



Electrification through CO₂

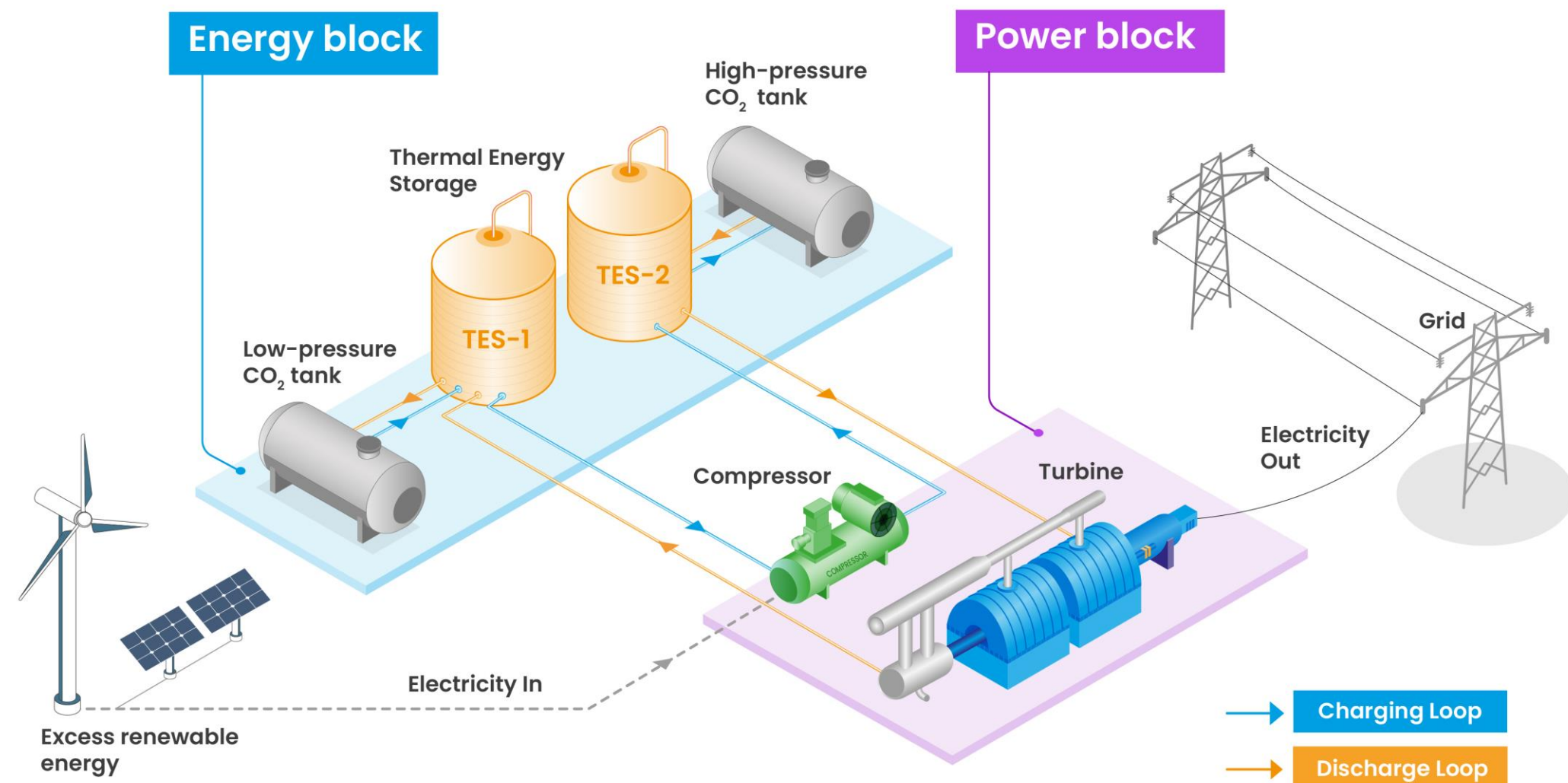
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Our Solution: Thermo-Mechanical Energy Storage

