Overview of G4-ECONS Current Features and Future Revisions

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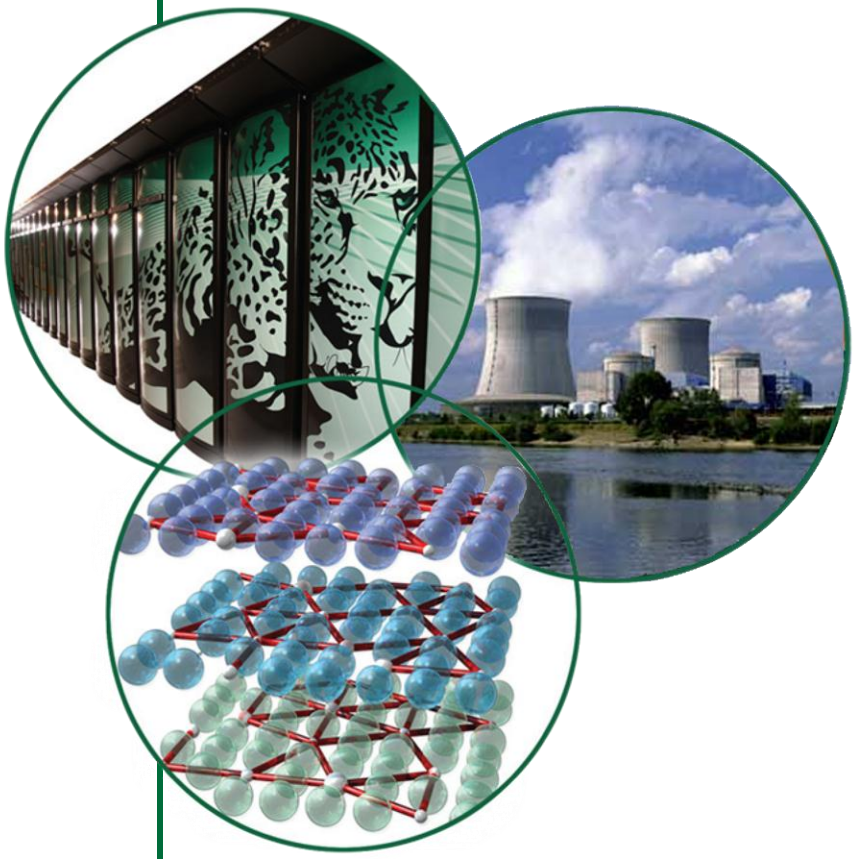

U.S. DEPARTMENT OF ENERGY

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Outline

- Description of G4-ECONS
- Step-by-step description of calculation
- Example calculations
- Discussion on future work

G4-ECONS Overview

- G4-ECONS
  - Generation IV (4)—Excel Calculation of Nuclear Systems
- Developed by the Generation IV Economic Modeling Working Group (EMWG)
- Microsoft Excel-based computation
- Cost estimating methodology and algorithms are explained in *Generation IV Cost Estimating Guidelines* and the *G4_ECONS User's Manual*
  - Available at http://www.gen-4.org

G4-ECONS Overview

- Generalized economic assessment
  - Does not account for nation-specific taxation, depreciation, or capital cost recovery methodologies
  - All costs calculated in constant-currency levelized annual bases
- Simplifying assumptions
  - Capital and financing recovery, D&D sinking fund occurs over operating life
  - Constant annual electrical production, capacity factor, and annualized costs
  - S-curve spending profile during construction

G4-ECONS Overview

- Divides nuclear system into four components
  - Capital recovery, including financing
  - Nonfuel operations and maintenance
  - Fuel cycle costs
  - Funding of decontamination and decommissioning
- Each component has different levels of detail
  - Some use 2-digit Code of Accounts
  - Some use commodity-specific costs
  - Some use lump-sum

Capitalized Pre-construction Costs

Capitalized Pre-Construction Costs List	
11--Land and Land Rights	$M
12--Site Permits	$M
13--Plant Licensing	$M
14--Plant Permits	$M
15--Plant Studies	$M
16--Plant Reports	$M
17--Reserved	$M
18--Reserved	$M
Contingency on 11-18	$M

Capitalized Direct Costs

Capitalized Direct Costs List	
21--Buildings, Structures, and Improvements on Site	$M
22--Reactor Plant Equipment	$M
23--Turbine/Generator Plant Equipment	$M
24--Electrical Equipment	$M
25--Water Intake and Heat Rejection Plant	$M
26--Miscellaneous Plant Equipment	$M
27--Special Materials	$M
28--Simulator	$M
Contingency on 21-28	$M

