific to the cost category.

Capital Cost

Capital cost portion of the LCOE requires input of parameters describing the reactor technology under review (size, efficiency, cost, etc).

The table below uses the following input data:

- Discount rate of 5 or 10 %
- Installed capacity average of a Gen II or a Gen III reactor
- Same capacity factor (% of days running at full capacity in a year) of 90 %
- Life expectancy of 40 years for Gen II and 60 years per Gen III
- Construction duration of 6 years for Gen II and 7 for Gen III
- Average cost / kWe found in the Literature

CAPITAL COST CALCULATION						
Line item	Unit	Gen II	Gen III	Gen II	Gen III	
Discount Rate	%	5,0%	5,0%	10,0%	10,0%	DATA INPUT
Installed Capacity	Mwe	1 006	1 348	1 006	1 348	
Load Factor	%	90%	90%	90%	90%	
Life expectancy	Years	40	60	40	60	
Construction Duration	Years	6,0	7,0	6,0	7,0	
Overnight Cost / kwe	\$ / kWe	3 186	4 044	3 186	4 044	
Annual Average Output	MWh	7 931	10 628	7 931	10 628	OUTPUT
NPV Energy Produced	MWh	101 555	142 970	43 781	54 357	
Overnight Cost	M\$	3 205	5 451	3 205	5 451	
Capital in LCOE	\$ / Mwh	31,6	38,1	73,2	100,3	

Front end Fuel Cost

Fuel cost calculation requires two sets of information:

- Technical data reflecting the reactor technology capabilities
- Pricing information on fuel cost factors.

For comparisons purposes, fuel factors pricing are assumed to be identical for all technology (which may not be true as pricing may depend upon quantity of fuel purchased, but will favour larger volume).

Plant thermal efficiency and fuel “burnup” (quantity of energy delivered per tons of fuel), are the primary factors influencing fuel cost / MWh.

FUEL COST CALCULATION						
Line item	Unit	Gen II	Gen III	Gen II	Gen III	
Thermal Efficiency	%	33,0%	35,0%	33,0%	35,0%	DATA INPUT
Fuel Burnup	Mwdays/ton	50 000	60 000	50 000	60 000	
Fuel Fabrication Price	\$ / kg UO ₂	250	250	250	250	
Enrichment Price	\$ / SWU	110	110	110	110	
Conversion Price	\$ / kg U	10	10	10	10	
Uranium Ore Price	\$ / lb U ₃ O ₈	40	40	40	40	
Enrichment (% to average)		1,00	1,00	1,00	1,00	
Annual Nuclear Fuel Usage	Tons	20,03	21,09	20,03	21,09	OUTPUT
Fuel Cost / kg	\$ / kg	1 910	1 910	1 910	1 910	
Nuclear Fuel fabrication	\$ / kg	250	250	250	250	
U Enrichment	\$ / kg	800	800	800	800	
Uranium Conversion	\$ / kg	80	80	80	80	
Uranium Ore	\$ / kg	780	780	780	780	
Fuel Value added	\$ / kg	1 130	1 130	1 130	1 130	
Fuel Annual Fuel Cost	M\$	38	40	38	40	
Fuel in LCOE	\$ / Mwh	4,8	3,8	4,8	3,8	

Technology performance has an impact on fuel cost; however such impact is quite small compared to the capital cost variation.

Spent Fuel Cost

The model utilizes an estimate based upon a certain % of the value added costs of fuel (value added is the value of enrichment services, conversion and fabrication of the fuel assemblies).

SPENT FUEL COST CALCULATION						
Line item	Unit	Gen II	Gen III	Gen II	Gen III	
Nuclear Fuel Back End	% Value Added	75%	75%	75%	75%	INPUT
Nuclear Fuel Back End	M\$	17	18	17	18	OUTPUT
Spent Fuel in LCOE	\$ / Mwh	2,1	1,7	2,1	1,7	

O & M Cost / Decommissioning Cost

Those costs are expressed as a % of capital spending and are assumed to be identical for all reactor technologies; this would favour low cost / kWe reactors, but this would be consistent with the fact that lower cost reactors may have lower costs spare parts and cheaper labour costs.

