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Thar has a history of successfully designing & commercializing Green Processes using CO2

1982

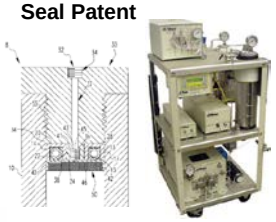
Launch Suprex-
First supercritical only
Company in the World

Carnegie Mellon University
Chemical Engineering

U.S. Patents
4,814,089 & 4,871,453
Chromatographic
Separation Method
and Associated
Apparatus

1990

Launch Thar Brand



Pressurized Vessel
with Self-Energizing
Seal Patent

Approached DOE with sCO_2 Brayton Cycle Concept

Launch Operating Div.
Thar Instruments
Thar Process
Thar Pharma

Thar Instruments, ~125 strong, Offices worldwide, Sold to Waters Corp.

Micro Refrigeration using CO_2 as the working fluid-
Patent US 7,140,197

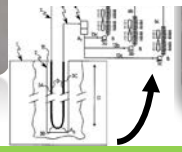
U.S. Patents #5,336,869, #5,461,648, #5,694,973, #5,850,934, #5,879,081, #5,886,293, #6,908,557, #7,091,366, #6,698,214. ……

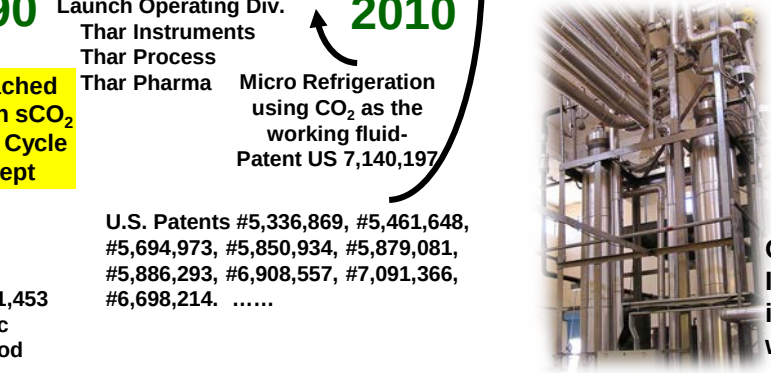
2010

First R744 (CO2)
Geothermal
Cooling
Demonstration

First 3D Printed, Inconel 718, sCO_2-sCO_2 Recuperator

Geothermal Energy System Patent US 8,468,845
Using CO2



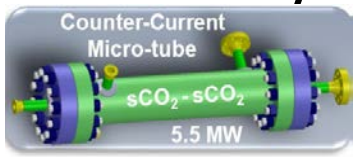


Over 20 Industrial green installations world wide

2001, 2002 Governor's Export Excellence Award Finalist
2002 National Small Business Exporter of the Year
2002 NIST ATP Awardee (Microrefrigeration)
2002, 2003 Top 25 Biotech Companies
2002, 2003 Top 100 Fastest Growing Companies
2003 Fastest Growing Small Manufacturer Award
2004 Manufacturer of the Year

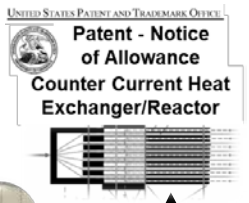
2014

Primary Heater for Sunshot
One MWe sCO_2Test Loop



Thar Pharmaceuticals sold to GRUNENTHAL

Design – Construct – Operate
sCO_2 Heat Exchanger Test Loop
In Pittsburgh



2017

High Pressure
sCO_2 Pumps
High Flow Rates

Low Cost
Gas Cooler
Air-sCO_2

Oxy Combustion Test Facility
Design – Construct – Operate
Demonstrate auto-combustion
In Pittsburgh

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Huge Interest: Over 275 attendees, 15+ countries

