Economic Modeling Working Group (EMWG) Activities

Ramesh Sadhankar
on behalf of
GIF EMWG

3rd GIF Symposium, Makuhari Messe, Chiba, Japan,
19 May 2015

Outline of the Presentation

- *GIF Economic Goals and EMWG methodologies*
- *Recent application of EMWG cost estimation guidelines*
- *Recent example of benchmarking EMWG tool G4-ECONS with IAEA's NEST*
- *Path Ahead*

EMWG Mandate

- EMWG was established in 2003 to create economic models and guidelines for assessment of Gen IV systems with respect to GIF economic goals:
- GIF economic goals
  - ✓ To have a life cycle cost advantage over other energy sources (i.e. to have lower levelized unit cost of energy on average over the lifetime)
  - ✓ To have a level of financial risk comparable to other energy projects (i.e., to involve similar total capital investment and capital at risk)

EMWG Products

- Cost Estimating Guidelines for Generation IV Nuclear Energy Systems Revision 4.2
- Spreadsheet (EXCEL-based) model, i.e., G4-ECONS (Generation 4-EXCEL Calculation Of Nuclear Systems) Ver 2.0
- User's Manual for G4-ECONS Ver. 2.0

Available on a CD-ROM from the GIF Secretariat, Nuclear Energy Agency, OECD

The GIF Economic Figures of Merit

1. *Levelized Unit Energy Cost (LUEC)*
2. *Capital-at-Risk /Total Capital Investment Cost (TCIC)*

- ***The Cost Estimating Guidelines define what is to be included in calculation of TCIC and LUEC***
- ***G4-ECONS calculates TCIC and LUEC***

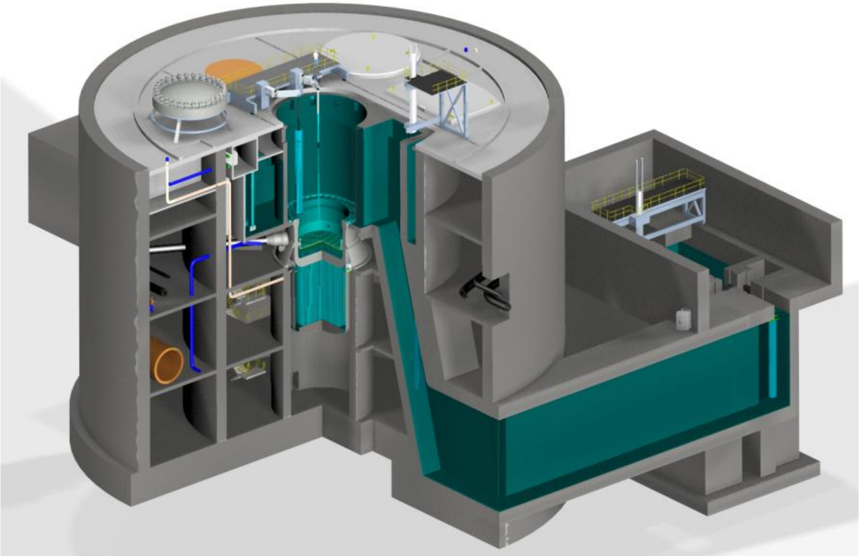
Application of GIF Cost Estimation Guidelines

GIF Guidelines - Cost Estimation Techniques

- "Bottom-Up Approach"
  - ✓ Detailed cost estimating technique for mature designs
- "Top-Down Approach"
  - ✓ Cost estimating technique for systems with less advanced design detail

Recent Application of Top-down Cost Estimation Technique for Canadian SCWR Concept

- *Grid Power : ~1,200 MWe*
- *Pressure-tube type, heavy water moderated*
- *Thermodynamic Efficiency: ~47%*
- *Direct cycle SC steam turbine*
- *Outlet Conditions: 25.0 MPa, 625ºC*
- *Th/Pu or Th/U MOx fuel*



