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DOE/INLJAEA Collaboration: HTTR Secondary System Modeling

February 2022

Changing the World's Energy Future

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DOE/INL—JAEA Collaboration: HTTR Secondary System Modeling

JAEA – INL Collaboration on Integrated Energy Systems

February 2, 2022

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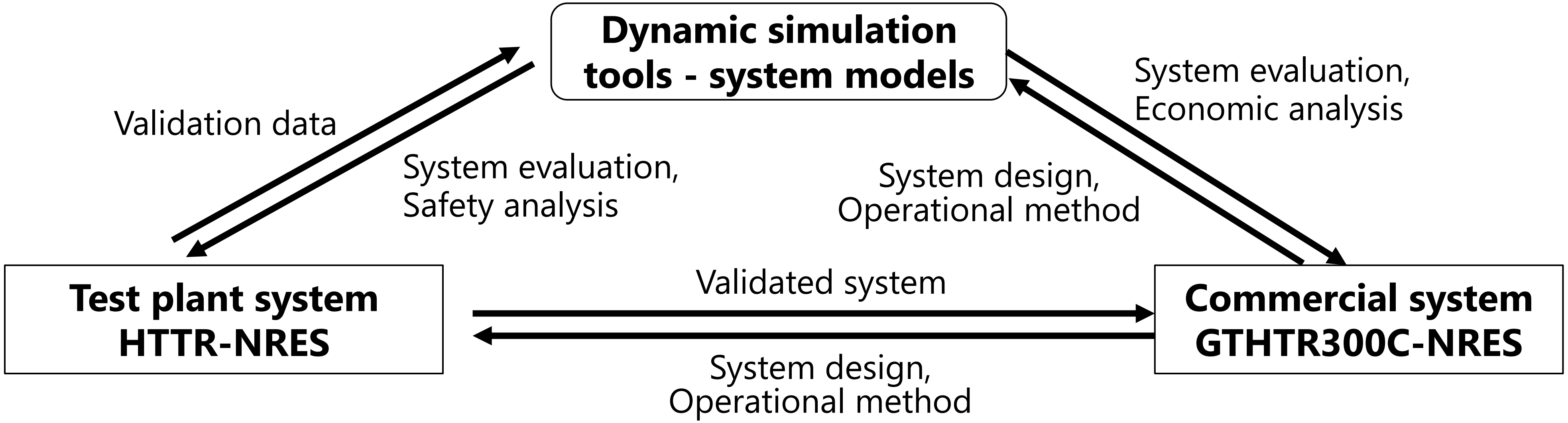
INL/JAEA Collaboration Scope (via CNWG)

- Objective
  - Develop the system technology for a high temperature engineering test reactor (HTTR) coupled, advanced reactor nuclear-renewable integrated energy system (HTTR-NRES).
- Subtasks
  1) Configure an advanced reactor (HTGR-based) integrated nuclear renewable integrated energy system
  2) Develop a dynamic simulation tool to assess performance (operability and economics) and safety of the HTTR-NRES
  3) Use HTTR as a test bed to validate the simulation tool and the system technology.



