Systems Code Cost Algorithm Status and Planned Enhancements

L. Waganer/ L. El-Guebaly

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Cost Of Electricity Is the Dominant Metric for Electrical Power Plants

Necessary Criteria

- It must be credible (solid basis)
- It must be reasonably accurate (sufficient data fidelity)
- It must be reasonably detailed (somewhat bottoms up)

Impediments

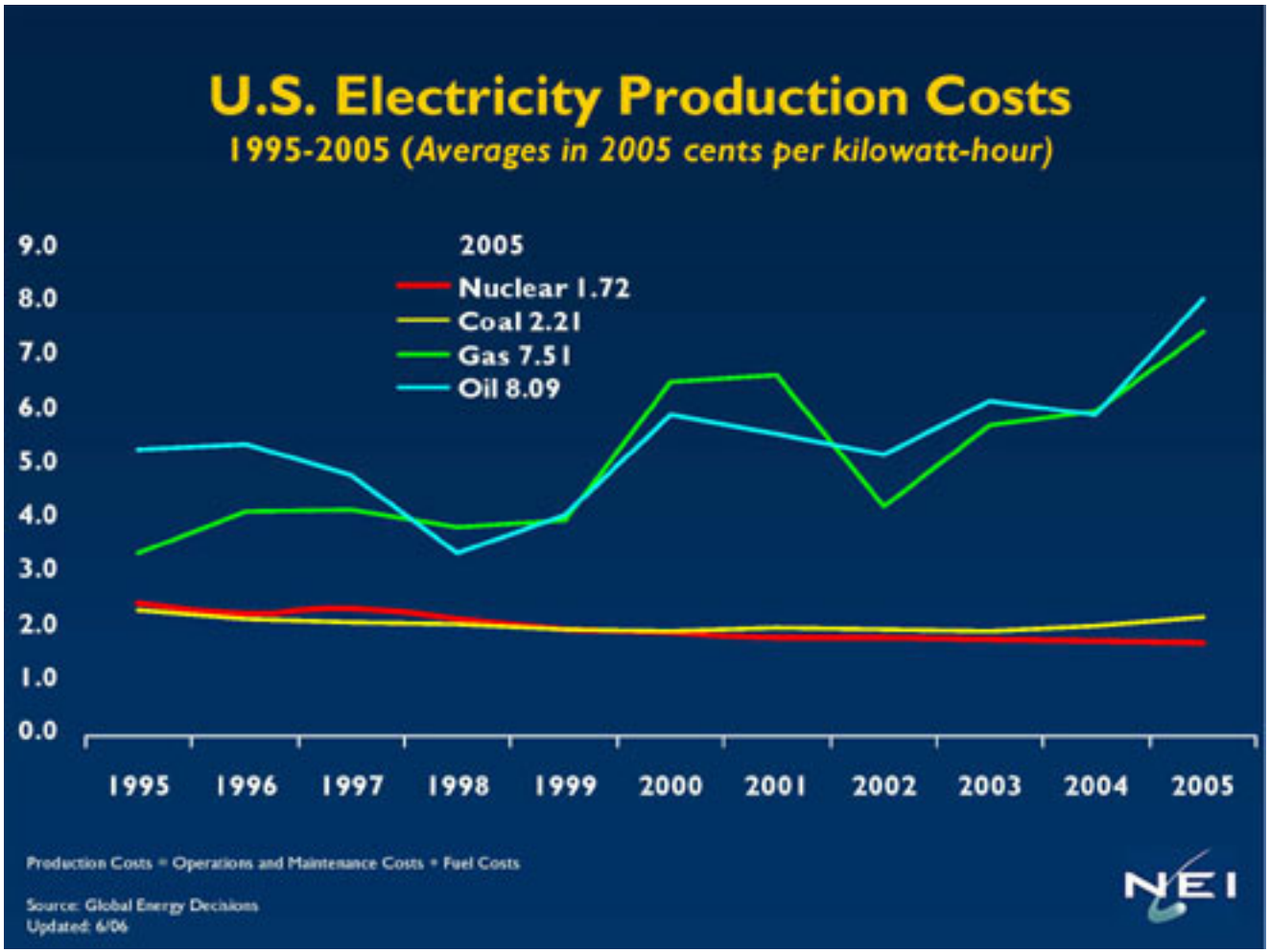
- Uncertainties exist on all current COE factors
- Future state estimate are even more uncertain
- Energy and environmental policies are evolving
- Financial arrangements are unclear and yet to be determined

