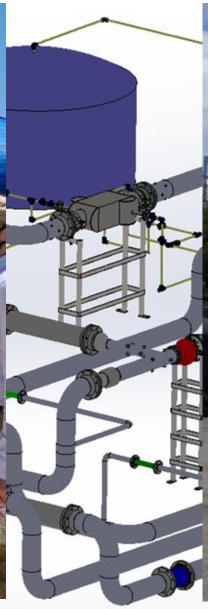
Small-scale PHES Demo

Solving System Integration and Operation Challenges

TMCES 2021 tour



last week

Natalie R Smith, PhD

Southwest Research Institute

August 3, 2022

Thermal, Mechanical, Chemical Energy Storage Workshop

The Project Team

Award No. DE-AR0001018
ARPA-E OPEN18 (DAYS)
$3.1M, 45 months

Southwest Research Institute

Applied R&D: *kW-scale demonstration development, transient modelling, and testing*

Prime recipient
Natalie Smith, Ph.D. (PI)
& a large team

Malta Inc.

LDES Developer: *techno-economic analysis and technology to market for 100 MW 10+ hr PTES*

Sub-recipient
Ben Bollinger, Ph.D.
Bao Truong

Gas Turbine OEM

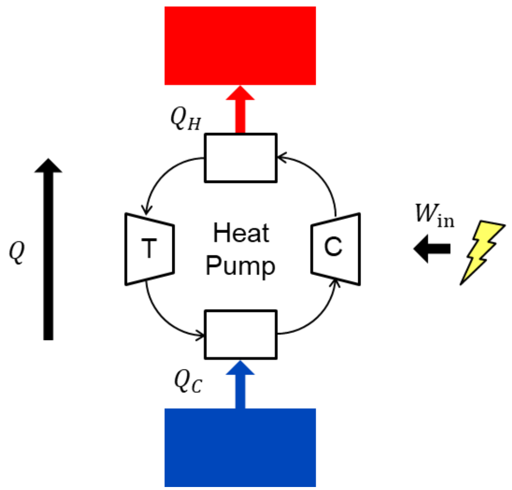
Techno-economic analysis

Sub-recipient

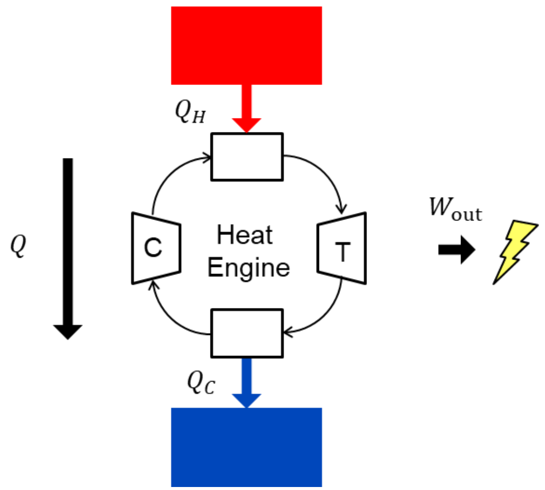
The Concept: Pumped Heat Energy Storage (PHES)

“Pumped Heat”, “Pumped Thermal”, etc. …

Charge Mode
Use excess energy to run heat pump
& store energy in hot and cold reservoirs



Discharge Mode
Use thermal reservoirs to run heat engine
& generate power



PHES Value Proposition

- 10+ hours of storage
- Separation of engine and storage
- Potential for high round trip efficiency (RTE)

Technology Gaps

- System costs
- Some component development
- First implementation challenges
- Control and operational unknowns

Developmental Challenges

- With well-established technologies, most performance-based demonstrations are required at scale
- Full-scale systems are aiming for 100 MW, 10+ hr, make at-scale demonstrations expensive

Project Objectives & Facility Expectations

What value is there with a small-scale demo?

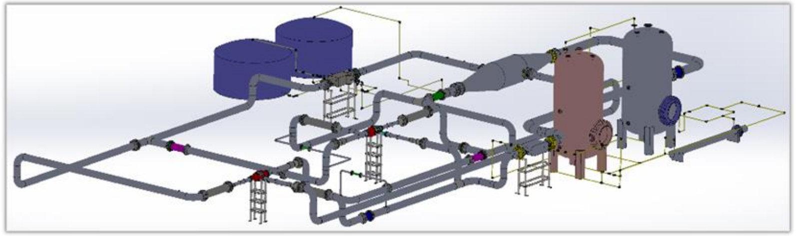
- "Machinery performance will not translate"
- "Performance will not be representative"

Demonstrate operation of a air Brayton PHES at laboratory scale to verify system control strategies. Address first implementation challenges and reduce the number of unknown unknowns.

- Operation of the full system will be ***first-of-a-kind***
- Operation and controls ***do*** translate
  - Transient sequencing
  - Thermal stresses
  - System dynamics
  - Control of balance of plant

