Thermochemical Storage for Industrial Heat Decarbonization and Long Duration Energy

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2024 TMCES Workshop

RedoxBlox Customer Offering: electrification and thermochemical energy storage solutions that replace natural gas/fossil fuel combustion

Zero-Carbon Industrial Heat

Two Paths to Decarbonization

Long Duration Energy Storage (LDES) for Grid-Scale Power

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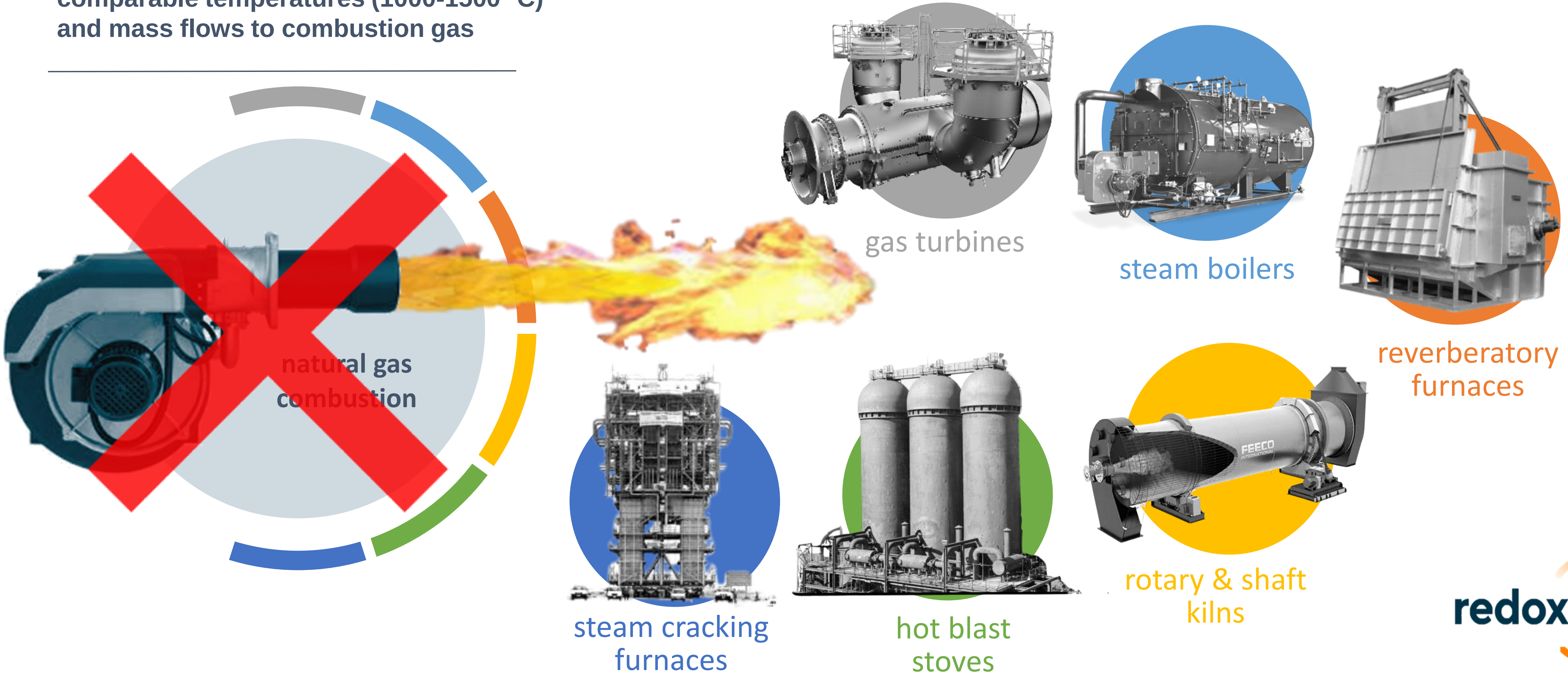
Thermochemical energy storage serves as true drop-in replacement for natural gas combustion

Fast charge capability (<4 hr) enables direct competition with natural gas combustion

Hot air from RedoxBlox storage units have comparable temperatures (1000-1500 °C) and mass flows to combustion gas



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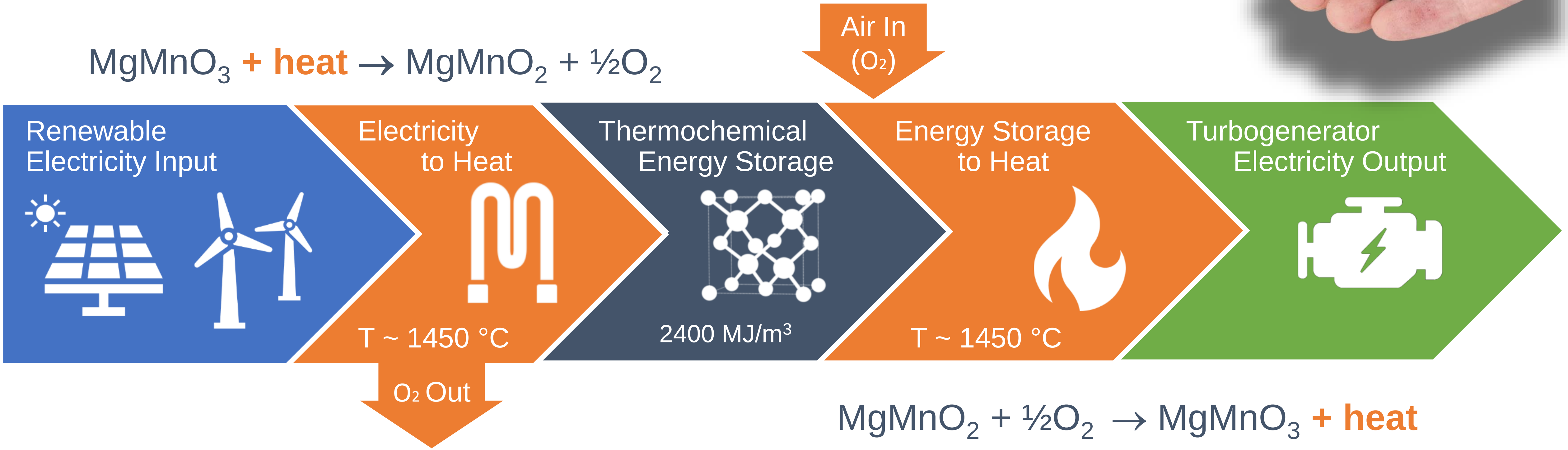
Daily Storage Technology

Carbon-free reversible solid-state redox reaction – "reversible combustion"

$$MgMnO_3 + \textbf{heat} \rightarrow MgMnO_2 + \tfrac{1}{2}O_2$$



$$MgMnO_2 + \tfrac{1}{2}O_2 \rightarrow MgMnO_3 + \textbf{heat}$$

- reversible redox chemical reaction
- energy storage ⇒ 2/3 chemical, 1/3 sensible
- energy storage density ⇒ 3× molten salt
- high temperature ⇒ high efficiency

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At the core of RedoxBlox is the discovery of a highly reversible thermochemical energy storage material

$MgMnO_3$ pellets

cheap & abundant

- 600 $/ton raw material cost
- literally dirt cheap
- earth abundant elements

record performance

- energy density of 2400 MJ/m^3
- specific energy of 1.5 MJ/kg
- 3x energy of molten salts

high temperature

- operation at 1000-1500°C
- ideal for gas turbines
- carnot efficiency over 77%

robust & long life

- 1000+ cycles & 2500+ h & counting
- no observed loss in capacity
- no pellet degradation