Top Down Cost Estimating Requirements

- Requires availability of reference plant cost data and associated plant characteristics
- Uses cost factors for adjusting reference costs (e.g. containment building M^3, pump capacity in kW etc.)
- Unique design features may require conceptual designs with a Bottom-Up approach (e.g. molten salt heat exchanger, pressure tubes for SCWR)

Top-down Cost Estimation of SCWR

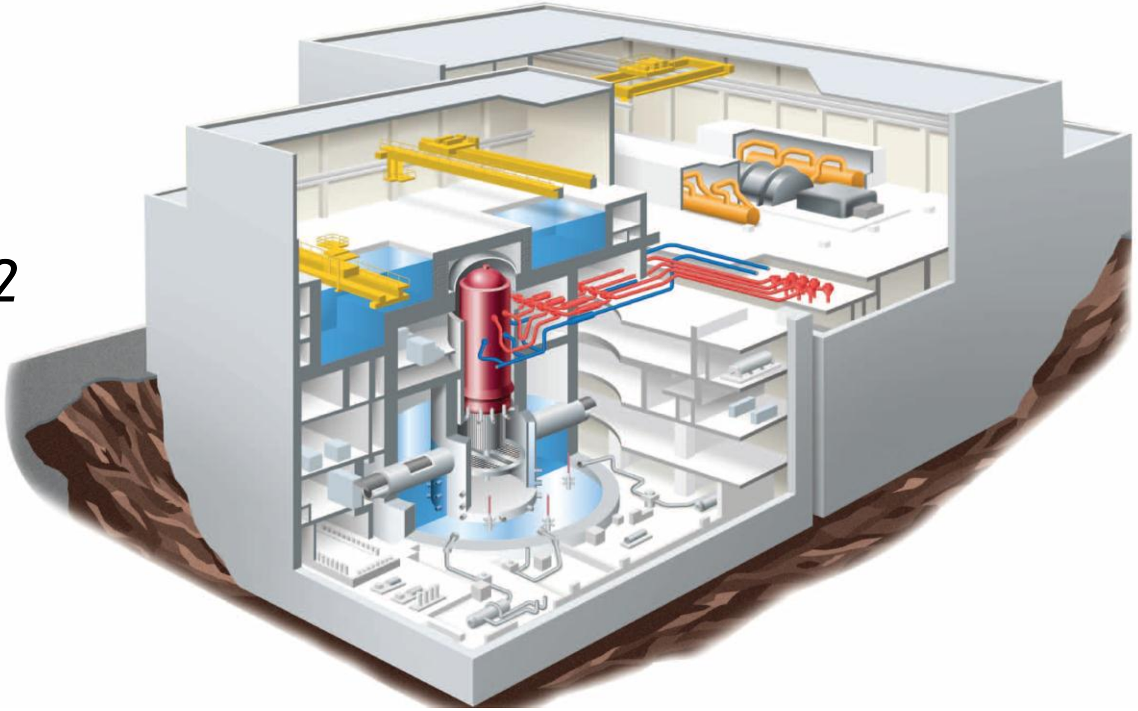
- ABWR costs were used as the reference for estimating the capital cost of the Canadian SCWR concept.

  This was done in 4 steps:

  1. All ABWR costs were expressed in 2007 US dollars
     - ABWR costs were from Tennessee Valley Authority's proposal for Bellefonte ABWR
  2. Direct capital costs were broken down by components.
  3. SCWR component costs were calculated from the costs of similar ABWR components based on size/service specifications using appropriate factors
  4. Appropriate uncertainty range was applied to the costs for the purpose of uncertainty analyses (SCWR is at the concept stage, ABWR is at detailed estimate stage)

ABWR

- Output – 1,371 MWe (SCWR – 1,177 MWe)
- Operating pressure – 7.2 MPa
- Feed water – 215 ^{0}C
- Direct cycle steam turbine
- Secondary containment



Toshiba Corp., GE Company, USEC, Bechtel Power Corp, & Global Nuclear Fuel (2005). “ABWR Cost/Schedule/COL Project at TVA’s Bellefonte Site”, Tennessee Valley Authority (TVA), Tennessee US.