Approach

- Comply with DOE direction* on costing format and general content
- Base estimates on projected performance and economic factors
- Benchmark with prior studies and competitive technologies

* PNL-2987 Fusion Reactor Design Studies – Standard Unit Costs and Cost Scaling Rules

US Electricity Production Costs



Insight into Electrical Generating Costs

The Nuclear Energy Agency (NEA), an agency within the Organization for Economic Cooperation and Development (OECD), and the International Energy Agency (IEA) recently published a 2005 update to their "Projected Costs of Generating Electricity" series.

The NEA/IEA study uses the levelized lifetime cost approach to compare generating costs for the future. This approach looks at generation costs over the plant economic lifetime, while taking into account the time value of money;. Levelized costs are comprised of all components of capital, Operations and Maintainence (O&M) and fuel costs that would influence a utility's choice of generation options, including construction, refurbishment and decommissioning, where applicable

The study finds that at a 5% discount rate, levelized costs for nuclear range between $21 and $31 per MWh (2.1 to 3.1 cents per KWh), with investment costs representing 50% of total cost on average, while O&M and fuel represent around 30% and 20%, respectively. For gas-fired plants, the study finds levelized costs ranging from $37 to $60 per MWh (3.7 to 6 cents per KWh), with investment costs accounting for less than 15% of total costs, O&M accounting for less than 10%, and fuel costs accounting for nearly 80% of total costs, on average. The study finds levelized costs for coal-fired plants ranging between $25 and $50 per MWh (2.5 to 5 cents per KWh). Investment costs for coal plants account for just over a third of total costs, while O&M and fuel account for around 20% and 45%, respectively.

If you are wondering why oil is not mentioned oil is more expensive and is rarely used in electric power plants anymore. Nuclear power is more sensitive to interest rate levels. But a nuclear builder can try to time financing for construction of a nuclear plant to periods when long term interest rates are low. Whereas a builder of coal or natural gas plants will have to live with fluctuations in fuel prices over the life of the plant. Nuclear plant construction could be made much more responsive to long term interest rates by shrinking time spent in the regulatory approval and construction stages. Uranium fuel costs also fluctuate considerably but count for a much smaller percentage of total costs of a nuclear plant.

Info from DOE Energy Information Administration

Table 38. Cost and Performance Characteristics of New Central Station Electricity Generating Technologies

