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Integrated Energy Systems Experimental Systems Development

Terry James Morton

September 2020

The INL is a U.S. Department of Energy National Laboratory
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IES Experimental Systems Development

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Goals for Today

- High-level discussion of Integrated Energy Systems
- Overview of Dynamic Energy Transport and Integration Laboratory (DETAIL)
- Overview of Thermal Energy Distribution System (TEDS)
- Overview of Microreactor Agile Non-Nuclear Experimental Test Bed (MAGNET)

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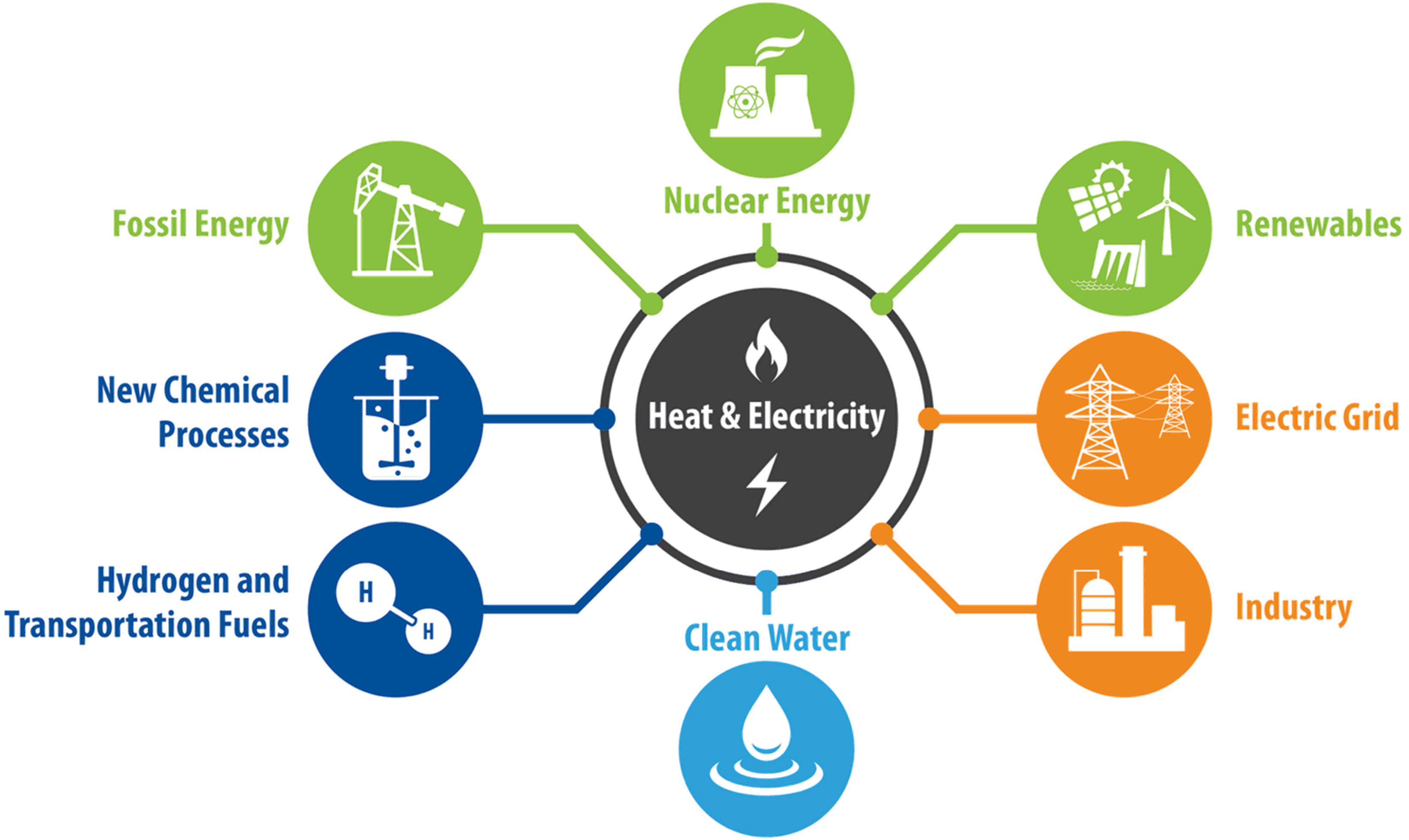
Integrated Energy Systems (IES)

…using energy efficiently and effectively…



"Right-sized" reactors offer new options for various community sizes and energy demands.

Large Light Water Reactors

Micro Reactors

Small Modular Reactors

Advanced Reactors

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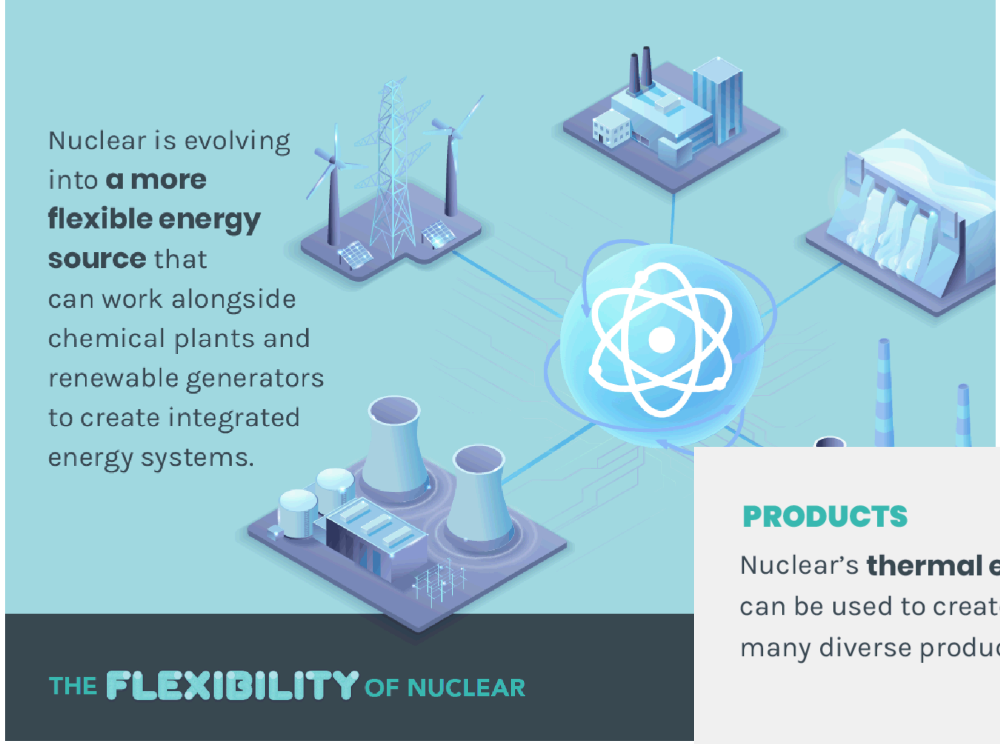
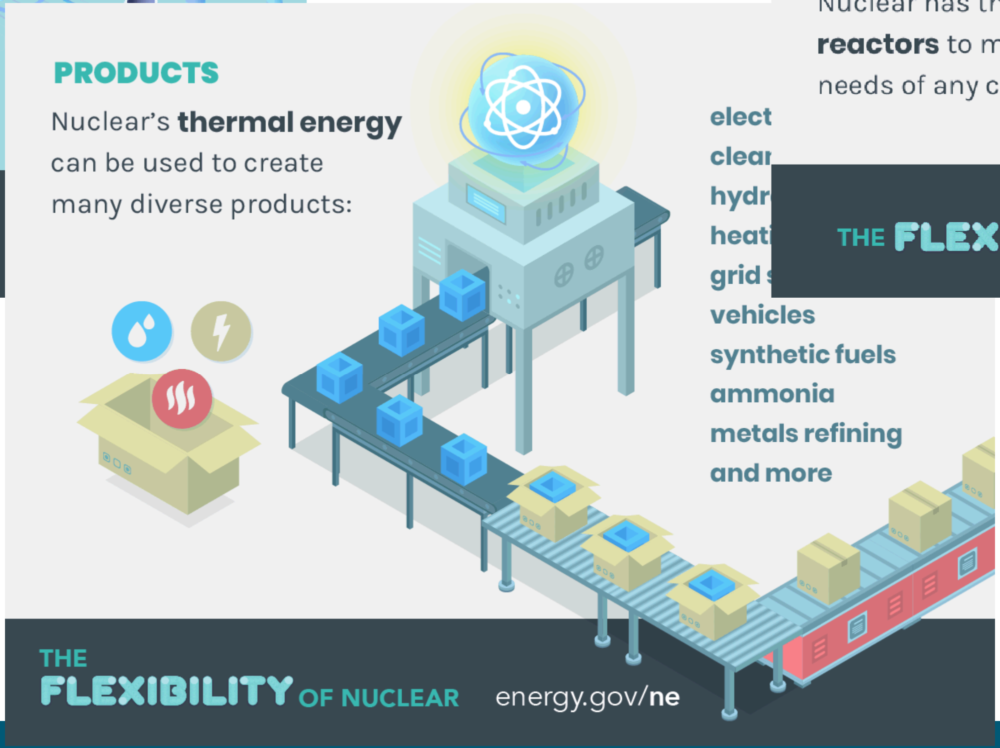
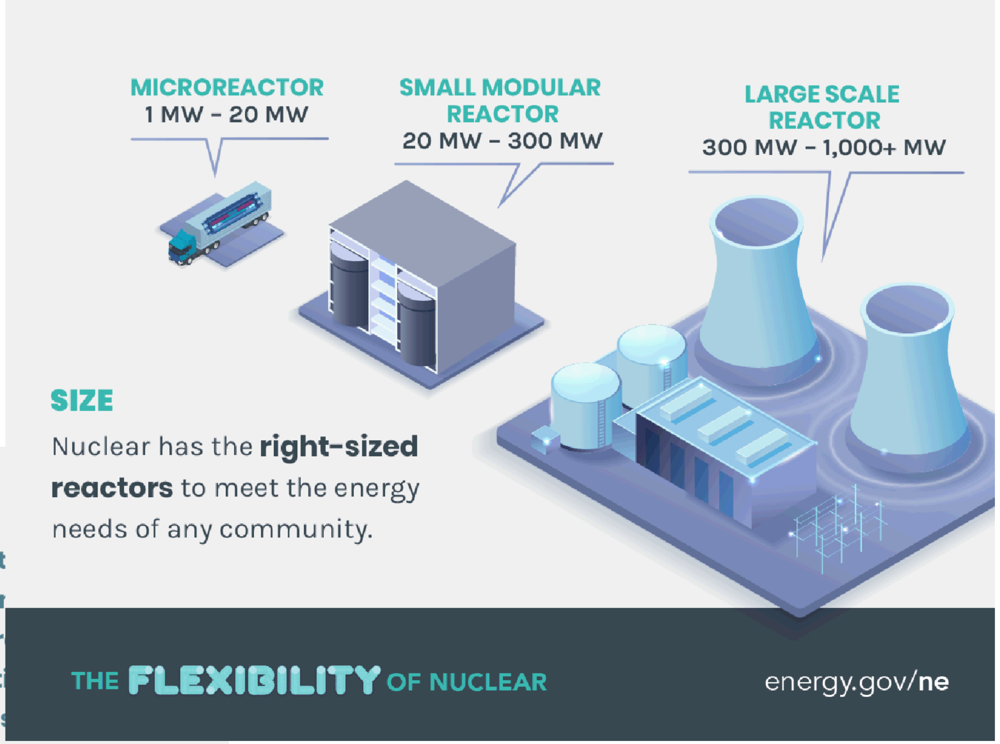
IES Offer a Key Opportunity for Energy System Flexibility







