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#### **Energy Arbitrage with Hydrogen: HTSE + Combustion Turbine**

August 2023

Samuel Jacob Root, Amey Shigrekar, Michael McKellar, Todd Knighton



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Idaho National Laboratory Idaho Falls, Idaho 83415

http://www.inl.gov

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# **ENERGY ARBITRAGE WITH HYDROGEN: HTSE + COMBUSTION TURBINE**

Sam J. Root<sup>1,2</sup> Intern Amey Shigrekar<sup>2</sup> | Mentor Michael G. McKellar<sup>1</sup> | co-Pl

L. Todd Knighton<sup>2</sup> P

<sup>1</sup>University of Idaho | Department of Nuclear Engineering and Industrial Management <sup>2</sup>Energy and Environment Science & Technology | Hydrogen and Thermal Systems



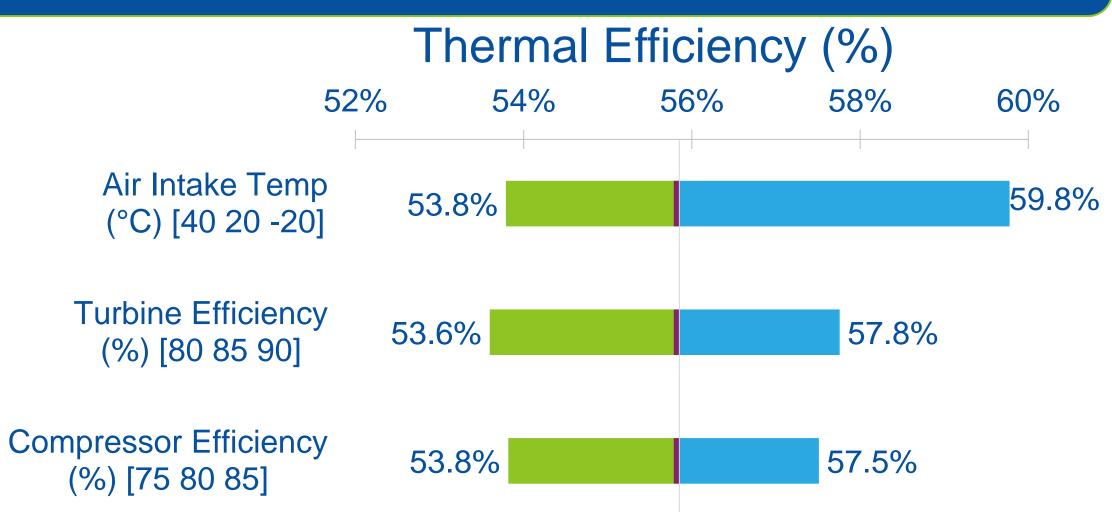
## H, ENERGY STORAGE FOR LWRS

De-carbonizing our electrical grid is crucial to the health of our planet

- Renewables are insufficient at responding to changes to grid demand
- They regularly produce surplus energy that depresses the wholesale electricity price, and at other times under-generate, putting customers at risk of black-outs/brown-outs
- Energy Storage is critical for Energy Security

Burn Hydrogen when **Divert** Heat and **Store** Chemical Grid Demand is High Electricity to Potential Energy as to produce Zero-TSE When Grid Hydrogen Emission Electricity Demand is Low