- We have created a new thermodynamic cycle
- Compress CO₂ –Charging
- Expand CO₂ –Discharging

Footprint requirements: 1 kWh/ft³ or 45 MWh/acre



Technology Deep Dive

1

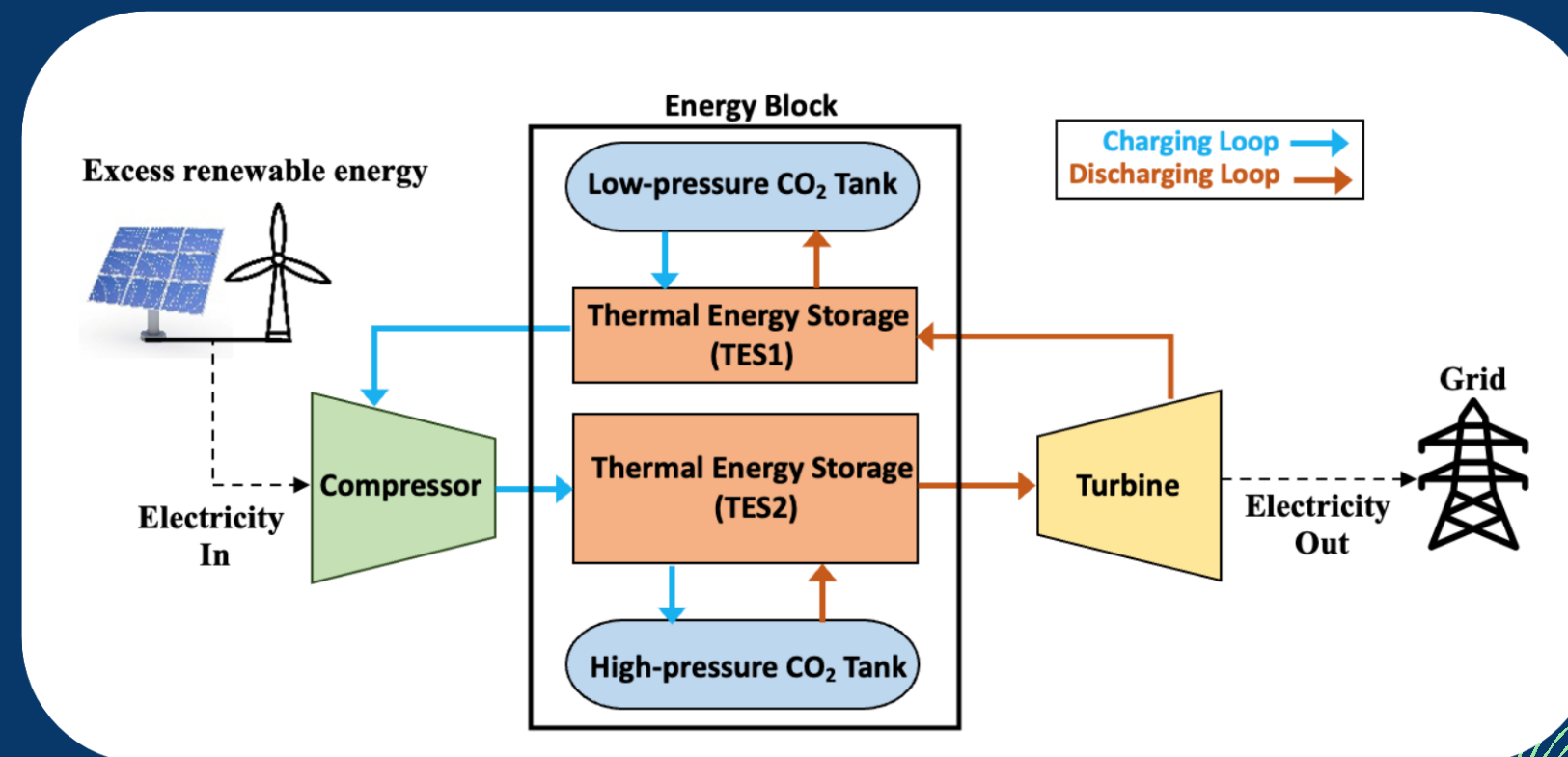
Charge: Compress CO₂

- Produces heat stored in a thermal energy storage (TES) system
- Produces pressurized supercritical CO₂ stored in high-pressure vessels