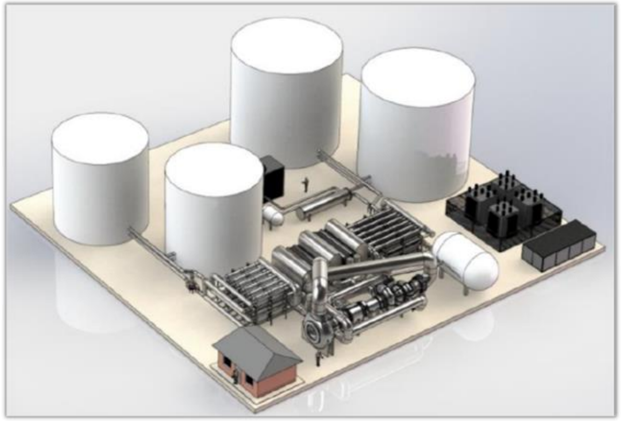
Small-scale Demo

5 kW, 1 hr | 0.25 acre | $2.5M



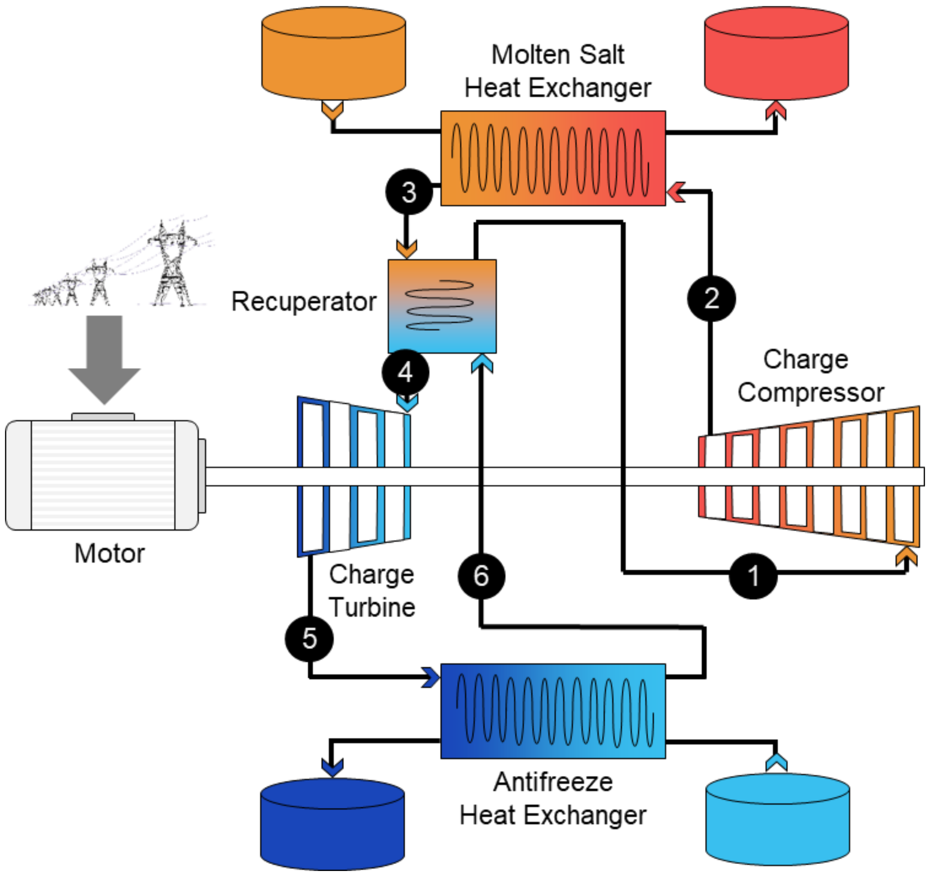
Full-scale System

100 MW, 10+ hr | 10 acres | $$$



Full-scale Pumped Heat Energy Storage

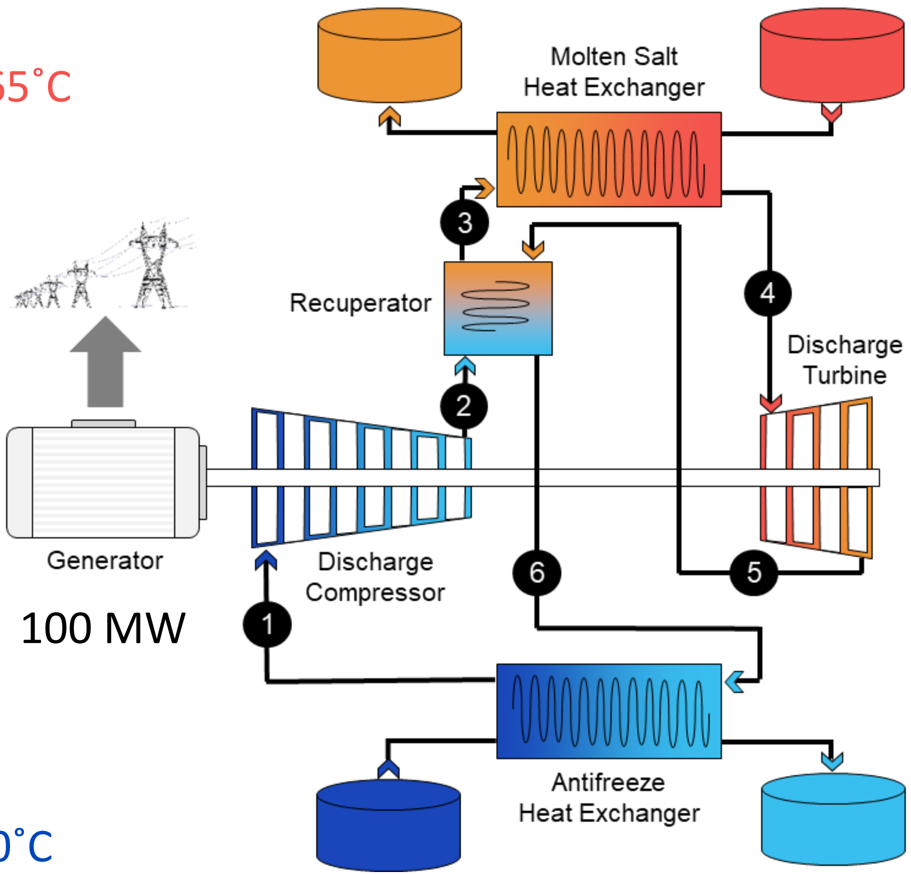
Charge Mode



Molten Salt at 565˚C

Antifreeze at -60˚C

Discharge Mode



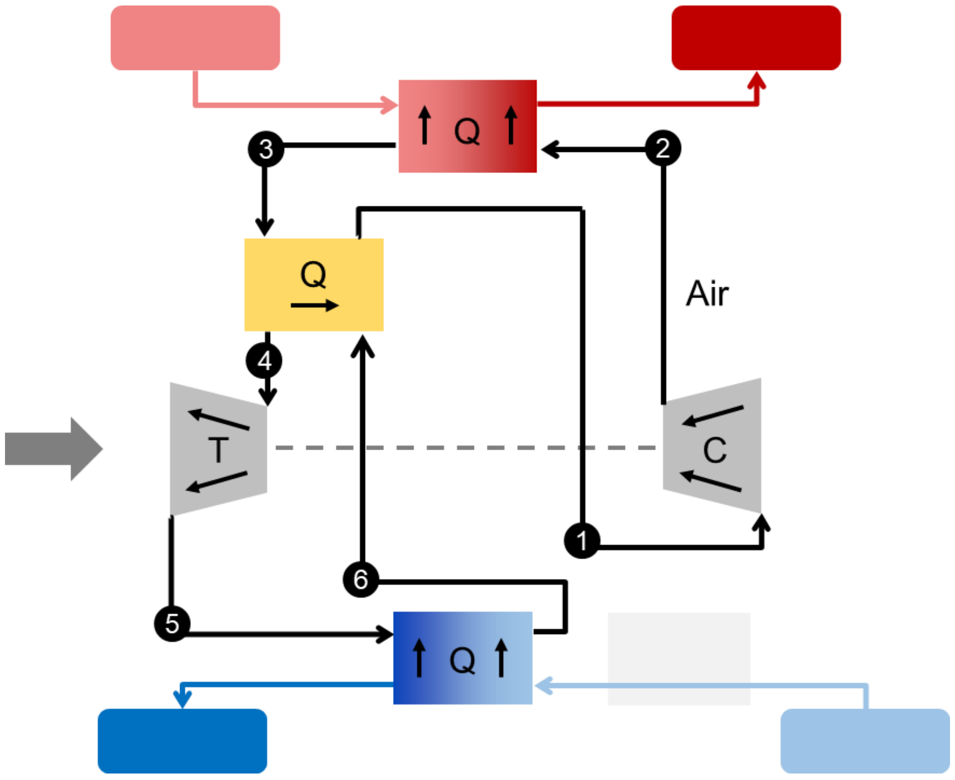
RTE ~60%

includes separate drivetrains for each mode with shared heat exchangers

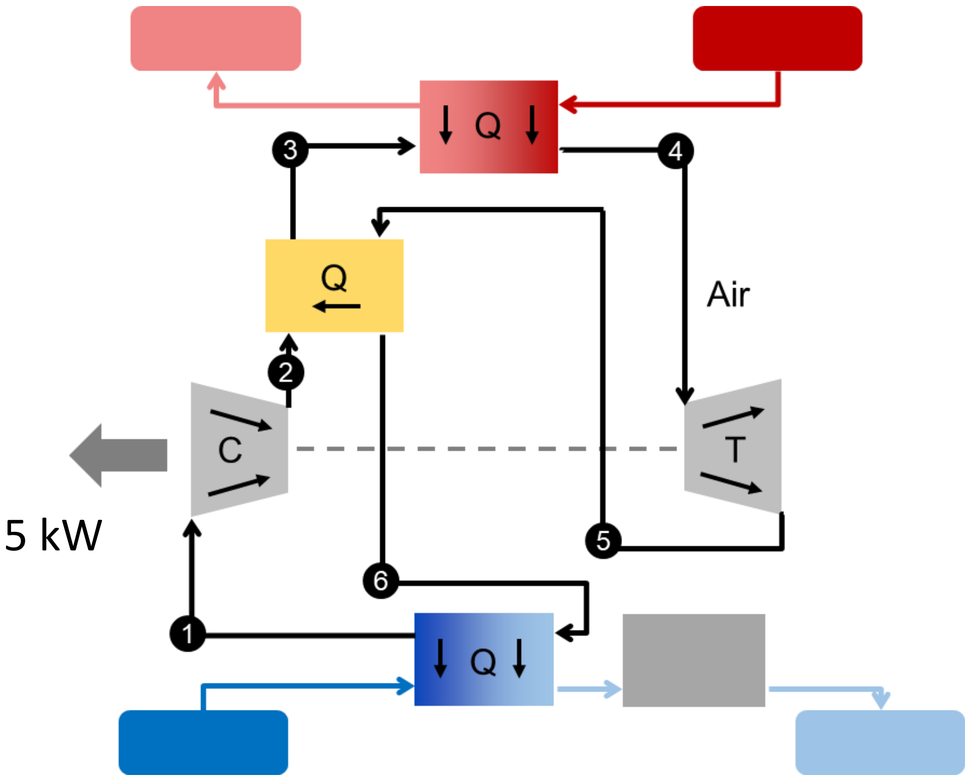
Lab-scale Pumped Heat Energy Storage

Incorporated many design decisions to reduce technical risks and project costs including scale and storage media

Charge Mode



Discharge Mode



Thermal Oil at 350˚C

Water-Glycol at -10˚C

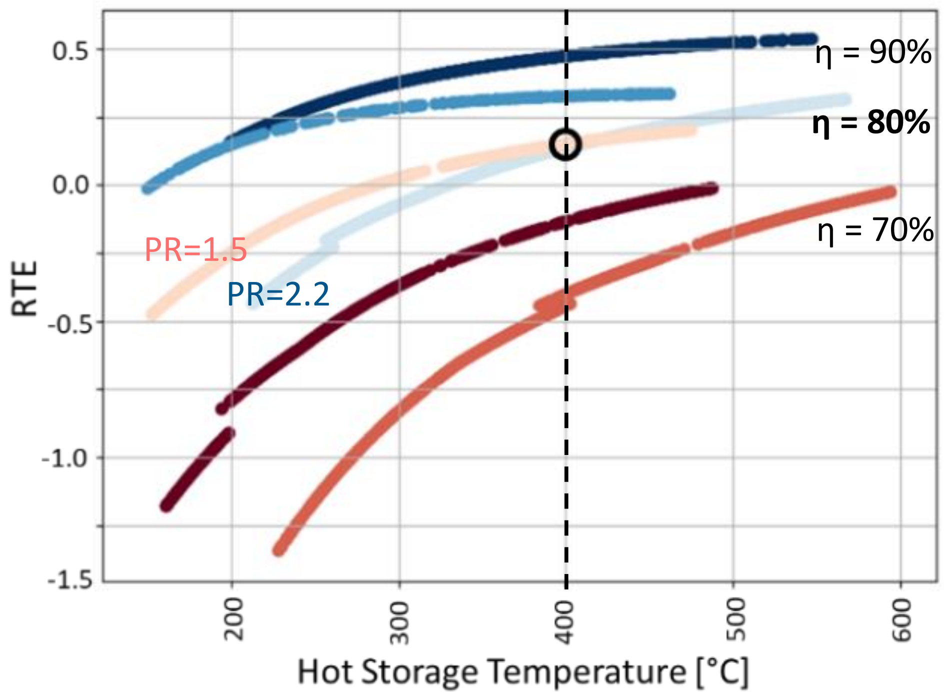
RTE ~10%

includes separate drivetrains for each mode with shared heat exchangers