O & M / DECOMMISSIONING COST						
<u>Line item</u>	<u>Unit</u>	<u>Gen II</u>	<u>Gen III</u>	<u>Gen II</u>	<u>Gen III</u>	
O & M Cost per year	% Cost	4,5%	4,0%	4,5%	4,0%	INPUT
Decommissioning Cost	% Cost	10%	10%	10%	10%	
Annual O & M	M\$	144	218	144	218	OUTPUT
O & M / kWe	\$ / kWe	143	162	143	162	
Decommissioning Provision	M\$	321	545	321	545	
O & M in LCOE	\$ / Mwh	18,2	20,5	18,2	20,5	
DECOM in LCOE	\$ / Mwh	3,2	3,8	7,3	10,0	

Appendix 4 – Fuel Costs

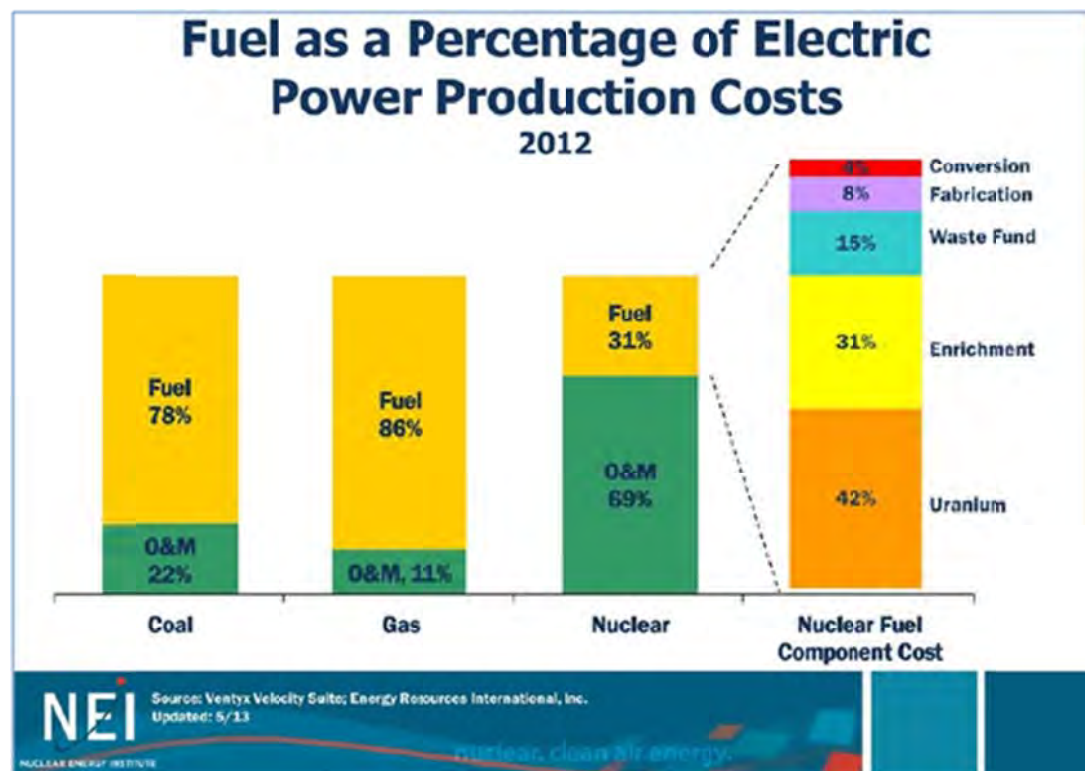
Fuel Cost Breakdown

Nuclear fuel cost per megawatt hour of electricity is a function of many factors, among them the most important are:

- The **performance of the reactor model and of the fuel itself**, in particular, the **thermal efficiency** of the reactor (generally expressed as a ratio between electric megawatt hour produced divided by the thermal megawatt hour produced by the reactor) and the **fuel burn-up** or discharge (generally expressed in megawatt days per tons of fuel),
- The **fuel price**, which is a function of the **market price of Uranium**, the **value of the Enrichment** of the Uranium, the **fabrication cost of the fuel assemblies**, the **transportation and storage costs**,
- The volume of fuel purchase, or of the components of the fuel (natural uranium, SWU, etc)
- The **contractual purchasing structure of fuel** by the utilities, as nuclear fuel is often purchased by the utilities on the basis of long term agreement,

US based Nuclear Energy Institute regularly publishes an update of production cost breakdown, that would cover both PWR and BWR (production cost is the sum of fuel cost and operations costs and excludes capital costs).In 2012, Uranium costs was the largest single component of the costs, followed by the enrichment activity costs. Conversion and fuel fabrication accounted for less than 15 % of the total cost.

It is worth noting that the NEI cost includes waste management (the scope remains not defined) whereas it is very likely that the EPRI cost does not include such cost. This explains why US utilities cited in the study appears to have a higher fuel cost than, say Kepco, among others.



