# Core Model Proposal #407:
# Add Small Modular Reactors

**Product:** Global Change Analysis Model (GCAM)

**Institution:** Joint Global Change Research Institute (JGCRI)

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**Related sector:** energy

**Type of development:** data

**Purpose:** The goal of this core model proposal is to add small modular reactors (SMRs) as a new nuclear technology in the Global Change Analysis Model (GCAM). We introduced new data processing in gcamdata that incorporates global assumptions about SMRs from the Annual Technology Baseline (ATB) across all GCAM regions. We replaced the "Gen III" reactor with a “large reactor” and added “SMR” as a new technology in GCAM. Note that this proposal was combined with Core Model Proposal #415 in GCAM v8.8.

# Description of Changes

## Approach

The nuclear energy sector in GCAM is represented by two types of nuclear reactors: currently operational conventional light-water reactors (Gen II) and advanced reactor designs with improved economics and safety features (Gen III).

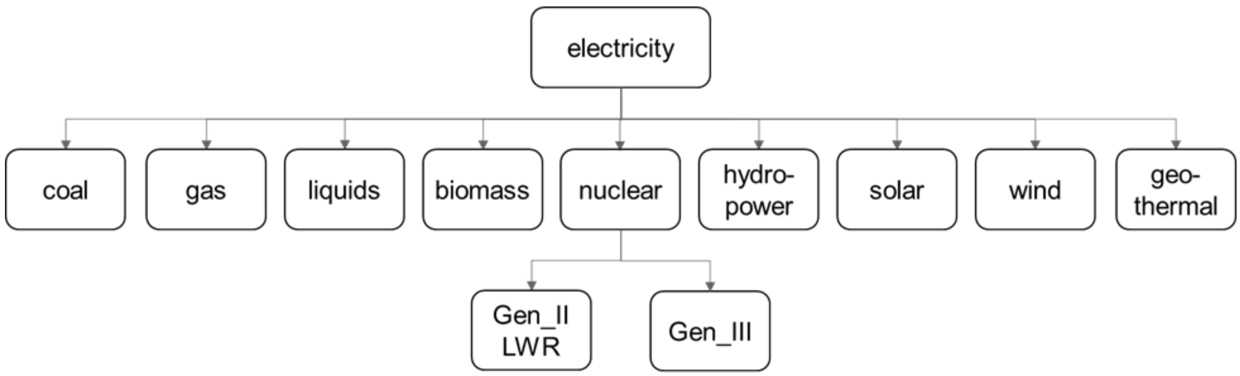


Fig 1. Nuclear energy sector in GCAM 8.0

The National Renewable Energy Laboratory (NREL) produces the Annual Technology Baseline (ATB) to document a set of input assumptions (e.g., technology cost, fuel costs), and a diverse set of potential futures (standard scenarios) to inform electric sector analysis. GCAM uses several key inputs from ATBs of various years, including overnight capital costs, fixed operations & maintenance (O&M) costs, and variable O&M costs for electric sector technologies. Since 2022, NREL has included cost estimates for small modular nuclear reactors (SMRs). We use data from the most recent ATB 2024 to add SMRs to the core model. We replaced the "Gen III" reactor with a “large reactor” and added “SMR” as a new technology in GCAM. As a result, the new structure of the power sector in GCAM looks as follows:

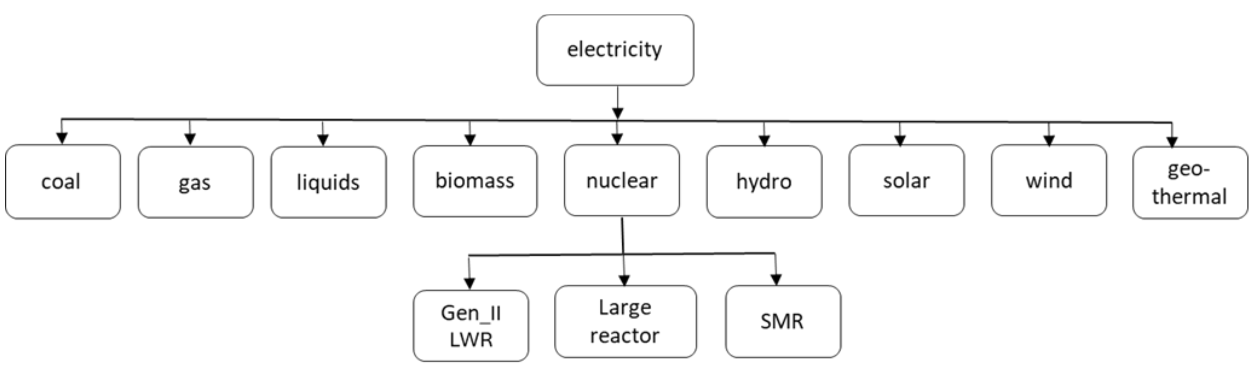


Fig 2. New nuclear energy sector in GCAM

The ATB 2024 edition has estimates of key SMR parameters (Variable O&M; Fixed O&M; Overnight Capital Cost) for three cost scenarios: Conservative, Moderate, and Advanced. The cost estimates are technology-agnostic, with a capacity of 1,000 MWe (1 GW) for a large reactor and 300 MWe for an SMR. The 2024 ATB projections are based on a compilation of historical cost estimates for various advanced nuclear energy technologies (NREL, 2024). Additional details on the methodology for providing the estimates are provided in (Abou-Jaoude, 2024). The **conservative** nuclear deployment projections were based on an average of two references: (Kim, 2022) and (EIA, 2022). Under this scenario, nuclear technology is deployed depending only on its cost and grid needs at a given time. No underlying assumption is made about potential innovations or government investments in the technology. The projections for nuclear deployments in the **moderate** scenario were primarily based on current (beginning of 2024) announcements for both contracted and potential deployments in public documents before 2024. The **advanced** scenario assumes government support and incentives in nuclear will continue, and private investment will be encouraged to achieve technological improvements. This will reduce long-term costs for new nuclear technologies and help achieve broader market penetration. By default, GCAM uses the **moderate** cost scenario.

The default GCAM capacity utilization rate for Gen II and Gen III reactors is 90%, and we maintain this rate for new large reactors and SMRs, although the ATB 2024 value is 93%.

For large reactors, we use the same cooling technologies and shareweights as for previous Gen_III reactors. For SMRs, the shareweight is zero in 2025 and 1 starting in 2030 – meaning these newer technologies cannot be deployed until the 2030 model period. SMRs use various novel cooling technologies, and some concepts are designed to use significantly less water than existing reactors or no water at all. We use the same set of cooling technologies for SMRs as for large reactors to ensure that cooling technology availability does not limit deployment in regions such as Japan, where only one cooling technology is available.

# Summary of Changes

The majority of model changes were limited to the nuclear electric sector. The following is a high-level, non-exhaustive summary of those changes:

- Updated several energy/A23 input files to reflect the change from Gen III to SMR and large reactor
- Added ATB 2024 data and mapping files to translate to the current GCAM ATB year convention (ATB 2022).

In GCAM-USA, the changes are similar to those in the global model regarding large reactors and SMRs. We made two additional changes:

- changed *elec share-weight by subsector* from zero to 1 in 2025 and 2030 to allow for new nuclear deployment in 2025 and 2030. This change was made in light of the fact that:
    - Two Vogtle reactors came online in 2023 and 2024
    - Several SMRs may come online before 2030 in the US.
- By updating the nuc_gen2.csv input file, we extended the lifetime of existing Gen II reactors, assuming license renewals for 80-year operational lifetimes, except for where closures have already been announced.

# Data Updates

Core Model Proposal #415 included updates to electricity technoeconomic data processing. For more information, see https://jgcri.github.io/gcam-doc/updates.html (GCAM v. 8.8).