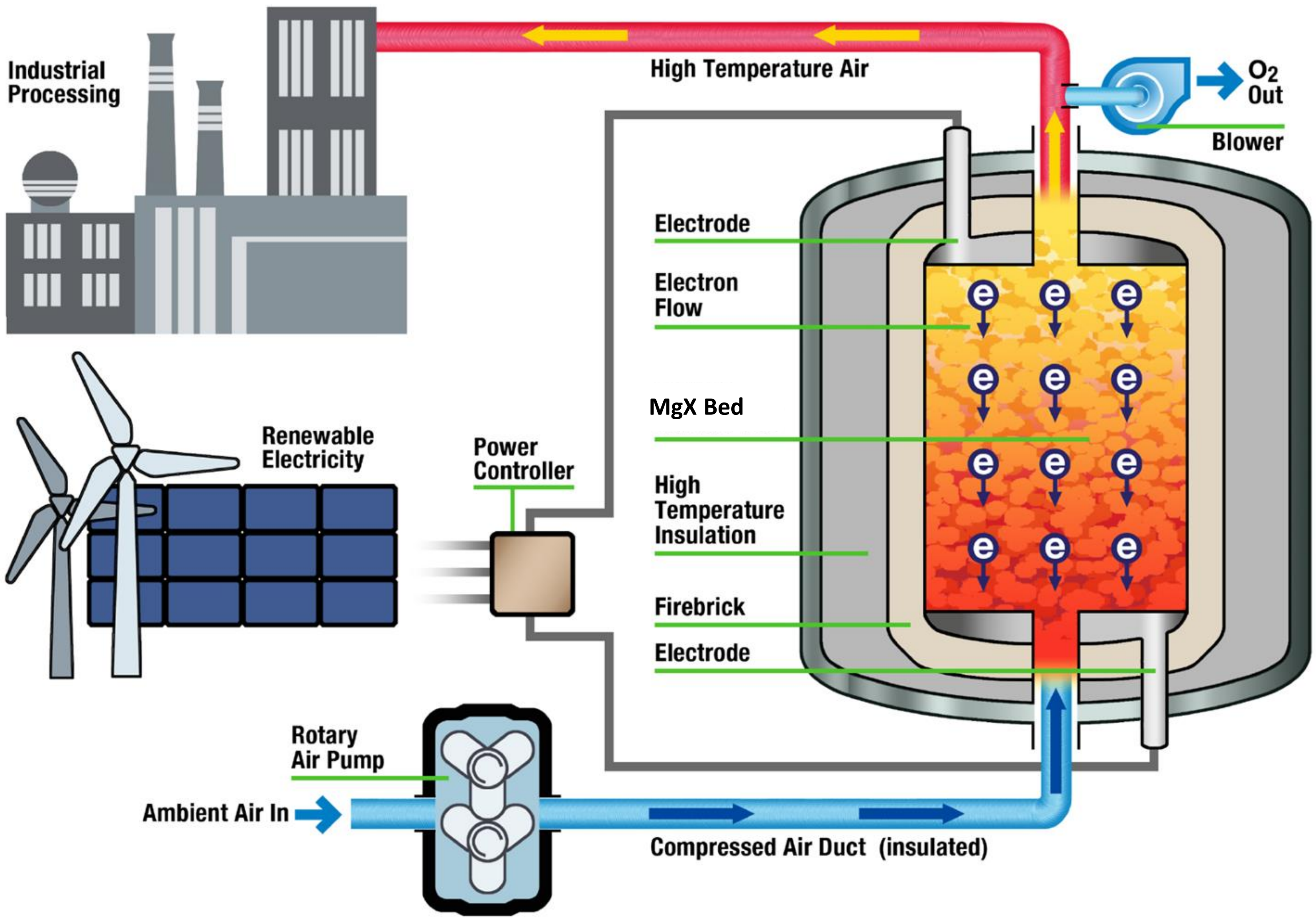
safe & sustainable

- non-toxic
- non-corrosive
- non-combustible
- 100% recyclable

patent protected

- 5 patent families,
- exclusive licenses with U.Florida & Michigan State

how does it work? *industrial heat*



industrial heat

> 95% efficient

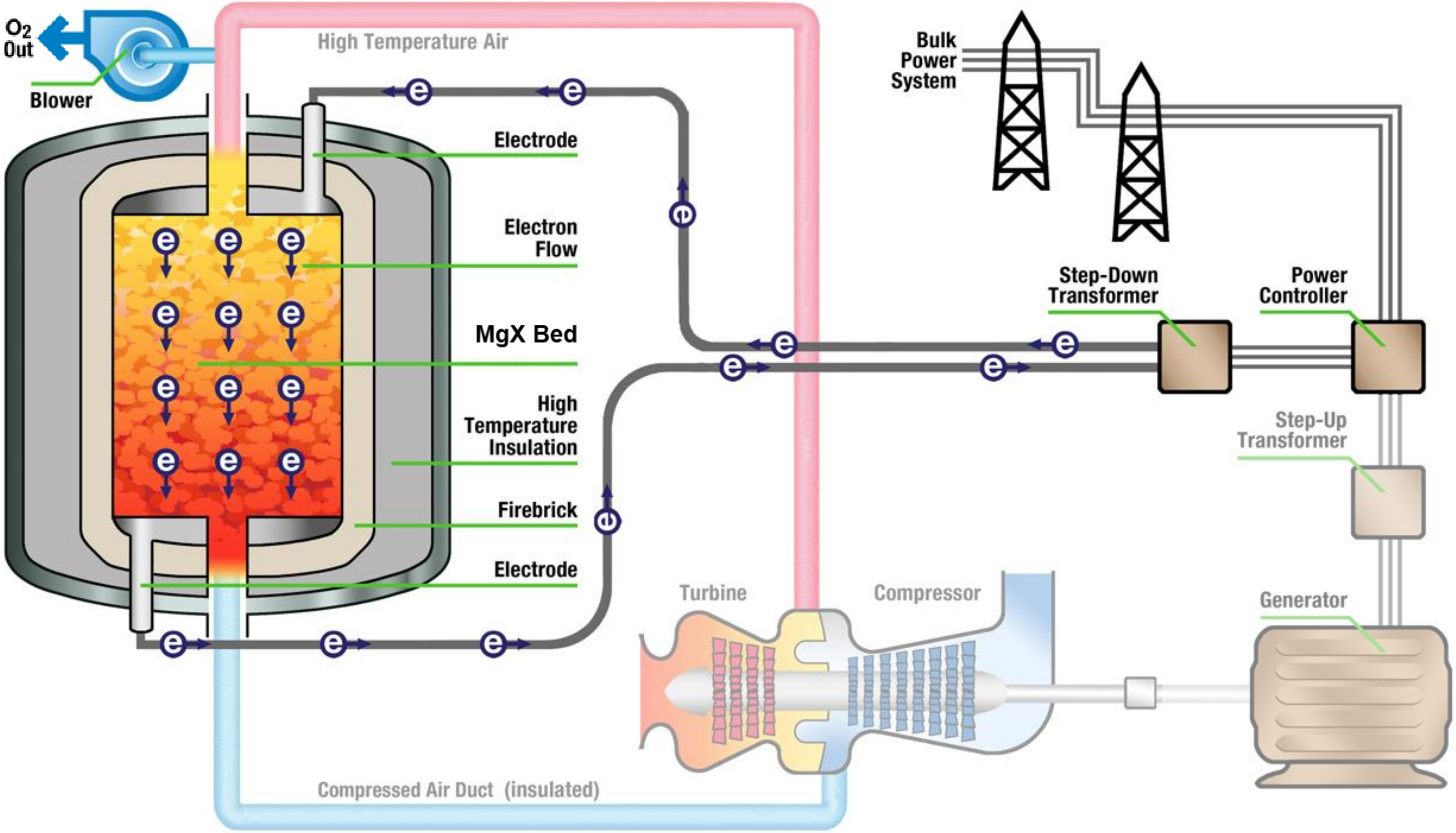
electricity

heat

store

heat

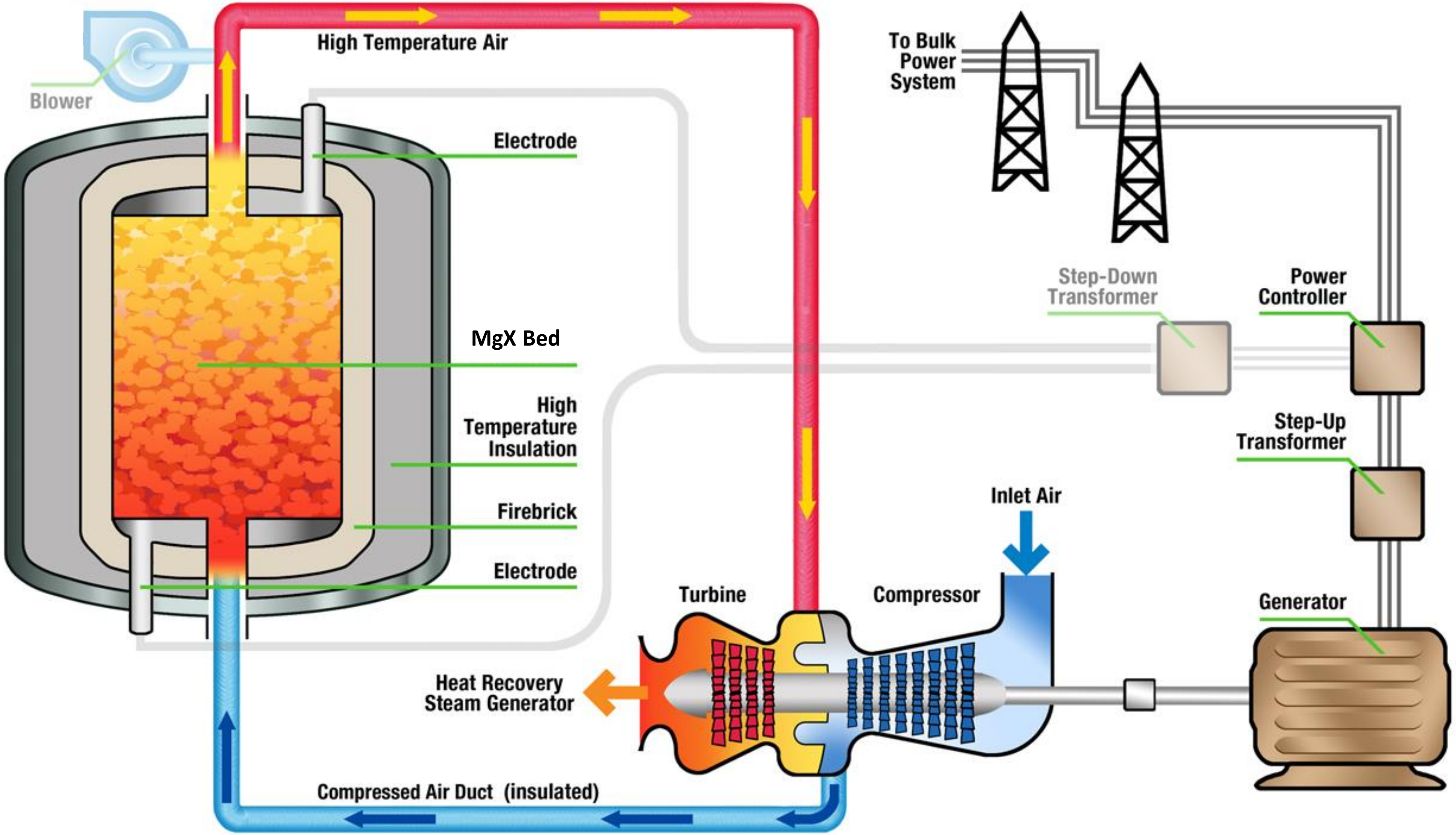
how does it work? LDES (charge)



grid storage
ˇ 55% efficient
(with CCGT)

electricity
⇩
heat
⇩
store
⇩
heat
⇩
electricity

how does it work? LDES (discharge)



grid storage

~ 55% efficient

(with CCGT)