The Consultant nuclear fuel cost central assumption for LWR, excluding spent fuel management cost or waste management cost, based upon current measured market prices and physical quantity used for the reactors, is the following:

Fuel Cost / kg	Units	Unit Cost	Per kg UO ₂	Value	%
Fabrication	\$/kg UO ₂	250,00	1,00	\$ 250	12,6%
Enrichment	\$/SWU	117,00	7,30	\$ 850	42,9%
Conversion	\$/kg U	10,00	7,50	\$ 80	4,0%
Uranium Ore	\$/lb U ₃ O ₈	41,00	19,58	\$ 800	40,4%
Nuclear Fuel Costs/kg				\$ 1 980	100,0%

The Consultant assumes that such price should be common to any PWR reactor technology in the remaining of the study.

Nuclear Fuel cost factor evolution

Most, if not all, electric utilities buy fuel services under long term agreements with nuclear fuel vendors. (First core load of any new nuclear plant is supplied together with the reactor itself).

However, in some countries where the volume justifies it, fabrication may be assumed locally (Korea, USA, Russia, etc). Total fuel price may be impacted by local costs conditions that might be less expensive than prices from international suppliers.

Market prices for the various cost components other than fabrication of the nuclear fuel usually follow trends on the international market. But they do not necessarily reflects contractual arrangements between vendors and users (as a reminder, favorable terms of fuel supply agreement between Russia and CEZ are correlated with long term relationships and contracts)

The table below reflects the most recent trend for the price of Uranium, the conversion service cost and the enrichment services (enrichment services are market prices, including the situation of countries which have enrichment facilities, and countries which have not):

Monthly Spot Market Prices										
	Change	Jul	Jun	May	2013 Apr	Mar	Feb	Jan	2012 Dec	Nov
Uranium (\$/lb U ₃ O ₈)										
Low	-4.65	+34.75	+39.40	+40.00	+40.00	+42.00	+41.75	+41.75	+42.30	+40.25
High	-0.55	+39.60	+40.15	+41.00	+42.00	+42.50	+43.30	+43.50	+45.00	+42.25
Conversion (\$/kgU)										
Low	-0.25	+9.25	+9.50	+9.50	+9.50	+9.50	+9.50	+9.50	+9.50	+9.00
High	+0.25	+10.25	+10.00	+10.00	+10.00	+10.75	+11.00	+11.50	+11.50	+11.00
Enrichment (\$/SWU)										
Low	-3.00	+105.00	+108.00	+110.00	+112.00	+115.00	+115.00	+118.00	+118.00	+118.00
High	-	+114.00	+114.00	+114.00	+116.00	+119.00	+122.00	+127.00	+127.00	+127.00

NIW monthly UF₆, SWU and U₃O₈ prices rely on the general consensus of direct market participants and is informed by actual market transactions. This section was previously known as the Nukem Weekly Report and the Nukem Price Bulletin. The methodology for NIW's weekly UPP price is different – more information about the methodology behind that price is available on page two.

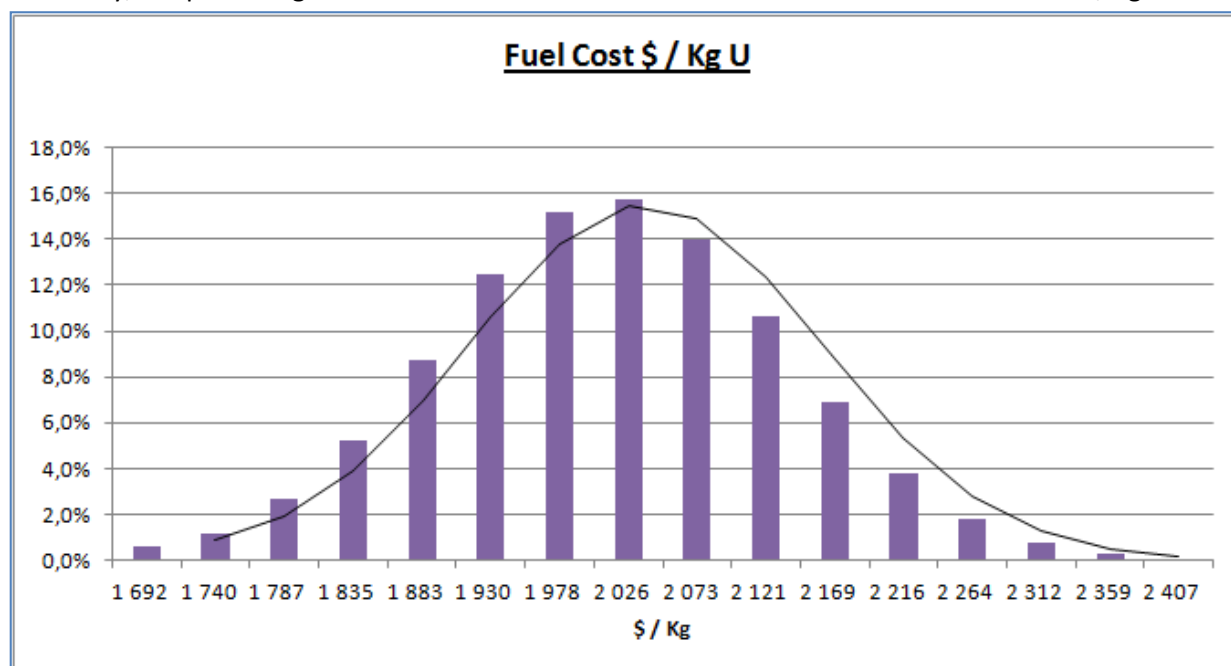
Those key costs drivers for nuclear fuel can be summarized below, as calculated upon the most recent trends:

Fuel Cost Factor		Average	Std.Dev
Uranium	\$/lb U ₃ O ₈	\$ 41,3	\$ 1,9
Conversion	\$/kg U	\$ 10,1	\$ 0,3

Enrichment	\$/SWU	\$ 116,6	\$ 5,2
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Fabrication costs are not largely published as they are very much vendor specific. It is however estimated that the range of values is between \$ 200 and 250 / KgU² for western technology (excluding Russia and China).

Statistically, the price range of nuclear fresh fuel can be valued between \$ 1 800 and \$ 2 200 / kg.



Appendix 5 – ABWR

The ABWR model was developed by General Electric with Hitachi and Toshiba in the early 1990s. It claims to be a Generation III or III+ design, although this latter qualification is disputable.

Four units were built in Japan from 1996 to 2006 (Kashiwazaki-Kariwa units 6 and 7 ; Hamaoka unit 5 and Shika 2. Extension plans which were underway at Fukushima site (Units 7 and 8) and at Shimane (Unit 3 are shelved following the Fukushima accident.

Two units are built at the Longmen site, in Taiwan ; they are facing serious delays, due to political opposition.

Toshiba offered the ABWR technology for an extension of the South Texas plant in the US; however, this project was also shelved following revision of budget, and the Fukushima accident.

The ABWR offered by Lithuania is also frozen, following political changes in this country.

Finally, in November 2012, Hitachi took over the UK Company Horizon, a former joint venture between RWE and E.On, which planned to build nuclear plants in Great Britain, at two sites owned by Horizon (Wilfa and Oldbury). Hitachi, through Horizon, is starting the licensing process of the ABWR (or a more advanced model) in the UK.

Due to this situation, there are no reliable figures on the cost of the ABWR

ABWR output: 1.350 MWe

Longmen construction cost – initial budget: US\$6.77 billion – actual: US\$ 9.40 billion ; these figures can be found on Internet (including in the Wikipedia page on Longmen) but are not seriously documented. However, they are correlated with a press release of the World Nuclear

Association dated March 12, 2009 [http://www.world-nuclear-news.org/NN-Taipower More money to complete Lungmen-1203097.html](http://www.world-nuclear-news.org/NN-Taipower-More-money-to-complete-Lungmen-1203097.html) which reports a budget increase bringing it at US\$7.8-8.1 billion. This would price the ABWR technology at **3 500 \$/kW** for the highest budgeted figure.

South Texas construction cost

NRG, a Texan utility, and Toshiba partnered in a Joint venture named “Nuclear Innovation North America” (Nina). NRG was the lead investor in the extension project to build South Texas Units 3 and 4. In April 2011, NRG stepped out of the project because of budget escalation, and the fear of the consequences of the Fukushima accident on future costs.

In 2009, CPS, one of the investors in the project beside NRG estimated its cost at 13 B \$, a 4 B \$ increase compared to the initial budget. It is likely that this cost includes interests during construction.

In 2006, the cost of the project was estimated at 9,2 B \$, excluding interests during construction, ie **3 400 \$/kWe**

<http://www.bizjournals.com/sanantonio/stories/2009/12/21/daily27.html?page=all>

Lithuania

In July 2011, Lithuania selected Hitachi—Hitachi-GE Nuclear Energy consortium as the strategic investor in the proposed Visaginas nuclear power plant. The strategic investor would take a 51% stake in the plant.