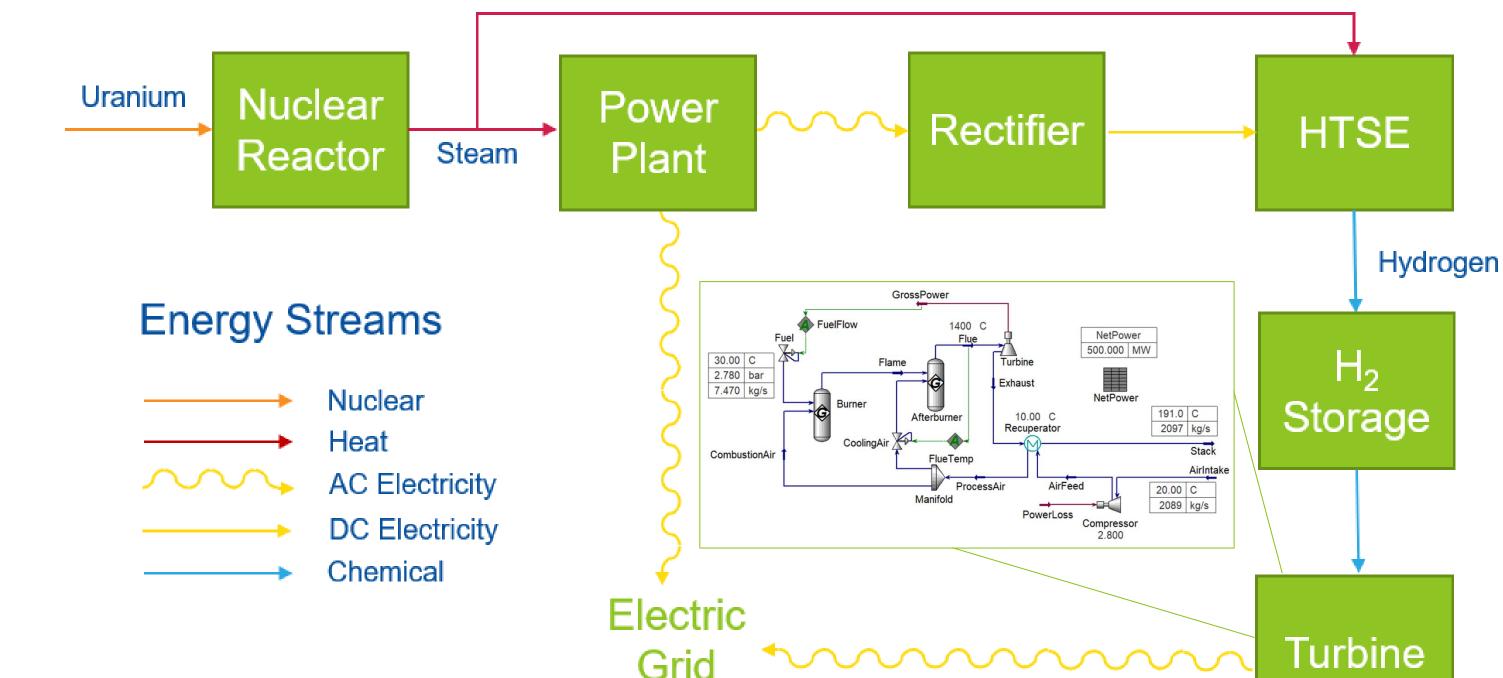
### **PARAMETRIC ANALYSIS**



- The Flexible Plant Operation and Generation (FPOG) pathway investigates Energy Storage System (ESS)
- ESSs can be used for Energy Arbitrage to give an alternative to curtailment or paying to put power on the grid
- High Temperature Steam Electrolysis (HTSE) connected to H<sub>2</sub> storage is one of the most promising energy arbitrage technologies due to scalability

## **PROCESS MODELING**

This work is focused on regenerating electricity by burning stored H<sub>2</sub> in a recuperated simple cycle combustion turbine. Previous and concurrent work at INL have investigated the HTSE and H<sub>2</sub> storage processes in more detail<sup>[1]</sup>.







Flame Temperature (°C) [1350 1400 1450]





55.6% 56.0%

# **TECHNO-ECONOMIC ANALYSIS**

Capital,

4.5 ¢

Fixed

O&N

55.3%

Levelized Cost Breakdown

Variable

**O&M**,

16.6 C

Nuclear

Power

#### Assumptions

\$473MM CAPEX

56.2%

- $3/kg H_2$  from HTSE, stored in pressurized tube trailers
- 8 full power hours/day
- 12% WACC
- 25-year project life

Levelized Cost of Storage (LCOS) – 21.5 ¢/kWh-e

Processes

Approach to Modeling the H<sub>2</sub> turbine in Aspen HYSYS

- Fuel flow rate adjusted to yield 500 MWe net power
- Air flow rate adjusted to provide 20 percent excess air and cool adiabatic flame temperature to 1400°C
- 2.8:1 Pressure Ratio
- Recuperator with 10°C minimum approach
- Burner and Afterburner modeled as Gibbs Reactors

#### **Results from the HYSYS Model**

 $2H_2$ 

- $18.59 \text{ kWh}_{e}/\text{kg-H}_{2}$
- 55.8% Thermal Efficiency
- 191°C stack gas can provide 200 MW<sub>th</sub> for district heating when cooled to 100°C and an additional 150 MW<sub>th</sub> at its dewpoint of 33°C

## FUTURE OF CLEAN HYDROGEN

Hydrogen will be used not only to store energy, but also as a building block to de-carbonize other industries Chemical





### ACKNOWLEDGEMENTS

[1] Knighton, Lane T, Shigrekar, Amey, Wendt, Daniel S, Frick, Konor L, Boardman, Richard D, Elgowainy, Amgad A., Bafana, Adarsh, Tun, Hla, and Reddi, Krishna R. Energy Arbitrage: Comparison of Options for use with LWR Nuclear Power Plants. United States: N. p., 2021. This work was supported by the LWRS Program on the FPOG Pathway under DOE Idaho **Operations Office Contract No. DE-AC07-05ID14517** 



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