•United States	•US DOE	•Thar	•U of Wisconsin
•China	•SWRI	•GE	•Xi'an Jiaotong Univ
•UK	•SNL	•Peregrine	•Univ of Central Fl
•Germany	•ORNL	•Hanwha	•Univ of Stuttgart
•Netherlands	•EPRI	•Net Power	•Univ of Seville
•Italy	•GTI	•Echogen	•Oregon State Univ
•Spain	•SMDERI	•Dresser-Rand	•Georgia Inst of Tech
•Korea	•KIER	•VPE	•Embry-Riddle Aero
•India		•Heatric	•Delfts University
•Saudi Arabia		•CompRex	•Indian Institute of Sc
•Japan		•Brayton	•Penn State Univ
		•Mohawk	•Tohuku University
		•Nooter-Erikson	

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Why sCO_2 Brayton Cycle Power Systems

- Higher Efficiency
  - Smaller Package enables it to be factory made
    - HX, expanders and pumps are smaller
    - A 5 MW system can fit into a 40 foot container
    - Smaller Package allows for easy installation
- Fuel Flexibility
  - Natural Gas, Biomass, and Coal
- Zero Emissions: Oxy-combustion
- Air Cooled: No water requirement

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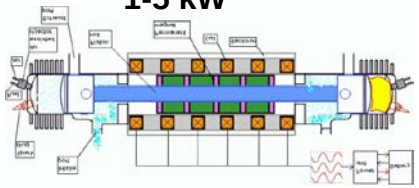
sCO_2 Brayton Cycle Applications