The structure of the deal was expected to be a Public Private Partnership, and no investment figure was officially released. <http://www.neimagazine.com/news/newslithuania-chooses-hitachi-ge-as-strategic-investor-for-visaginas>

However, it was reported that the initial investment figure quoted by Hitachi was 5 B Euros (OSW - Center for Eastern Studies <http://www.osw.waw.pl/en/publikacje/osw-commentary/2012-07-26/visaginas-nuclear-power-plant-still-highrisk-investment>), ie **4 800 \$/kW**.

Discussions are going on between Lithuania and neighboring Baltic countries (Latvia and Estonia) but it seems difficult for them to structure a financial agreement.

<http://www.15min.lt/en/article/business/latvia-and-estonia-show-no-enthusiasm-about-lithuanian-nuclear-power-plant-project-527-371341> .

Great Britain

The ABWR project in the UK is at a very early stage of development and no figures have been reported on this project so far.

Generic information

Overnight costs for ABWR were estimated for Japan by IEA and EPRI at **\$3009/kWe**, and EPRI contributed a generic estimate for ABWR of **\$2970/kWe** (ADVANCED NUCLEAR POWER PLANT CONCEPTS AND TIMETABLES FOR THEIR COMMERCIAL DEPLOYMENT – Stephen Cholly - Institute of Safety/Security and Risk Sciences, University of Natural Resources and Life Sciences – June 2013); but these estimates are old, and very likely below present costs.

Appendix 6 – Decommissioning Costs

With respect to decommissioning, it would be difficult to claim that there is an established set of regulations, established processes, and therefore a well-established market and reference costs. For the purpose of this study, the Consultant used four types of data, which were converted to 2013 Dollars, using the conversion table of Section “data analysis”.

1. Data collected from the literature for decommissioning costs of large civil nuclear power plants, which are summarized in the next two pages. From these data, it is found that :
 - The decommissioning budget of French units which decommissioning is currently underway (with the exception of Brennilis which is a specific case) is in the range of **1,08 to 1,530 \$/kWe (2013)**
 - The decommissioning of Connecticut Yankee, a 582 MWe PWR reactor, which ended in 2004 was done under a budget of 2,550 \$/MWe (2013)
 - The World Nuclear Association, in a report issued in 2003 claims that the decommissioning of PWRs should be in the range of 330 \$/MWe (2003), ie **420 \$/MWe (2013)**
 - The IAEA in 2004 estimated decommissioning costs in the range of 250 to 500 \$/kWe (2004) with a Median value of 350 USD; in 2013 USD, it converts to **310 to 620 \$/kWe**, with a median value of 433 \$/MWe.
2. Data issued by the IAEA in a synthesis report related to the decommissioning of research reactors, which refers to a data base regularly updated by the Agency ; the paragraph “ Decommissioning Data base - Power reactors ” provides the detailed information for reactors which decommissioning costs is or was above 50 M\$. Some reactors which decommissioning costs seems to be unduly high have 2900 \$/MWth been eliminated; for the remaining reactors (a total of eleven), the average decommissioning costs is 2900 \$/MWth. Most of these reactors did not generate electricity; however, we estimate that this would be roughly equivalent to **1100 \$/MWe**, should these reactors have been equipped to generate electricity.
3. Financial information disclosed by Utilities on their accruals related to decommissioning activities, and summarized in the section “data analysis” is quite substantial and accurate on decommissioning issues. They are summarized hereafter:
4. This data were supplemented by data provided by the DOE for four US PWR reactors

CALCULATION BASED ON PROJECTED COSTS	12/31/2012	Capacity				Cost
	Million \$	MW				\$/kWe
EDF France	34 100	63 130				540
GEORGIA POWER	1 002	3 000				334
CALCULATION BASED ON ACTUAL ACCRUALS	12/31/2012	Capacity	Past life	Life to Go	Future Value	Cost
	Million \$	MW	years	years	Million \$	\$/kWe
EDF Group	19 400	77 471	25	25	38 800	501
CEZ	627	4 040	25	25	1 255	311
EXELON	3 720	17 202	25	25	7 440	433
KEPCO	8 516	20 716	25	30	18 735	904

The range is 310 to 904 \$/kW with an average of 537,25 \$/kW (2013).

In total, the range of decommissioning costs lies somewhere between 500 and 1000 \$/kW; depending on the assumption made on discount rate, this cost may have no or a limited influence on the LCOE.