electricity

⇩

heat

⇩

store

⇩

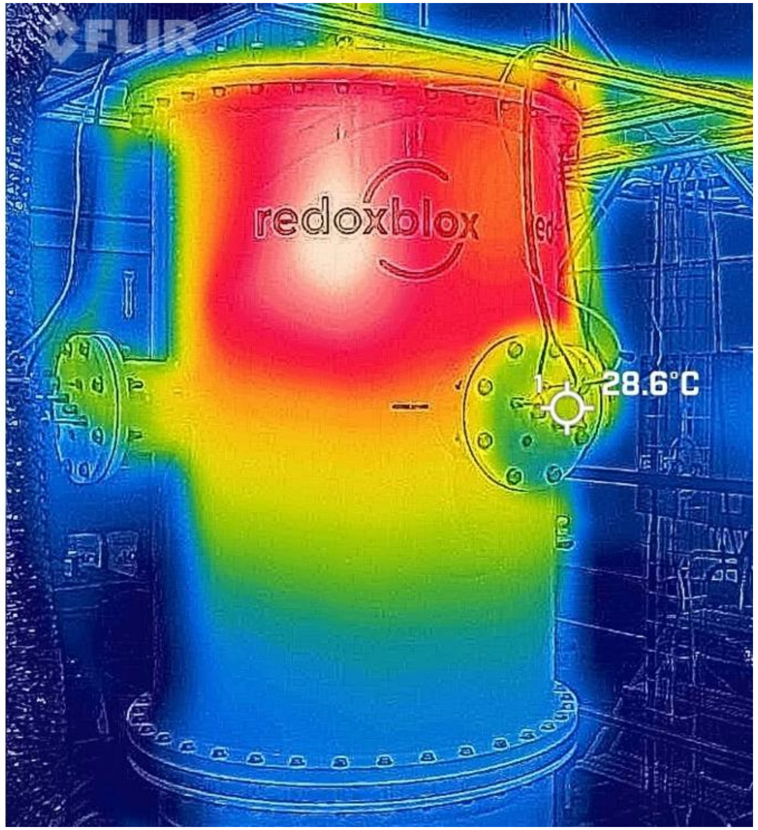
heat

⇩

electricity

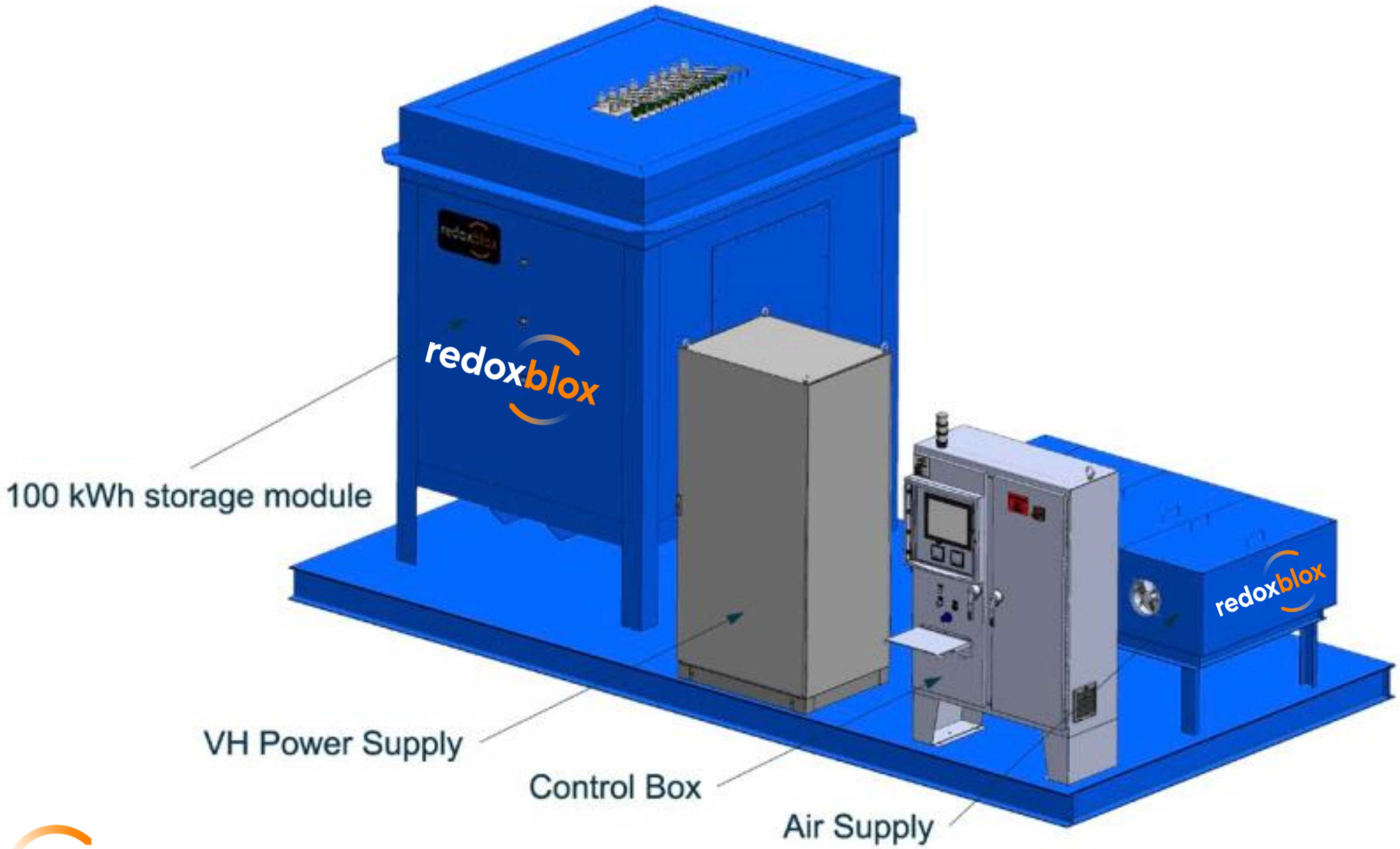
RedoxBlox Prototype Scaling

100 kWh with Heating Elements



10 kWh Volumetric Heating; 120 Cycles

100 kWh Volumetric Heating Prototype Installation



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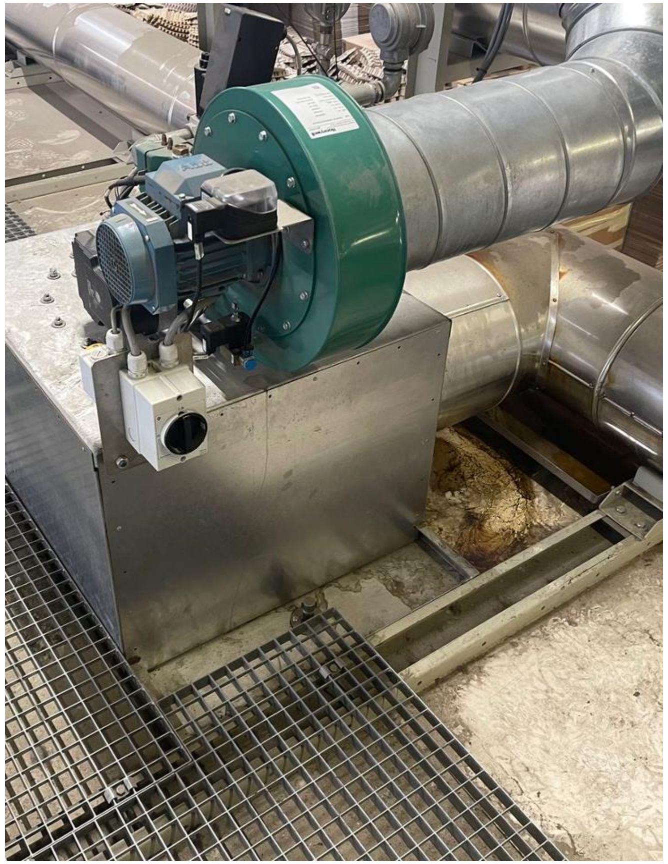
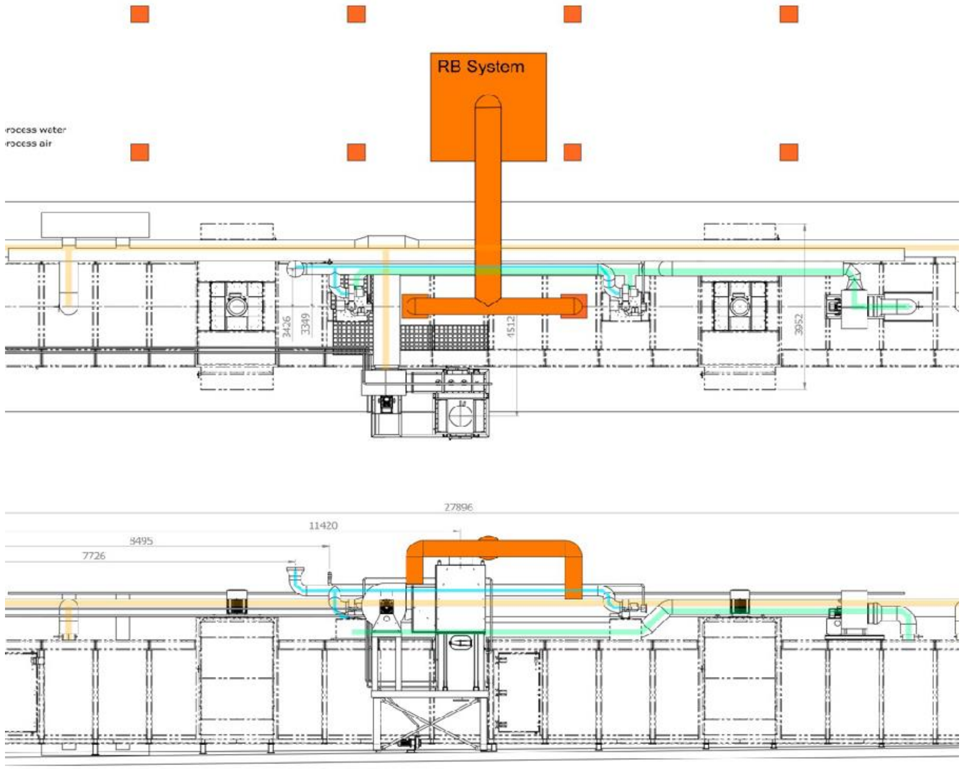
RedoxBlox Demonstration Projects