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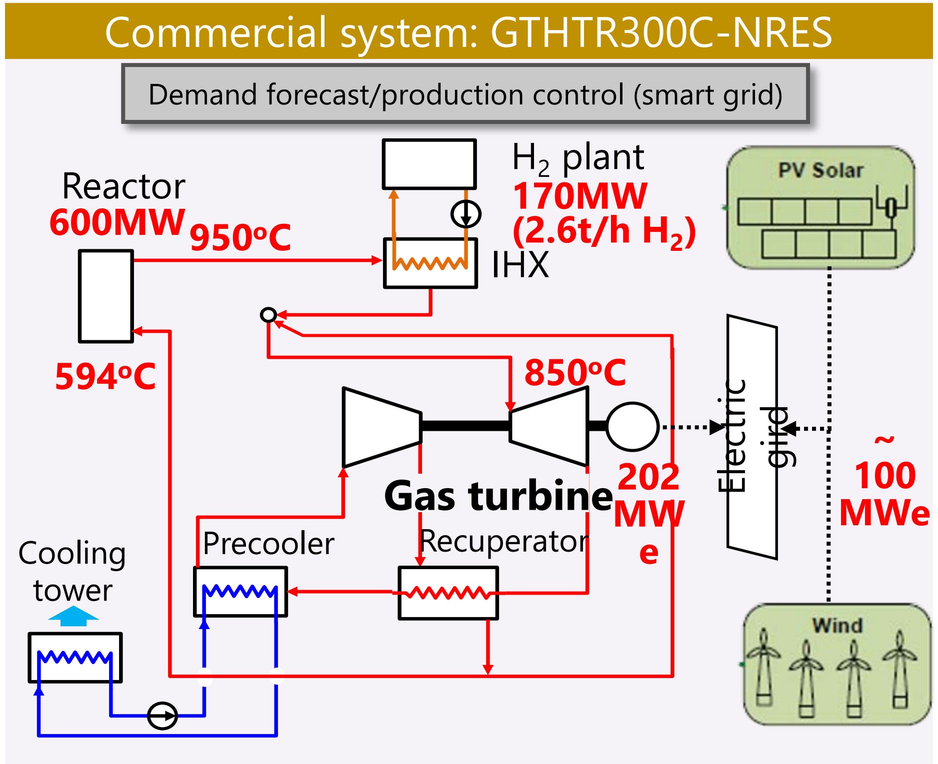
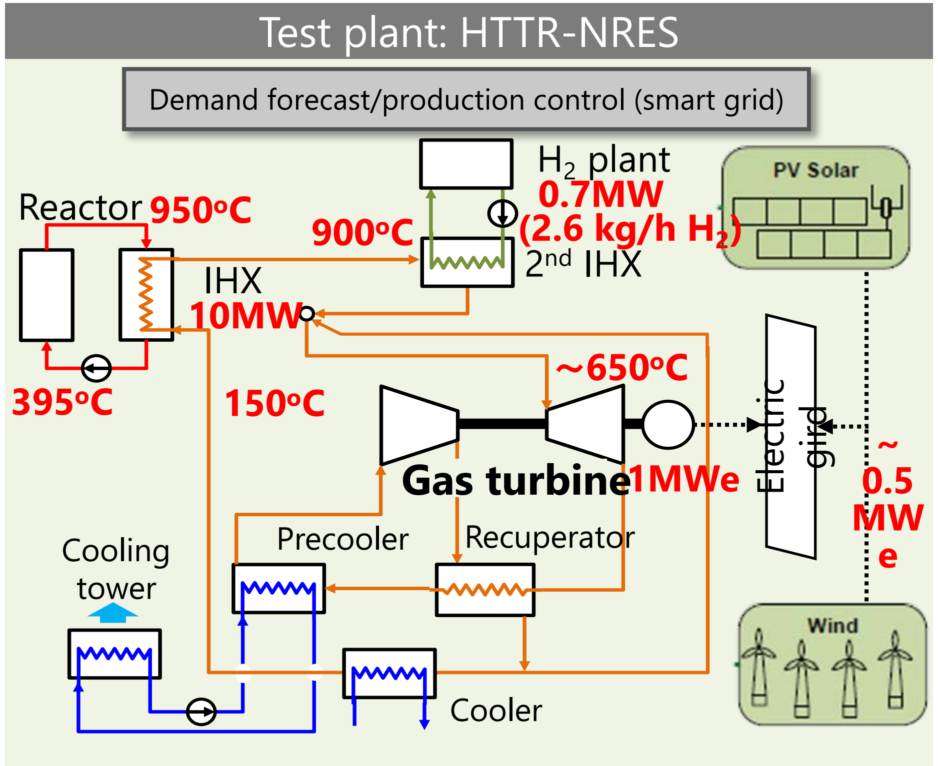
Secondary System Modeling Tasks

- RELAP5-3D Secondary System Modeling
- Primary System Input Conversion
- Economic Dispatch Model