Decommissioning Data base - Power reactors

Name	Type	Power (Mwe)	Date of final shut down	End of decommissioning	Decommissioning budget (M€ 2010)	Decommissioning budget (M\$ 2013)	Decommissioning budget (k\$ 2013) per kwe
Chinon A1	Gas cooled	70	1973	2035	820	\$ 1 143,82	\$ 1,53
Chinon A2		200	1985	2034			
Chinon A3		480	1990	2031			
St Laurent A1		480	1969	2036	813	\$ 1 134,05	\$ 1,14
St Laurent A2		515	1971	2031			
Bugey 1		540	1994	2026	417	\$ 581,67	\$ 1,08
Brennilis	Pressurised Heavy Water Reactor	70	1967	2023	378	\$ 527,27	\$ 7,53
Chooz A	Pressurised Water Reactor	300	1967	2019	223	\$ 311,06	\$ 1,04
Creys Malville	Fast Breeder	1200	1997	2026	955	\$ 1 332,13	\$ 1,11

Reference: French General Accounting Office - 2013

Connecticut Yankee Nuclear Power Plant (CY)	Power : 582 MW	Decommissioning cost M\$1200 (2004)	Decommissioning cost M\$1485,6 (2013)	Cost per MWe 2013 \$2,55
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Reference: Reuters <http://www.reuters.com/article/2011/06/13/idUS178883596820110613>

Decommissioning of a power reactor	250 to 500 USD/kWe (2004) - Median value : 350 USD
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Reference: **IAEA** - Status of the decommissioning of nuclear facilities around the world (2004)
http://www-pub.iaea.org/MTCD/publications/PDF/Pub1201_web.pdf

World Nuclear Association : An OECD survey published in 2003 reported US dollar (2001) costs by reactor type. For western PWRs, most were \$200-500/kWe , for VVERs costs were around \$330/kWe , for BWRs \$300-550/kWe , for CANDU \$270-430/kWe . For gas-cooled reactors the costs were much higher due to the greater amount of radioactive materials involved, reaching \$2600/kWe for some UK Magnox reactors
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Reference: World Nuclear Association <http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Decommissioning-Nuclear-Facilities/#.UlaqlzVOLIU>

Decommissioning data base Research reactors

FACILITY NAME	REACTOR TYPE	COST PER MWth	THEMAL POWER	START OF PREL,	END OF FINAL	COST	Cost M \$ - year of dismantling	Cost M\$ - 2013
			STEADY	DECOMM,	DISMANTLING			
			(KW)	(YEAR/MONT H)	(YEAR/MONT H)	ORIG, CURRENCY		
FFTF - FAST FLUX TEST FACILITY	FAST NA COOLED	1,368	400000	N/A	e2016	547,0 M USD	547	711
HFBR - HIGH FLUX BEAM REACTOR	HEAVY WATER	1,900	60000	2001	e2020	114,0 M USD	114	124
FR-2	TANK	1,920	44000	1986/07		65,0 M UR	85	95
HFR	TANK IN POOL	2,000	45000			69,0 M UR	90	104
EL 4	HEAVY WATER	2,347	267000	1985	e2015	482,0 M URO	627	727
SAFARI-1	TANK	2,500	20000			50,0 M USD	50	64
SILOE	POOL	2,914	35000	1999	2011	102,0 M USD	102	106
DOUNREAY FAST REACTOR	FAST BREEDER NA	3,692	65000	1978	e2032	240,0 M USD	240	288
RAPSODIE	FAST POWER	4,128	40000	1987	e2017+	127,0 M URO	165	179
TFTR	FUSION TEST REACTOR	4,299	10700	N/A	2002/09	46,0 M USD	46	62
BR-3	PWR POWER	4,831	40900	N/A	e2012	152,0 M URO	198	245
FRJ-2 (DIDO)	HEAVY WATER	5,652	23000	N/A	N/A	100,0 M UR	130	147
BGRR - BROOKHAVEN GRAPHITE RESEARCH REACTOR	GRAPHITE	6,000	20000	1969/09	e2011/11	120,0 M USD	120	129
TRIGA II PITESTI - SS CORE	TRIGA DUAL CORE	7,143	14000	N/A	N/A	100,0 M UR	100	116
R-A	HEAVY WATER	9,231	6500	N/A	e2014/01	60,0 M USD	60	70
FRG-1	POOL	20,000	5000	N/A	N/A	100,0 M UR	100	113
TRR-1	HEAVY WATER- NRX	21,250	40000	1990	e2007	850,0 M NT\$	850	986
R2-0	POOL	74,490	1000	N/A	e2016	57,3 M URO	74	84
ISPRA-1	TANK	167,70	5000	1975	e2015	645,0 M UR	839	946
Average		2,900		Standard deviation		1,16		