2 MWh Decarbonization of Cardboard Drying; Ganahl AG, Austria; 2024





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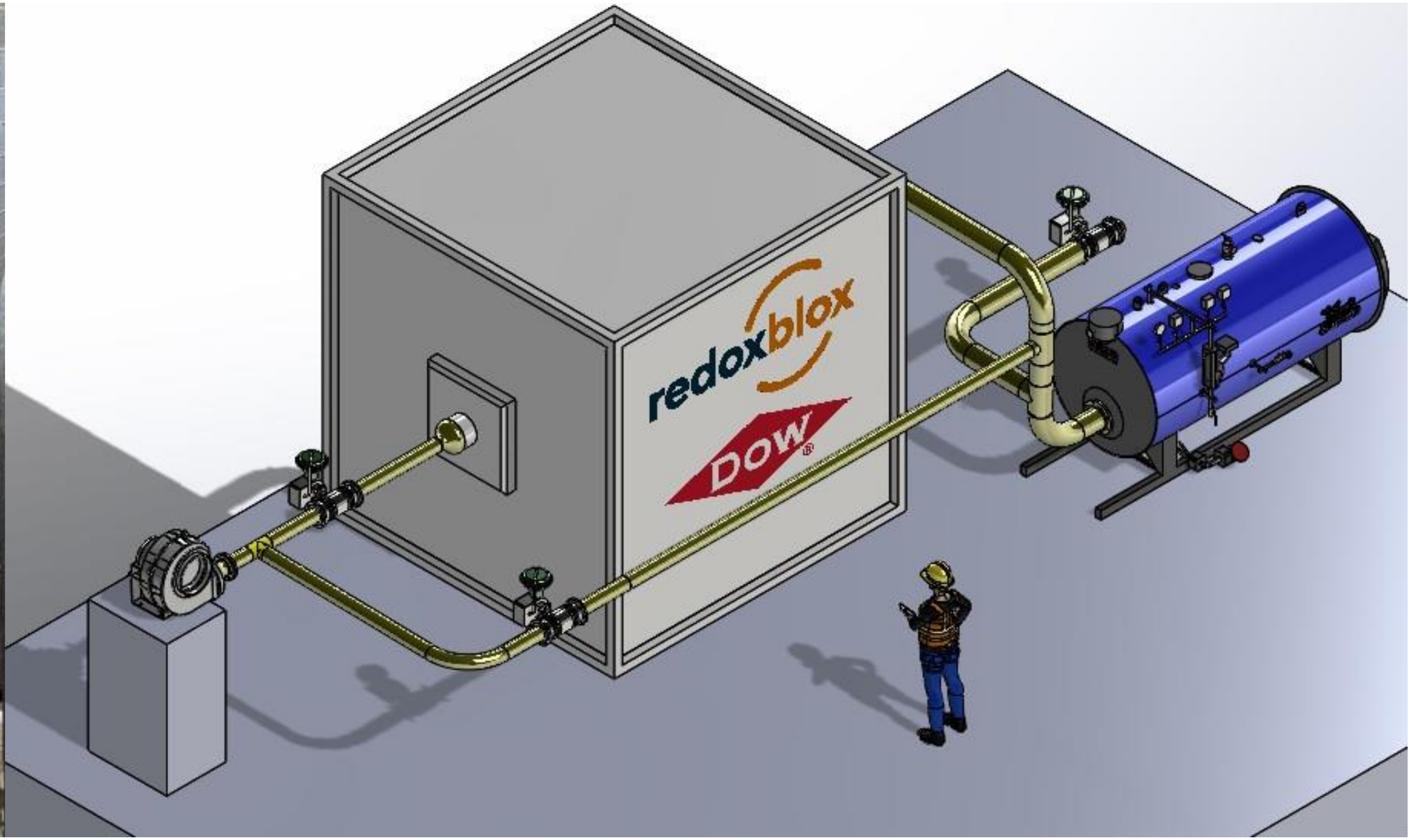
10 MWh Decarbonization of Steam Generation; DOW, West Virginia; 2026



10 MWh Long Duration Energy Storage (e-to-e) & CHP; UC San Diego Medical Campus; 2026

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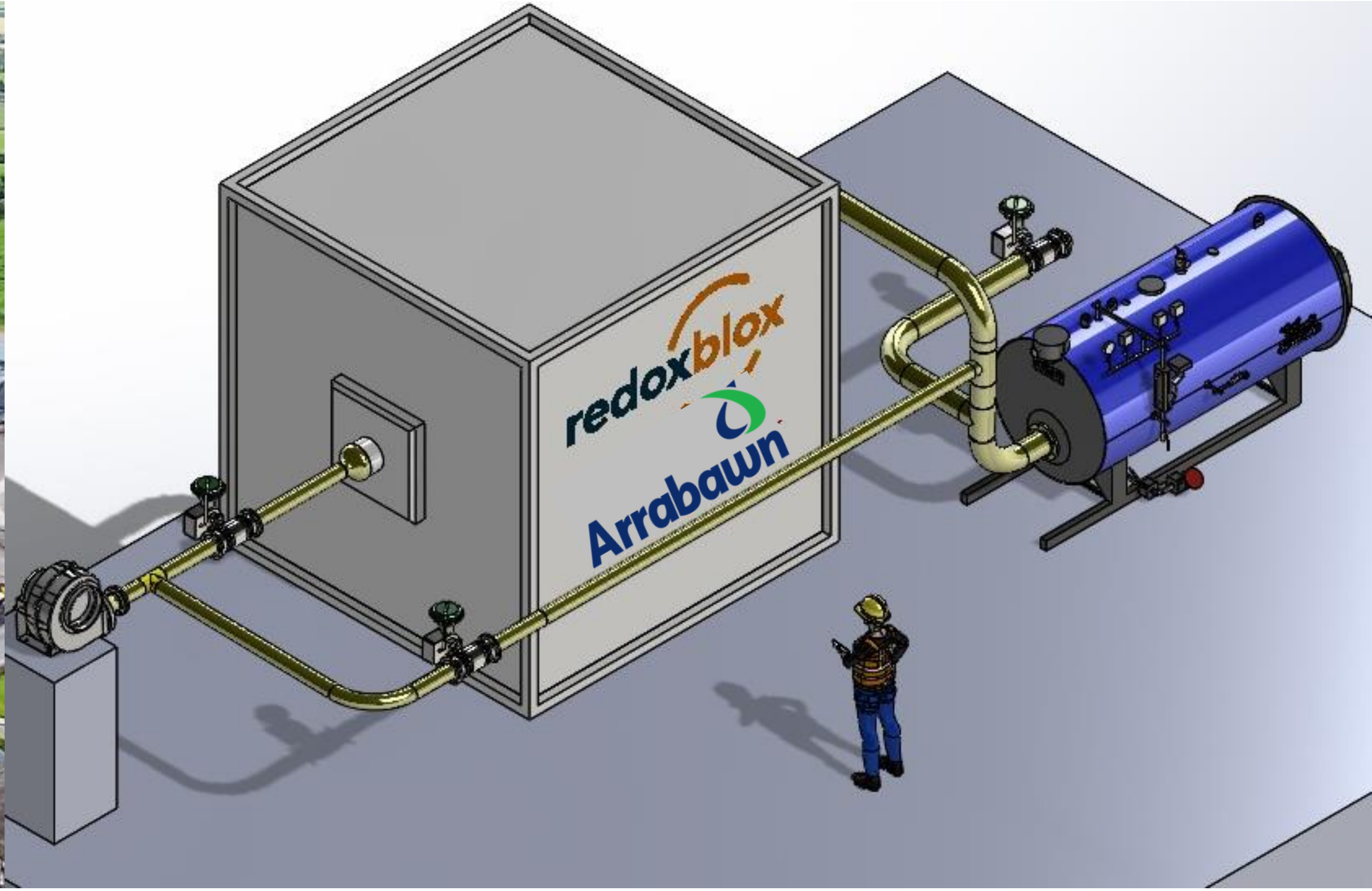
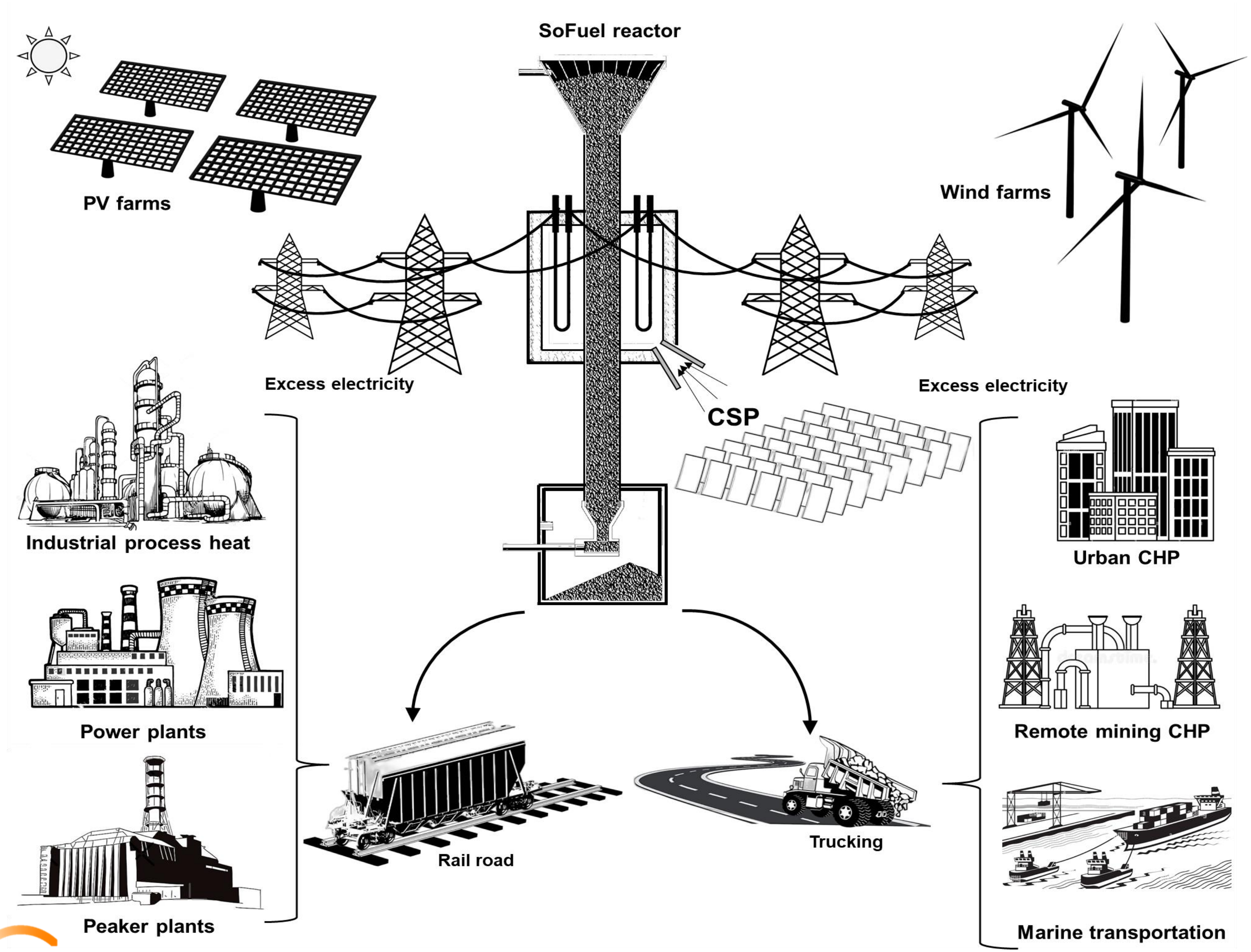
10 MWh Decarbonization of Steam Generation; Arrabawn, Tipperary, Ireland; 2027