Example: Derivation of SCWR costs from SCWR/ABWR Comparison

ABWR Containment Building:

- Reinforced concrete structure.
- Contains: reactor, suppression pool, reactivity control mechanism and safety systems.
- Circular with a volume = 23,800 m^3, 29m diameter and 36m high.
- Design containment pressure = 3.1 bar.

SCWR Containment Building:

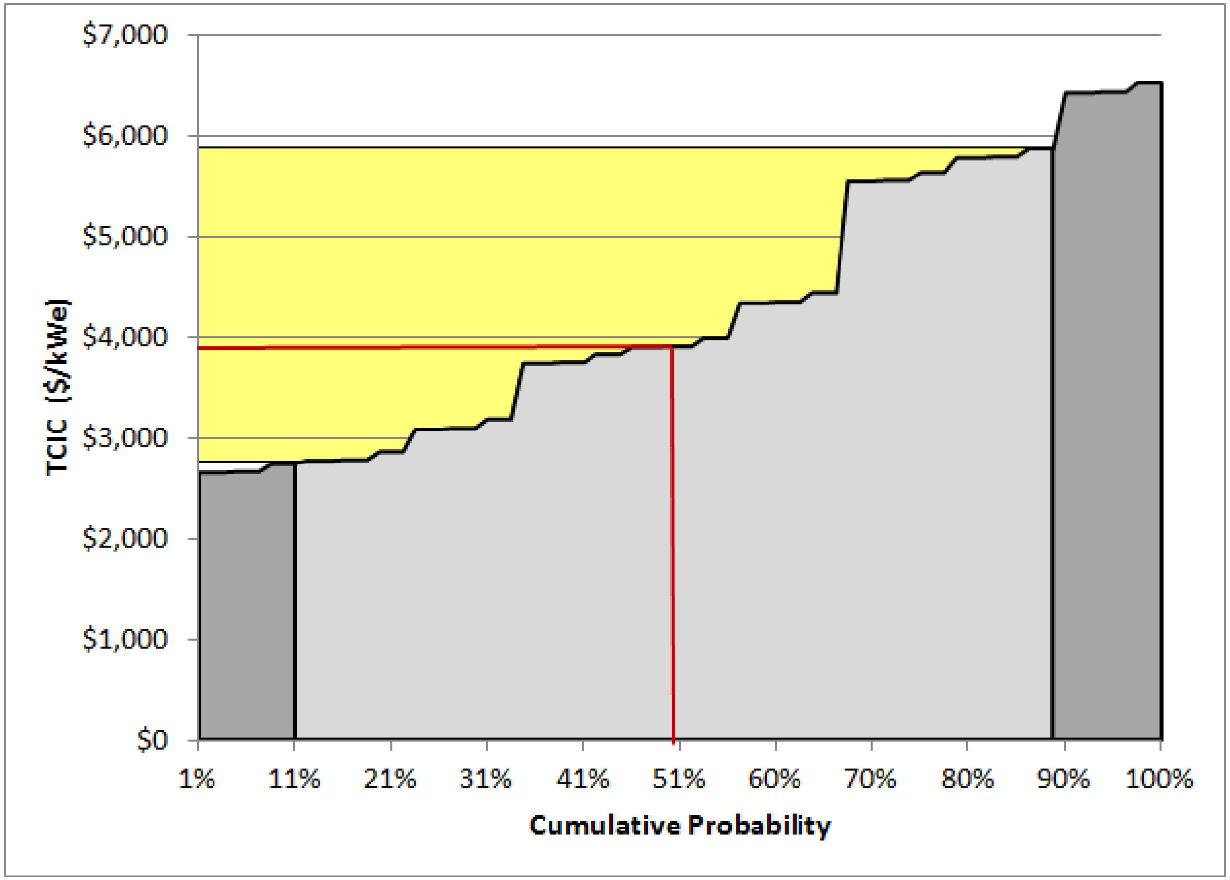
- Reinforced concrete structure that is missile hardened.
- Contains: reactor, suppression pool, reactivity control mechanism and safety systems.
- Circular with a volume = 15,700 m^3, 25m diameter and 32m high.
- Design containment pressure = 5 bar.