Data provided by DOE						Cost k\$ per kW (2013) *
USA	Yankee Rowe (1)	PWR 185 MWe	31 years (1960–1991)	Decon completed - Demolished (greenfield open to visitors) ^[17]	\$608 million with \$8 million per year upkeep	3,28
USA	Maine Yankee	PWR 860 MWe	24 years (closed in 1996)	Decon completed - Demolished in 2004 (greenfield open to visitors) ^{[18][19]}	\$635 million ^[20]	0,914
USA	Connecticut Yankee	PWR 590 MWe	28 years (closed in 1996)	Decon - Demolished in 2007 (greenfield open to visitors) ^[21]	\$820 million ^[22]	1,57
USA (2)	Exelon - Zion 1 & 2	PWR - Westinghouse 2 x 1040 MWe	25 years (1973–1998) (Incident in proceedings, abandoned because of the excessive cost of vaporizers substitution)	SAFSTOR-EnergySolutions (opening of the site to visitors for 2018) ^[23]	\$900–1,100 million (2007 dollars) ^[24]	0,51

* Conversion to 2013 USD/MW done by NucAdvisor

(1) Consistent with DECOMMISSIONING LESSONS LEARNED AT YANKEE ROWE - M. S. Terrell, D. McGee, Duke Engineering and Services (USA) - <http://www.wmsym.org/2001/50/50-1.pdf>

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Appendix 7 – Preparatory Works

There is no unanimously approved definition of Preparatory works. When referring to IAEA “Infrastructure milestones” document NG-G-3.1, Preparatory works include all items necessary for a country to be “ready to invite bids for the first nuclear power plant”, including items like Human resource development of the safety authority, finalization of a legal framework for nuclear power plants, securing the financing, preparing the Request for bids, etc. Those activities may be assigned to several bodies, including ministerial departments, national agencies, and owner-operator. However, this broad concept of preparatory works does not fit well to the South African situation, as the country is not a new comer to the nuclear business. Although it is clear that Preparatory works for the next NPPs to be built in South Africa shall be performed by several entities as mentioned above, most of the works will be performed by the utility, which will have to support the bulk of the expenses. Therefore, in this evaluation, based on information stemming from different projects, the focus is given to preparatory works to be done by the utility.

Preparatory works start at an early stage of the project development process, at a time when no firm commitment is made; therefore, all expenses cannot be capitalized, and are accounted as operating expenses. Therefore, they are more difficult to identify in the publicly disclosed accounts of utilities. However, it was possible to collect some information on recent projects, summarized hereafter.

It is understood that the Preparatory works hereafter reported include Project development (Basic design of the site works, grid connexion, preparation of request for bids documentation, call for bids and negotiation; Site works themselves to the extent they are not technology specific (excavation, and earthing, site access, offices, harbour facility if needed; Site qualification (Site licensing, environmental report, pre-licensing of the selected technology, etc.). Unfortunately, it was not possible to find in the literature such breakdown; however, it should be acknowledged that the amount of effort to be done widely depends on the site conditions, and the country specific licensing requirements.

South Texas 3 & 4, USA

When NRG decided to shelve the extension of the South Texas site (planned to have two ABWR reactors built) it took a charge of about **\$481 million** for the impairment of net assets of Nuclear Innovation North America (NINA), its nuclear development joint venture with partner Toshiba American Nuclear Energy Corp (TANE), an affiliate of Toshiba Corp. (Ref. <http://www.reuters.com/article/2011/04/19/us-nuclear-nrg-idUSTRE7317E620110419> April 19, 2011).

Nuclear Innovation North America (NINA) was a partnership between NRG Energy (88%) and Toshiba (12%) focused on developing new nuclear expansion projects using Advanced Boiling Water Reactor (ABWR) technology (Business wire February 17, 2010 ; <http://www.businesswire.com/news/home/20100217007066/en/Nuclear-Innovation-North-America-NINA-Moving-South>). Therefore the total write off of already completed preparatory works was 547 M\$ (2010). However, a large part of it had been devoted to the licensing of the ABWR technology in the US, which usually is supported by the vendor only.

Paks, Hungary

In the late 1980s, the Hungarian utility (MVM) prepared the extension of the Paks site, for which four additional VVER-1000 units were planned. Preparatory works were in the range of three billion forints (according to MVM Paks NPP - <http://paksnuclearpowerplant.com/new-units>), ie. 100 millions USD (2013 value). The preparatory works included preparation of the landscaping, ground replenishment and in the building of the on-site transportation infrastructure. “

Visaginas, Lithuania

The Lithuanian daily newspaper 15Min released some information on the preparatory works of the Visaginas project (two ABWR units to be built by Hitachi), available at <http://www.15min.lt/en/article/business/details-of-visaginas-nuclear-power-plant-project-revealed-527-217444> ; from the document, it can be understood that site and project preparatory works amount to ~ 300 M€ (~400 M\$), ahead of the signature of the concession agreement (including construction of new roads or upgrade of existing roads from the port of Klaipeda to Visaginas).

