GEN IV International Forum℠
Expertise | Collaboration | Excellence

Estimating Costs of Generation IV Systems

Summary / Objectives:

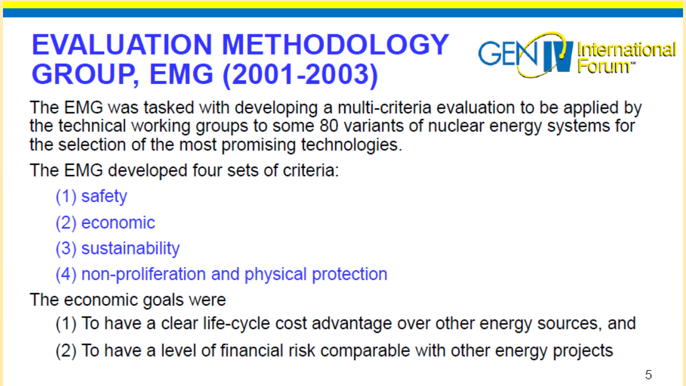
This webinar will provide an overview of the Economic Modelling Working Group's Cost Estimating Guidelines for Generation IV Nuclear Energy Systems (GIF, 2007). Topics include an overview of the Guidelines, a comparison of the Guidelines with other nuclear power plant cost estimating models, and a discussion of benchmarking activities by the EMWG with INPRO.

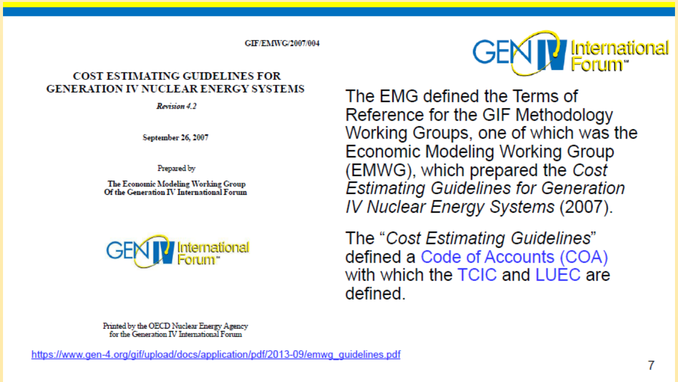
Meet the Presenter:

Dr. Geoffrey Rothwell since 2013 has been the Principal Economist of the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD, Paris, France), where he acts as the Secretariat for the Economic Modelling Working Group (EMWG). For EMWG he wrote the TOR in 2003 as the Chair of the Economics Cross-cut Group of the Generation IV Roadmap Committee. He was active in writing the Cost Estimating Guidelines for Generation IV Nuclear Energy Systems (GIF, 2007). While teaching at Stanford University from 1986-2013, he consulted to Idaho, Oak Ridge, and Pacific Northwest, and Argonne National Laboratories, for whom he updated the University of Chicago's 2004 report, The Economic Future of Nuclear Power, published as The Economics of Nuclear Power, Routledge, London, 2016. Dr. Rothwell grew up in Richland, Washington, and received his PhD in economics from the University of California, Berkeley.

Looking back over the startup phase of the GIF-EMWG:

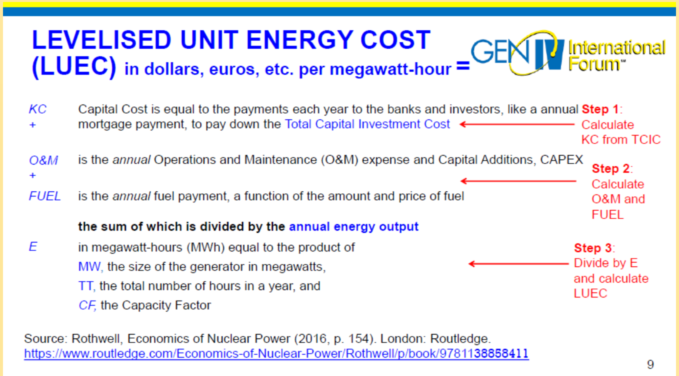
Economic Modeling Working Group (EMWG) created to define the economic criteria for selecting GIF supported technologies (GIF systems) by the cross-cutting Evaluation Methodology Group (EMG) composing the early Gen-IV Roadmap Committee which selects GIF systems. Two economic criteria: EC-1 low total capital investment cost, and EC-2 low average cost, levelized unit energy costs, LUEC were selected, “Cost Estimating Guideline” and a transparent cost estimating tool, G4-ECONS, were developed by EMWG in 2007.