2

Discharge: Expand CO₂

- Uses high-pressure CO₂ heated by thermal energy storage to run a turbine
- CO₂ returns to low-pressure vessels



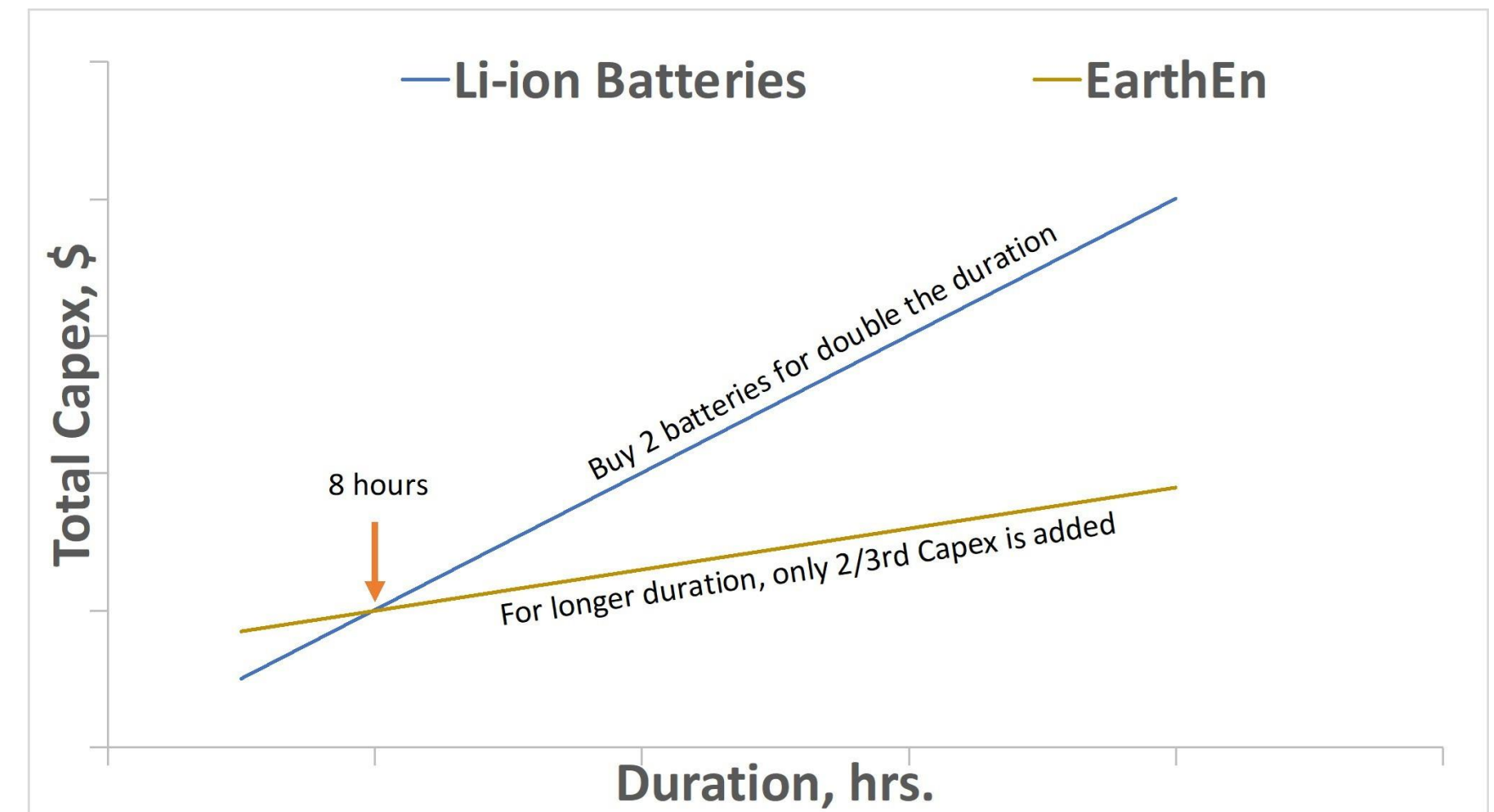
(12) **United States Patent**
Pathak

(10) Patent No.: US 11,569,663 B1
(45) Date of Patent: Jan. 31, 2023

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Our Advantage

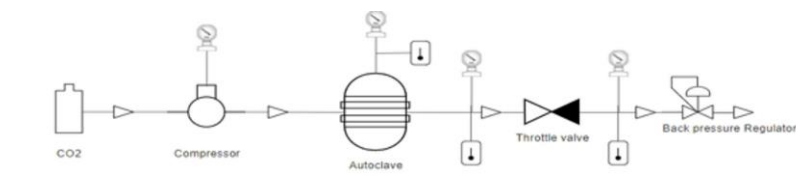
- Safer
- RTE of 78% due to reduced heat loss.
Turbine/compressor efficiencies have minimal impact on RTE.
- No land or material constraints
- 30 years lifetime, no cycling-based degradation 3%
- heat loss over 72 hrs