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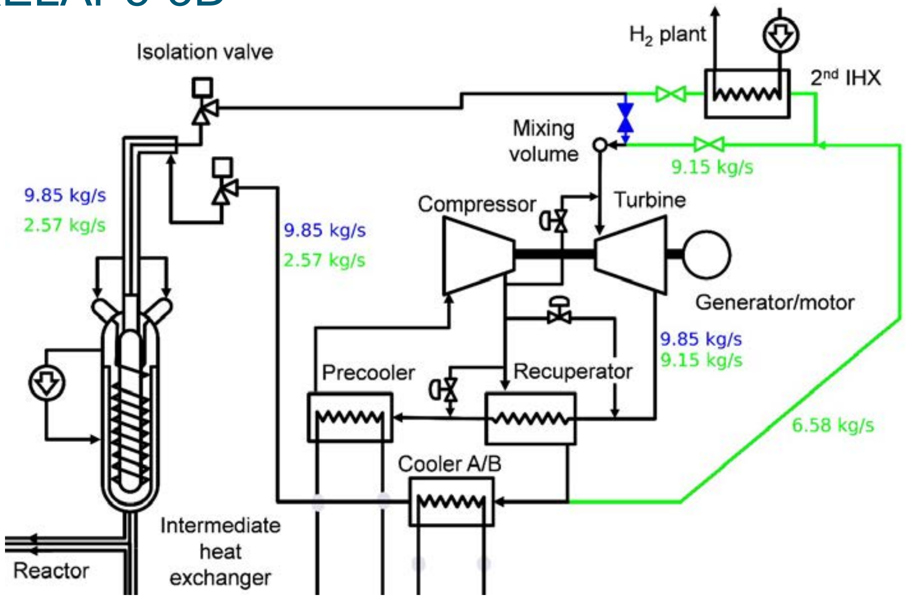
RELAP5-3D Secondary System Modeling

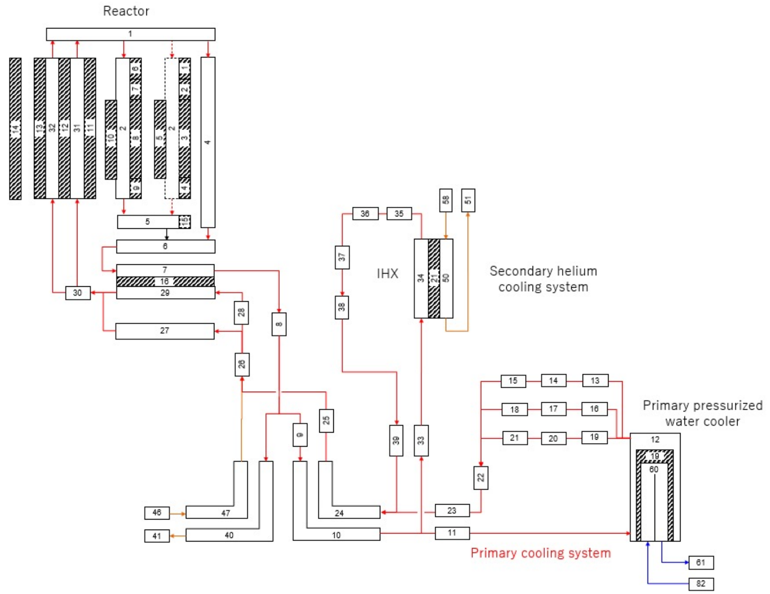
- The proposed HTTR-GT/H_2 secondary system was modeled with RELAP5-3D
- The sole power generation and hydrogen co-generation modes were modeled
  - The RELAP5-3D calculation results for sole power generation mode matched design values well; the largest difference in temperature was about 7 K and the largest pressure difference was about 50 kPa
  - The calculation results did not match as well for the hydrogen co-generation mode; the largest differences are shown in the table below, typically observed in locations where the flow was split/combined
- The compressor pressure ratio and the heat transfer area of the recuperator are areas that could be modified to potentially improve results