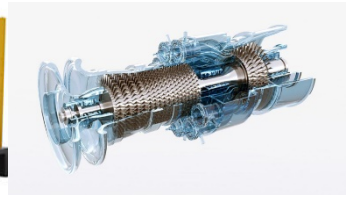
Natural Gas
Portable Genset
1-5 kW



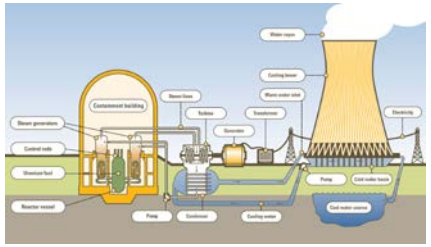
Solar Thermal Power
10-200 kW

Natural Gas Genset
500-5000 kW

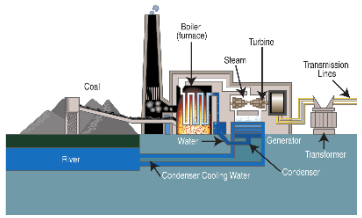
Waste Heat Recovery
Airplane
500-2000kW



Nuclear Power Plant
50-200 MW



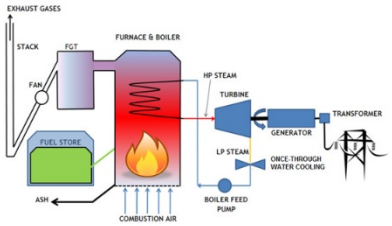
Coal Power Plant
100-500 MW



1 kW

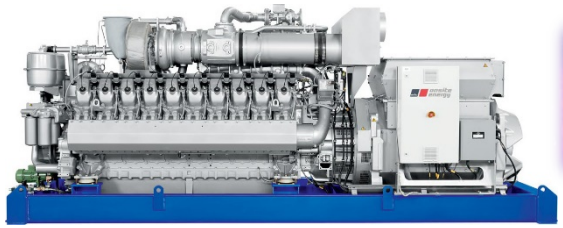
500 MW

Natural Gas Genset
10-200 kW



Biomass Thermal Power
10-5000 kW

Waste Heat Recovery
Gas Turbines
Cement Plants
Steel Plants
Ships
1-25 MW

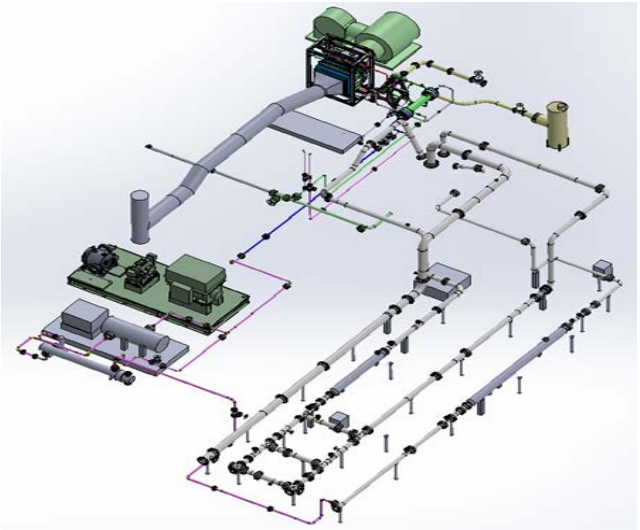


Natural Gas
Power Plant
50-500 MW

Oxy Combustion
200-500 MW

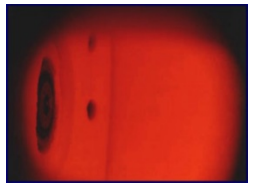
One MW DOE sCO_2 Pilot Loop

SwRI, Thar Energy, GE



Flameless Pressurized Oxy-Combustion Pilot Plant Planning
(SwRI, ITEA for DOE NETL)

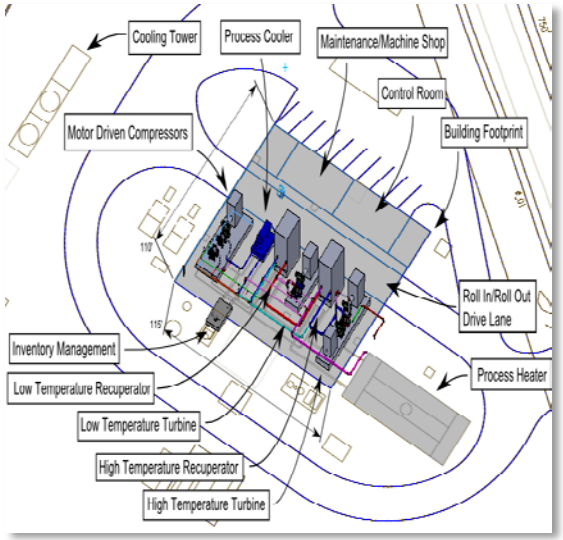
Traditional Combustion with Flame Front



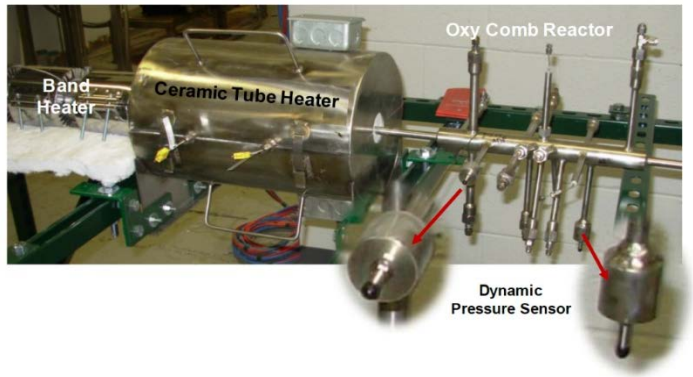
Flameless Pressurized Combustion

10 MW DOE STEP Pilot Plant Project

GTI, SwRI, and GE



High Inlet Temperature Combustor for Direct Fired Supercritical Oxy-Combustion
(SwRI, Thar for DOE NETL)



- Currently $100M+ in sCO_2 R&D projects
- 25 active sCO_2 related projects
- Topics include:
  - Component design and testing
  - Oxyfuel combustion
  - Cycle optimization
  - Pilot plants
  - Gas physical properties
- 1 MW Sunshot loop operational
- 10 MW STEP loop in design phase

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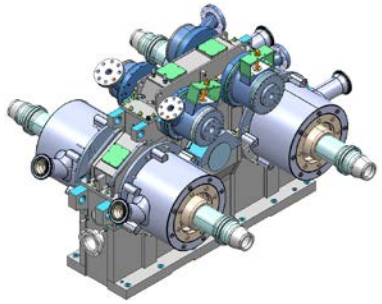
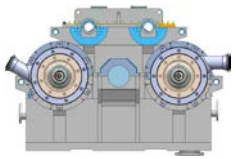
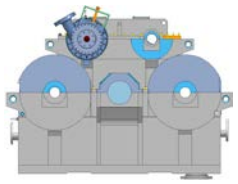
sCO_2 Compressor-Expander Configurations Offer Clean Energy Solutions