Capitalized Support Services Costs

Capitalized Support Services Costs List	
31--Design services at A/E Offices (Home Office)	$M
32--PM/CM Services at A/E Offices (Home Office)	$M
33--Design Services at Plant Site (Field Office)	$M
34--PM/CM Services at Plant Site (Field Office)	$M
35--Construction Supervision at Plant Site (Field Supervision)	$M
36--Field Indirect Costs (Rentals, Temp Facilities, Etc.)	$M
37--Plant Commissioning Services	$M
38--Plant Operation-Demonstration Run	$M
Contingency on 31-38	$M

Capitalized Operations Costs

Capitalized Operation Costs List	
41--Staff Recruitment and Training	$M
42--Staff Housing Facilities	$M
43--Staff Salary-related Costs	$M
44--Reserved	$M
45--Reserved	$M
46--Other Owners' Capital Investment Costs	$M
47--Reserved	$M
48--Reserved	$M
Contingency on 41-48	$M

Capitalized Supplementary Costs

Capitalized Supplementary Costs List	
51--Shipping and Transportation Costs	$M
52--Spare Parts and Supplies	$M
53--Taxes	$M
54--Insurance	$M
55--Reserved	$M
56--First Core Costs (Calculated Above)	$M
57--Reserved	$M
58--Reserved	$M
Contingency on 51-58	$M

Other Costs

Other Financial Costs List	
61--Real Escalation (Beyond General Inflation)	$M
62--Interest During Construction	$M
63--Fees/Royalties	$M
64--Other	$M
65--Other	$M
66--Other	$M
67--Other	$M
68--Other	$M
Contingency on 61-68	$M

Non-fuel Operational Annual Costs

Non-fuel Operational Annual Recurring Costs for Reactor	
71 + 72--On-site Staffing Cost (Non-Management + Management)	$M/y
73--Pensions and Benefits	$M/y
74 + 76--Consumables	$M/y
75--Repair Costs Including Spare Parts	$M/y
93--Charges on Working Capital	$M/y
84--Purchased Services and Subcontracts	$M/y
78--Insurance Premiums and Taxes	$M/y
X1--Regulatory Fees	$M/y
X2--Radioactive Waste Management	$M/y
X3--Other General and Administrative	$M/y
Capital Replacements as a Percentage of Direct Capital	%/y
77--Capital Replacements as a Percentage of Direct Capital	$M/y
79--Contingency on Non-Fuel O&M Costs	$M/y

Specific Costs

Natural Th Mining/Milling Cost	$/kgU
Natural U Mining/Milling Cost	$/kgU
Natural U Conversion Cost	$/kgU
Natural U Enrichment Cost	$/SWU
Depleted U Conversion and Disposition Cost	$/kgU
Fuel Fabrication Cost	$/kgU

Specific Costs

Wet Storage of UNF	$/kgHM
Dry Storage of UNF	$/kgHM
Monitored Retrievable Storage of UNF	$/kgHM
Geologic Disposal of UNF--Energy Based	$/MWeh
Geologic Disposal of UNF--Mass Based	$/kgHM
Geologic Disposal of Separated Waste	$/kgHMeq
Aqueous Separation Cost	$/kgHM
Electrochemical Separation Cost	$/kgHM
Voloxidation Separation Cost	$/kgHM
Other Separation Cost (Optional)	$/kgHM
D&D Fraction of Total Capital Cost	%
Calculated as Fraction	$M
D&D Direct Input	$M

Fuel Cost Calculations

First Core Cost	
Natural Th Mining/Milling	$M
NU Mining/Milling and Conversion--For Enrichment	$M
Other NU Mining/Milling and Conversion	$M
NU Enrichment	$M
DU Conversion--From Enrichment	$M
Overall Fuel Fabrication	$M
Total First Core Cost	$M
Equilibrium Fuel Cost	
Natural Th Mining/Milling	$M/y
NU Mining/Milling and Conversion--For Enrichment	$M/y
NU Enrichment	$M/y
DU Conversion--From Enrichment	$M/y
Other NU Mining/Milling and Conversion	$M/y
Overall Fuel Fabrication	$M/y
Equilibrium Fuel Cost	$M/y

Basic Parameters

- Requires some basic parameters for fuel cycle calculation
  - Reactor thermal power and thermal efficiency
  - Reactor lifetime
  - Relevant interest/discount rates
  - Construction period
  - Fuel composition and burnup
- Establishes mass balance and mass flow

Basic System Parameters

Plant Thermal Power	MWt
Plant Thermal Efficiency	%
Plant Capacity Factor	%
Fuel Burnup	GWtd/MTIHM
Specific Power	MWt/MTHM
Fraction of Power Used for Electrical Production	%
Fraction of Power Used for High-heat Production	%
Plant Efficiency for High-heat Users	%
Assemblies per Core (optional)	#
Assemblies per Reload (optional)	#
Number of Cycles	#
Plant Lifetime	y
Years to Construct	y
Used Fuel Wet Storage Time	y
Used Fuel Dry Storage Time	y