Technology	Online Year[1]	Size (mW)	Leadtimes (Years)	Base Overnight Costs in 2005 ($2004/kW)	Contingency Factors: Project Contingency Factor	Contingency Factors: Technological Optimism Factor[2]	Total Overnight Cost in 2005[3] (2004 $/kW)	Variable O&M[4] ($2004 mills/kWh)	Fixed O&M[5] ($2004/kW)	Heatrate in 2005 (Btu/kWhr)	Heatrate nth-of-a-kind (Btu/kWr)
Scrubbed Coal New[7]	2009	600	4	1,167	1.07	1.00	1,249	4.18	25.07	8,844	8,600
Integrated Coal-Gasification Combined Cycle (IGCC)[7]	2009	550	4	1,349	1.07	1.00	1,443	2.65	35.21	8,309	7,200
IGCC with Carbon Sequestration	2010	380	4	1,873	1.07	1.03	2,065	4.04	41.44	9,713	7,920
Conv Gas/Oil Comb Cycle	2008	250	3	556	1.05	1.00	584	1.88	11.37	7,196	6,800
Adv Gas/Oil Comb Cycle (CC)	2008	400	3	532	1.08	1.00	575	1.82	10.65	6,752	6,333
ADV CC with Carbon Sequestration	2010	400	3	1,021	1.08	1.04	1,147	2.68	18.12	8,613	7,493
Conv Combustion Turbine[6]	2007	160	2	388	1.05	1.00	407	3.25	11.03	10,842	10,450
Adv Combustion Turbine	2007	230	2	367	1.05	1.00	385	2.89	9.59	9,227	8,550
Fuel Cells	2008	10	3	3,787	1.05	1.10	4,374	43.64	5.15	7,930	6,960
Advanced Nuclear	2013	1000	6	1,744	1.10	1.05	2,014	0.45	61.82	10,400	10,400
Distributed Generation -Base	2008	2	3	791	1.05	1.00	831	6.49	14.60	9,650	8,900
Distributed Generation -Peak	2007	1	2	951	1.05	1.00	998	6.49	14.60	10,823	9,880
Biomass	2009	80	4	1,659	1.07	1.02	1,809	3.13	48.56	8,911	8,911
MSW - Landfill Gas	2008	30	3	1,443	1.07	1.00	1,544	0.01	104.03	13,648	13,648
Geothermal[6,7]	2009	50	4	2,100	1.05	1.00	2,205	0.00	75.00	32,173	35,460
Conventional Hydropower[6]	2009	500	4	1,320	1.10	1.00	1,452	3.20	12.72	10,338	10,338
Wind	2008	50	3	1,091	1.07	1.00	1,167	0.00	27.59	10,280	10,280
Solar Thermal[7]	2008	100	3	2,589	1.07	1.10	3,047	0.00	51.70	10,280	10,280
Photovoltaic[7]	2007	5	2	3,981	1.05	1.10	4,598	0.00	10.64	10,280	10,280

[1]Online year represents the first year that a new unit could be completed, given an order date of 2005.

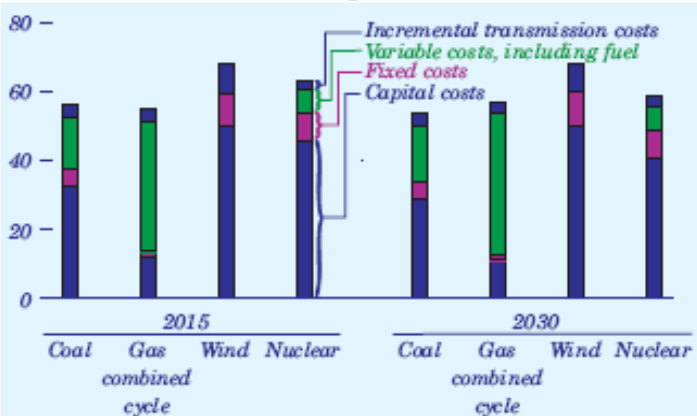
[2]The technological optimism factor is applied to the first four units of a new, unproven design, or regulatory structure. It reflects the demonstrated tendency to underestimate actual costs for a first-of-a-kind unit.

[3]Overnight capital cost including contingency factors, excluding regional multipliers and learning effects. Interest charges are also excluded. These represent costs of new projects initiated in 2005.