Reduction in RTE for Small-scale Demonstration

Max RTE	Case
49%	Full-scale system with current technologies
24%	Small-scale turbomachinery efficiency • 75% isentropic compressor efficiency • 85% isentropic turbine efficiency

10%	Storage systems
	• Thermal oil instead of molten salt for hot storage media
	  • 400 °C max storage temperature
	• Water-Glycol instead of advanced refrigerant for cold storage media
	  • -35 °C min storage temperature

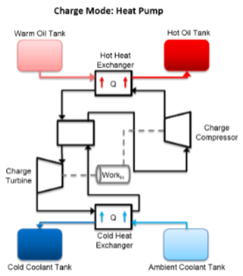


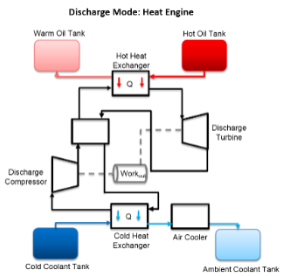
At lower Hot Storage Temperatures, lower PR results in higher RTE

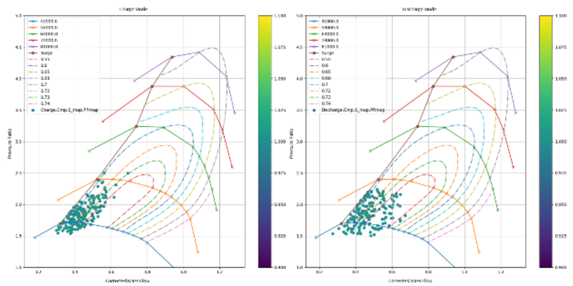
Highly coupled and iterative design process

Cycle Optimization

Are all design/hardware constraints captured?
Does the model reflect updated controls?