Basic System Parameters

Annual Interest Rate During Construction (discrete)	%
Annual Interest Rate During Operation (discrete)	%
Amortization Lifetime	y
Annual Interest Rate For D&D Fund (discrete)	%

First-core Fuel Definition

First Core Fuel Definition	
Fraction Th in First Core	%
Fraction DU in First Core	%
Fraction NU in First Core	%
Fraction LEU in First Core	%
Initial Core Average Fuel Enrichment	%
Initial Core Feed Assay	%
Initial Core Tailings Assay	%
Fraction RU in First Core	%
Fraction Pu in First Core	%
Fraction Np + Am + Cm in First Core	%
Fraction FP in First Core	%

Equilibrium Fuel Definition

Equilibrium Fuel Definition	
Fraction Th in Fresh Equilibrium Fuel	%
Fraction DU in Fresh Equilibrium Fuel	%
Fraction NU in Fresh Equilibrium Fuel	%
Fraction LEU in Fresh Equilibrium Fuel	%
Equilibrium Core Average Fuel Enrichment	%
Equilibrium Core Feed Assay	%
Equilibrium Core Tailings	%
Fraction RU in Fresh Equilibrium Fuel	%
Fraction Pu in Fresh Equilibrium Fuel	%
Fraction Np + Am + Cm in Fresh Equilibrium Fuel	%
Fraction FP in Fresh Equilibrium Fuel	%

Used Fuel Definition

Used Fuel Definition	
Used Fuel U Fraction	%
Used Fuel Pu Fraction	%
Used Fuel Np + Am + Cm Fraction	%
Used Fuel FP Fraction	%

Cost Calculations

Capital (Including First Core and Interest During Construction)	$M/y
Operations	$M/y
Fuel Cycle--Front End	$M/y
Fuel Cycle--Back End	$M/y
D&D Sinking Fund	$M/y
Total Annual Cost	$M/y
Capital Fraction	%
Operations Fraction	%
Front End Fraction	%
Back End Fraction	%
D&D Fraction	%
Total Levelized Unit Electric Cost (LUEC)	mills/kWeh

Example Calculation Results

Parameter	G4-ECONS $M/y
Capital (Including 1st Core and Financing)	212.08
Operations Cost	95.78
Fuel Cycle - Front End	75.85
Fuel Cycle - Back End	12.62
D&D Sinking Fund	2.9
TOTAL LUEC	399.23
TOTAL LUEC (mils/kWeh)	38.95

Calculation Note

- Interest during construction assumes sinusoidal curve
- Given
  - total construction cost *C*
  - continuous interest rate *r*
  - time of construction *T*
  - the interest during construction = $C\left(\frac{\pi^2\left(e^{rT}-1\right)-2T^2r^2}{2(T^2r^2+\pi^2)}\right)$

Current Revision Work

- Incorporates uncertainty analysis
  - Based on propagation of error using parameter distributions
- Includes combined heat and electricity generation
  - May need refinement
- Follows fission product and transuranic generation/destruction
- Includes material utilization calculations

Uncertainty Analysis

- The current work can analyze three distribution types
  - Uniform
  - Gaussian
  - Triangular
- Given "high" = b, "low" = a, and "nominal" = c
  - St. Dev. Uniform distribution = $\frac{(b-a)}{\sqrt{12}}$
  - St. Dev. Triangular distribution = $\sqrt{\frac{a^2+b^2+c^2-ab-ac-bc}{18}}$
  - St. Dev. Gaussian distribution *assumed* = $\frac{(b-a)}{6}$

Uncertainty Analysis Description

- **Based on propagation of error**
  - **If** $y = f(x_1, x_2, x_3, \dots, x_N)$ **then** $\sigma_y{}^2 = \sum_{n=1}^{N} \frac{\partial f}{\partial x_n}^2 \sigma_{x_n}{}^2$
  - **Assumes all parameters independent**
    - **May not be a valid assumption for all parameters**
- **Based on definition of derivative**
  - **If** $y = f(x_1, x_2, x_3, \dots, x_N)$ **then** $\frac{\partial f}{\partial x_n} = \lim_{h \to 0} \frac{f(x_1, x_2, \dots, x_n + h, \dots, x_N) - f(x_1, x_2, \dots, x_n, \dots, x_N)}{h}$

Uncertainty Analysis Description

- Caveat
  - Assumes linear derivative at nominal point; extrapolation beyond perturbation values may invalidate that assumption
  - Derivative calculation dependent on perturbation range

Future Work Focused on SMR Economics

- Incorporation of learning curve and modular fabrication/construction effects
  - Different items within 2-digit Code of Accounts "learn" differently

Final Slide

- **Questions or comments?**