GENIUS Version 2: Modeling the Worldwide Nuclear Fuel Cycle

Kathryn Huff | P. Wilson | K. Oliver | R. Elmore| T. Ahn | M. Gidden , Nuclear Engineering and Engineering Physics U. Wisconsin - Madison

GENIUSv2 (Global Evaluation of Nuclear Infrastructure Utilization Scenarios) *is a top-level, nuclear fuel cycle simulation code able to provide quantitative assessment of worldwide nuclear energy production, material flows, energy costs, environmental impact, proliferation resistance, and robustness against supply disruption.*

Facility Hierarchy in the Nuclear Fuel Cycle

- Facilities in the nuclear industry owned by distinct governments and institutions buy, sell, and trade nuclear materials.

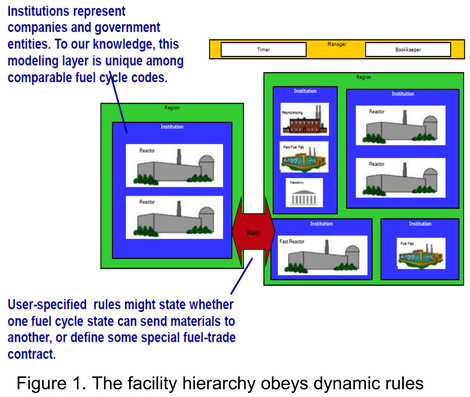


Figure 1. The facility hierarchy obeys dynamic rules regulating trade between regions and facilities.

Discrete Region, Institution, Facility Data Model

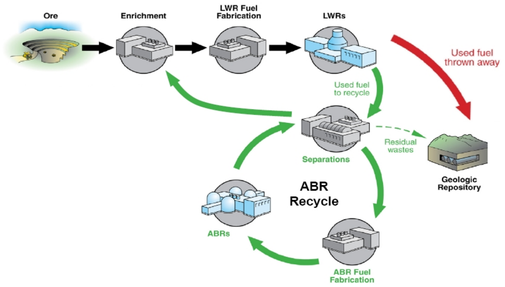


Figure 2. Distinct facilities in the nuclear fuel cycle perform distinct tasks, but are significantly interdependent, each relying on the production capacity of others upstream.

References

- Jain, R. and Wilson, P. P. H. (2006). "Transitioning to global optimization in fuel cycle system study tools." *Transactions of the American Nuclear Society*, **95**, pages 162–3.
- Juchau, C. (2008). "Development of the global evaluation of nuclear infrastructure and utilization scenarios (GENIUS) nuclear fuel cycle systems analysis code." Master's thesis, Idaho State University.
- Juchau, C. & Dunzik-Gougar, M.L. (2006). "A Review of Nuclear Fuel Cycle Systems Codes." Accessed 10 October 2009 from SINEMA Web site: http://thesinema.org/.
- Dunzik-Gougar, M.L. et al. (2007). "Global Evaluation of Nuclear Infrastructure Utilization Scenarios.
- Lisowski, P. (2007). Global Nuclear Energy Partnership. In *Global Nuclear Energy Partnership Annual Meeting*, Litchfield Park, AZ. Global Nuclear Energy Partnership.

Demand Driven Simulation

- From user-specified data about predicted energy demand over the lifetime of the simulation (hundred of years), GENIUSv2 builds facilities according to energy needs. Often, tens of thousands of facilities are built.

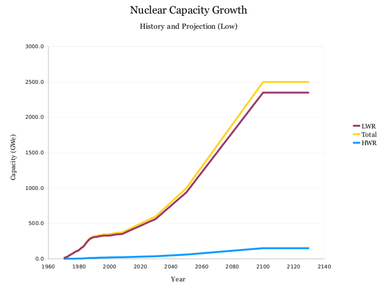
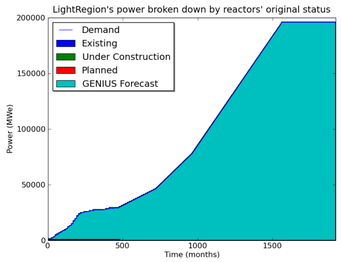


Figure 3. A user specified electricity or nuclear capacity demand scenario is given as an input parameter.



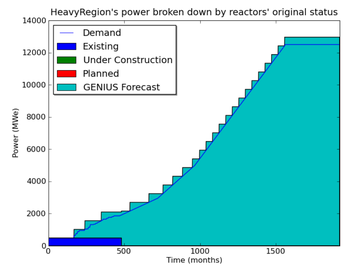


Figure 4. GENIUS builds reactors in order to meet demand, according to the type of capacity specified in the input parameters.

- This demand driven input structure eliminates the heuristics present in other simulation schemes and offers greater flexibility to the user.