Seasonal Storage

Synthesis of $MgMnO_2$ Zero-Carbon Solid-State Fuel (SoFuel)



Advantages

- SoFuel synthesis is continuous; decouples solar field from power block
- Metal oxide is recyclable
- SoFuel and gas in and out of the reactor is at low temperature; all handling is done at low temperature
- Heat recuperation is built into the design

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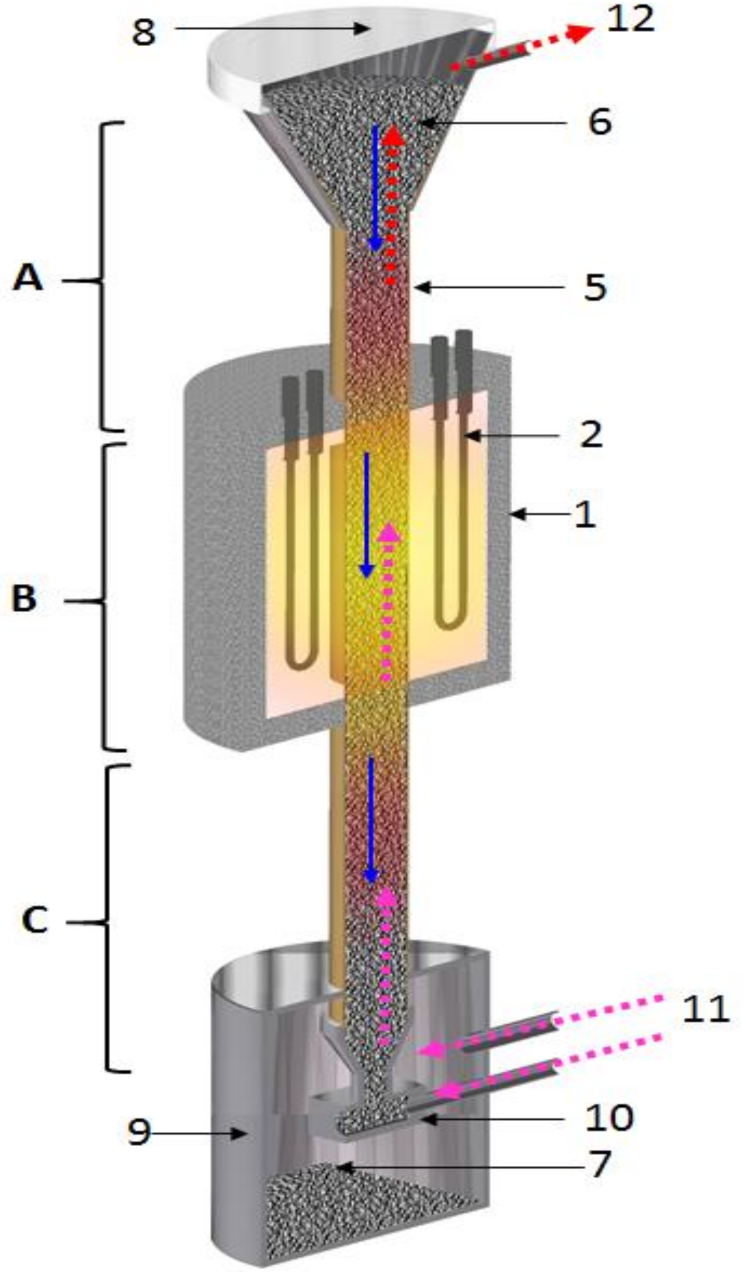
Contributors: Profs. Like Li, Andre Benard, Nick AuYeung, Michael Hayes, Dr. Phil Schimmels, and Dr. Dr. David Korba, Dr. Assad Al-Sahlani, Prof. Nesrin Ozalp

Process for Synthesis of $MgMnO_3$ Zero Carbon Solid-State Fuel (SoFuel)

Operational Constraint for Heat Recuperation

$$\dot{m}_s \overline{C_{p,s}} = \dot{m}_g \overline{C_{p,g}}$$



3 mm spherodized pellets with a porosity of 36% flowing through a 50 mm ID tube at 1 atm pressure

Oxidized Pellets

Reduced Pellets

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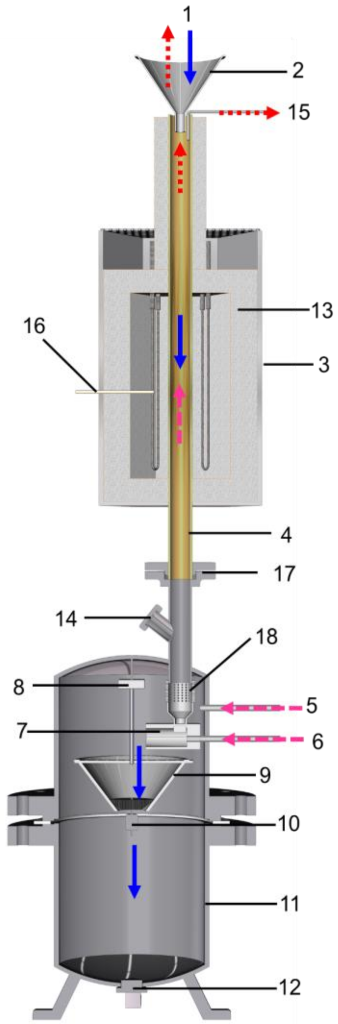
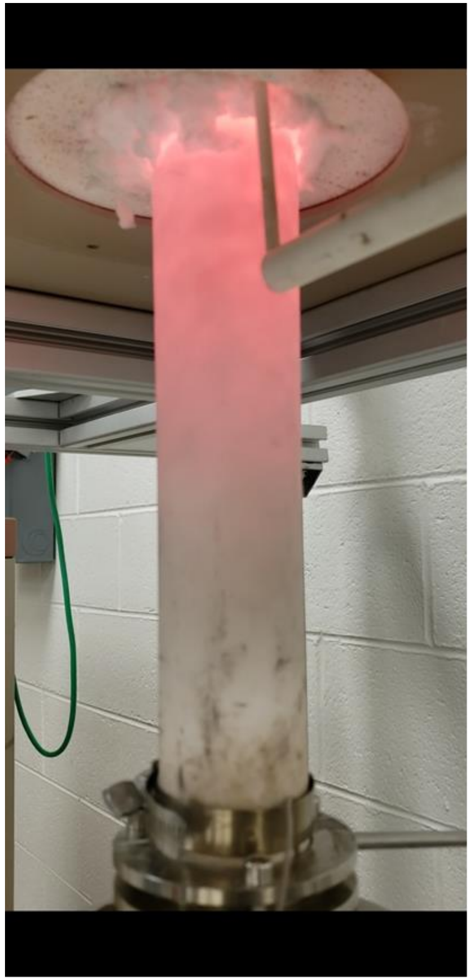
Laboratory Scale Apparatus for SoFuel Synthesis