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LWR-H_2 Demonstration Projects: Exelon, USA

Exelon®

Partners: Nel Hydrogen, ANL, INL, NREL (via DOE)

Analysis Report: Evaluation of Hydrogen Production for a Light Water Reactor in the Midwest

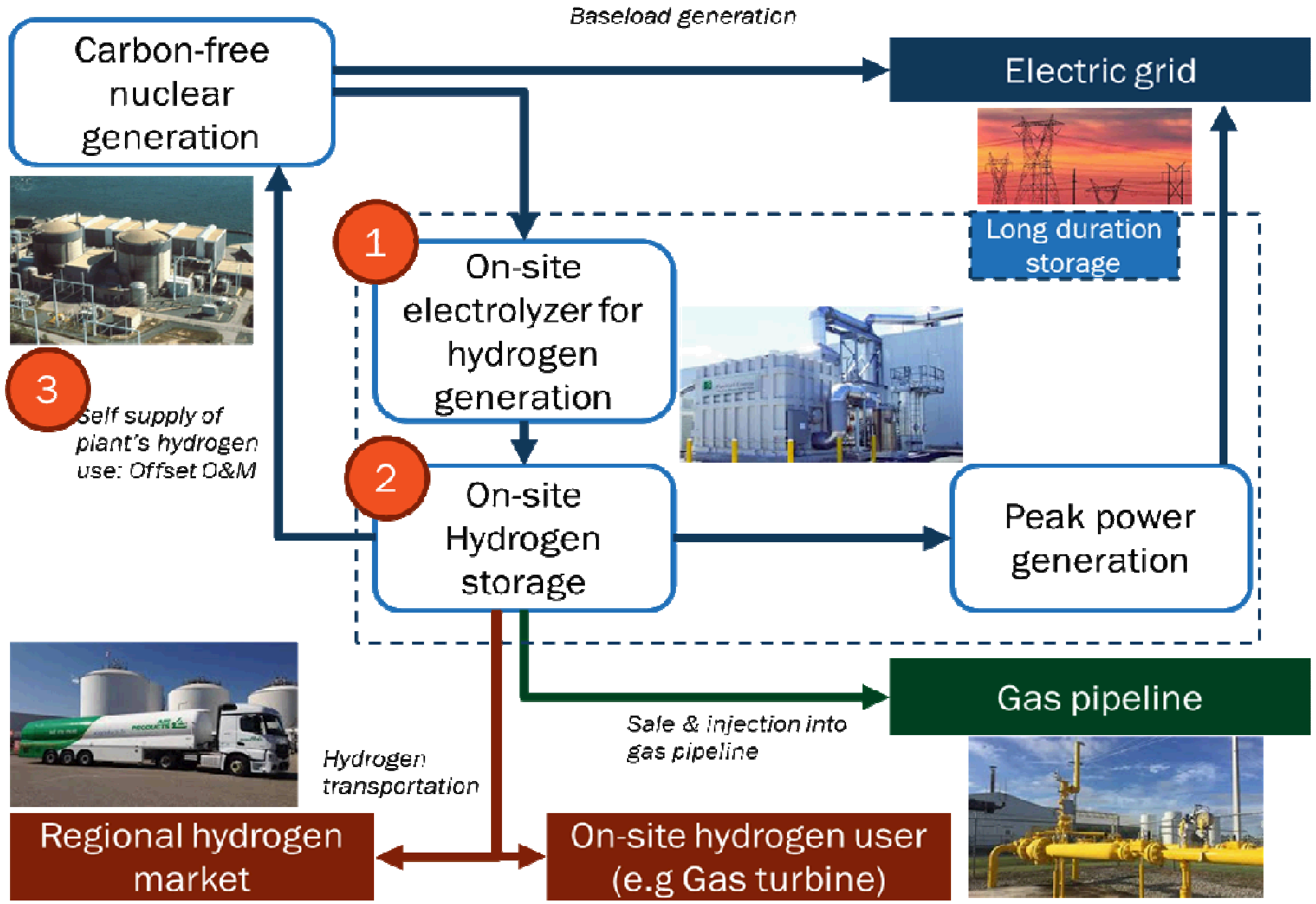
Purpose & Scope:

1. Demonstrate hydrogen production using direct electrical power offtake from a nuclear power plant and acquaint plant operators with methods and controls for scaling up to large commercial plants.

2. Evaluate power offtake dynamics and inverter control response to provide grid contingency, ramping reserves, and volt/reactive control reserve.