Location	Temperature [K]		Pressure [MPa]	
	Design	RELAP	Design	RELAP
Turbine inlet	**841.35**	**815.13**	4.077	4.07664
Turbine outlet	**779.45**	**740.13**	**3.283**	**3.11917**
Compressor outlet	347.35	341.76	**4.402**	**4.13551**
Recuperator HP side outlet	**737.15**	**702.02**	4.134	4.13032

Primary System Input Conversion

- A primary system model of the HTTR was provided to INL from JAEA. This model was built with RELAP5/MOD3.3
- INL was tasked with modifying the input to be compatible with RELAP5-3D
- Various changes were made to the input deck including:
  - RELAP5 keywords were changed from upper to lower case
  - The original input deck used the helium noncondensable gas as the working fluid – the deck was modified to use the helium primary working fluid
  - Pipe components required the addition of the CCC1201-CCC1299 volume initial conditions cards
  - Branch components required the addition of the CCC0200 volume initial conditions cards
- After the conversion, the primary system input deck was connected to the secondary system input deck
  - Some component, heat structure, and control variable numbers were changed to prevent their inadvertent deletion



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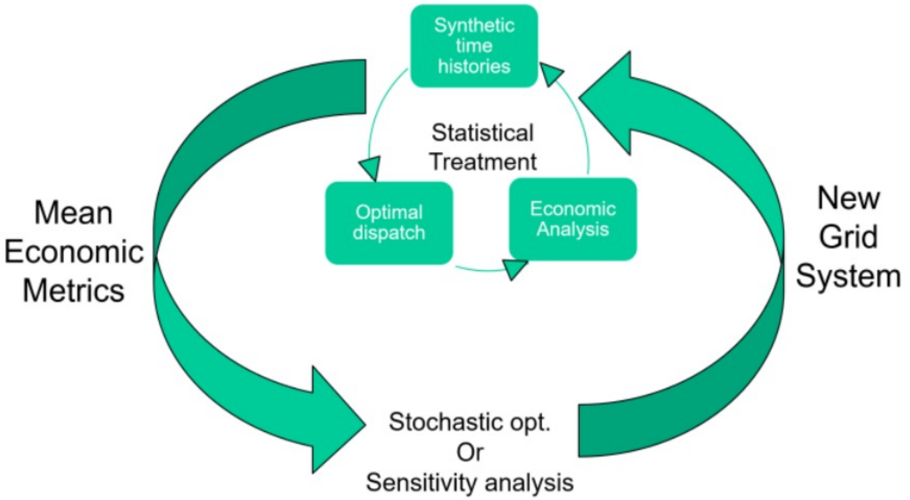
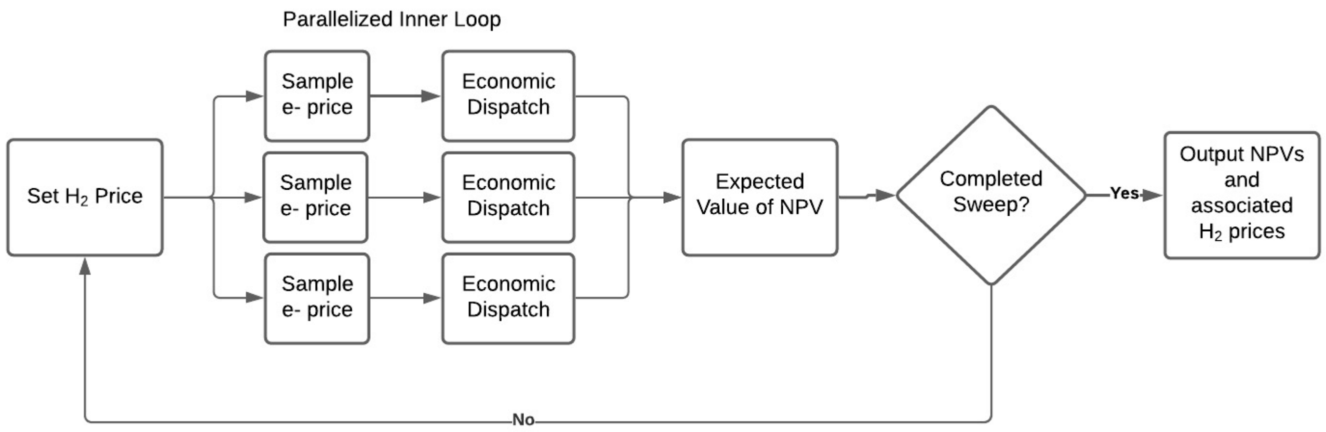
Economic Dispatch Model