$$\dot{m}_s \overline{C_{p,s}} = \dot{m}_g \overline{C_{p,g}}$$

Maximum Energy Storage Flux:
Q" = 1200 kW/m^2

Energy density =1700 MJ/m3

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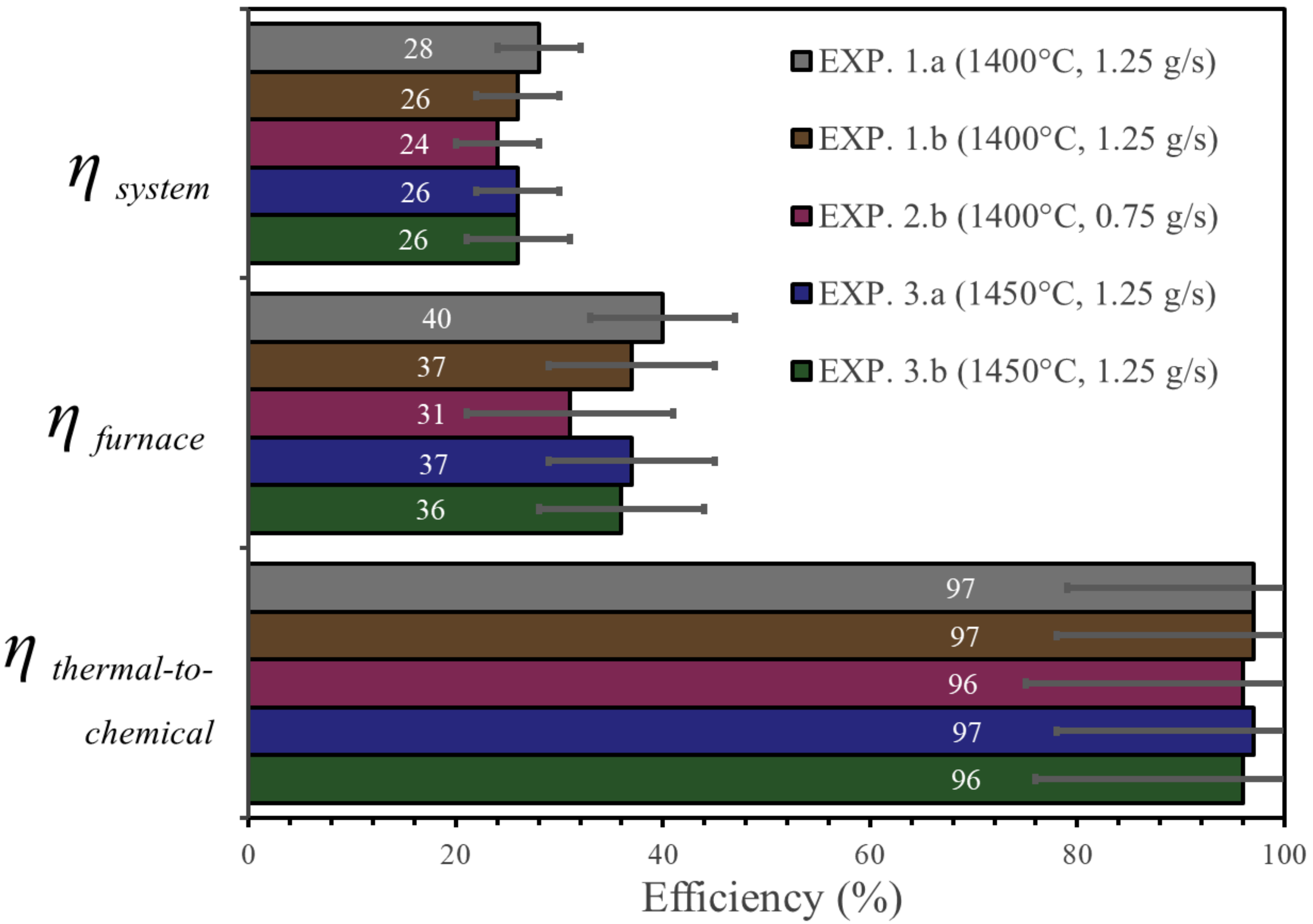
SoFuel Conversion Efficiencies

$$\eta_{thermal-to-chemical} = \frac{\dot{n}_{O2}\Delta H_{rxn}}{P_{furnace} - \dot{Q}_{loss}}$$

$$\eta_{furnace} = \frac{\dot{n}_{O2}\Delta H_{rxn}}{P_{furnace}}$$

$$\eta_{system} = \frac{\dot{n}_{O2}\Delta H_{rxn}}{\dot{Q}_{reactor} + \dot{Q}_{loss} + P_{O_2 sep} + P_{pump}}$$



Energy Density of Pellets after 125 Days Ambient Exposure

No loss in chemical energy storage capacity after extended storage

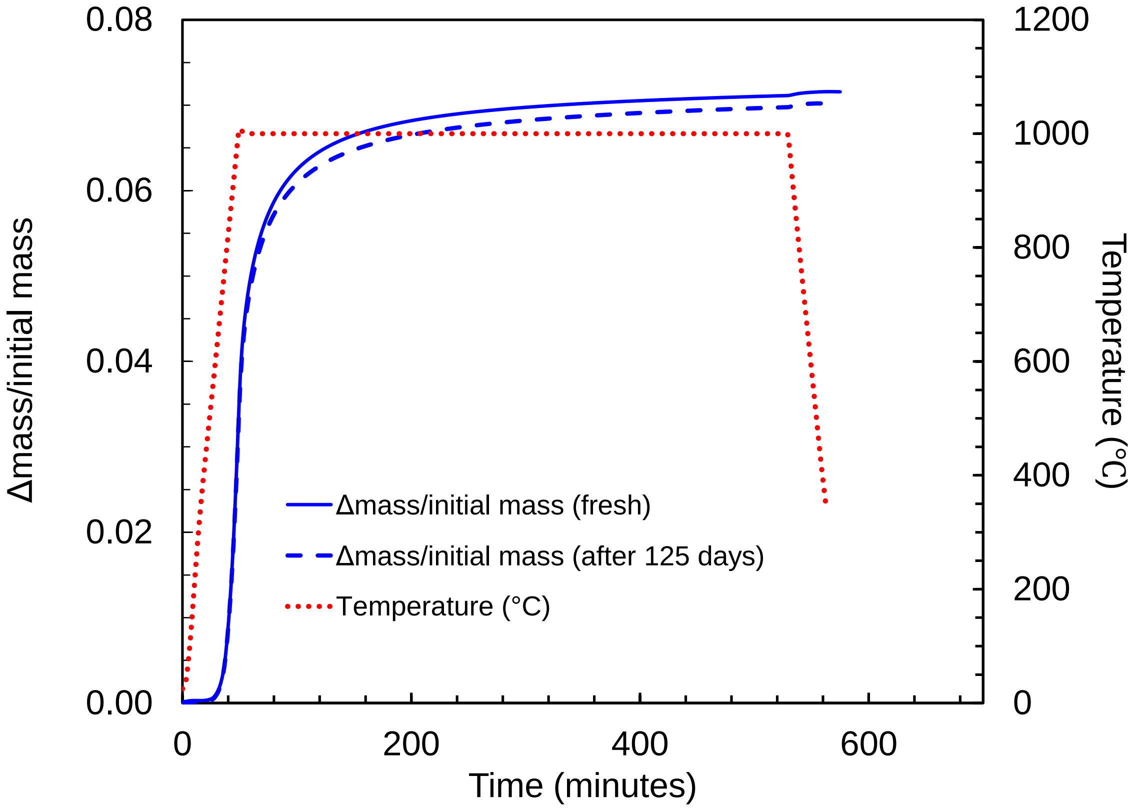


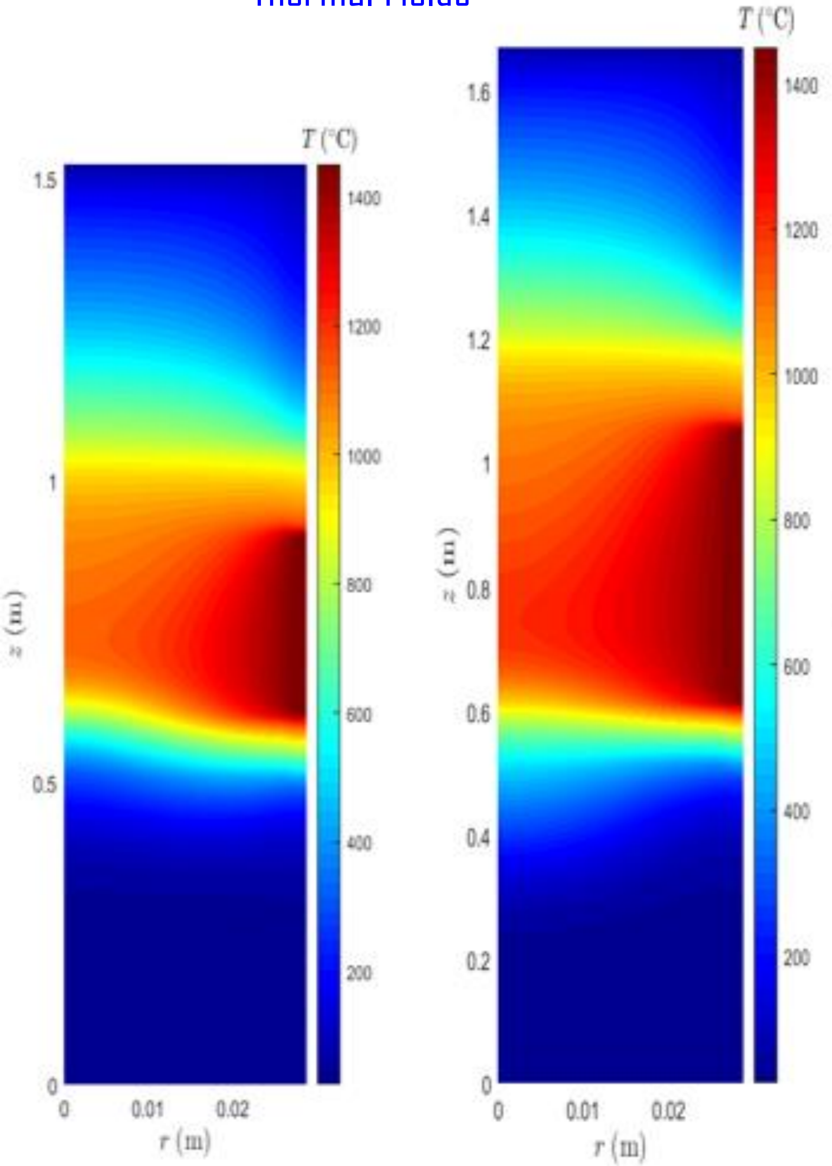
Fig. TGA data for oxidation of samples before and after 125 days of storage