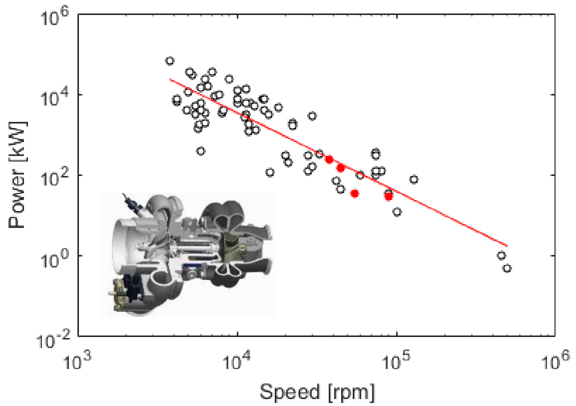






Component Specification

Turbomachinery, HX, Storage systems
Can a design result from this cycle?

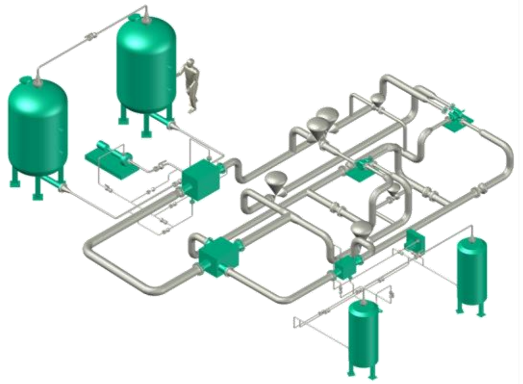


Controls

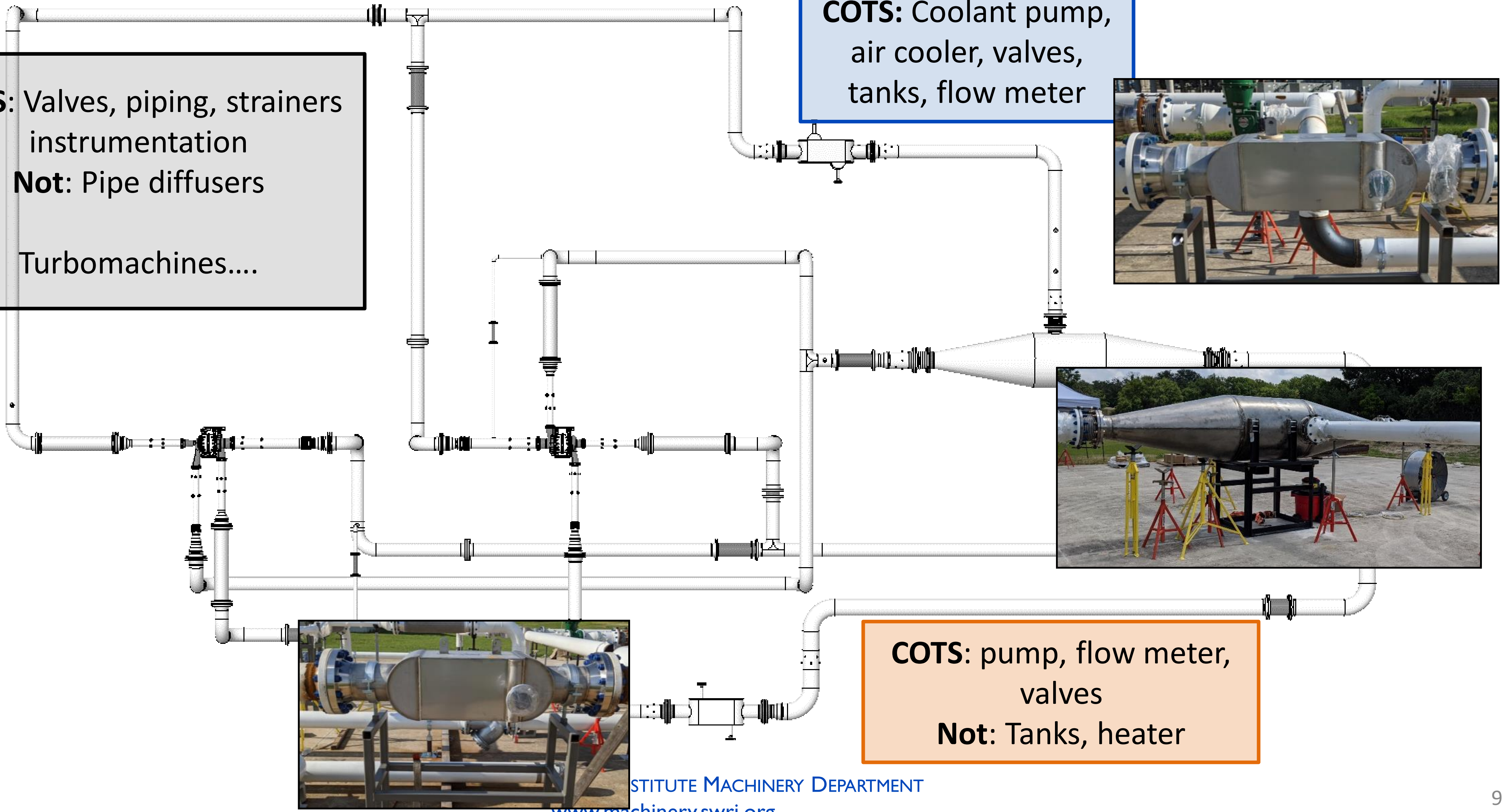
What are the best control methods for the system?
Do these adequately represent the full-scale system?
Is our valve configuration and selection sufficient for the model?

Plant Layout

Pipe losses, thermal stresses



We intended to leverage commercial off-the-shelf (COTS) hardware…



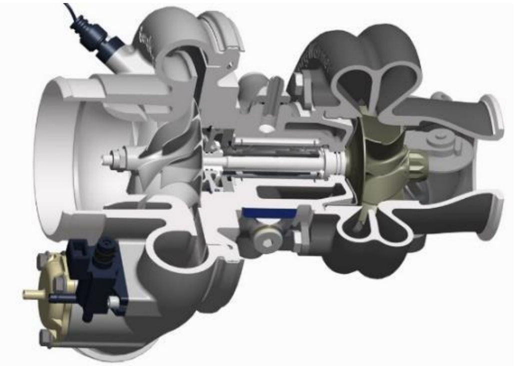
COTS: Valves, piping, strainers instrumentation
Not: Pipe diffusers

Turbomachines….