- Provides mechanical inertia
- High energy density and small footprint
- Duration can grow after installation (starting at 8 hrs and can go up to 100 hrs over time) at incrementally lower cost by just adding energy components



Flexible and future-proof

Roadmap

Today
Lab prototype



TRL 4 <10 kW
Completed in December 2023
“Science de-risked”

2024–2025

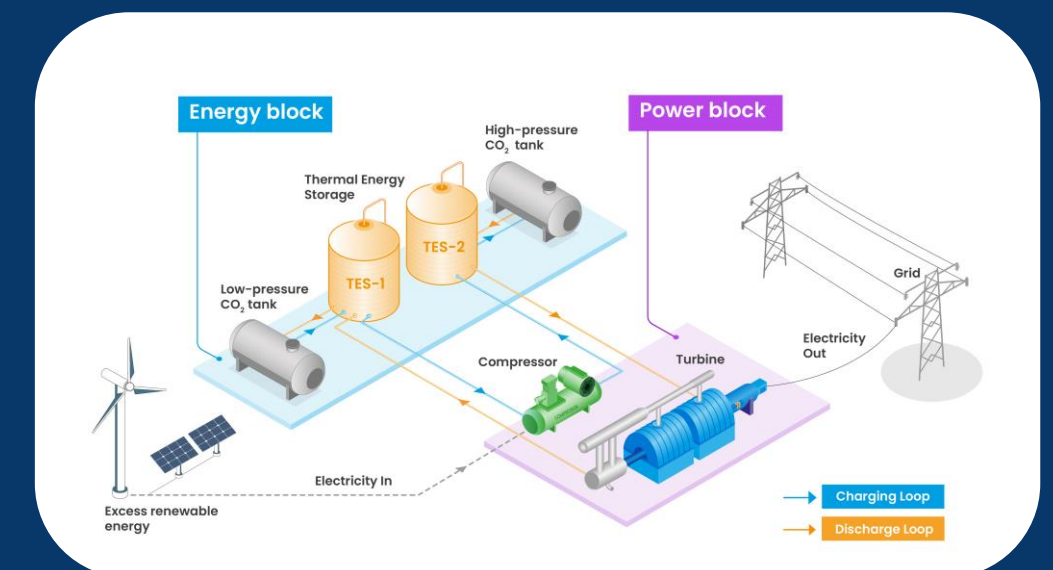
Already funded by DOE and in construction



ORNL loop is being built, this is picture of similar loop in SNL

TRL 5, 100 kW
at Oak Ridge National Laboratory

2026–2027



Two potential sites in the U.S.