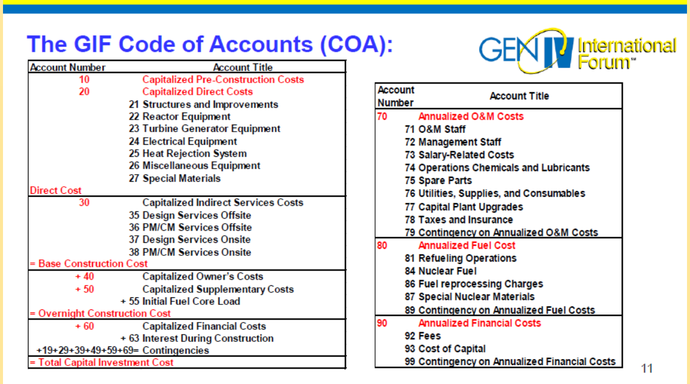




Code of Accounts and LUEC:

GIF Code of Account (COA) developed for estimated LUEC. COA is bottom-up approach to accumulate the total capital investment cost (TCIC). LUEC composed by annualized TCIC, Operation and Maintenance (O&M), and Fuel costs.

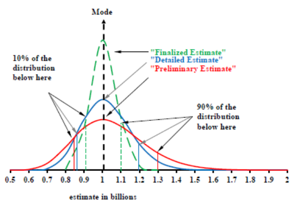




TCIC:

TCIC composed by Direct cost, Indirect Services Costs, Owner's Costs, financial cost, interest during construction (IDC) and contingencies. TCIC except financial, interest and contingency costs is called as overnight cost. Some case consider Initial Fuel Core Load cost as fuel cost but this case consider this as TCIC because this cost is significant as initial cost. The overnight cost of Molten Salt Reactor (MSR) estimated by Oak Ridge National Laboratory (ORNL) was $3350/kWe (2011USD) for example. IDC estimated depend on construction period. Estimation of appropriate contingency is needed. The rate of contingency could be decrease in stage of project definition. TCIC was estimated by ORNL in 2011 as $3149/kWe for the Advanced High Temperature Reactor (AHTR) System with 9% enriched uranium compare with $4012 of PWR12 for example.

LEVELS OF PROJECT DEFINITION:



	Mode	Median	Mean	Standard Deviation	80% Confidence
Preliminary Estimate	1.000	1.033	1.049	18.30%	-18% to +31%
Detailed Estimate	1.000	1.017	1.025	13.10%	-14% to +20%
Finalised Estimate	1.000	1.005	1.008	7.00%	-8% to +10%

Source: Rothwell, Economics of Nuclear Power (2016, p. 114). London: Routledge.
https://www.routledge.com/Economics-of-Nuclear-Power/Rothwell/p/book/9781138858411

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TOTAL CAPITAL INVESTMENT COST

Advanced High Temperature Reactor Systems and Economic Analysis calculates the TCIC for a "Better Experience" BE ("Nth-of-a-Kind") version of the PWR-12 and compares it with 19.75% and 9% enriched uranium for the AHTR. However, these estimates do not include contingency, which would "increase the cost estimate by at least 25%" (p. 88)