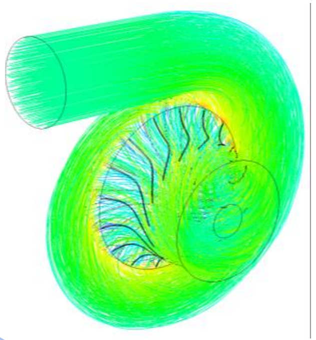
COTS: Coolant pump, air cooler, valves, tanks, flow meter

COTS: pump, flow meter, valves
Not: Tanks, heater

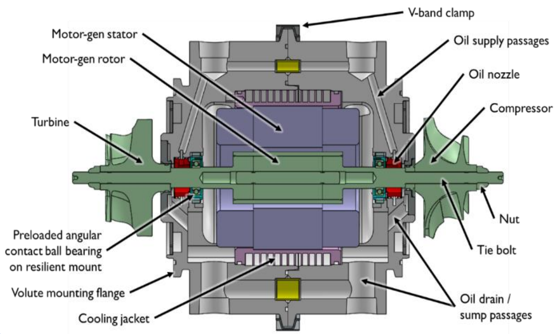
Turbomachine Customization



Jan 2020

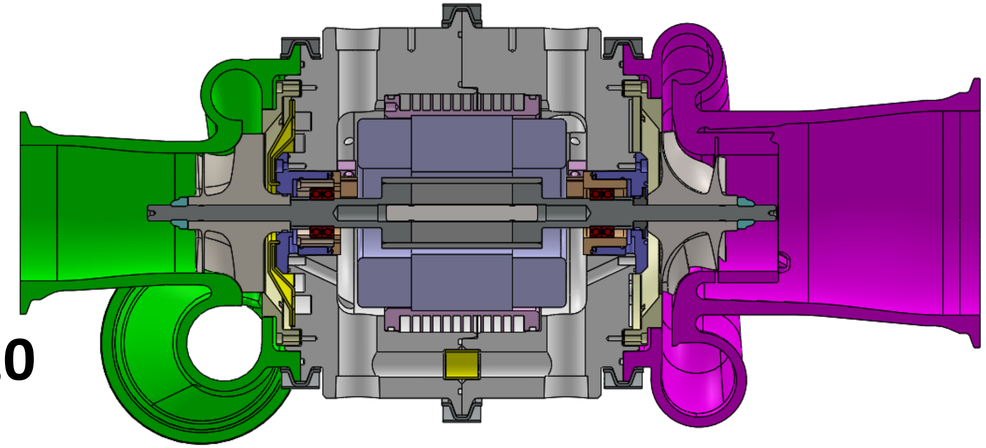


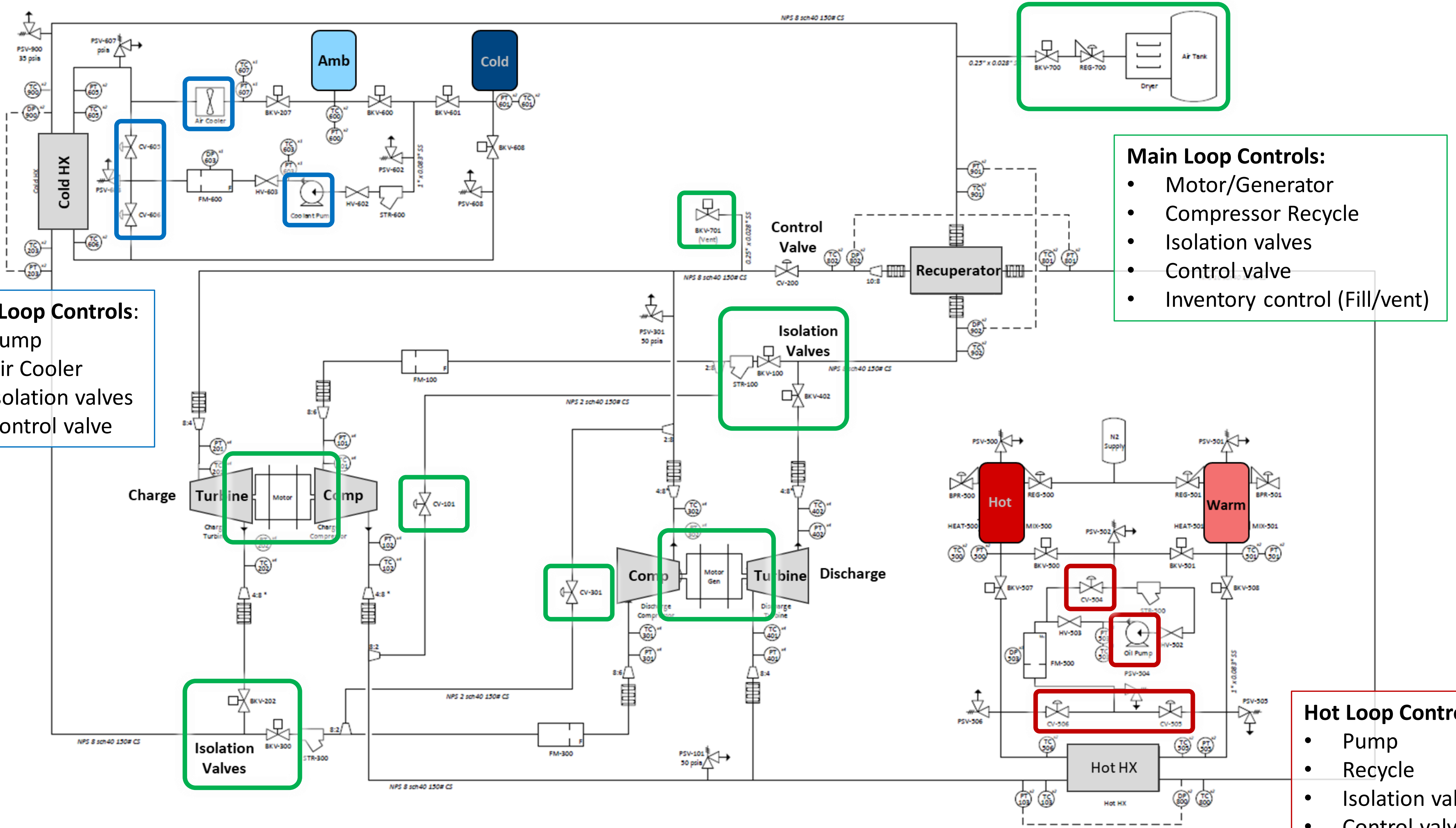
Feb 2022



- Two new turbine aero designs
- Integrated a motor-generator between the impellers
- New bearing and seal layout
- Thrust balance mechanism
- Incorporated multiple cooling features

Aug 2020





Cold Loop Controls:

- Pump
- Air Cooler
- Isolation valves
- Control valve

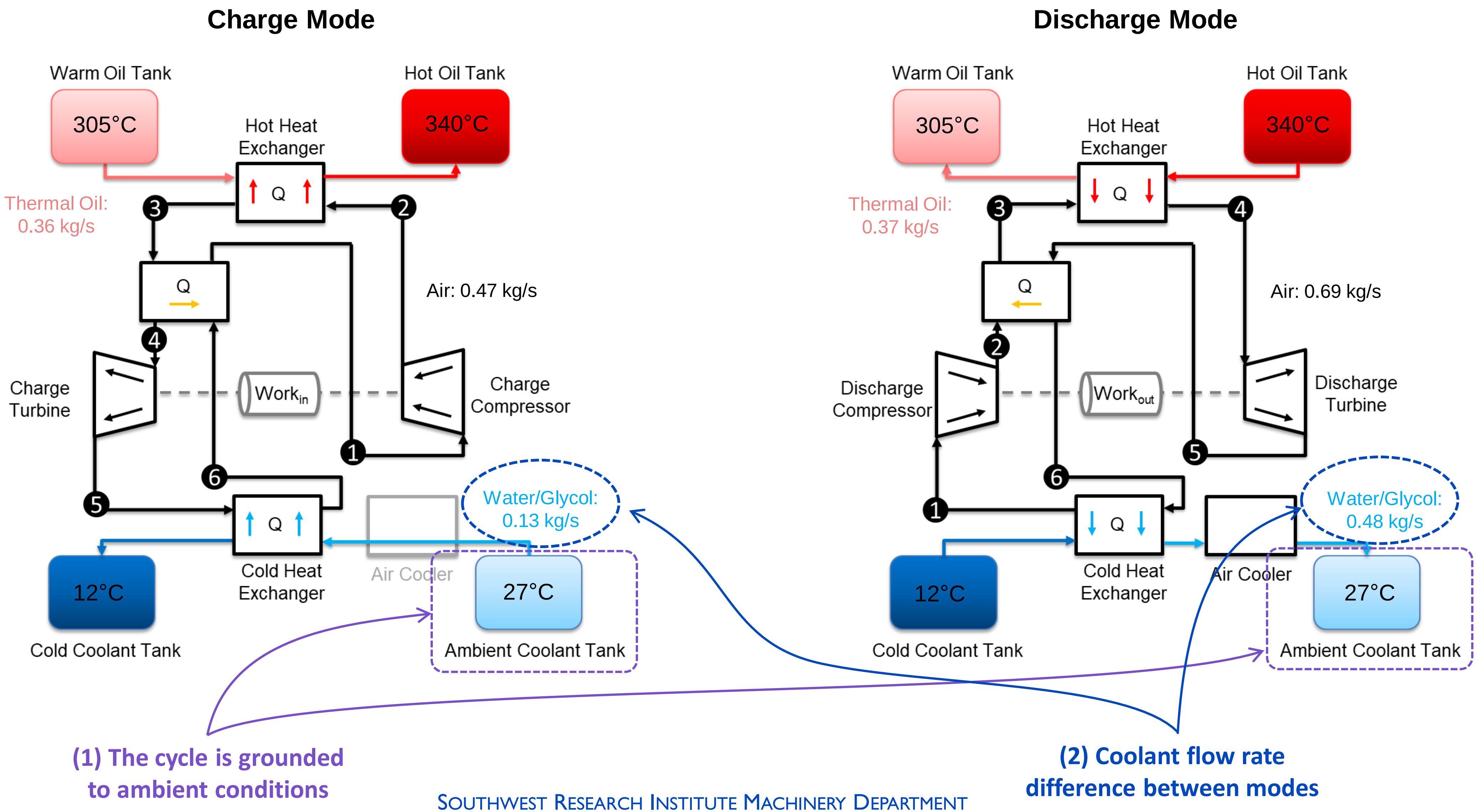
Main Loop Controls:

- Motor/Generator
- Compressor Recycle
- Isolation valves
- Control valve
- Inventory control (Fill/vent)

Hot Loop Controls:

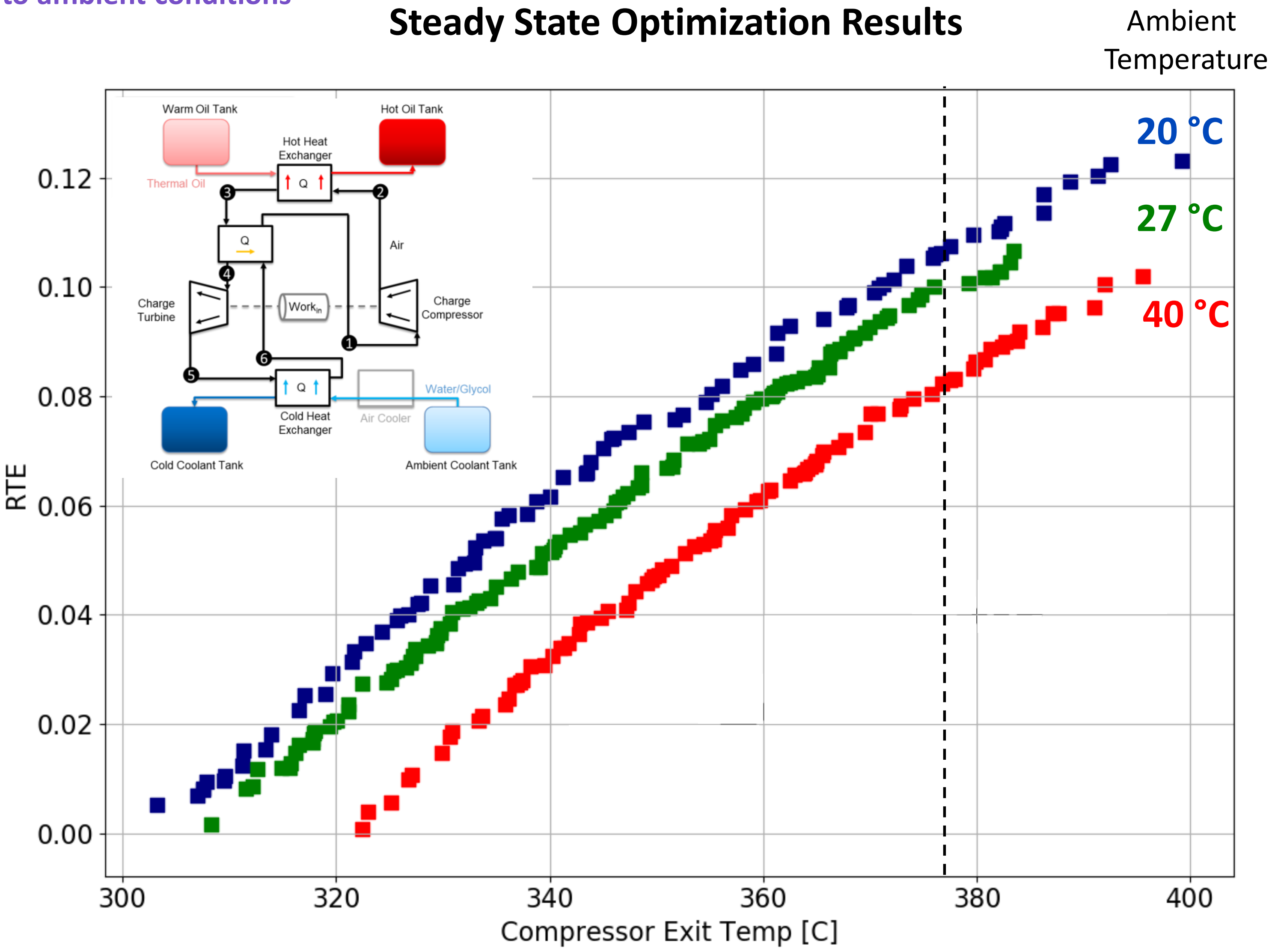
- Pump
- Recycle
- Isolation valves
- Control valve