Table 1: Summary of the code and data changes in this CMP to add SMRs.

| Object | Change |
|---|---|
| **input/gcamdata/inst/extdata/energy/mappings** | |
| A23.globaltech_capacity_factor.csv | Updated to include SMR and large reactor. Assumed consistent capacity factor of 0.9 for both new technologies. |
| A23.globaltech_eff.csv | Updated to include SMR and large reactor. Assumed consistent efficiency of 0.333 for both new technologies. |
| A23.globaltech_input_driver.csv | Updated to include SMR and large reactor. Linked both to nuclearFuelGenIII. |
| A23.globaltech_keyword.csv | Updated to include SMR and large reactor. |
| A23.globaltech_retirement.csv | Updated to include SMR and large reactor. Assumed consistent lifetime, median.shutdown.point, and profit.shutdown.steepness with Gen III. |
| A23.globaltech_shrwt.csv | Updated to include SMR and large reactor. Set large reactor shareweight to 1 starting in 2025 and SMR shareweight to 1 starting in 2030. |
| A23.subsector_shrwt_nuc_R.csv | Updated nuclear technology shareweights in the US to better represent observed technology developments in 2025. |
| **gcam-usa** | |
| A23.elec_delete.csv | Updated to include SMR and large reactor. |
| A23.elecS_globaltech_shrwt.csv | Updated to include SMR and large reactor. |
| A23.elecS_subsector_shrwt_interpto.csv | Updated shareweight interpolation rules for nuclear technologies. |

| | |
|---|---|
| A23.elecS_subsector_shrwt.csv | Updated shareweight interpolation rules for nuclear technologies. |
| A23.elecS_tech_availability.csv | Updated to include SMR and large reactor. |
| A23.elecS_tech_mapping_cool_shares_fut.csv | Updated to include SMR and large reactor. |
| A23.elecS_tech_mapping_cool.csv | Updated to include SMR and large reactor. |
| A23.elecS_tech_mapping_new.csv | Updated to include SMR and large reactor. |
| A23.elecS_tech_mapping.csv | Updated to include SMR and large reactor. |
| elec_tech_water_map.csv | Updated to include SMR and large reactor. |
| us_nuclear_legacy.csv | Added updated legacy nuclear reactor data for the US to improve Gen II behavior. This replaces the old nuc_gen2.csv input file. |
| **water** | |
| elec_tech_water_map.csv | Updated to include SMR and large reactor. Assumed same cooling technologies as Gen III for large reactors and SMR. |
| Macknick_elec_water_m3MWh.csv | Updated to include SMR and large reactor. Assumed the same cooling technologies as Gen III for large reactors and SMR. |
| **R** | |
| zgcamusa_L2244.nuclear.R | Updated to include updated US nuclear legacy data. |

# Validation

This proposal was combined with Core Model Proposal #415 in GCAM v8.8. Validation results in Core Model Proposal #415 reflect the changes introduced in this proposal.

# Limitations and Future Work

One difference between large reactors and SMRs, which is not captured in our current GCAM representation, is construction time. ATB 2024 estimates different construction durations for large reactors and SMRs (7 years and 5 years in the Moderate cost case, respectively). This in turn influences the Construction Financing Cost (CFC) for nuclear technologies, with large reactors facing a higher CFC per unit of capacity due to their longer construction period where interest is accrued without revenue generation. GCAM uses overnight capital cost (OCC), rather than CAPEX (OCC + CFC), in calculating levelized cost of energy (LCOE), as well as a 0.13 fixed charge rate for annualizing investment costs (this FCR is constant across technologies). Thus, differences in construction time do not influence the cost competition between large and small reactors, or between nuclear and other generation technologies. Future work could improve upon this representation by accounting for CFC in investment costs or applying technology-specific FCRs.

# References


Abou-Jaoude, A., Levi Larsen, Nahuel Guaita, Ishita Trivedi, Frederick Josek, Christopher Lohse, Edward Hoffman, Nicolas Stauff, Koroush Shirvan, and Adam Stein, 2024. Meta-Analysis of Advanced Nuclear Reactor Cost Estimations. Idaho National Laboratory, https://www.osti.gov/biblio/2371533.

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