Result: The SCWR building is 35% smaller than the ABWR, but the walls are 40% thicker due to higher containment pressure. The result is a 6% ($23 M) more cost for SCWR compared to ABWR.

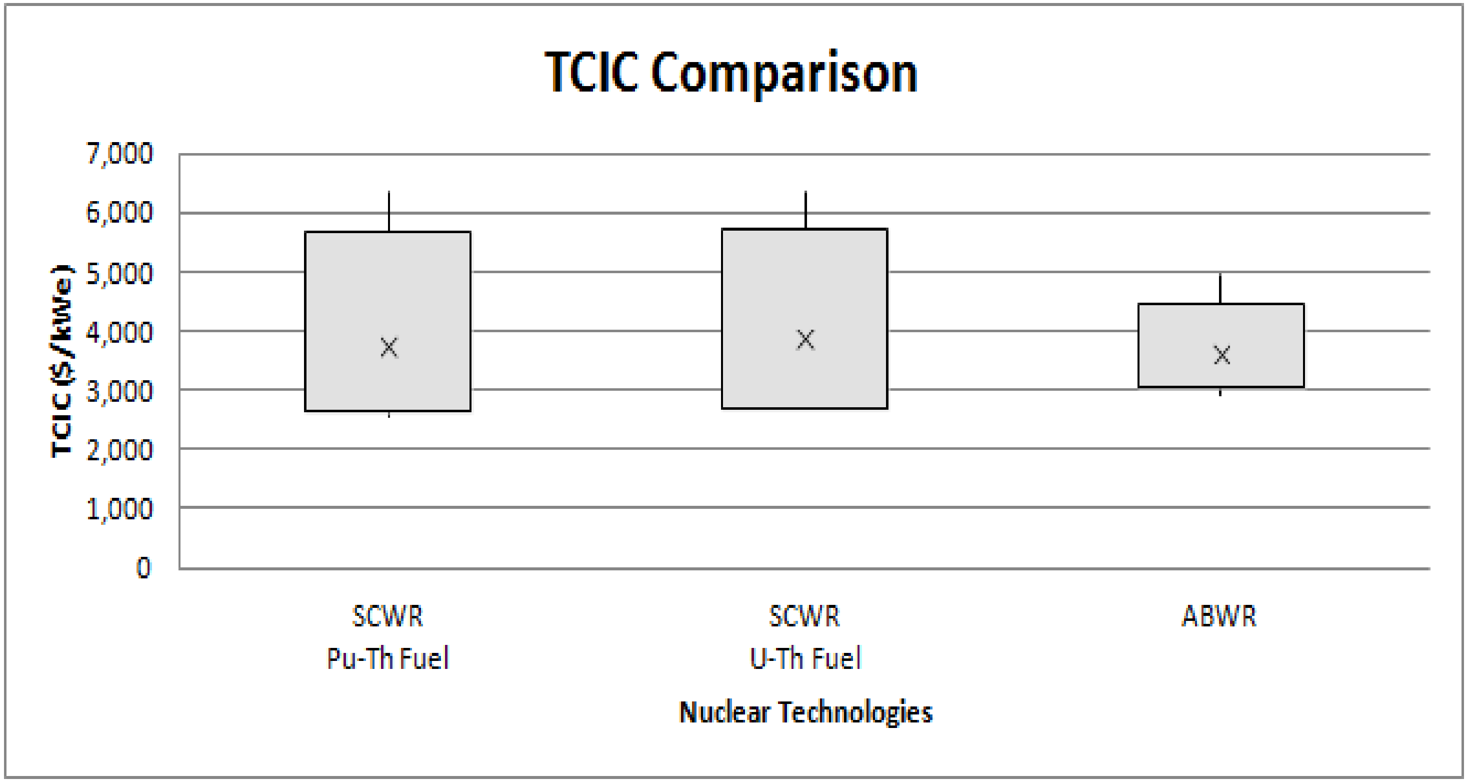
Total Capital Investment Cost

- TCIC = Overnight capital Cost + Interest during construction
- Uncertainties
  - Overnight Costs
    - GIF guidelines recommend minimum contingency range -30% to +50% for concept stage (-15% to +20% for ABWR)
    - Includes first fuel load
  - Real discount rate (3% to 10%)
  - Construction time (assumed 4 years fixed in this case)

SCWR TCIC Uncertainty



Capital Cost Comparison



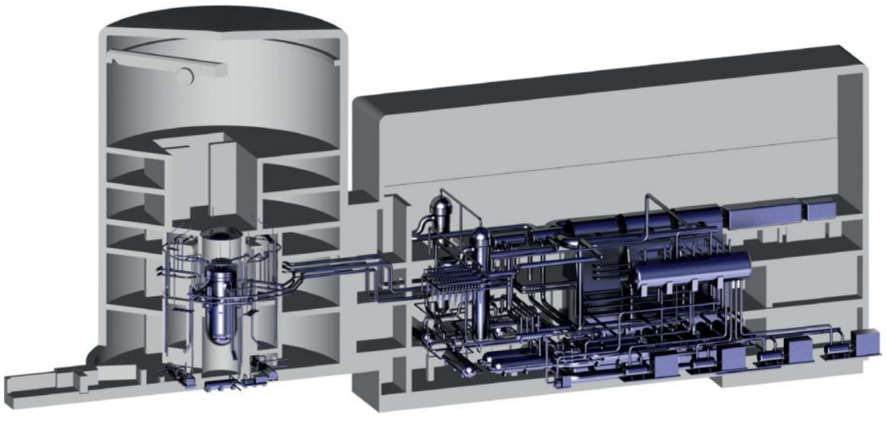
- ➢ Capital Costs of Gen IV SCWR and Gen III+ ABWR are comparable
- ➢ ABWR costs could be higher with post-Fukushima upgrades

G4-ECONS Benchmarking

G4-ECONS Assumptions

- *Capital costs for NOAK – distributed as per S-curve during construction period*
  - ✓ *Construction period in multiples of quarters (e.g. 5.25 years), interest calculated on quarterly basis*
- *The same real (inflation-free)discount rate used for construction financing, capital amortization and D&D escrow fund accumulation*
- *Amortization life of the plant is the same as the operational life*
- *Annual power production/capacity factor same over the plant life*
- *Fuel cycle:*
  - ✓ *Only two types of fuel loads – initial core and reload*
  - ✓ *Unit costs of fuel cycle services constant over plant life*
    - » *No material losses in fuel cycle steps*
    - » *No lag and lead times*

HPLWR Economics Benchmarking
(European SCWR)