5. Produce hydrogen for captive use by NPPs

6. Produce hydrogen for first movers of clean hydrogen; fuel-cell buses, heavy-duty trucks, forklifts, and industrial users



**Exelon will commence testing within 18-24 months at a to-be-announced LWR plant.

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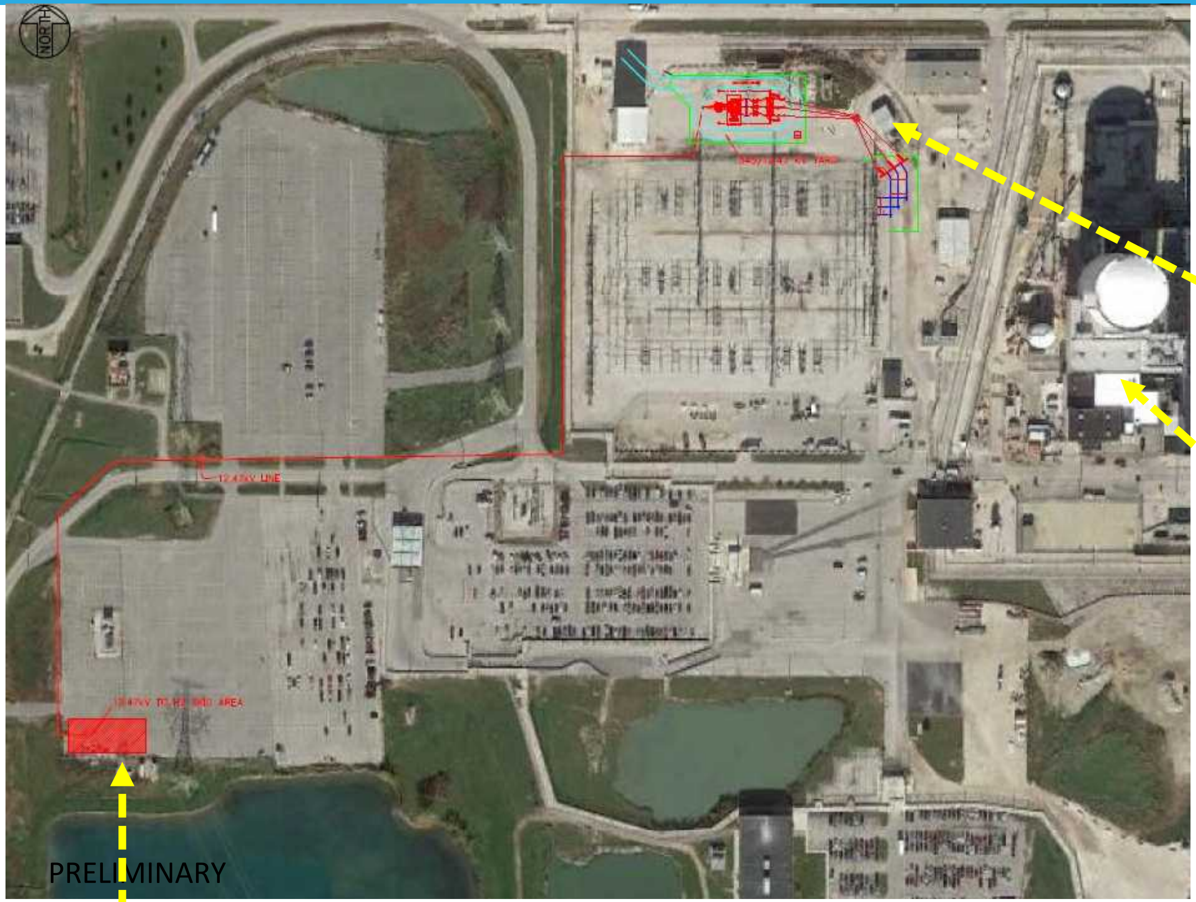
LWR-H_2 Demonstration Projects: Davis Besse, Ohio, USA



Electrical Tie-In

Power Block

Hydrogen Production Area

**Commence testing in 24-36 months.

Industry Consortium of Energy Harbor, Xcel Energy, Arizona Public Service, DOE Labs

—

The engineering design team will design and locate the hydrogen production equipment such that the effect on the design and licensing basis is mitigated (to the extent practical).

Analysis Report: Evaluation of Non-electric Market Options for a Light-water Reactor in the Midwest

LWRS LIGHT WATER REACTOR SUSTAINABILITY

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Dynamic Energy Transport and Integration Laboratory (DETAIL)

Human-in-the-Loop

Flexible
Industrial
Process

Grid-in-the-Loop

Thermal Energy Generation and Transport

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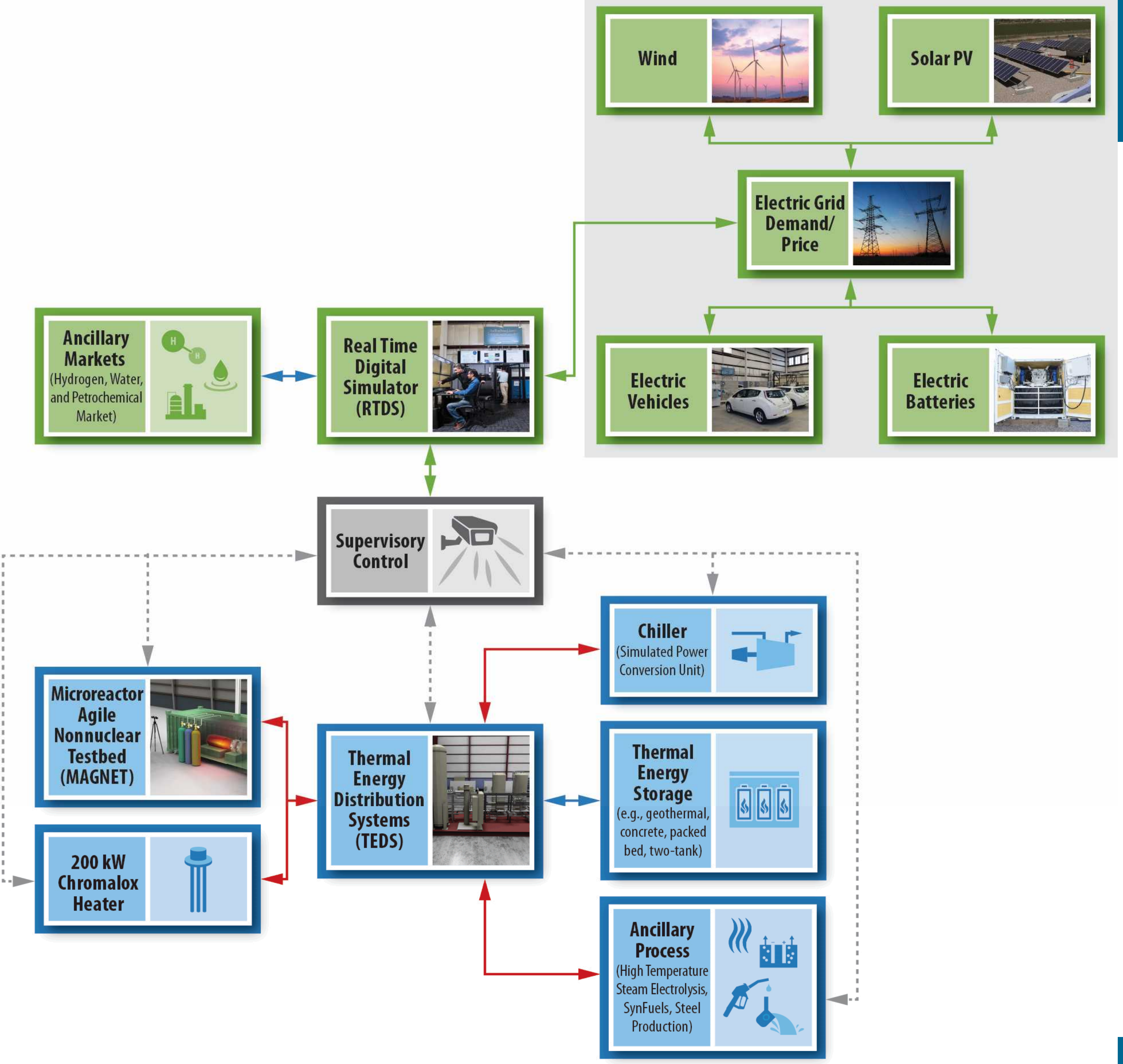
Dynamic Energy Transport & Integration Lab (DETAIL)



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Dynamic Energy Transport & Integration Lab (DETAIL)