TRL 7/8, 3 MW
After this, we are commercial

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3 MW Pilots – Timeline

Sites: Tennessee (front of the meter) and Texas (behind the meter)

Value Generation	Energy arbitrage and firming up solar
Decision Makers	Customers’ Innovation teams
LDES System	3 MW / 3 MWh, which will be upgraded to a 3 MW / 30 MWh
Target Annual Return	TBD
Project Life	30 years
Asset Operator	TBD

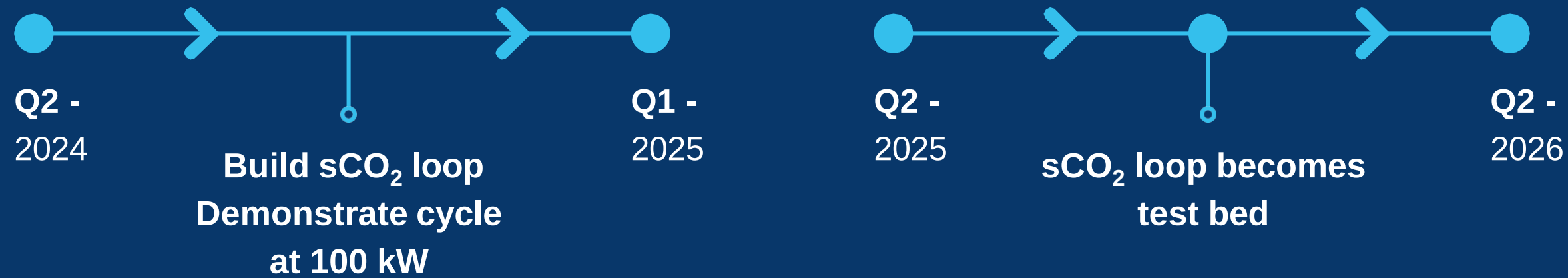


Work	When	Performer	Dependency
FEL-1 (pre-FEED)	Done, Nov 2023	Black & Veatch / EarthEn	EarthEn (process – simulations and lab data)
Lab Demonstration	Done, Dec 2023	EarthEn	
FEL-3 / FEED (Front End Engineering Design)	Q1, 2025 kickoff	EPC / EarthEn / Customer	Site and funding
Construction & Commissioning	2026	EPC / EarthEn / Customer	Site access and funding
Testing	2027	EPRI	