- New Nuclear Capacity is assumed to have 20% lower capital and operating costs in 2030 than in (current) reference case

Least Expensive Technology Options Are Likely Choices for New Capacity, ref DOE EIA

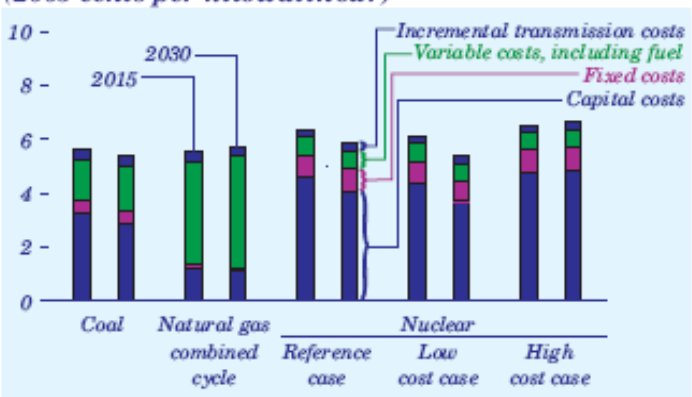
Figure 56. Levelized electricity costs for new plants, 2015 and 2030 (2005 mills per kilowatthour)



When Lower Costs Are Assumed, New Nuclear Plants Are More Competitive

Conventional Nuclear is close to Coal and Gas, and surprisingly, Wind is reasonably competitive

Figure 59. Levelized electricity costs for new plants by fuel type, 2015 and 2030 (2005 cents per kilowatthour)



When lower cost case economics are applied to Conventional Nuclear, it is very competitive with Coal and Gas

Relevant COE Metric Factors

- Cost of Electricity = $\frac{\text{(D + ID Capital Cost) x FCR + Fuel + O\&M}}{\text{(Gross Electric x Effcy – Recir Power) x Avail}}$

- Direct capital costs are usually estimated at subsystem level in power core and at systems levels for remainder of plant
- Direct capital costs are based on performance factors or cost / unit mass
- Indirect cost factors (Construction Services & Equipment, Engineering & Services, Owners Cost, Interest, and Escalation) have been prescribed for construction periods and interest/escalation rates, but need to be re-evaluated
- Fixed charge rate (FCR) is 9.65% but needs to be re-evaluated
- Tritium is processed on site, but there is some charges for this processing. Deuterium is a small cost element. Replacement power core components are considered as consumables in this account.
- Operational costs are predicted to be reduced in the future due to increased automation. Maintenance is more automated, but component parts are subject to inflationary influence.

Acct Detail

Relevant COE Metric Factors (Cont'd)

- Cost of Electricity = $\dfrac{\text{(D + ID Capital Cost) x FCR + Fuel + O\&M}}{\text{(Gross Electric x Effcy – Recir Power) x Avail}}$

- Gross Electricity is the combination of all thermal energy production elements in power core (plasma performance, energy and particle capture, and energy multiplication)
- Efficiency is the gross thermal to electrical energy conversion that considers Blanket materials, heat transport fluids, high temperature operation, HX materials, and energy conversion cycles
- Recirculating power is all the electrical power necessary for the plant operation (pumping, plasma heating, magnets, cryogenics, tritium handling, lights, etc).
- Availability is the percentage of time the plant is available for energy production
- All remaining plant functions must be modeled and their costs estimated to determine their contributions toward power production and capital costs

Example Indirect Cost Factors

Indirect Factors for ARIES-AT

6 yr construction time, 5% inflation rate

Account		1	2	3	4	
91	Constr Serv & Equipment	0.1130 ✓	0.1200	0.1280	0.1510	x TDC [90]
92	Home Office Engr and Serv	0.0520 ✓	0.0520	0.0520	0.0520	x TDC [90]
93	Field Office Engr and Serv	0.0520 ✓	0.0600	0.0640	0.0870	x TDC [90]
94	Owners (Other) Costs	0.1826 ✓	0.1848	0.1866	0.1935	x TDC [90+91+93]
95	Design or Process Contingency	0.0000	0.0000	0.0000	0.0000	x TDC [90+91+93+94]
96	Project Contingency	0.2050	0.2391	0.2565	0.2808	x TDC [90+91+93+94]
97	Interest During Constr (IDC)	0.2651	0.2736	0.2878	0.2915	x TDC [90+91+93+94+95+96]
98	Escal During Constr (EDC)	0.0000	0.0000	0.0000	0.0000	x TDC [90+91+93+94+95+96]