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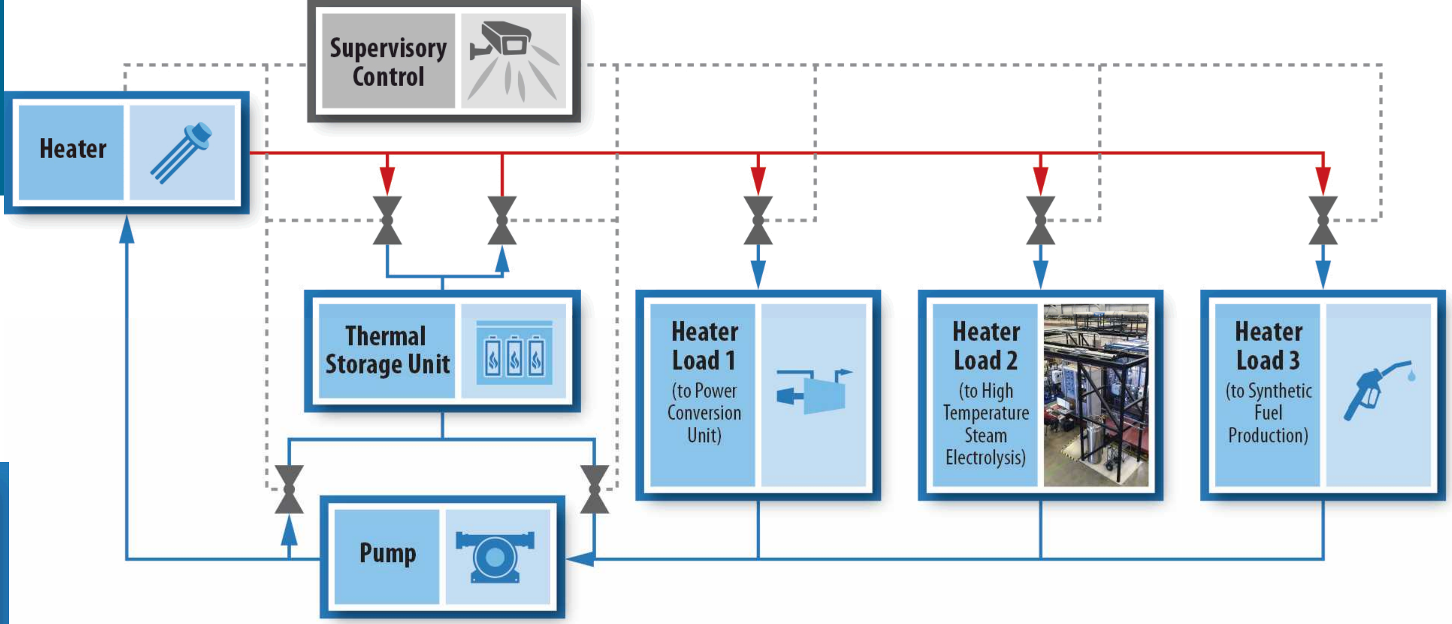
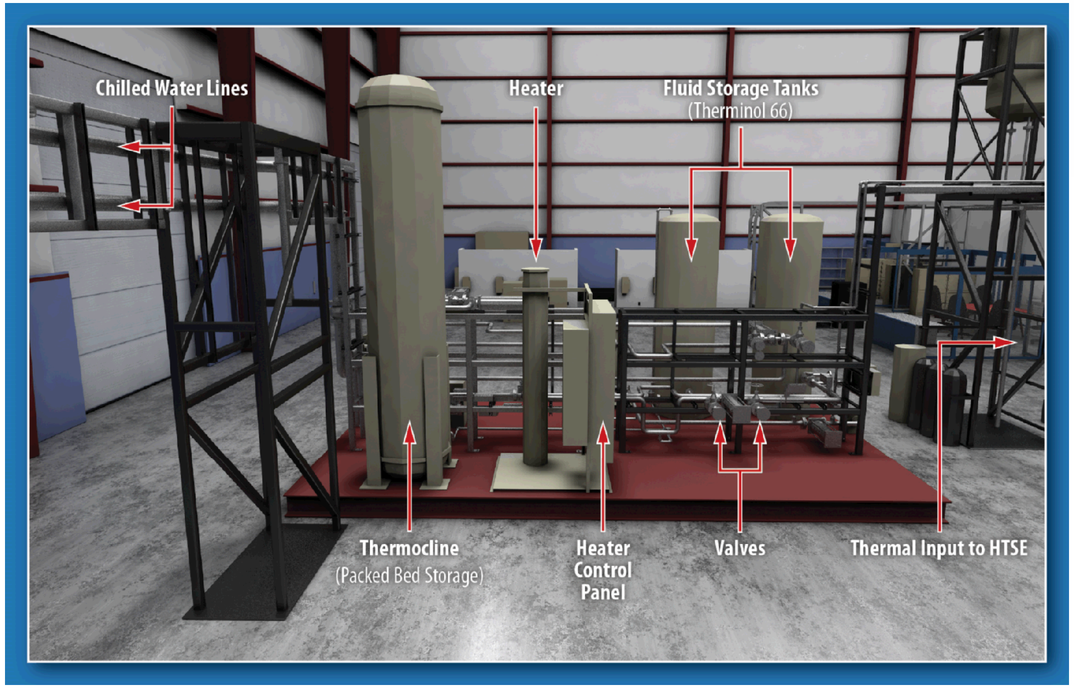
TEDS



To begin initial operation in December 2020



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TEDS Objectives

- **Performance analysis and demonstration** of:
  - Energy storage in charge and discharge modes
  - Energy storage in the context of integrate) system operation strategy
  - Valves, flanges, instrumentation, and other associated components (such as gaskets, seals, filler materials) under steady-state and cycling modes
  - Distribution of thermal energy to and from various co-located systems, further providing information on the dynamic operation and characteristic time constants associated with moving thermal energy between systems of different sizes and heat requirements.
- **Develop and demonstrate** monitoring and control systems and to investigate real-time, hardware-in-the-loop **response characteristics** relative to grid operations. The system can be used to characterize thermal energy inertia and thermal energy management relative to the interoperability of a nuclear plant, power generation, and industrial heat applications.
- **Validate computational models** such as RELAP, Modelica, and other transient physics-based models that can support scale-up of integrated energy systems.
- **Demonstrate** transport/transmission characteristics and performance in a flexible and dynamic manner, such that the envisioned **operating modes** can be tested and performance verified.
- **Provide** a test platform to test standard regional grid operations and to experimentally simulate the buildout of potential future grids that may include excessive renewable (solar and wind) penetration.
- **Provide** an opportunity to experimentally **demonstrate grid stressors** that otherwise may not be simulated and see how such stressors may impact the generators in one-way feedback.
- **Support unattended operation** and provide a platform for **demonstrating** safe shutdown procedures.
- Provide a test/demonstration platform to **support** cyber-informed engineering of controls and hardware systems.

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TEDS Process and Instrumentation Diagram (P&ID)

P&ID Legend

- FM-000 Flow Meter
- TC-000 Thermocouple
- PT-000 Pressure Transducer
- DP-000 Differential Pressure Meter
- LDP-000 Level Differential Pressure Meter
- RXX-000 PWR HX System Instrumentation
- FO-000 Fiber Optic Cable for Temperature & Strain
- CV-000 Check Valve (CV)
- Globe Valve (GBV)
- Ball Valve (BV)
- Flange

0XX: TEDS Instrumentation
1XX: PWR-HX Interface Instrumentation
2XX: TES Instrumentation
3XX: HTSE Instrumentation