Design point cycle conditions updated with as-built hardware



(1) The cycle is grounded to ambient conditions

Steady State Optimization Results



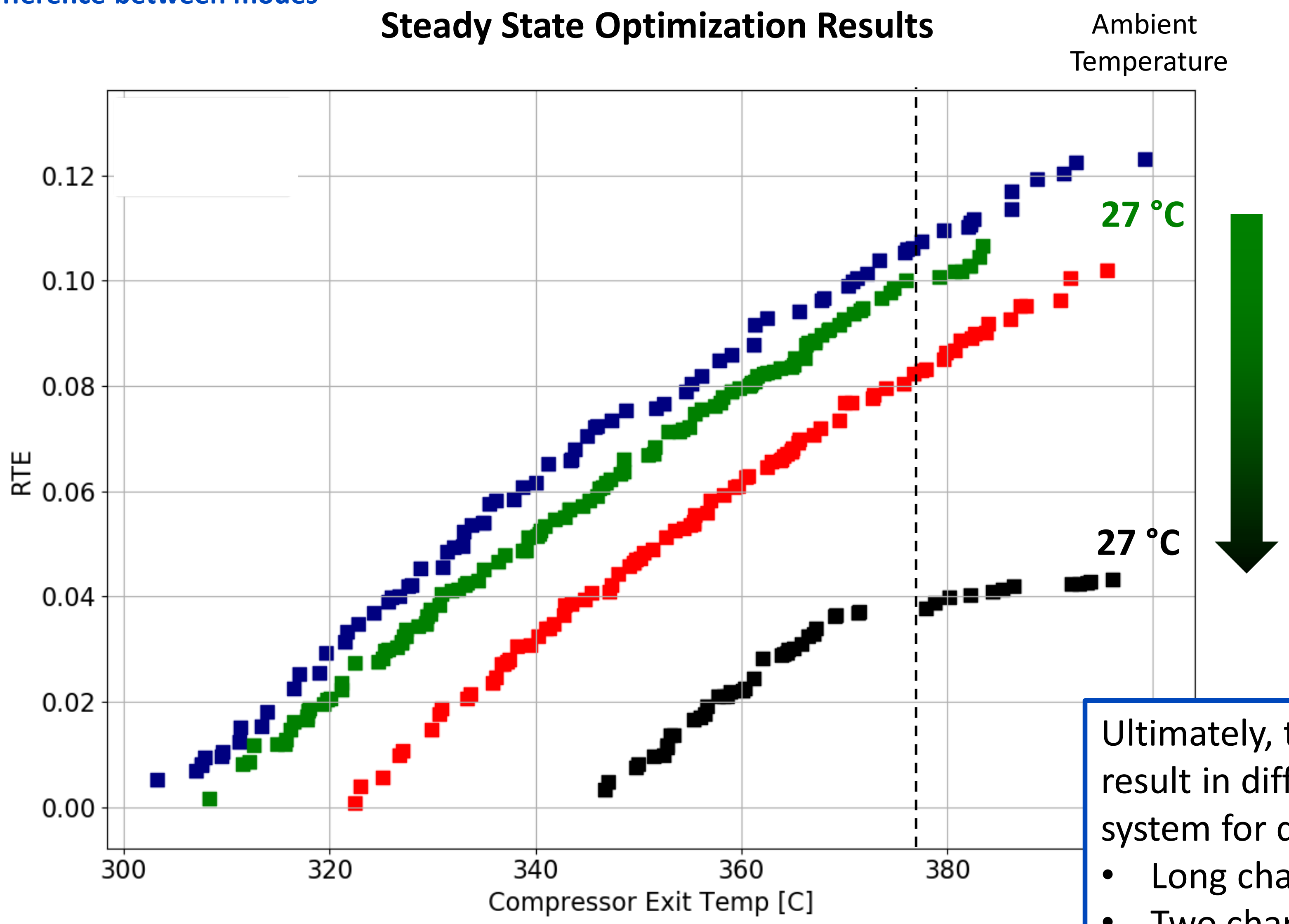
2

		27 °C	20 °C	40 °C
Main Loop				
Charge PR	-	1.73	1.73	1.82
Charge MF	*kg/s*	0.58	0.58	0.58
Discharge PR	-	1.62	1.58	1.59
Discharge MF	*kg/s*	0.52	0.52	0.52
Hot Storage				
Hot T	°C	348	338	335
Charge MF	*kg/s*	0.32	0.38	0.38
Discharge MF	*kg/s*	0.52	0.24	0.21
Cold Storage				
Cold T	°C	-14.7	-13.45	-13.19
Charge MF	*kg/s*	0.09	0.11	0.08
Discharge MF	*kg/s*	0.27	0.32	0.24
System				
RTE	*%*	10%	10.5%	8%

As Ambient Temperature ↓
- Charge cold MF ↑
- Discharge cold MF ↑
- RTE ↑

As Ambient Temperature ↑
- Charge cold MF ↓
- Discharge cold MF ↓
- RTE ↓

(2) Coolant flow rate difference between modes



Forcing $\dot{m}_{charge}$ & $\dot{m}_{discharge}$ for the coolant and oil separately to be no more than 25% different

results in a decrease in RTE.

Ultimately, this is a design variable and could result in different implementations of the same system for different use cases.

- Long charge mode with short discharge mode
- Two charge systems and one discharge system

Where are we today?

Cycle Analysis → Facility Design → Procurement → Transient Analysis → Assembly → Commission → Test