Capital cost, in millions of 2011 dollars (enrichment)	PWR12 3%	AHTR 19.75%	AHTR 9.00%
Capitalized preconstruction costs (accounts 11–19)	$6	$6	$6
Capitalized direct costs (accounts 21–29)	$2,171	$2,391	$2,391
Capitalized support services (accounts 31–39)	$1,323	$1,323	$1,323
Capitalized operations costs (accounts 41–49)	$300	$300	$300
Overnight cost without initial fuel load	$3,800	$4,019	$4,019
Initial fuel load	$135	$419	$111
Total overnight cost with initial fuel load	$3,935	$4,438	$4,130
Interest during construction (calculated)	$655	$739	$688
Total Capitalized Investment Cost (TCIC)	$4,590	$5,177	$4,818
Reactor net electrical capacity (MW)	1,144	1,530	1,530
Specific TCIC ($/kWe)	$4,012	$3,384	$3,149

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O&M and Fuel Costs:

Such kind of staffing cost and repair cost are estimated as O&M cost. Decontamination & Dismantling (D&D) cost are estimated as contributions to a sinking fund. Fuel cost includes front end and backend cost. Fuel cost was estimated as $10.74/MWh for AHTR System with 9% enriched uranium compare with $5.60 of PWR12 for example.

ANNUAL O&M COSTS IN G4ECONS

System 80+ (PWR that became the APR1400)	
70 OPERATIONS COST CATEGORY	
71+72 On-site Staffing Cost (71: non-mgt 72: mgt)	31.50 $M/yr
73 Pensions and Benefits	6.29 $M/yr
74+76 Consumables	18.64 $M/yr
75 Repair costs including spare parts and services	10.93 $M/yr
77 Capital replacements/upgrades (levelized)	0.00 $M/yr
78 Insurance premiums & taxes & fees	11.12 $M/yr
79 Contingency on O&M	0.00 $M/yr
70 Total O&M	78.47 $M/yr
Annualized D&D cost per MWh	0.27 $/MWh
Total O&M + D&D	8.61 $/MWh

58 Decontamination & Dismantling (D&D)	300 $M
Sinking fund interest	5% /yr
Sinking fund factor	0.83% /yr
	40 yrs
Annualized D&D	2.48 $M/yr

Annual D&D costs are calculated as contributions to a sinking fund, earning the same rate of return as the weighted average cost of capital, r:

$$A = D\&D \cdot \{ r / [(1 + r)^N - 1] \},$$

where D&D is a fraction of Direct Cost (Account 20), e.g., 33%

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ANNUAL FUEL COSTS

$$FC = NU \cdot P_{UF6} + SWU \cdot P_{SWU} + P_{FAB}$$

NU is the ratio of natural uranium input to enriched uranium output,
P_{UF6} is the price of natural uranium input *plus its conversion to* UF6,
SWU is the number of Separative Work Units (SWU) required in enrichment,
P_{SWU} is the price of enriching uranium hexafluoride, UF6,
P_{FAB} is the price of fabricating UO2 fuel from enriched UF6, and

$$F = \{ [FC / (24 \cdot B \cdot eff)] + WASTE \} \cdot E$$

FC is the cost of nuclear fuel in US dollars per kilogram of uranium (US$/kgU),
24 is the number of thermal MWh in a thermal megawatt-day,
B is the burnup rate measured in thermal megawatt-days per kgU,
eff is the thermal efficiency of converting MW-thermal into MW-electric,
WASTE is the interim storage cost per MWh

Source: Rothwell, Economics of Nuclear Power (2016, p. 156). London: Routledge.
https://www.routledge.com/Economics-of-Nuclear-Power/Rothwell/p/book/9781138858411

