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# Power and Energy Systems Technologies & Economics

## Case Study Integrated Model for Nuclear Generation Cost Calculation

### Notes:

1. Cells with black characters include inputs
2. Cells with red characters include formulas
3. Download of Add-Ins from website is required
4. Description of Case Study in section 4.2 in the book

Last update Oct. 2015



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### **Disclaimer**

The Examples are solely and exclusively indented to provide support and assistance to the readers for practicing and better understanding of the theoretical part of this book.

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Proposals for improvements of the contents are welcome and will be considered in upcoming updates!

**Last Update June 2015**

Item	Unit	Value
<b>Power and Energy balance</b>	-	
Rated power each, total, gross	MW <sub>e</sub>	2,400
Thermal reactor power, total	MW <sub>t</sub>	6,800
Electricity generation, net	GWh <sub>e</sub> / a	16,740
Fuel consumption, in thermal units	GWh <sub>t</sub> / a	47,430
metric tons nuclear fuel	t / a	35.4
<b>Technical-financial constraints</b>		
Service life for calculation	a	50
Discount rate, on real terms (WACC)	% / a	7.1%
Cost of nuclear fuel *)	US\$ / kg UO <sub>2</sub>	1,651
Reserve funds for decommissioning, waste disposal	US\$ / MWh <sub>e</sub>	3.65
<b>Capital expenditures (CAPEX), US\$ 2013 **)</b>	<b>MIn US\$</b>	<b>13,720</b>
<b>Annual costs, US\$ 2013</b>	<b>MIn US\$ /a</b>	<b>1,483</b>
Annualized CAPEX	MIn US\$ /a	1,002
Fixed Operating expenses (fixed OPEX)	MIn US\$ /a	362
Variable operating expenses (variable OPEX)	MIn US\$ /a	120
<b>Capacity cost ref. to net power</b>	<b>US\$ / (kW a)</b>	<b>611</b>
<b>Energy cost, ref. to net electricity production</b>	<b>US\$ / MWh<sub>e</sub></b>	<b>7.14</b>
<b>Composite cost</b>	<b>US\$/ MWh<sub>e</sub></b>	<b>88.60</b>

\*) Average 2013, book, Engineering Economics

\*\*) **Source:** eia - U.S. Energy Information Administration, updated capital cost estimates 2013,

\*\*) including EPC price, owner's expenses and interest during construction

Item	Equity	Debt
<b>Asset shares</b>	<b>30%</b>	<b>70%</b>
<b>Expected returns after tax</b>		
Risk free rate of return / interest	5.0 %/a	5.0 %/a
Venture risks premium *)	7.5 %/a	1.0 %/a
Country risk premium (depends on country)	0.0 %/a	0.0 %/a
<b>Cost of capital in nominal terms, after tax</b>	<b>12.5 %/a</b>	<b>6.0 %/a</b>
Corporate tax                      25%	4.2 %/a	0.0 %/a
<b>Cost of capital in nominal terms, before tax</b>	<b>16.7 %/a</b>	<b>6.0 %/a</b>
<b>WACC<sub>n</sub> in nominal terms, before tax</b>	<b>9.20 %/a</b>	
./. Expected Inflation rate **)	2.00 %/a	
<b>WACC<sub>r</sub> inflation adjusted</b>	<b>7.1 %/a</b>	

\*) 1.5 percentage points higher compared to conventional PPs due to the longevity risk of investment

\*\*) Benchmark for inflation for longterm investment, worldwide

Component	Explanation	Units needed for 1 kg UO <sub>2</sub> *)	US\$/Unit**)	Total
Uranium oxide U <sub>3</sub> O <sub>8</sub>	This is the form Uranium is offered in the market place. It includes 0.7% of the fissile isotope U-235.	8.90 kg U <sub>3</sub> O <sub>8</sub>	72.64	646
Conversion in UF <sub>6</sub>	The Uranium oxide is converted in gaseous form in Uranium hexafluoride (UF <sub>6</sub> ).	7.50 kg U	7.92	59
Enrichment	Uranium hexafluoride (UF <sub>6</sub> ) is enriched in centrifuges to enriched UF <sub>6</sub> with a concentration of 3 to 4 percent U-235.	7.30 kg SWU	91.83	670
Fuel fabrication	The enriched UF <sub>6</sub> is converted in Uranium dioxide (UO <sub>2</sub> ), the actual nuclear fuel, in form of powder. It is compressed in pellets and filled in thin pipes bundle up in fuel assemblies.	-	-	275
<b>Nuclear fuel</b>	Assemblies of nuclear fuel	<b>1 kg UO<sub>2</sub></b>	-	<b>1,651</b>

\*) **Source:** World Nuclear Association, information library, July 2015

<http://www.world-nuclear.org/info/Economic-Aspects/Economics-of-Nuclear-Power/>

\*\* ) Power & Energy Systems Engineering Economics, average 2013

<b>Uranium:</b>	8.9 kg U <sub>3</sub> O <sub>8</sub> x \$97	US\$ 862	46%
<b>Conversion:</b>	7.5 kg U x \$16	US\$ 120	6%
<b>Enrichment:</b>	7.3 SWU x \$82	US\$ 599	32%
<b>Fuel fabrication:</b>	per kg (approx)	US\$ 300	16%
<b>Total, approx.:</b>		US\$ 1880	