EDF Penly (France)

EDF considered the construction of one EPR unit at the Penly site (already equipped with two 100 MWe reactors). The Site director estimated the cost of site preparatory works, before any commitment to invest, between 50 and 70 M€ (70-100 M\$) <http://www.usinenouvelle.com/article/le-cnpe-de-penly-se-prepare-a-lancer-le-3eme-epr.N146845>

Slovakia

In 2008, the Slovakian utility considered the extension of the Bohunice site. Preparatory works were estimated at Sk7.5 billion (ie 340 M\$ 2008). Of this, initial costs for project works, amounting to Sk4 billion, represented the biggest portion. Personnel costs were forecast to come to Sk1.7 billion. The feasibility study was to cost Sk250 million and documentation for an EIA Sk350 million (from the Slovak spectator - 30 Apr 2008 - Flash News

http://spectator.sme.sk/articles/view/31605/10/preparatory_work_on_new_nuclear_plant_should_start_this_autumn.html).

Hinkley Point, UK

On April 23, 2013, EDF announced that it was scaling back its preparatory works for the Hinkley Point site, to be equipped with two EPR reactors. No specific information was provided on the past expenditures. A site preparation contract had been awarded for fencing, and drainage had been assigned for 4 M€, and an earthworks contract for 100 M€ (Construction news - <http://m.cnplus.co.uk/8625664.article> January 30, 2012). However, the total amount of EDF expenses is estimated to be much higher, including licensing costs). According to the Consultant information, it amounts to ~ 1,000 € (1,3 B\$).

Horizon Joint venture, UK

The two German utilities E.ON and RWE developed a Joint Venture (Horizon) to build nuclear reactors in the UK; before selling this joint venture to Hitachi for a disclosed amount of , the claimed to spend 1,54 USD per week(Bloomberg <http://www.bloomberg.com/news/2011-10-03/rwe-eon-keep-spending-on-u-k-reactors-as-germany-scraps-nuclear-plants.html> Oct 4, 2011). The Consultant estimates their total spending at 150 M\$.

Conclusion with respect to preparatory works

There is a wide variation of the cost of preparatory works from one project to the other, since their scope varies widely, and is quite dependent on the site situation (already equipped with nuclear plants, or new site), and the licensing effort (for the project and for the site). Therefore it is not really meaningful to compare the figures which were collected on a statistical basis.

From the Consultant experience, these preparatory works are not very dependent upon the size, and technology of reactors; on the other hand, they increase very slowly when the number of reactors at a given site increases (very large scale factor).

For the purpose of completeness of the cost study, and for a two units site, the Consultant suggest to consider preparatory works in the range of 250 M\$ per unit, with a dispersion from 100 to 500 M\$.

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Appendix 9 – Glossary

ABWR	Advanced Boiling Water Reactor (GE/Hitachi/Toshiba)
AGR	Advanced Gas Reactors
ATMEA	1100 MW reactor designed by ATMEA (Areva- MHI)
BWR	Boiling Water Reactor
CAPEX	Capital Expenditure
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CEZ	Czech Republic Utility
DCF	Discounted Cash Flow
EDF	Electricité de France
EIA	Energy Information Administration
EPC	Engineering, Procurement and Construction
EPCC	Engineering, Procurement and Construction Cost
EPR	European Pressurised Reactor (AREVA)
EPRI	Electric Power Research Institute
EWEA	European Wind Energy Association
FBC	Fluidized bed coal with desulfurization
FGD	Flue gas desulfurization
IEA	International Energy Agency
IAEA	International Atomic Energy Agency
IGCC	Integrated gasification combined-cycle
IGCC	Integrated Gasification Combined Cycle
KEPCO	Korea Electric Power Corporation
kWe	Electrical output expressed in kW
LCOE	Levelised Cost of Energy
LHV	Lower Heating Value
MWe	Electrical output expressed in MW
NEA	Nuclear energy agency
NEI	Nuclear Energy Institute
NPP	Nuclear Power Plant
O&M	Operation and Maintenance
OCGT	Open Cycle Gas Turbine
OECD	Organisation for Economic Co-operation and Development
OPEX	Operation Expenditure
PCC	Pulverized coal with flue gas desulfurization
PWR	Pressurised Water Reactor
UK	United Kingdom
VGB Powertech	European technical association for power and heat generation
VVER	Russian acronym for PWR
WNA	World Nuclear Association
WNA	World Nuclear Association