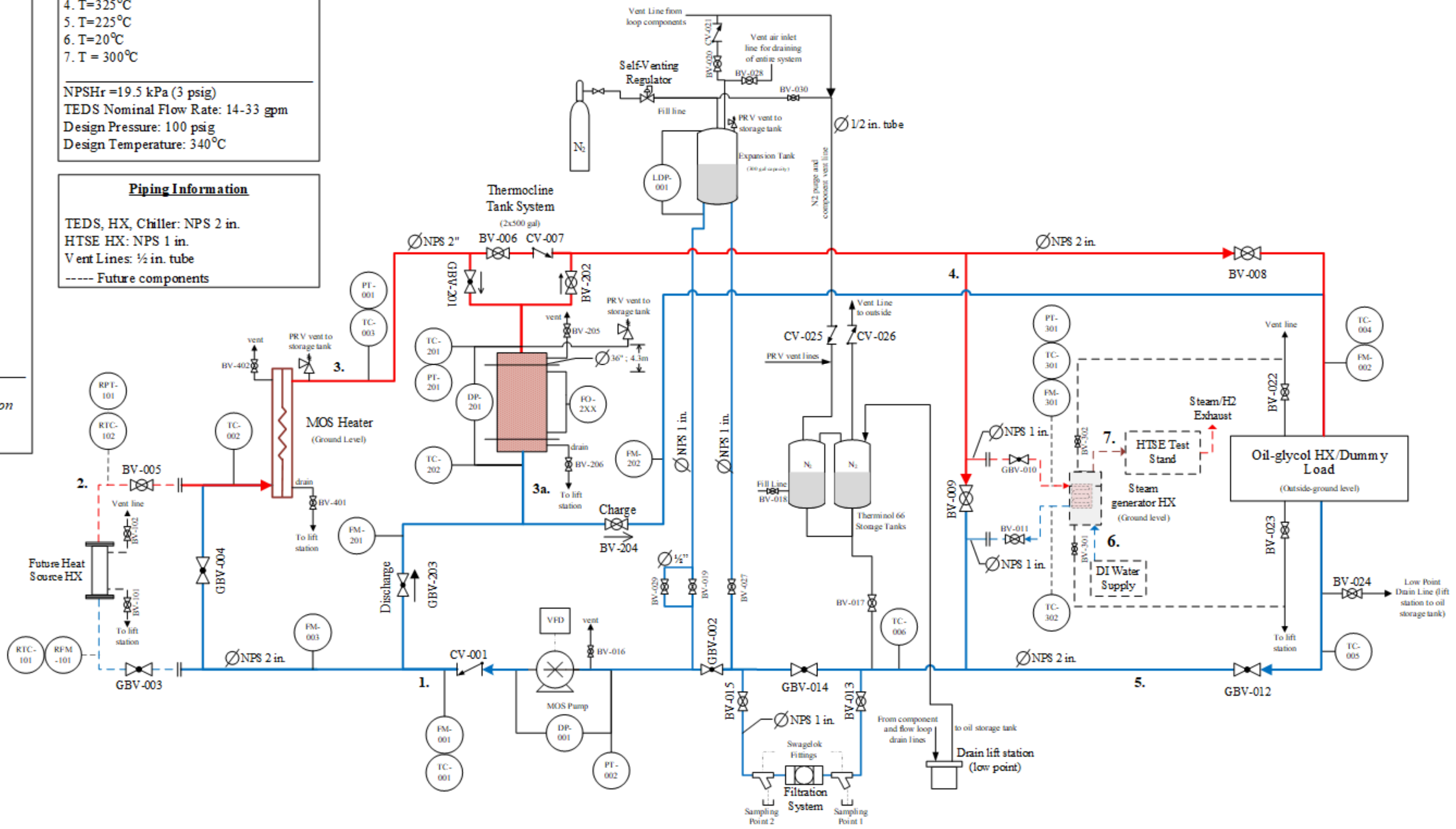
State Point Information

1. T=225°C
2. T=300°C
3. T=325°C
3a. T=225°C
4. T=325°C
5. T=225°C
6. T=20°C
7. T = 300°C

NPSHr =19.5 kPa (3 psig)
TEDS Nominal Flow Rate: 14-33 gpm
Design Pressure: 100 psig
Design Temperature: 340°C

Piping Information

TEDS, HX, Chiller: NPS 2 in.
HTSE HX: NPS 1 in.
Vent Lines: ½ in. tube
----- Future components



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TEDS Design Parameters

• Design Pressure	100 psig
• Design Temperature	340 °C
• Maximum Operating Temperature	325 °C
• Maximum Operating Pressure	14 psig
• Electric Heater Capacity	200 kW
• Nominal Flow Rate	14-33 gpm)
• Working Fluid	Therminol 66

- Therminol 66 Properties:
  - wide operating temperature range (-3 to 343°C)
  - low vapor pressure at high temperatures (10.3 psi at 340°C)
  - wide range of material compatibility

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MAGNET

To begin initial operation in December 2020

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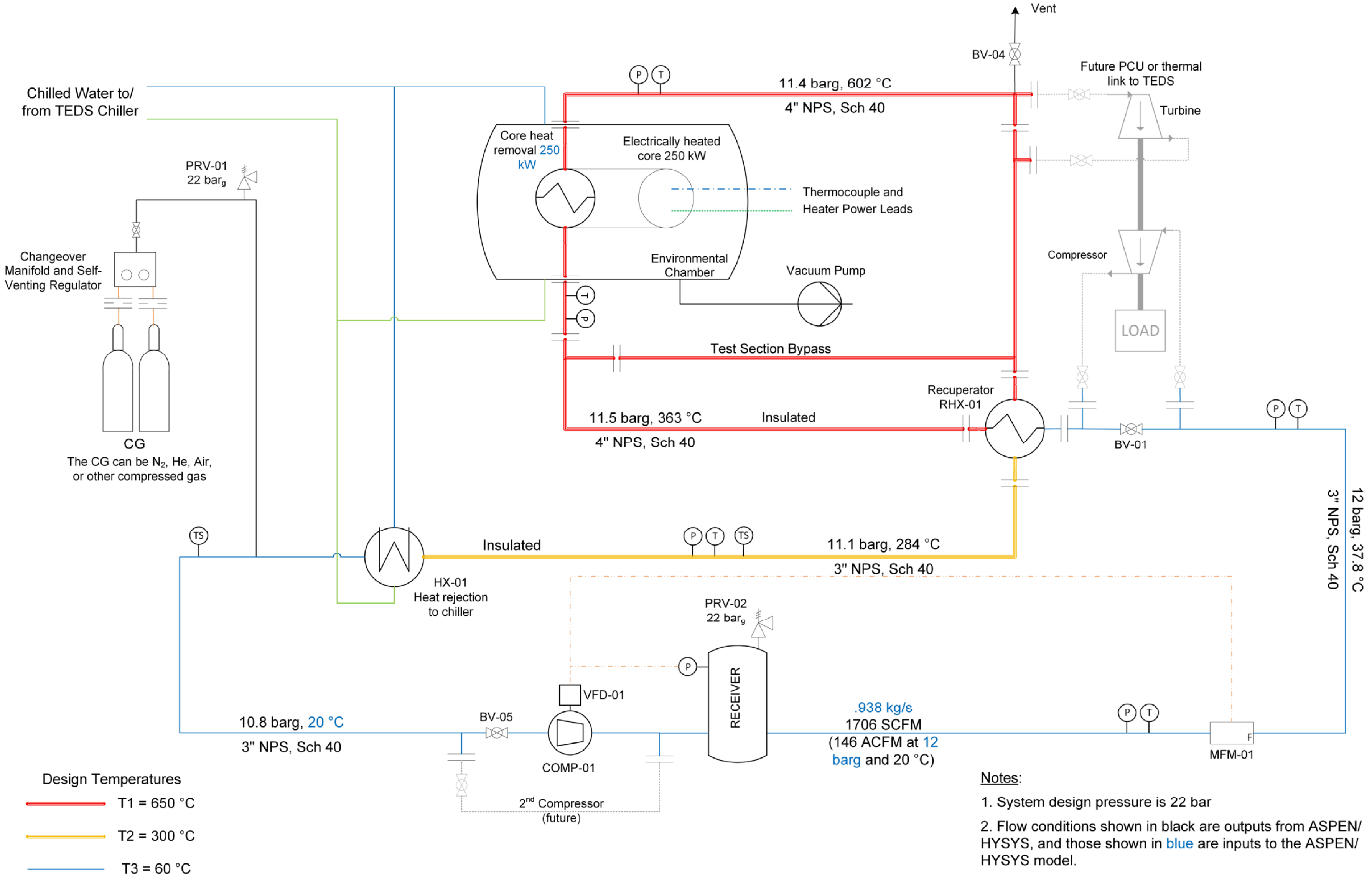
MAGNET Objectives

- Provide a general-purpose, non-nuclear test bed to evaluate microreactor designs
- Provide detailed thermal-hydraulic, performance data for prototypical geometries and operating conditions
  - Test article/flow loop temperature-time histories during start up, shut down, steady state, and off-normal operations
  - Displacement and temperature field data for potential design performance verification and accompanying analytical model validation
- Demonstrate integration of a power conversion unit
- Demonstrate applicability of advanced manufacturing techniques, such as additive manufacturing and diffusion bonding for core and heat removal section designs
- Identify and develop advanced sensors and power conversion equipment including instrumentation and controls for autonomous operation
- Enhance readiness of public stakeholders, particularly DOE laboratories and US NRC, to design, operate, and test high-temperature reactor components

MAGNET P&ID



Notes:

1. System design pressure is 22 bar
2. Flow conditions shown in black are outputs from ASPEN/HYSYS, and those shown in blue are inputs to the ASPEN/HYSYS model.