Item	Unit	Value
<b>Technical parameters</b>		
Number of units	-	2
Type	Westinghouse AP 1000	
Nominal capacity, total	MW	<b>2,234</b>
<b>Cost Components, US\$ October 2013</b>		
<b>EPC</b>	<b>mIn US\$</b>	<b>10,127</b>
Civil structure material and installations	mIn US\$	1,792
Mechanical equipment, supply and installation	mIn US\$	3,519
Electrical Equipment, supply and installation	mIn US\$	652
Project indirects *)	mIn US\$	2,818
Fee and contingency	mIn US\$	1,346
<b>Owner Cost</b> (excluding project finance)	mIn US\$	2,228
<b>Total project cost</b> (excluding project finance, and IDC))	<b>mIn US\$</b>	<b>12,355</b>
<b>Specific cost</b>		
Total project EPC	US\$ / kW	<b>4,533</b>
Owner Cost (excluding project finance)	US\$ / kW	<b>997</b>
Total project cost (excluding project finance)	US\$ / kW	<b>5,530</b>

\*) includes, engineering, distributable costs, scaffolding, construction management, and start-up

**Source:** eia - U.S. Energy Information Administration, updated capital cost estimates 2013

Item		Unit	Value
<b>Basic constraints</b>			
Installed capacity		MW	2,234
Electricity production		GWh / a	16,740
Capital expenditures, US\$ 2013		mIn US\$	12,355
Total annual costs		mIn US\$	1,483
<b>Cost for nuclear waste disposal</b>			
Per MWh <sub>e</sub>		US\$ / MWh <sub>e</sub>	1.50
Annual amount		mIn US\$ / a	25
in percent of the total annual costs		-	1.7%
<b>Reserves for decommissioning</b>			
Required fund in US\$ 2013 *)	650 US\$/kWe	mIn US\$	1,452
in percent of CAPEX		-	11.8%
<b>Future value after 30 yrs, in US\$ 2013</b>			
Per MWh <sub>e</sub> **)		US\$ / MWh <sub>e</sub>	2.15
Annual amount		mIn US\$ / a	36
Bank interest rate for deposits		% / a	3.50%
Value in 30 years in US\$ 2013	30 years	mIn US\$	1,858
in percent of initial CAPEX **)		-	15%
per kW installed capacity		US\$ / kW	832
Value in 50 years in US\$ 2013	50 years	mIn US\$	4,715
in percent of initial CAPEX **)		-	38%
per kW installed capacity		US\$ / kW	2,110

\*) OECD survey 2013, decommissioning nuclear power plants

\*\*) Considering uncertainty due longevity risk of investment it is assumed that an amount

This corresponds to a fee of 2.15 US\$/MWh<sub>e</sub>

Item		Unit	Value
<b>Technical Parameters</b>			
Number of units ,Westinghouse AP1000		-	2
Rated power each, gross		MW <sub>e</sub>	1,200
Net power output, each	7%	MW <sub>e</sub>	1,116
Thermal reactor power, each		MW <sub>t</sub>	3,400
Electrical efficiency, gross		%	35.3%
Fuel burnup rate		MWd / kg	60
<b>Energy balance</b>			
Full load equivalent operation time	FLH	h / a	7,500
	days	d / a	312.5
Electricity generation, net		GWh <sub>e</sub> / a	16,740
Fuel consumption, in thermal units		GWh <sub>t</sub> / a	47,430
metric tons nuclear fuel		t / a	35.4
<b>Technical-financial constraints</b>			
Service life for calculation		a	50
Construction time		a	6.0
Discount rate, on real terms (WACC)		% / a	7.1%
Operating staff		Persons	400
Costs of personnel		US\$ / (Pers. a)	100,000
Fixed O&M cost referred to EPC		% / a	1.5%
Insurance referred to EPC		% / a	0.5%
Cost of nuclear fuel *)		US\$ / kg UO <sub>2</sub>	1,651
Cost for nuclear waste disposal		US\$ / MWh <sub>e</sub>	1.50
Reserve funds for decommissioning		US\$ / MWh <sub>e</sub>	2.15
<b>Capital expenditures (CAPEX), US\$ 2013</b>		<b>MIn US\$</b>	<b>13,720</b>
EPC price **)		MIn US\$	10,127
Owners expenditures **)		MIn US\$	2,228
Interest during construction		MIn US\$	1,365
<b>Annual costs</b>		<b>MIn US\$ /a</b>	<b>1,483</b>
<b>Annualized CAPEX</b>		MIn US\$ /a	1,002
<b>Fixed Operating expenses (fixed OPEX)</b>			362
Cost of personnel		MIn US\$ /a	40
Fixed O&M costs		MIn US\$ /a	152
Insurance		MIn US\$ /a	51
<b>Variable operating expenses (variable OPEX)</b>		<b>MIn US\$ /a</b>	<b>120</b>
Fuel direct costs		MIn US\$ /a	58
Costs for waste disposal		MIn US\$ /a	25
Reserve funds for decommissioning		MIn US\$ /a	36
<b>Capacity cost ref. to net power</b>		<b>US\$ / (kW a)</b>	<b>610.9</b>
<b>Energy cost, ref. to net electricity production</b>		<b>US\$ / MWh<sub>e</sub></b>	<b>7.14</b>
<b>Composite cost</b>		<b>US\$ / MWh<sub>e</sub></b>	<b>88.60</b>

\*) Average 2013, Engineering Economics

\*\*\*) source U.S. Energy Information agency – eia, 2013



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Item	Unit	Value
<b>CAPEX, incl. IDC *)</b>	<b>US\$ /kW</b>	<b>5,716</b>
<b>Levelized electricity cost</b>		<b>88.60</b>
Annualized CAPEX		59.83
Fixed OPEX	<b>US\$ / MWh</b>	21.63
Fuel costs		3.49
Variable non-fuel cost **)		3.65

\*) IDC: Interest during construction 6.0 years

\*\*) Mainly costs for decommissioning and nuclear waste disposal