Table. Reduction extent and energy density before and after extended storage

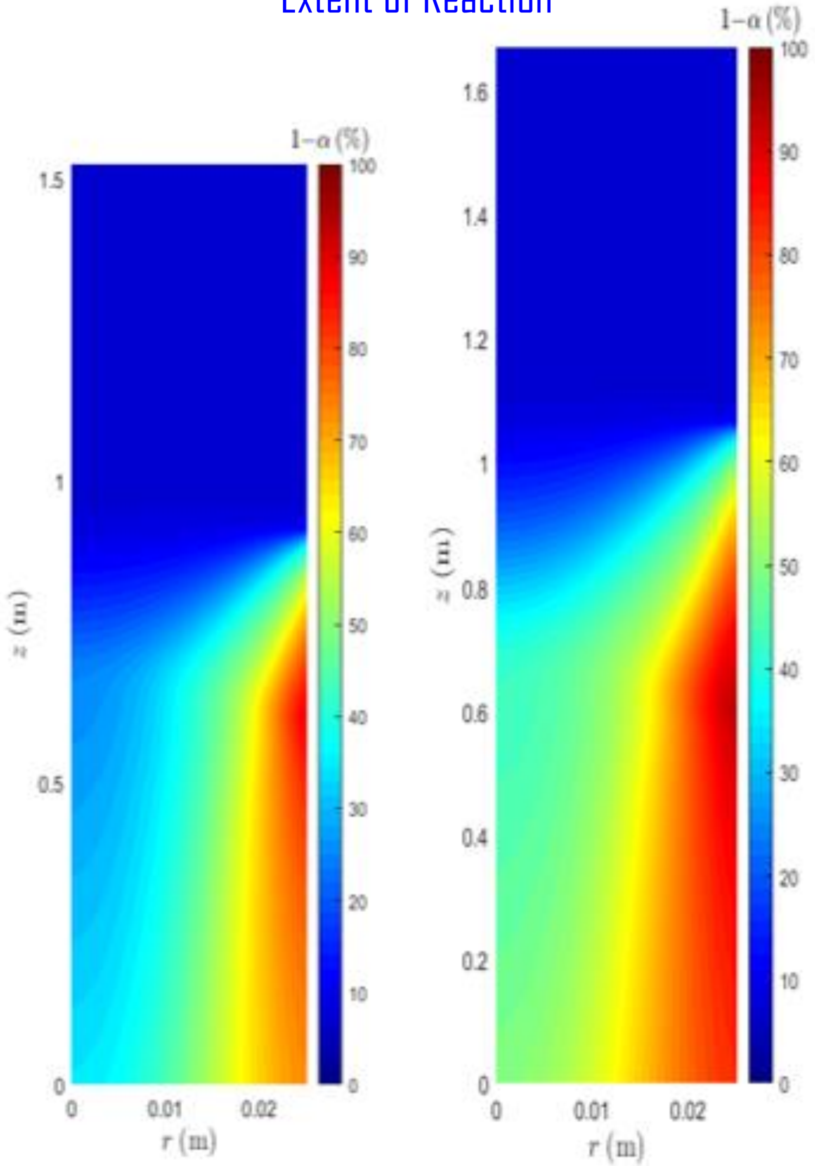
	Reduction extent	Energy density
Freshly reduced sample	**94.8%**	**1699 MJ/m^3**
Reduced sample tested after 125 days	**93.2 %**	**1667 MJ/m^3**

Temperature and Extent of Reaction Contour Plots Within Reactor

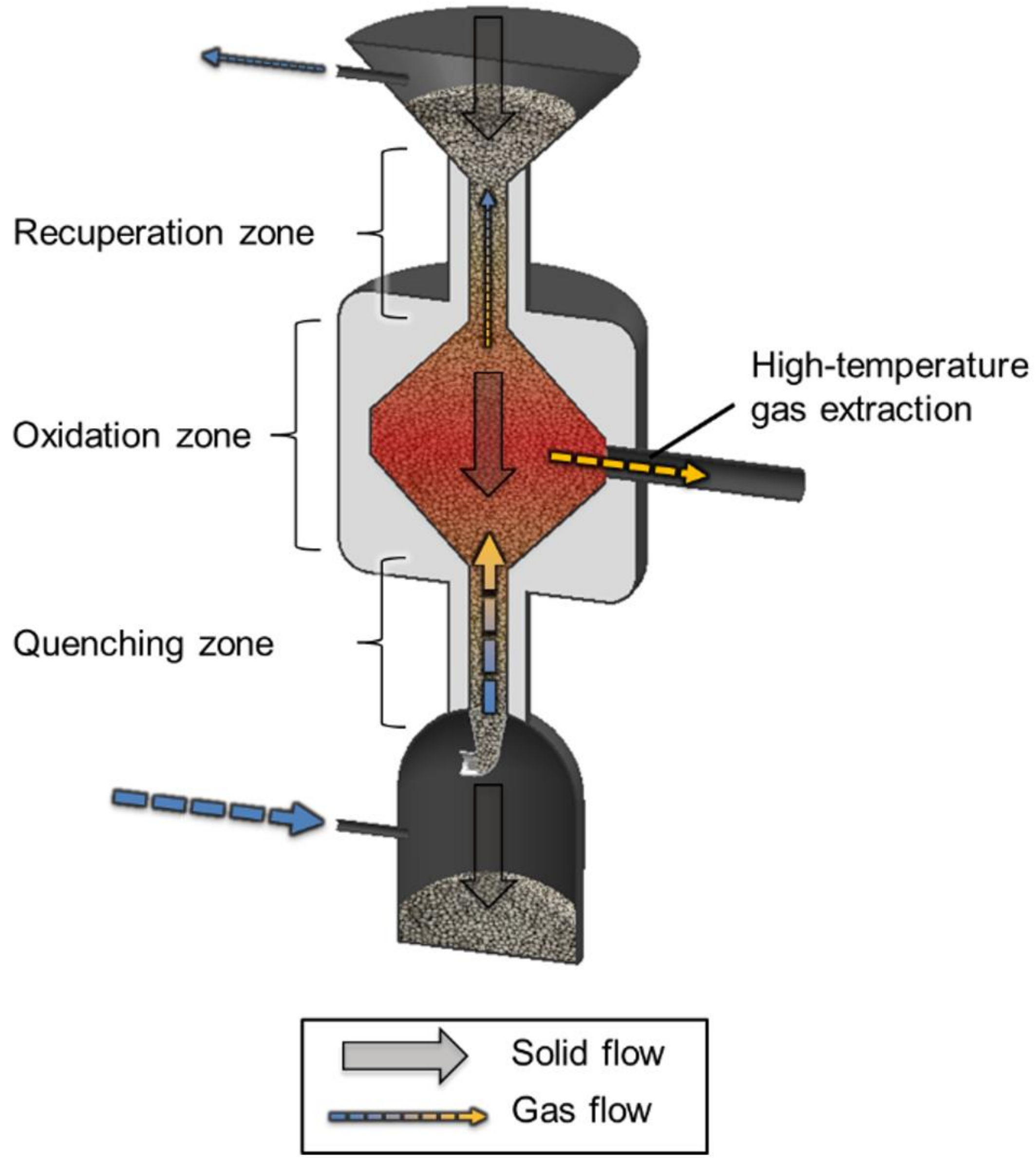
Thermal Fields



Extent of Reaction

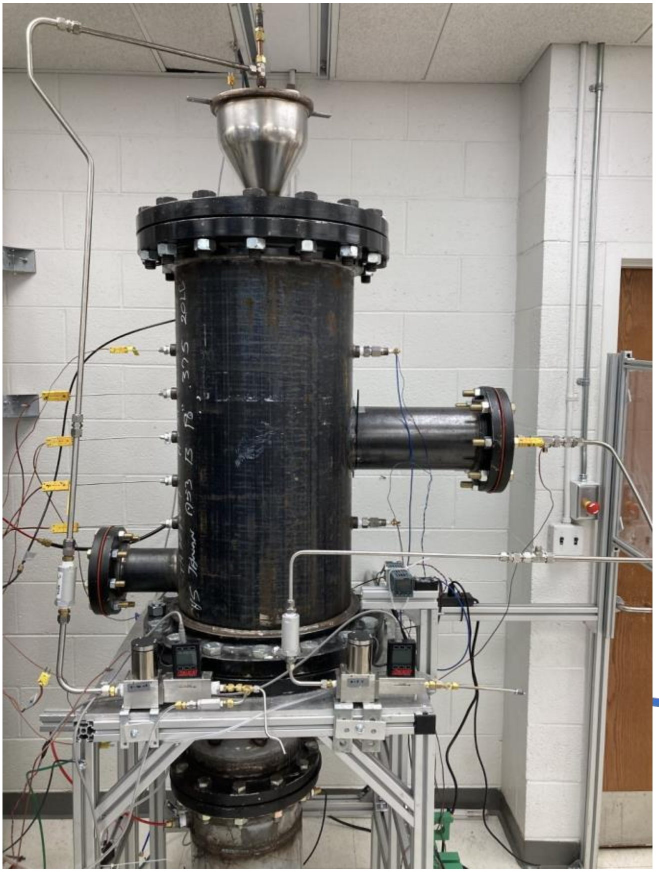


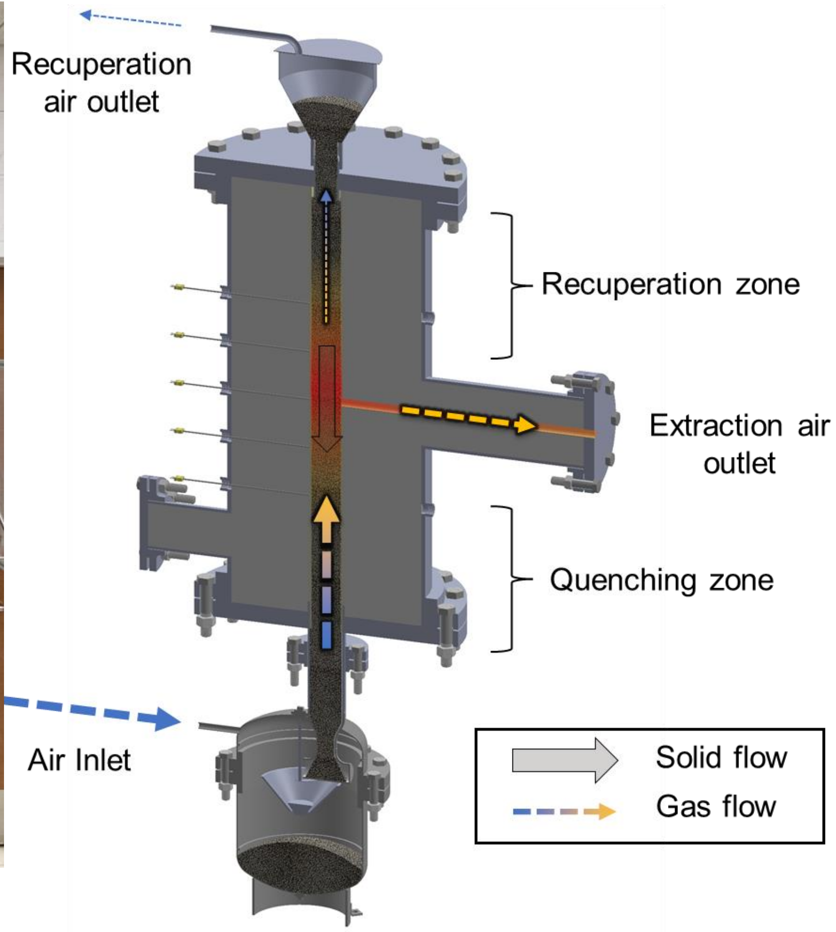
Solid-State Fuel (SoFuel) Oxidation Reactor for Heat Extraction