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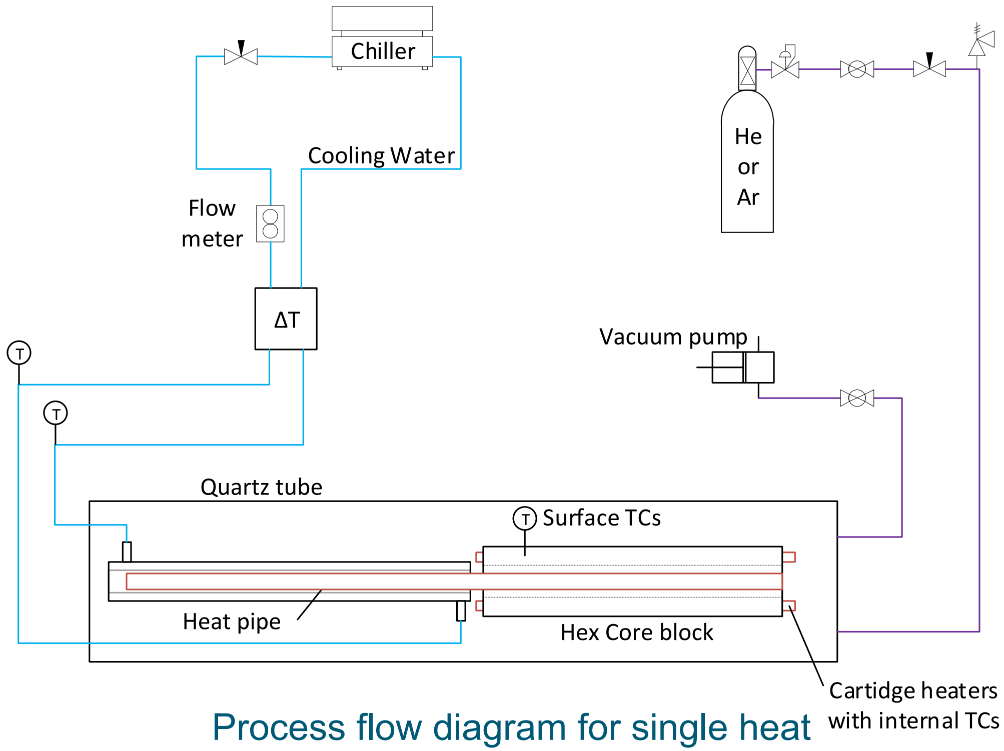
MAGNET Design Parameters

- Heat removal capacity: 250 kW
- Design pressure: 22 bar
- Hot section design temperature: 650 °C
- Coolant: Compressed N_2 or He
- Heat sink: Chilled water
- Expandable with potential to add power conversion unit or HX interface with collocated system in the future
- Recuperative HX

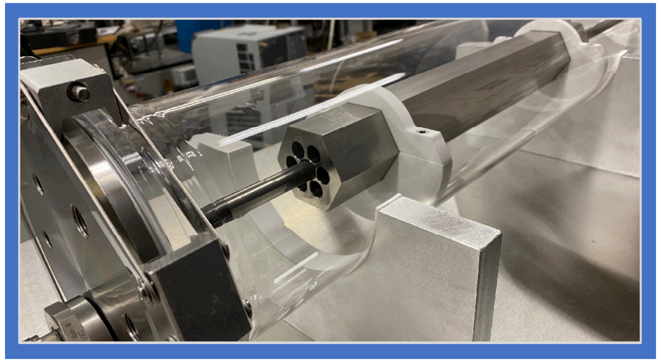
(Designed with air-Brayton cycle design parameters for temperature and pressure in mind)

Single-Heat-Pipe Preliminary Testing

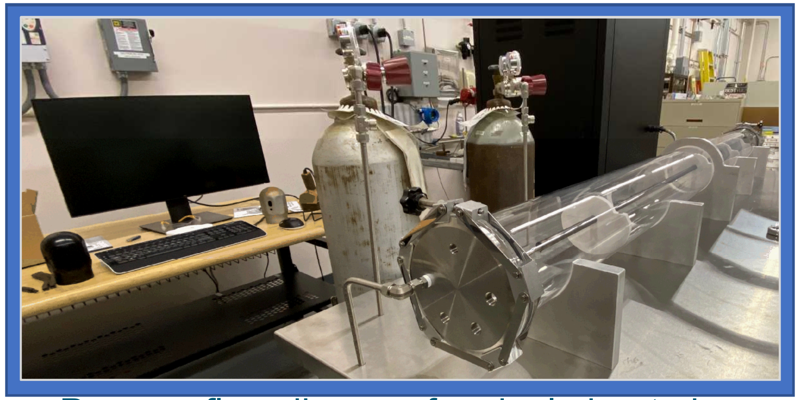


Process flow diagram for single heat pipe (7-hole hex block) experiments

- Quartz tube will be evacuated and back filled with inert gas
- Flow and ΔT meters allow determination of heat removal rate and comparison to total heater power at steady state
- Recirculated cooling water from 2.5 kW chiller



Quartz tube allows testing in vacuum or inert gas environments



Process flow diagram for single heat pipe (7-hole hex block) experiments

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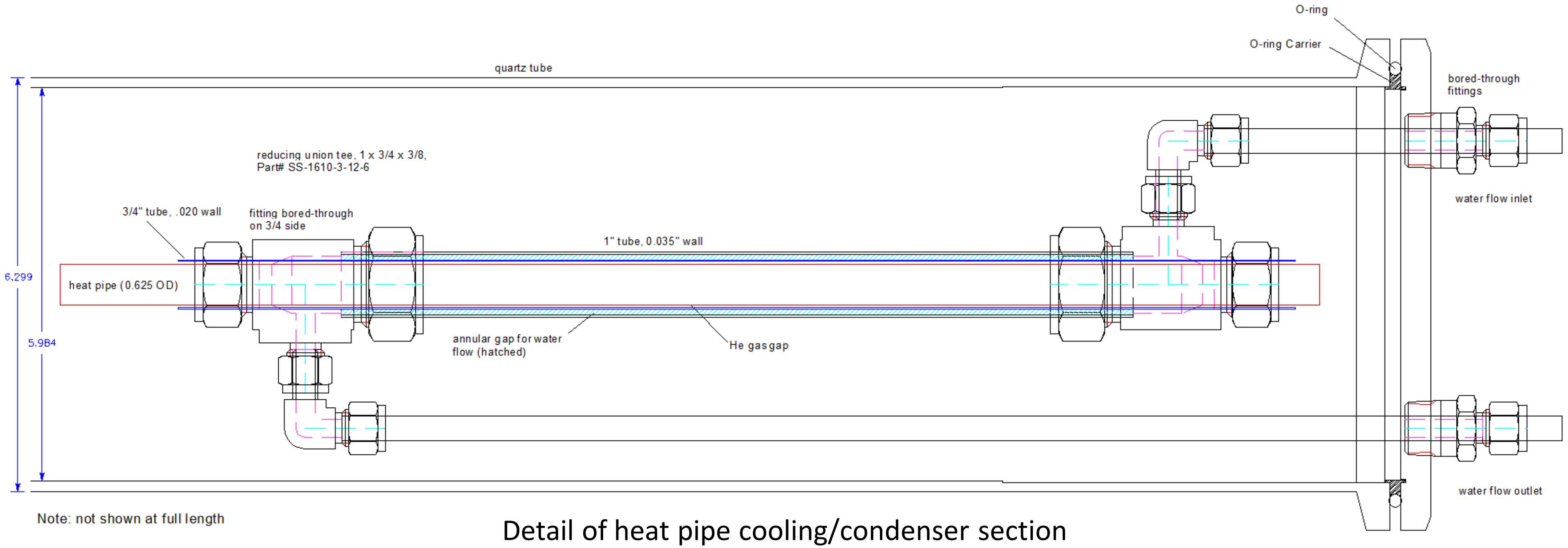
Single-Heat-Pipe Preliminary Testing



Detail of heat pipe cooling/condenser section

- Surrounded by a water-cooled shroud with a gas gap (wire wrap will center the heat pipe inside the shroud)
- Water cooling can support high heat removal rates - greater than the heat pipe rating
- Heat transfer across gap is a combination of radiation and conduction (conduction is dominant)
- Steady-state heat pipe temperature and heat flux can be varied by using He or Ar gas or by varying the length of the condenser section

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Printed Circuit Heat Exchanger Testing

Advantages of PCHE-style Heat Exchangers for Microreactor Heat Removal

- High heat transfer coefficients (gas flow in microchannels)
- Inherent suitability for high pressure, high temperature applications
- High heat transfer surface area (extended surface heat transfer)
- Low temperature gradients and thermal stresses through optimized designs
- Lower susceptibility to damage from single-channel flow blockages
- Very low axial temperature gradient
- Uniform heat transfer per unit axial length takes full advantage of entire length of heat removal section of heat pipes