- The HTTR-GT/H_2 dispatch model was developed to generate insights into the optimal dispatch of the electricity and hydrogen. The goal of the dispatch model is to find the sale price of hydrogen where the system can sell hydrogen to break even economically
- The RAVEN framework was used in conjunction with the HERON plugin to develop economic dispatch models; the general schematic of the HERON dispatch model workflow is shown below





- A synthetic electricity price time history was developed using an autoregressive moving average (ARMA) model coupled with a Fourier detrending model, known as FARMA

Economic dispatch model, etc.

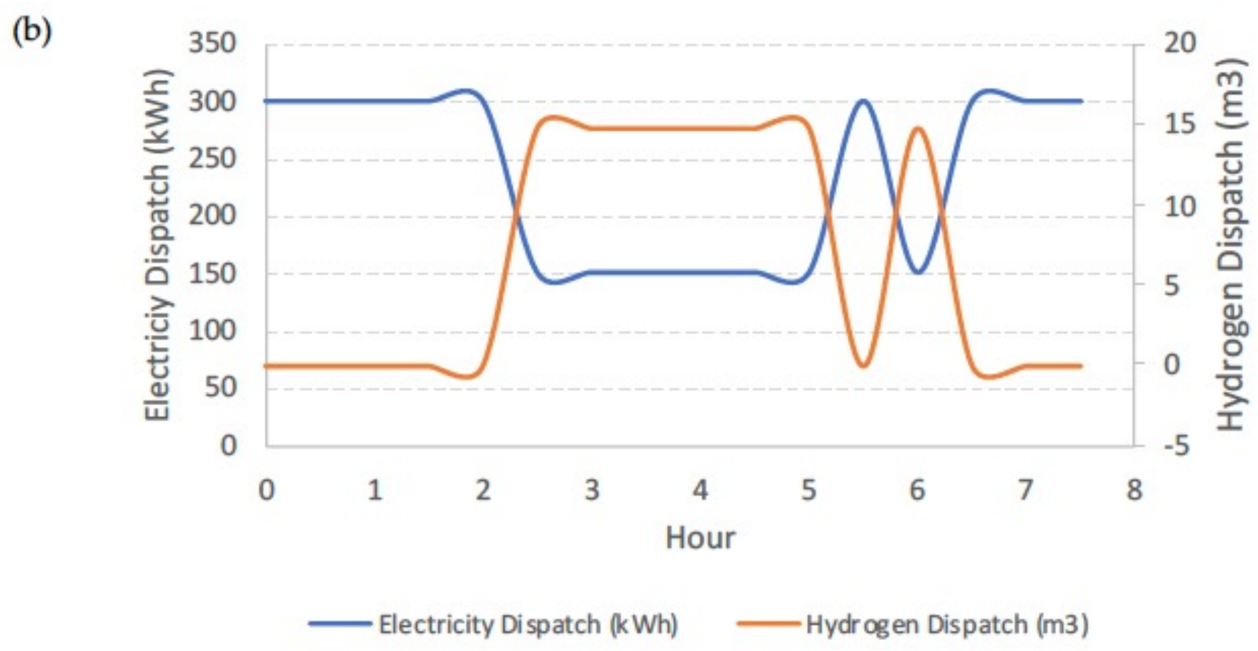


Figure 20. Example of dispatch logic over an 8-hour period. (**a**) The opportunity cost for producing hydrogen or electricity. (**b**) Hydrogen or electricity modes dispatched in accordance with the higher opportunity cost. This strategy ensures that electricity is sold only when profitable.