Timeline of Work at ORNL



CRADA active



GOAL: To demonstrate full cycle at 100 kW scale

HX

CaT

Vessels

TES



DOE target of
\$50/MWh LCOS

EarthEn Cycle demonstration and sCO₂ test bed

Sponsor: Office of Electricity

| Sponsor: AMMTO, IEDO, and
BTO

Confidential

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Thermal Energy Storage

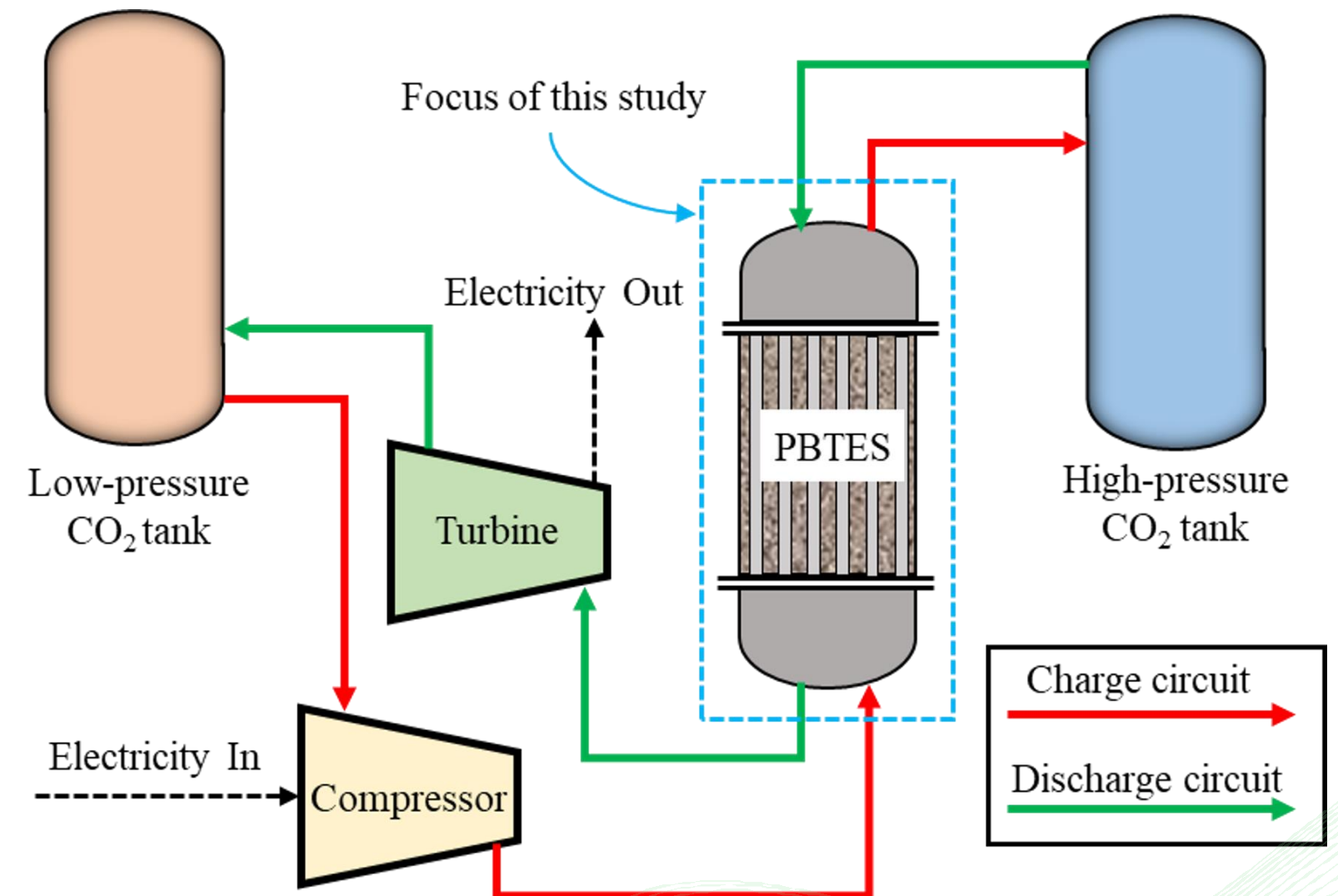
1 Today: Black & Veatch FEL-1

1. Two-tank molten salt and mineral oil systems were used
2. While commercial, they are expensive

2 Now evaluating: PBTES

- Packed-bed Thermal Energy Storage (PBTES) System with alumina/graphite balls
- Sponsored by NSF

PBTES systems store heat in solid particles / blocks within insulated vessels as fluid flow makes direct contact through void space or indirect contact through tubular casings