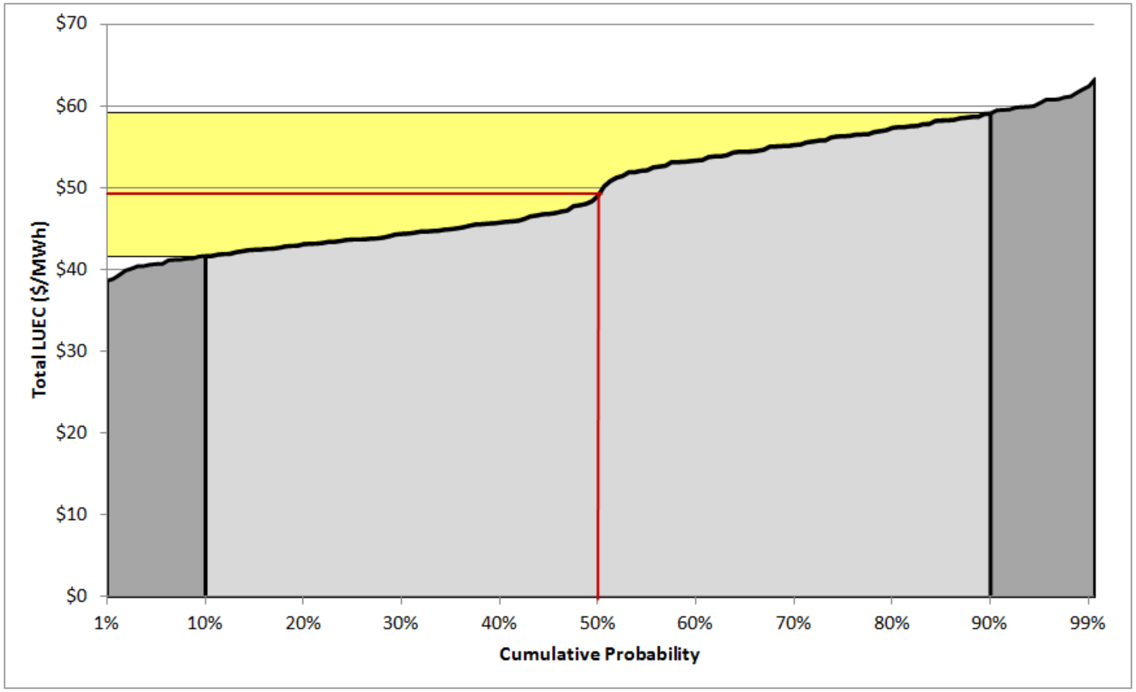


- *HPLWR - 1000MWe*
- *Analyzed with G4ECONS*
- *Analysis compared with NEST model developed by INPRO-IAEA*

Ref: High Performance Light Water Reactor Design and Analyses,
Thomas Schulenberg // Jörg Starflinger (eds.), KIT scientific Publishing, 2012