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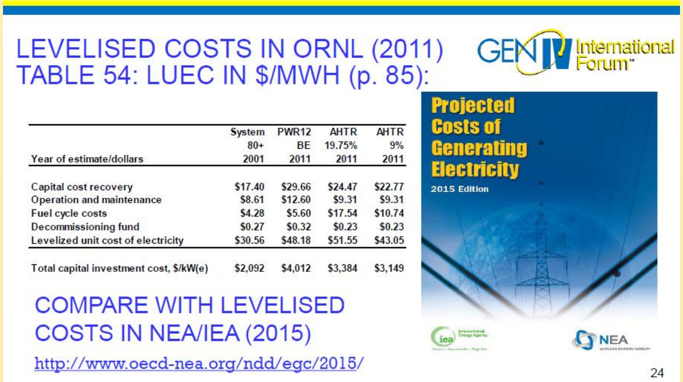
Cost estimation of LUEC by ORNL and NEA:

ORNL estimated as $30.56 /MWh for System 80+, $48.18/MWh, $43.05/MWh for AHTR System with 9% enriched uranium. NEA is regularly reporting the estimated levelized cost of each counties. Relatively low overnight cost was estimated for AR1400 in Korea and AP1000/CPR1000 in China.


LEVELISED COSTS IN ORNL (2011)
TABLE 54: LUEC IN $/MWH (p. 85):

Year of estimate/dollars	System 80+ 2001	PWR12 BE 2011	AHTR 19.75% 2011	AHTR 9% 2011
Capital cost recovery	$17.40	$29.66	$24.47	$22.77
Operation and maintenance	$8.61	$12.60	$9.31	$9.31
Fuel cycle costs	$4.28	$5.60	$17.54	$10.74
Decommissioning fund	$0.27	$0.32	$0.23	$0.23
Levelized unit cost of electricity	$30.56	$48.18	$51.55	$43.05
Total capital investment cost, $/kW(e)	$2,092	$4,012	$3,384	$3,149

COMPARE WITH LEVELISED COSTS IN NEA/IEA (2015)
http://www.oecd-nea.org/ndd/egc/2015/

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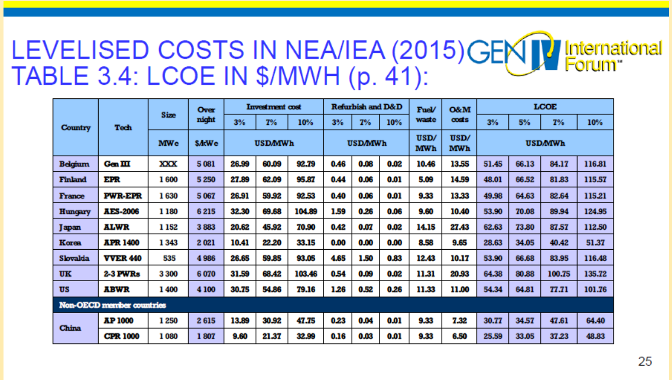
LEVELISED COSTS IN NEA/IEA (2015)
TABLE 3.4: LCOE IN $/MWH (p. 41):

Country	Tech	Size	Over night	Investment cost			Refurbish and D&D			Fuel/ waste	O&M costs	LCOE			
				3%	7%	10%	3%	7%	10%			3%	5%	7%	10%
		MWe	$/kWe	USD/MWh			USD/MWh			USD/ MWh	USD/ MWh	USD/MWh			
Belgium	Gen III	XXX	5 081	26.99	60.09	92.79	0.46	0.08	0.02	10.46	13.55	51.45	66.13	84.17	116.81
Finland	EPR	1 600	5 250	27.89	62.09	95.87	0.44	0.06	0.01	5.09	14.59	48.01	66.52	81.83	115.57
France	PWR-EPR	1 630	5 067	26.91	59.92	92.53	0.40	0.06	0.01	9.33	13.33	49.98	64.63	82.64	115.21
Hungary	AES-2006	1 180	6 215	32.30	69.68	104.89	1.59	0.26	0.06	9.60	10.40	53.90	70.08	89.94	124.95
Japan	ALWR	1 152	3 883	20.62	45.92	70.90	0.42	0.07	0.02	14.15	27.43	62.63	73.80	87.57	112.50
Korea	APR 1400	1 343	2 021	10.41	22.20	33.15	0.00	0.00	0.00	8.58	9.65	28.63	34.05	40.42	51.37
Slovakia	VVER 440	535	4 986	26.65	59.85	93.05	4.65	1.50	0.83	12.43	10.17	53.90	66.68	83.95	116.48
UK	2-3 PWRs	3 300	6 070	31.59	68.42	103.46	0.54	0.09	0.02	11.31	20.93	64.38	80.88	100.75	135.72
US	ABWR	1 400	4 100	30.75	54.86	79.16	1.26	0.52	0.26	11.33	11.00	54.34	64.81	77.71	101.76
Non-OECD member countries															
China	AP 1000	1 250	2 615	13.89	30.92	47.75	0.23	0.04	0.01	9.33	7.32	30.77	34.57	47.61	64.40
	CPR 1000	1 080	1 807	9.60	21.37	32.99	0.16	0.03	0.01	9.33	6.50	25.59	33.05	37.23	48.83