Heat Exchangers

1

Today: Black & Veatch FEL-1

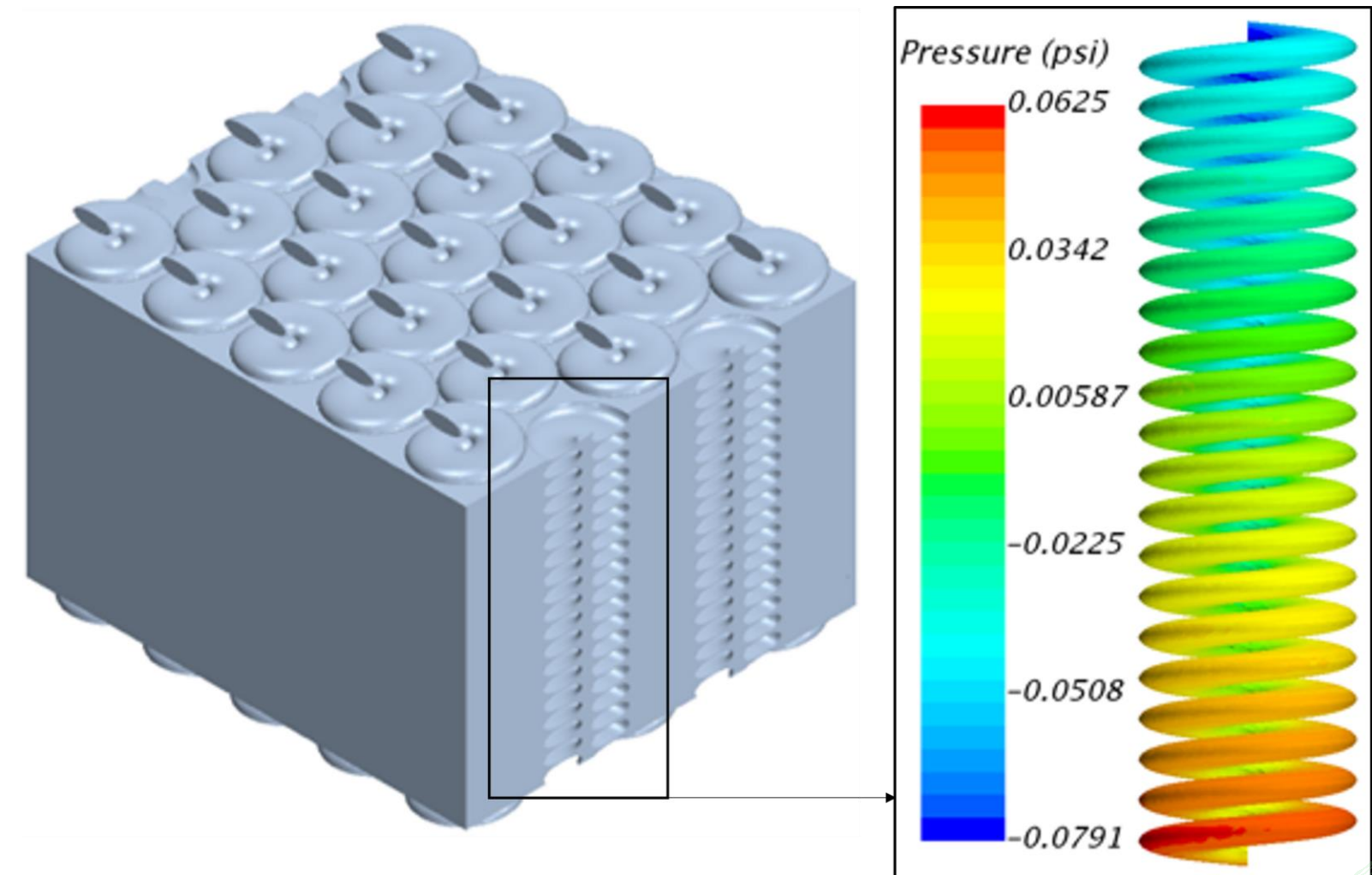
1. Industry-standard PCHEs were used
2. PCHE – Printed-Circuit Heat Exchanger

2

Now evaluating: 3D-printed PCHE

1. Additively manufactured heat exchangers are more efficient and less expensive
2. \$650K received from the US Department of Energy (DOE)

ORNL Patent, US 11,633,789 B2



Turbine and compressor development

- Working with Tier-1 OEMs for 3 MW sCO₂ turbine and compressor
- Design and development is in progress
- Part of the 3 MW pilots scheduled for 2026





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