Materials Tracking at the Isotope Level

- Quantitative assessments are driven by information about the state of the world's nuclear material at all stages of the nuclear fuel cycle.
- GENIUSv2 therefore tracks the history of each isotope involved in the entire simulation.
- Each facility type deals with the fuel at a different stage of its life cycle. These stages are treated as different commodities in the GENIUSv2 simulation.

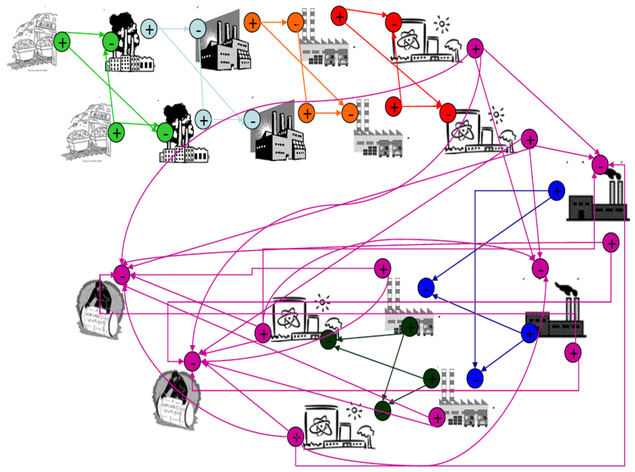
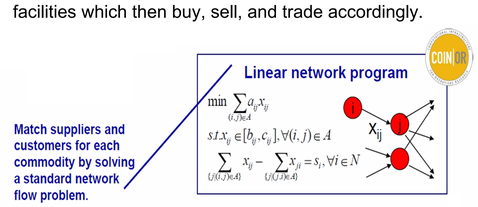


Figure 5. Each color represents a separately traded commodity. While each facility receives a different input feed, many facilities produce spent fuel destined for the repository.

Supply/Demand Matching Algorithm

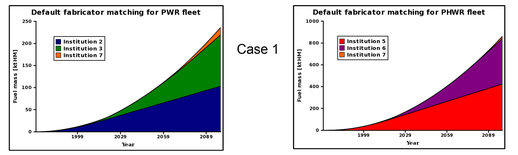
- Each facility in the simulation makes requests in order to fulfill its needs for feed commodities every month.
  - For example, a reactor with no fresh fuel on site might request some in order to be ready for refuel requirements of its next cycle.
- Simultaneously, each facility makes an offer of its current stocks of product commodity.
  - For example, a fuel fabrication facility might offer to sell the amount of fuel it has in stock from fabrication in the previous months.
- Finally, the SolverWrapper applies a matching algorithm to find a best fit for all of the offers and requests for that month. A Manager sends instructions to the various facilities which then buy, sell, and trade accordingly.



Current and Future Applications

- Benchmarking is a key step in software development, and GENIUSv2 is currently being benchmarked against similar codes.
- Economic Analysis to evaluate the cash flows in the fuel cycle is being pursued.
- Analysis of fuel cycle robustness against supply disruption is in the beginning stages.
  - Previous work shows that the GENIUSv2 matching algorithm accurately responds to dynamic affinity changes.

Region	Institution	Facilities
1	1	1 PWR in Jan. 1970 Linear growth: 1.71 GWe/year
	2	1 LWR Fuel Fab (78.66 tHM/month)
	3	1 LWR Fuel Fab (157.3 tHM/month)
2	4	1 PHWR in Jan. 1970 Linear growth: 675 MWe/year
	5	1 PHWR Fuel Fab (333.7 tHM/month)
	6	1 PHWR Fuel Fab (667.3 tHM/month)
3	7	1 LWR Fuel Fab (157.3 tHM/month) 1 PHWR Fuel Fab (667.3 tHM/month)



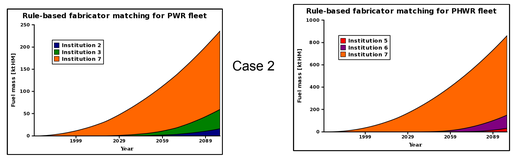


Figure 6. In Case 1, Institutions 1 & 4 have affinities with the foreign fabricator set to default values. In Case 2, however, those affinities increase at a set date during the simulation.

- This functionality will be useful for a case study underway in conjunction with WAGE, the Center for World Affairs and the Global Economy. This study is concerned with proliferation implications of technology transfer and the robustness of fuel cycle scenarios against supply disruptions.

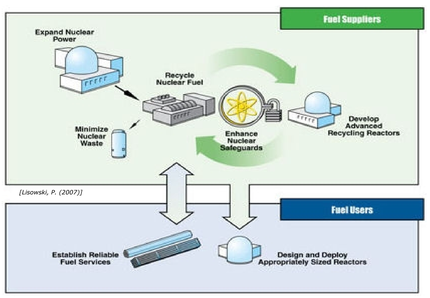


Figure 7. Nuclear Fuel supply security is a topic of great concern for international energy policy. Supplier nations and receiver nations lie in a delicate international balance.