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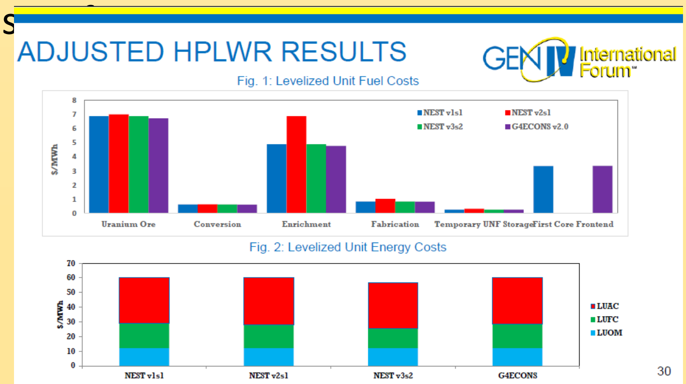
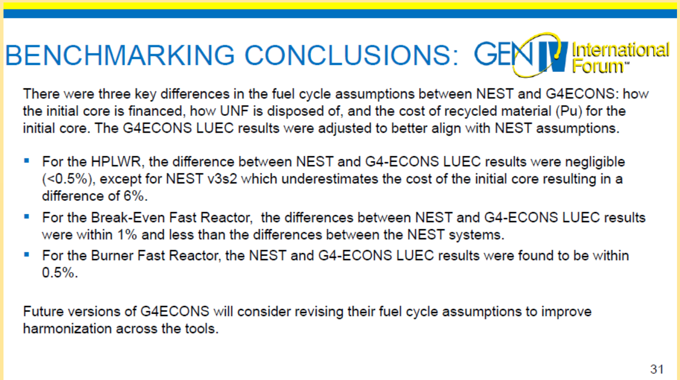
Benchmarking G4-ECONS and NEST developed by IAEA:

NEST was developed in 4 phases by IAEA, and it was extended to treat designs of break-even closed fuel cycle and multiple conversion rates in Version 4. The benchmark study between G4-ECONS and NEST was carried out with selected thermal reactor (high performance LWR by KIT) and fast reactor (BN-800 by Rosatom) and identified little deference but not s




BENCHMARKING CONCLUSIONS:

There were three key differences in the fuel cycle assumptions between NEST and G4ECONS: how the initial core is financed, how UNF is disposed of, and the cost of recycled material (Pu) for the initial core. The G4ECONS LUEC results were adjusted to better align with NEST assumptions.

- For the HPLWR, the difference between NEST and G4-ECONS LUEC results were negligible (<0.5%), except for NEST v3s2 which underestimates the cost of the initial core resulting in a difference of 6%.
- For the Break-Even Fast Reactor, the differences between NEST and G4-ECONS LUEC results were within 1% and less than the differences between the NEST systems.
- For the Burner Fast Reactor, the NEST and G4-ECONS LUEC results were found to be within 0.5%.

Future versions of G4ECONS will consider revising their fuel cycle assumptions to improve harmonization across the tools.

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