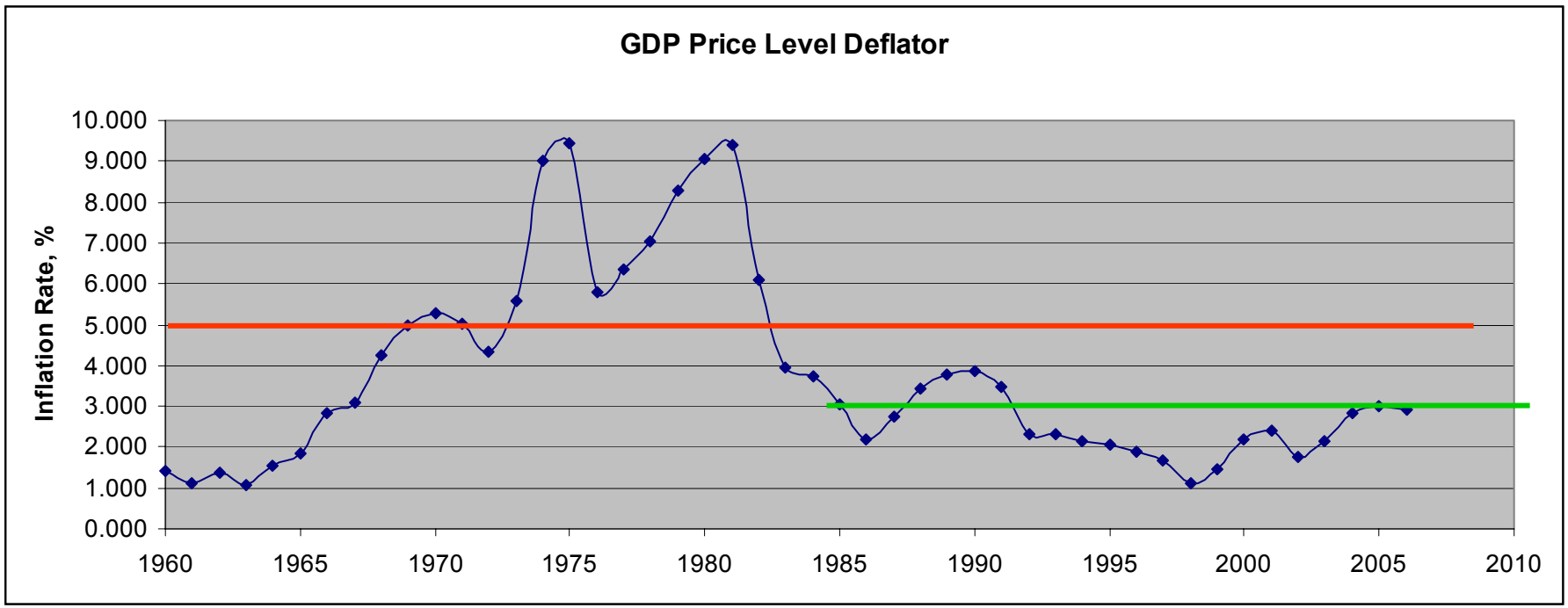
		Starfire (80$)		Prometheus-H (91$)		ARIES-AT (92$, LSA=1)	
		6y, 5%	Fraction	6y, 5%	Fraction	6y, 5%	Fraction
		1726.48		1940.64		1521.117	
91	Constr Serv & Equipment	172.65	0.1000	219.29	0.1130	171.886	0.1130
92	Home Office Engr and Serv	138.12	0.0800	100.91	0.0520	79.098	0.0520
93	Field Office Engr and Serv		0.0000	100.91	0.0520	79.098	0.0520
94	Owners Cost	86.32	0.0500	354.26	0.1825	277.756	0.1826
	Subtotal	2123.57		2716.01		2128.955	
95	Design Contingency	0	0.0000	0	0.0000	0	0.0000
96	Project Contingency	0	0.0000	397.9	0.1465	311.829	0.1465
	Subtotal	2123.57		3113.91		2440.784	
97	Interest During Constr (IDC)	276.7	0.1303	514.42	0.1652	403.218	0.1652
98	Escal During Constr (EDC)	0	0.0000	0	0.0000		0.0000
	Total	2400.27		3628.33		2844.002	