http://digbib.ubka.uni-karlsruhe.de/voltexte/1000025989

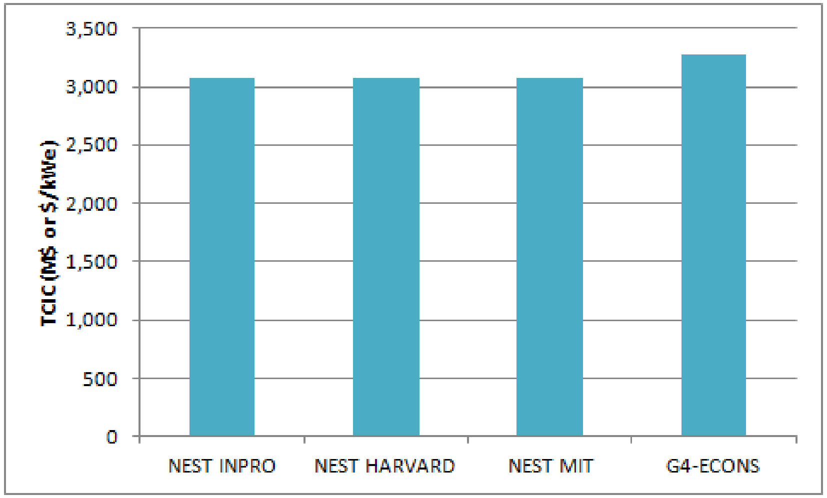
Sensitivity Analysis: G4-ECONS LUEC



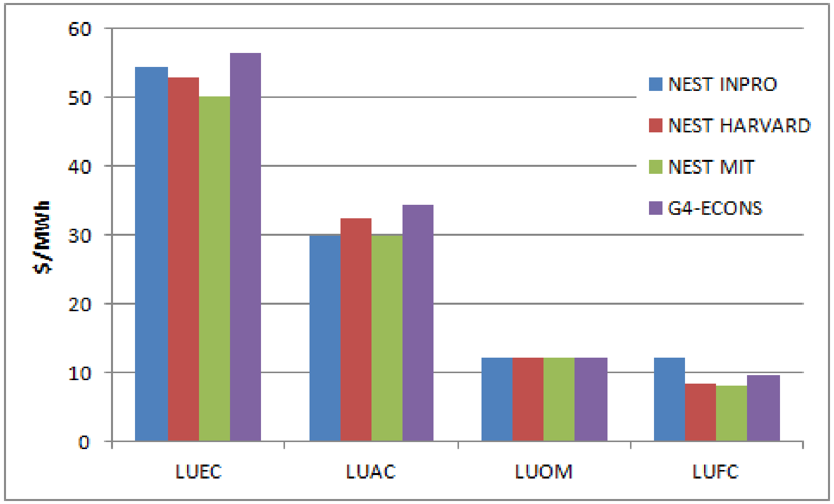
- *Sensitivity analysis on: operation life, years to construct, real discount rate, capital costs, and non-fuel operating costs was performed.*
- *80% confidence interval for LUEC was calculated as $42/MWh to $59/MWh*
- *This aligns with the HPLWR estimate of $24/MWh to $62/MWh*

Comparison of Results from G4-ECONS and NEST

Total Capital Investment Cost



Levelized Costs (LUEC)



- The TCIC is about 6% greater for the G4-ECONS model; a result of defining the first core as a capital cost in the G4-ECONS model.
- The LUAC is 13% higher for the G4-ECONS compared to NEST-INPRO and NEST-Harvard because the TCIC is higher.
- The LUFC for G4ECONS is 25% less than NEST-INPRO because the first core is not considered a fuel cost in the G4-ECONS analysis.
- The LUFC for G4ECONS is also 13-15% greater than the other NEST models (Harvard and MIT). This is also due to a difference in how the initial core is modelled.

Conclusion from the first Benchmarking Exercise

- *For once-through fuel cycles, NEST Version 1 and G4-ECONS produce very similar results (minor differences could be explained)*
- *Further economic assessments of fast reactor systems operating in closed fuel cycles would provide a valuable bench mark*

Three Modules of G4-ECONS

- **The "Reactor Cost" Module**

  Calculates TCIC and LUEC for electricity and/or heat

- **The "Nuclear Heat Applications" Module**

  Calculates levelized cost of other products, such as the cost of hydrogen or desalinated water, based on LUEC

- **The "Fuel Cycle Facilities" Module**

  Calculates levelized costs of fuel cycle products and services; results are used to calculate LUEC

Extent of G4-ECONS Applications

- Over 200 CD-ROMs requested from NEA
- Several papers based on G4-ECONS analyses have been published
- G4-ECONS and cost estimation methodologies demonstrated for
  - Gen III and Gen III+ systems – HWR, LWR
  - Gen IV systems – SCWR, Japanese SFR, GT-MHR
  - Hydrogen and process heat – GT-MHR, PH-MHR
  - Fuel Cycle Facility costing

Path Ahead

- Next Version of G4-ECONS to be released soon for beta-testing. Improvements include
  - Uncertainty analysis (uncertainties in multiple inputs of capital and operating costs)
  - Streamlined user interface
    - Simplify data entry
    - Clarify uncertainty analysis outputs
- Continue collaboration with IAEA
  - Benchmarking of G4-ECONS with INPRO's NEST for fast reactors in closed fuel cycle
- Outreach – promoting use of G4-ECONS amongst GIF community and beyond

Questions ?