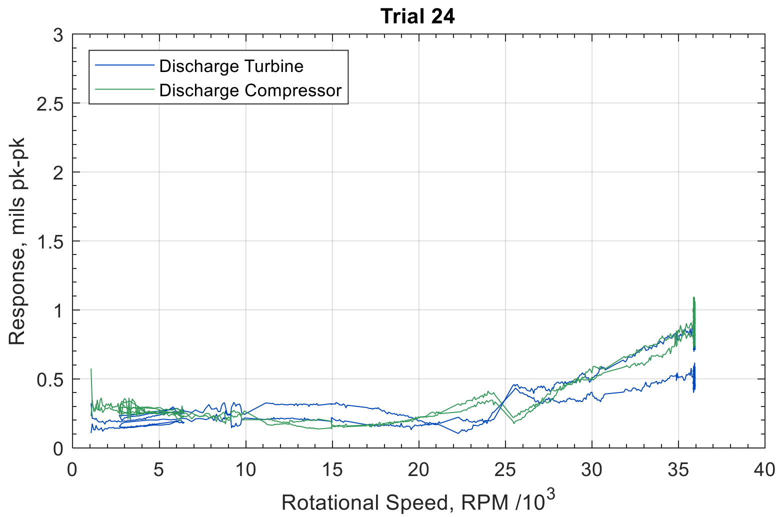
Aug 2022

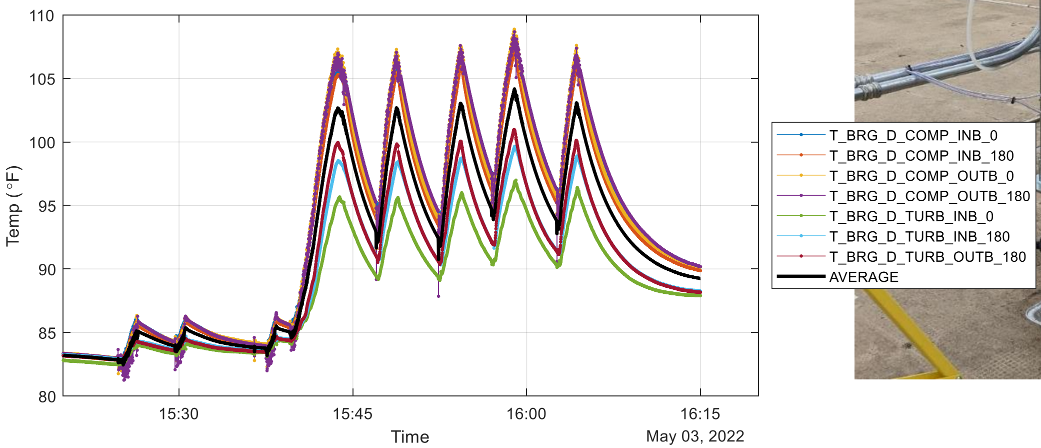
Turbocompressors

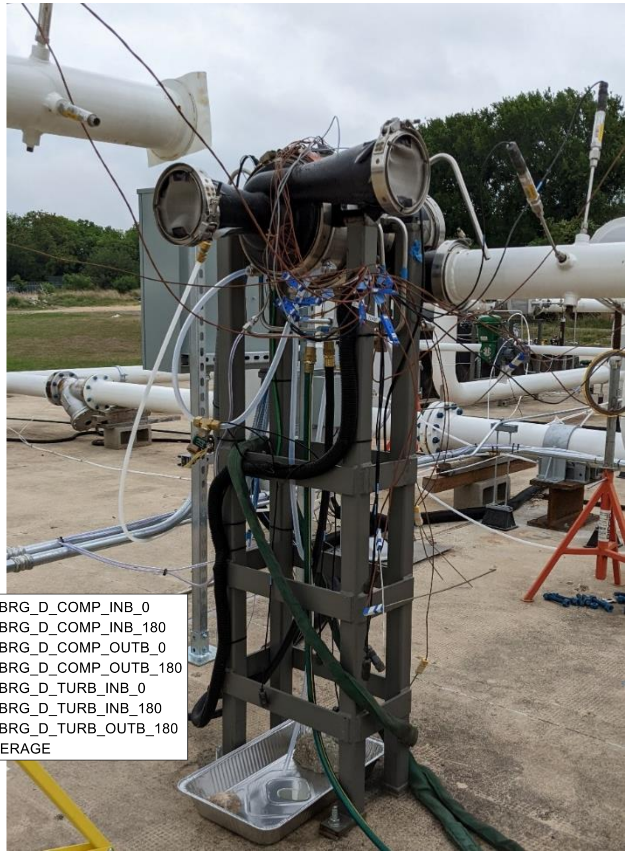
- Mechanical check-out (**complete**)
- Bearing break-in (**complete**)
- Instrumentation verified (**complete**)
- Closed loop operation (**in process**)

Main Piping Loop

- Pressure check (**complete**)
- Instrumentation verified (**complete**)







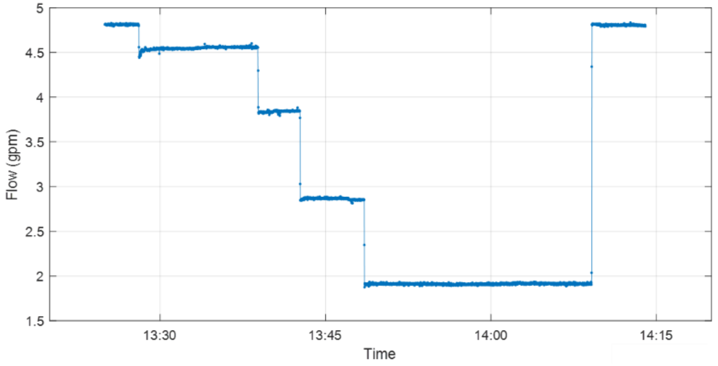
Where are we today?

Cycle Analysis → Facility Design → Procurement → Transient Analysis → Assembly → Commission → Test

Aug 2022

Cold Storage System
- Pressure check (**complete**)
- Instrumentation verified (**complete**)
- Coolant filled & circulating (**complete**)

Hot Storage System
- Pressure check (**complete**)
- Instrumentation verified (**complete**)
- Coolant filled & circulating (**in process**)
- Pre-heat check-out



Operational Goals

Steady State Operation

- One hour steady state in both modes
- Operation across a 20 °C range of ambient temperature
- Demonstrate generation power control

Transient Operation

- Many operational profiles with sequencing variations
- Charge mode cold start with various recycle flows
- Hot start with variations on sequencing and timing for both modes
- System balancing

Translating Technical Challenges

Purpose-Built Machinery

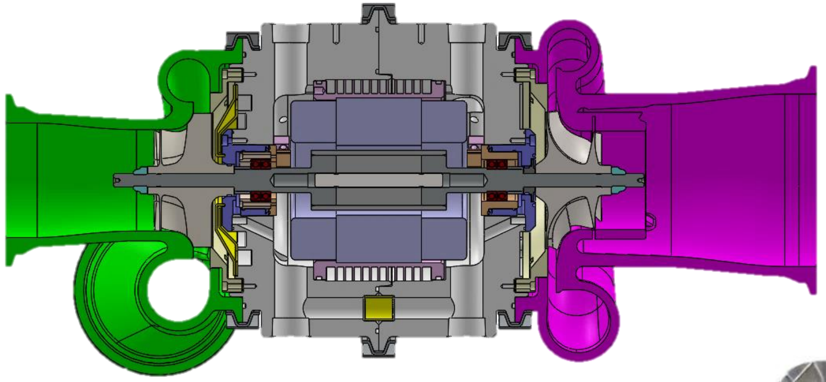
- While machinery conditions were within design experience (similar to turbochargers), purpose build hardware did not exist
- Small modifications eventually became custom design to achieve desired steady-state performance and off-design operational requirements.

Optimal Performance v. Operational Balance

- Optimizing for RTE performance results in cycle conditions that cause storage system imbalance
- Maintaining a balanced system will incur a performance penalty

Both design challenges are true for the small-scale demo and full-scale commercial system

Custom aerodynamic & mechanical designs



Small-scale PHES Demo

San Antonio, Texas

SwRI MALTA U.S. DEPARTMENT OF ENERGY

Award No. DE-AR0001018

Natalie Smith
natale.smith@swri.org