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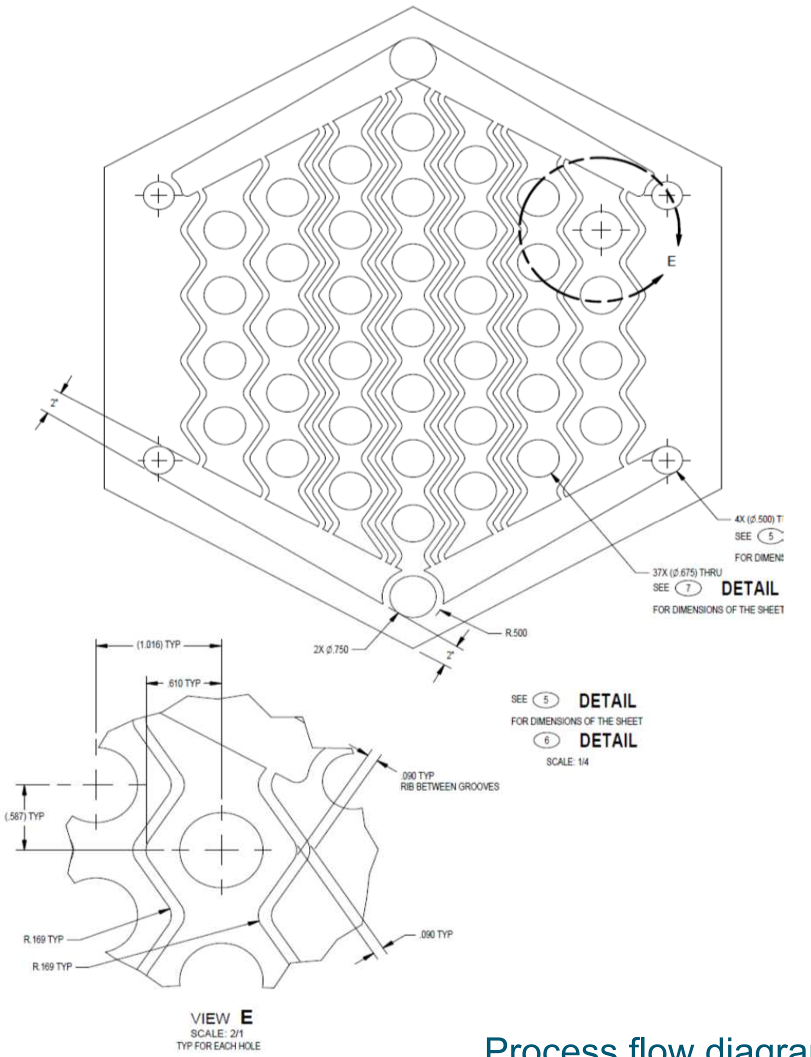
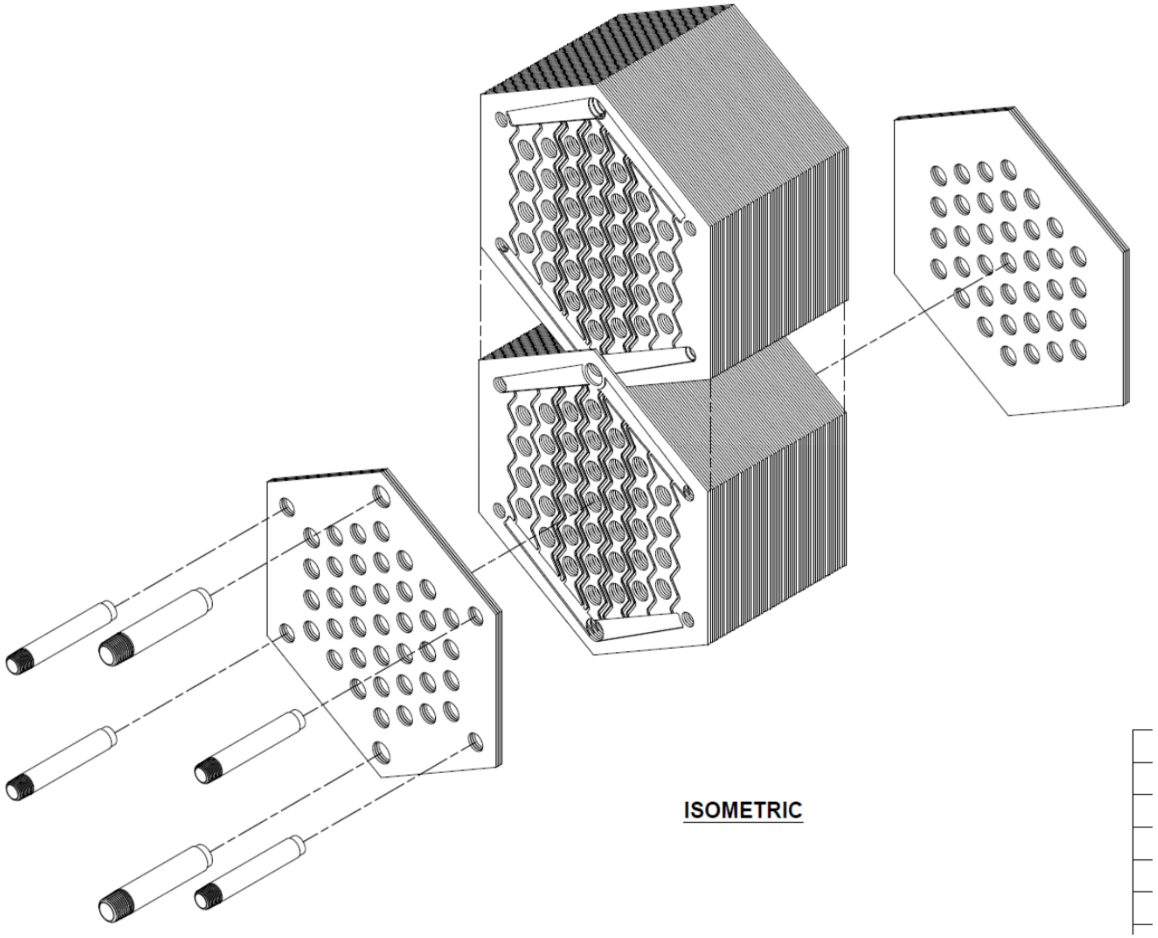
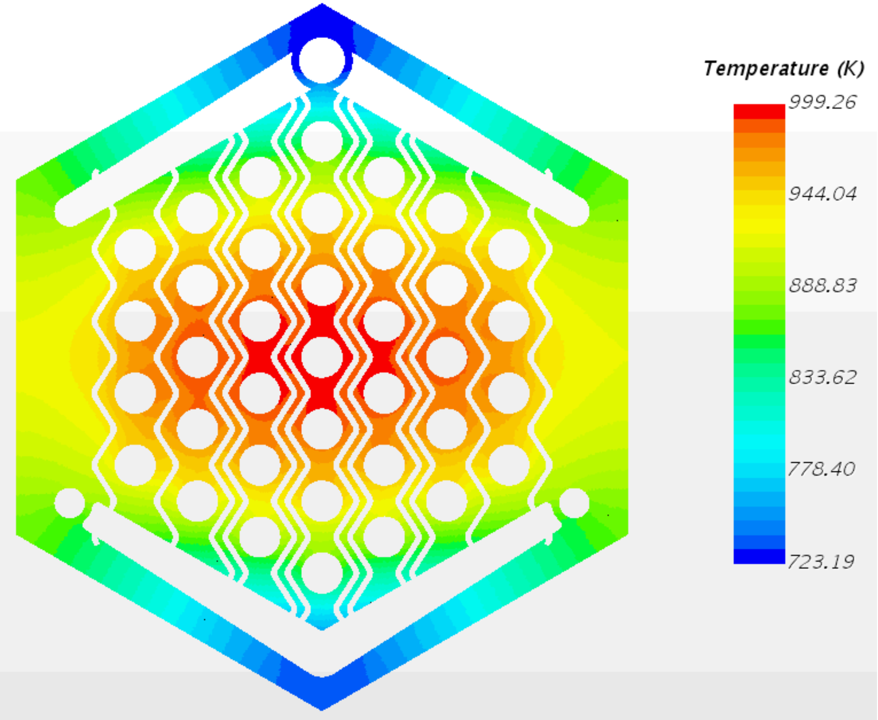
Initial PCHE Design