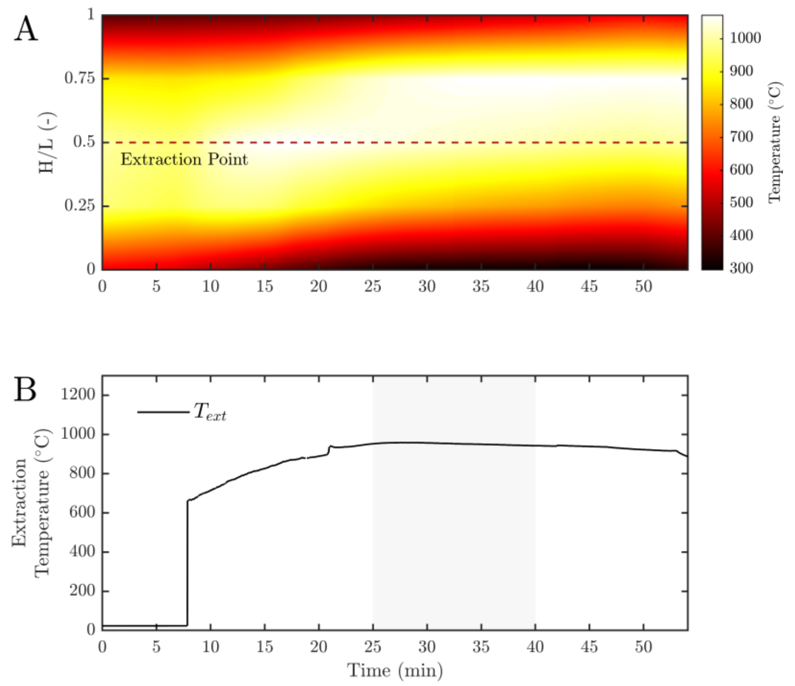
Heat Extraction from Reduced SoFuel Pellets

Bench scale oxidation reactor





Achieving high oxidation temperature (>1000°C)



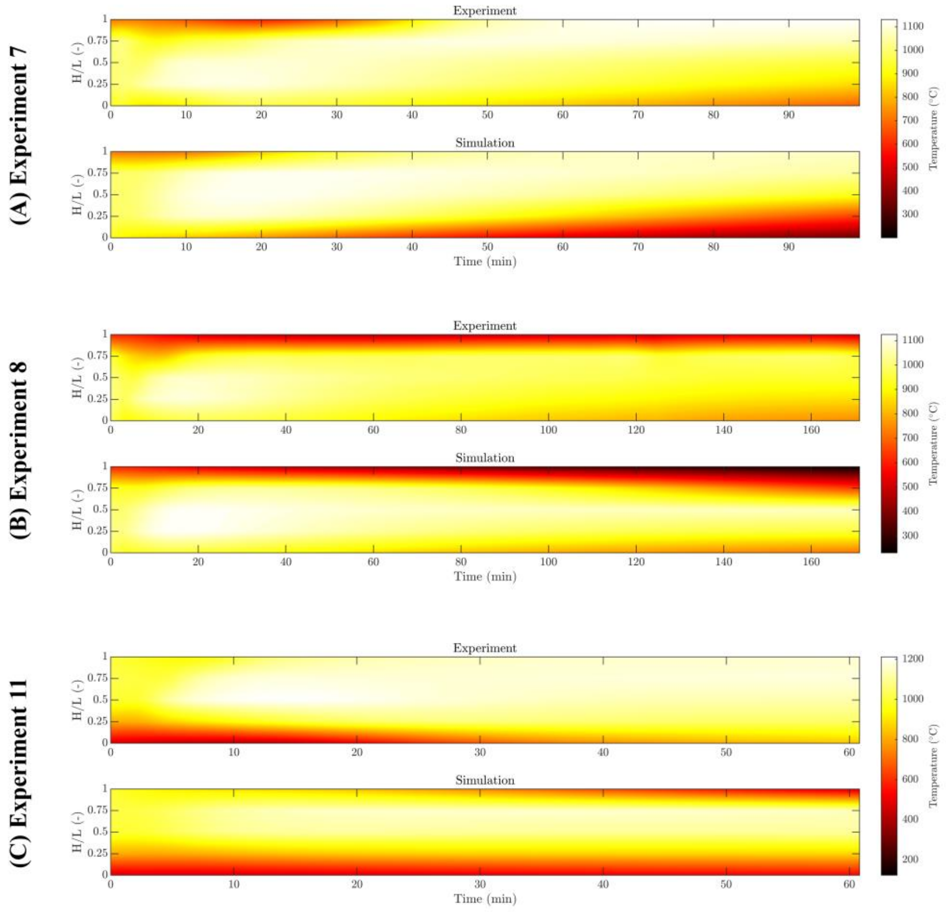
Extraction air temperature > 940°C

Energy density (heat loss + heat extracted) =1440 MJ/m^3

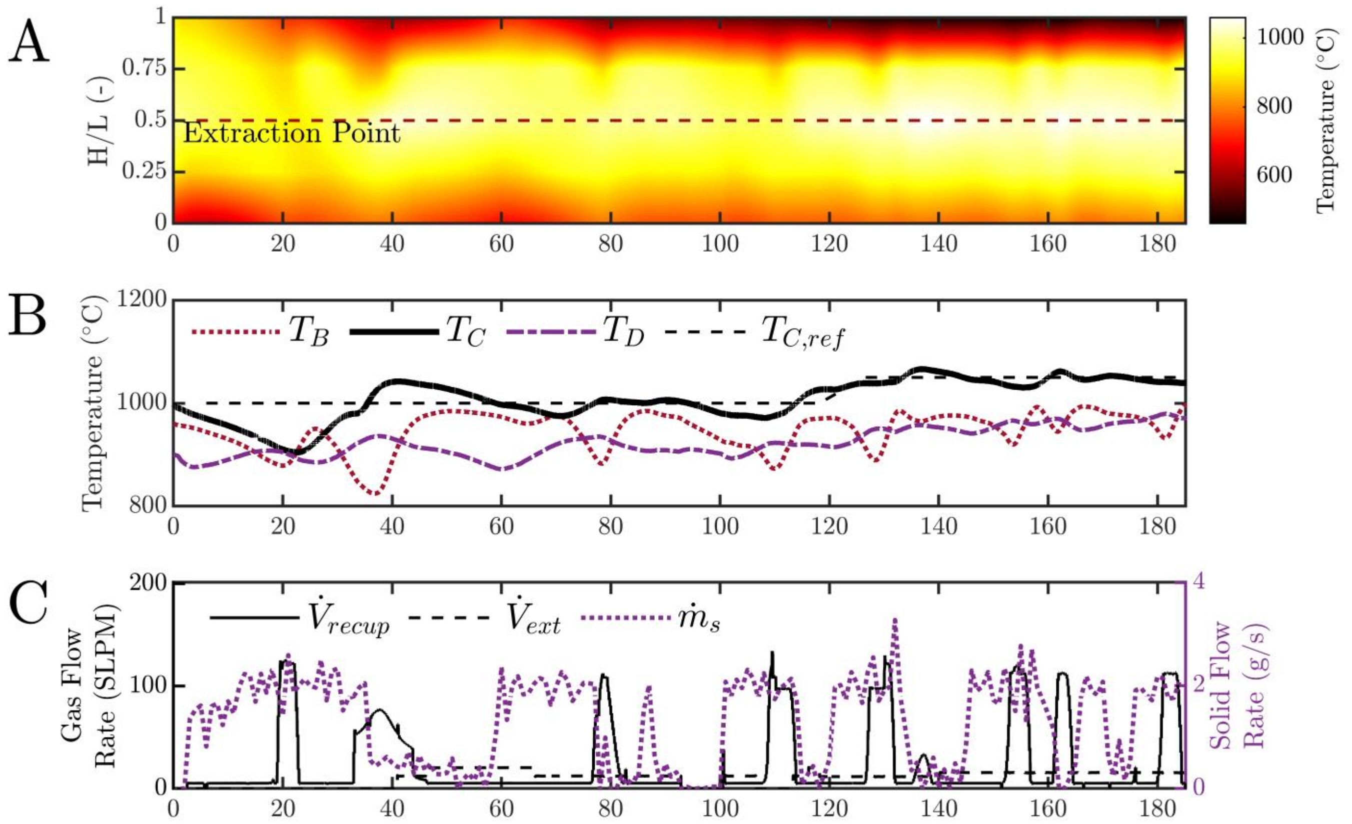
Without active control, hot zone moves up the reactor

Active Control to Manage Thermal Field

Comparison of measured and simulated thermal fields



Active control allows management of the reactor thermal field



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Creating a Carbon-Free Future

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