ARIES-AT Tabular Factors data differs from Cost summary data

Prometheus (and Osiris/SIRIUS) and ARIES Economic bases were revised based on DOE oversight committee in 1980.

Fusion Studies Have Traditionally Used 5% Inflation Rates

However, since 1983, the inflation rate is consistently below 5% and more like 3% or below



Costing Basis and Approach

- Reassess current ARIES Systems Code algorithms for correctness and accuracy
- Research other fusion studies, guideline documents, and current competitive sources
- Re-evaluate basic study economic groundrules and assumptions for validity in projected environment
- Recommend performance based or cost/ unit mass algorithms to estimate at subsystem level in power core and systems in other areas – Subject matter experts should compile relevant cost data on subsystems
- Provide alternate technical solutions for trade studies
- Document all costing algorithms and bases for estimates

Background Info

ARIES-AT ECONOMIC BASIS

Costing reference year	1992
Construction lead time (y)	6.00
Escalation/general-inflation rate (%/y) [nominal]	0.0500
Escalation/general-inflation rate (%/y) [constant]	0.0000
Ave. cost of money (AFUDC), xCOM (%/y) [nominal]	0.1135
Ave. cost of money (AFUDC), xCOM (%/y) [constant]	0.0605
Capitalization factor, fcap [nominal]	0.5614
Capitalization factor, fcapo [constant]	0.1651
Interest during construction, fIDC [nominal]	0.3178
Interest during construction, fIDC [constant]	0.1652
Dollar discount rate, dis [nominal]	0.0957
Dollar discount rate, diso [constant]	0.0435
Fixed charge rate, FCR [nominal]	0.1637
Fixed charge rate, FCR [constant]	0.0965
FW/B neutron end-of-life fluence (MW yr/m^2)	18.5000
R/M neutron fluence protection/extension factor	3.0000

Background Info

UCSD/LANL fusion reactor economic evaluation (ver. 16.1) LSA=1 12/11/00 0

Acc. # Account Title	M$ (1992)
20. land & land rights	10.589
21. structures & site facilities	253.537
22. reactor plant equipment	761.016
22. 1. 1. FW/blanket/reflector	64.280
22. 1. 2. shield	69.409
22. 1. 3. magnets	126.686
22. 1. 4. supplemental-heating/CD systems	37.060
22. 1. 5. primary structure & support	26.933
22. 1. 6. reactor vacuum systems (unless integral elsewhere)	98.772
22. 1. 7. power supply, switching & energy storage	50.746
22. 1. 8. impurity control	4.094
22. 1. 9. direct energy conversion system	0.000
22. 1.10. ecrh breakdown system	3.975
22. 1. reactor equipment	481.956
22. 2. main heat transfer & transport systems	125.968
23. turbine plant equipment	243.034
24. electric plant equipment	98.505
25. miscellaneous plant equipment	47.353
26. heat rejection system	23.317
27. special materials	83.766
90. direct cost (not including contingency)	1521.117

Background Info

UCSD/LANL fusion reactor economic evaluation (ver. 16.1) LSA=1 12/11/00 0

Acc. # Account Title	M$ (1992)
90. direct cost (not including contingency)	1521.117 (from prior page of direct costs)
91. construction services & equipment	171.886
92. home office engineering & services	79.098
93. field office engineering & services	79.098
94. owner's cost	277.756
96. project contingency	311.829
97. interest during construction (IDC)	403.218
99. total cost	2844.002

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