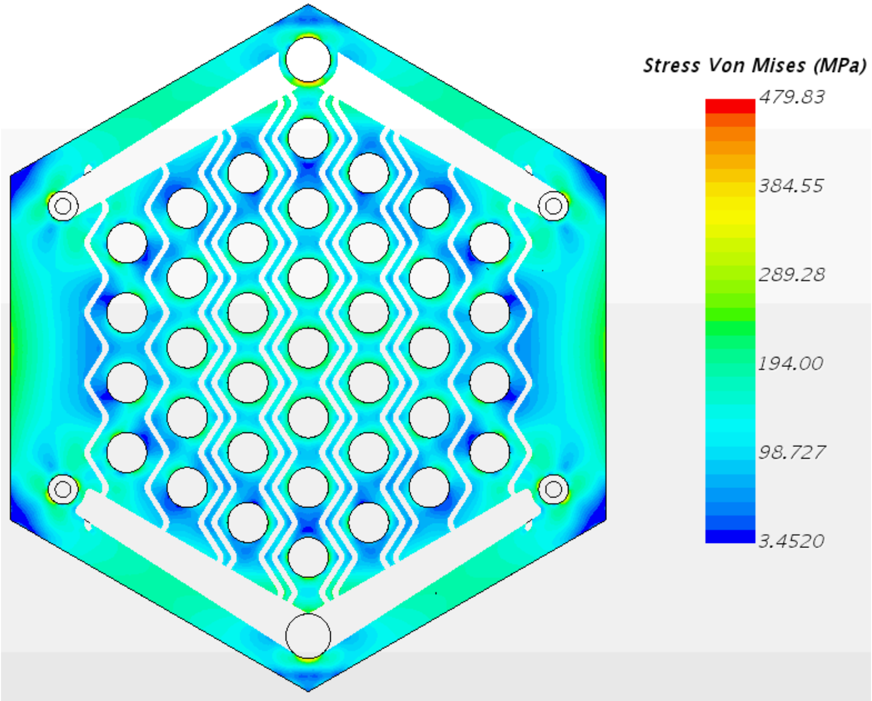




Process flow diagram for single heat pipe (7-hole hex block) experiments

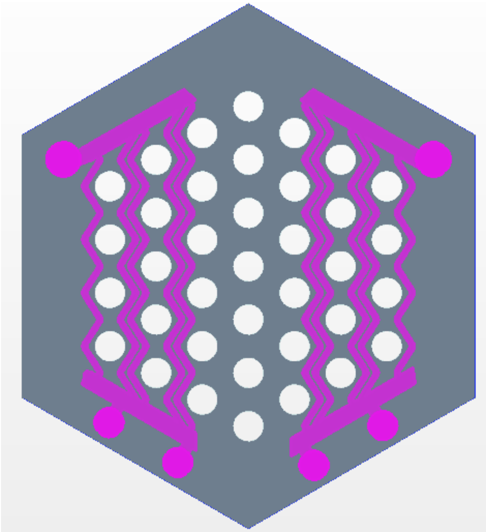
Initial PCHE Design



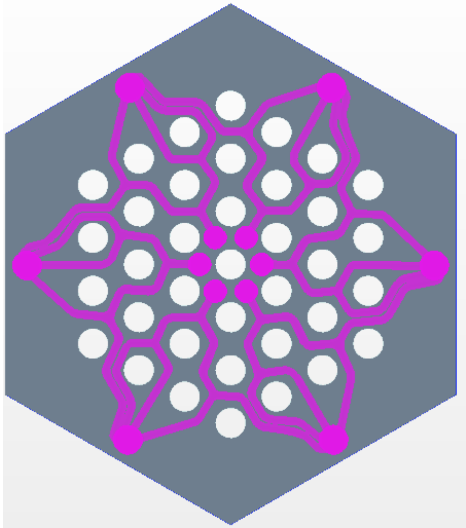


Temperature and Stress Fields For Top Platelet

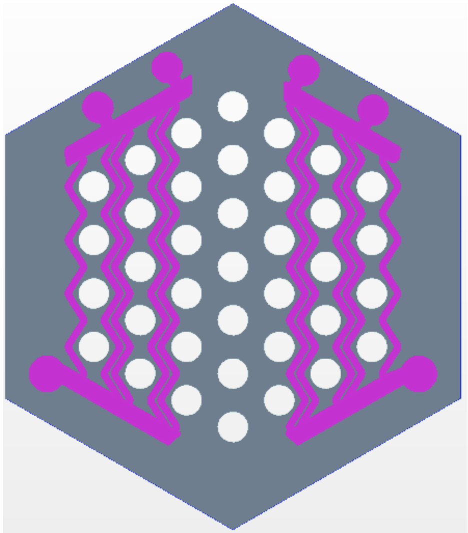
Second PCHE Design (Hybrid Cooling)



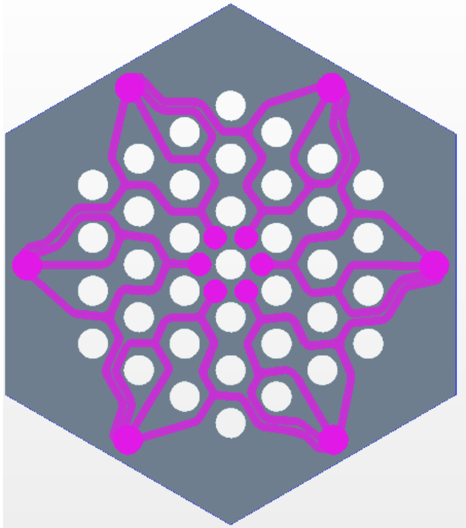
1st plate



2nd plate



3rd plate



4th plate

- Design Improvements: (i) Outward Flow Path, (ii) Counter Current Flow (iii) Multiple Inlets, (iv) 3-Way “Counter-Current” Flow Paths
- Flow Path Configuration

5th-8th plates **rotated 120°**
9th-12th plates **rotated 240°**

→ ***A total of 12 plates are simulated***

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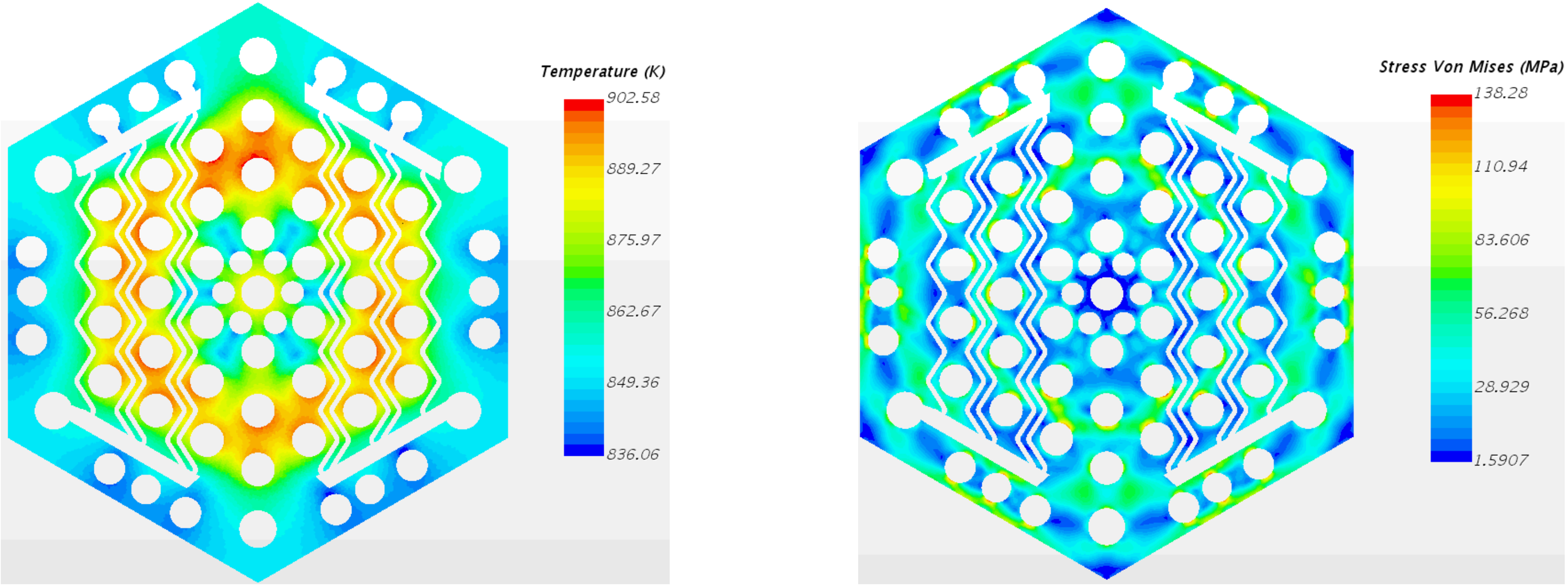
Second PCHE Design (Hybrid Cooling)



Temperature and Stress Fields For Top Platelet

Questions?

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