- After sampling the FARMA to produce a synthetic data set, the model dispatches either electricity or hydrogen, depending on the electricity price at each time step
- The breakeven cost of hydrogen was found to occur at 67.5 JPY/m^3
- A breakeven cost of 67.5 JPY/m^3 equates to 431 expected hours of hydrogen production per year
- Hydrogen price increases result in boosting the number of hours in which hydrogen production is economically advantageous

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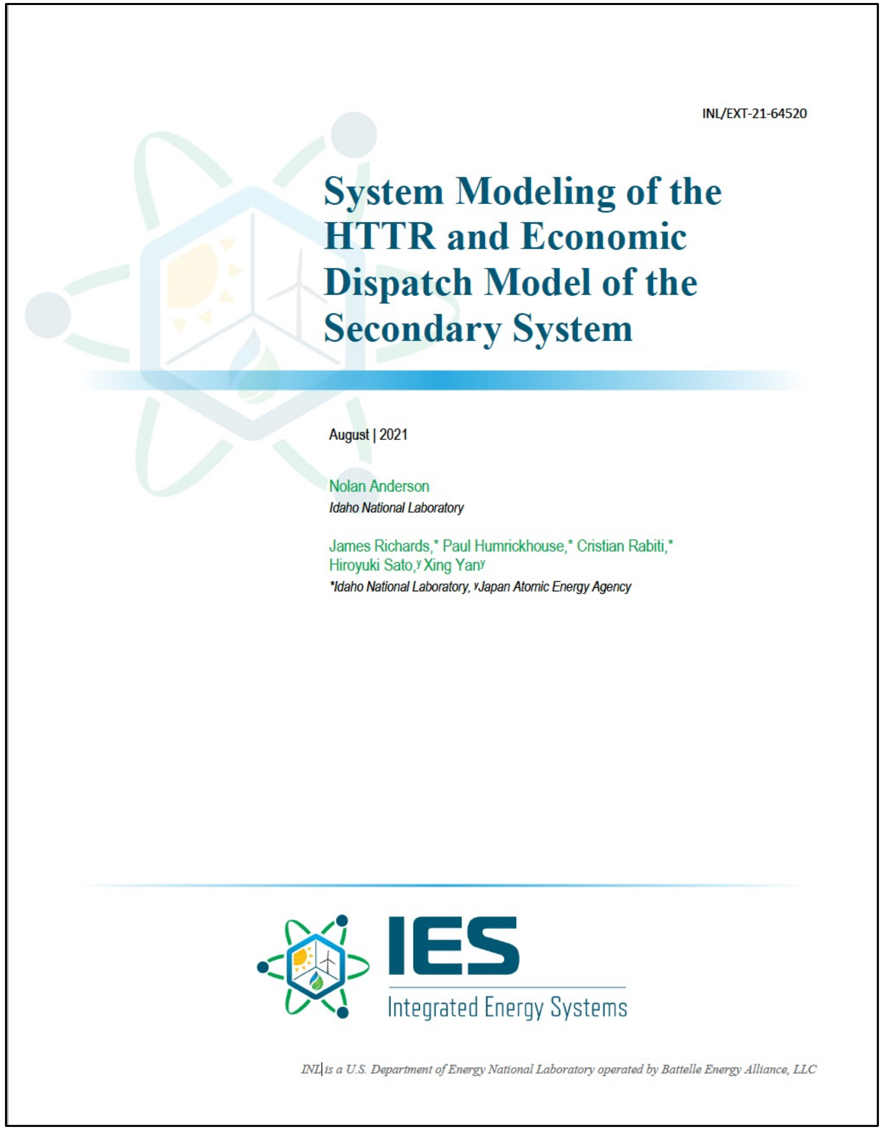
Final report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System Modeling of the HTTR and Economic Dispatch Model of the Secondary System

August | 2021

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- Final report available at: https://www.osti.gov/biblio/1836104-system-modeling-httr-economic-dispatch-model-secondary-system
- 2 journal articles in development and in final journal review