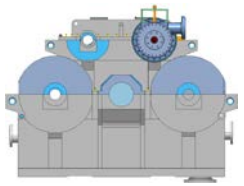




Integrally Geared Expander Configuration



Integrally Geared Compressor Configuration



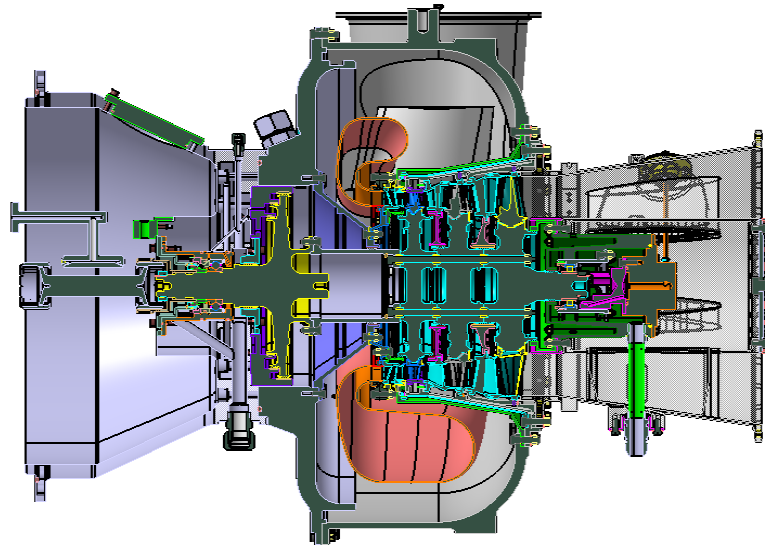
Integrally Geared Re-Compressor Configuration

Offers:
✓50% efficiency for CSP
✓WHR recovery options
✓ Flexibility
✓ zero emissions

Integrated Turbomachinery for:
Recompression Brayton Cycle,
Recuperated Cycle,
sCO_2 Expander Only,
sCO_2 Compressor Only,
sCO_2 Re-compressor only,

Allows:
Optimal stage rotational speeds
Variable flow control

Direct Fired Oxy-Combustion Gas Turbines offer Clean Efficient Power Potential



ThárEnergy

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Net Power

NET POWER'S VISION FOR SCO_2 BRAYTON CYCLES

NET Power's 50MWth sCO2 Demonstration Plant in La Porte, TX

Timeline:

- **Today:** 50MWth Demonstration Plant in startup and early testing
- **Late 2018:** Freeze commercial designs and secure an MOU/order for first 300MWe commercial scale plant
- **Mid-2021:** First commercial plant delivery

Using the natural gas-fired Allam Cycle, NET Power's goal is to:

- Achieve efficiencies and capital costs that are competitive with combined cycle…
- Enabling NET Power plants to compete head-to-head with incumbent technologies on sales of electricity alone…
- Which will mean that carbon dioxide can be captured at pipeline quality and pressure for no added cost.

By doing this, NET Power hopes to enable the world to meet all of its climate targets without having to pay more for electricity.

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Quoting Andrew Maxson of EPRI

EPRI thinks that sCO2 power cycles – both indirect and direct-fired – have potential as higher efficiency cycles.

These cycles still have to show their reliability and viability in the field and especially they must prove to be cost competitive.

Lower cost than any comparable steam-Rankine applications), preferably by a significant margin – at least 20% in terms of cost of electricity, if not more, to overcome the worries of risk of using a new system.

What Does This All Mean

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- Cost, Cost and Cost
- $/kW is the driver, and not just efficiency
- Competition
  - Small Scale
    - Diesel Gensets are $600-700/kW
    - Natural Gas Gensets are $700-$800/kW
  - Large Scale
    - Traditional Steam Rankine Cycle
- SCO2 system has to be in the $1000/kW range

- There is going to be competition from so many places
  - US, Europe, Korea, China, India, etc…

Recuperated Recompression Cycle

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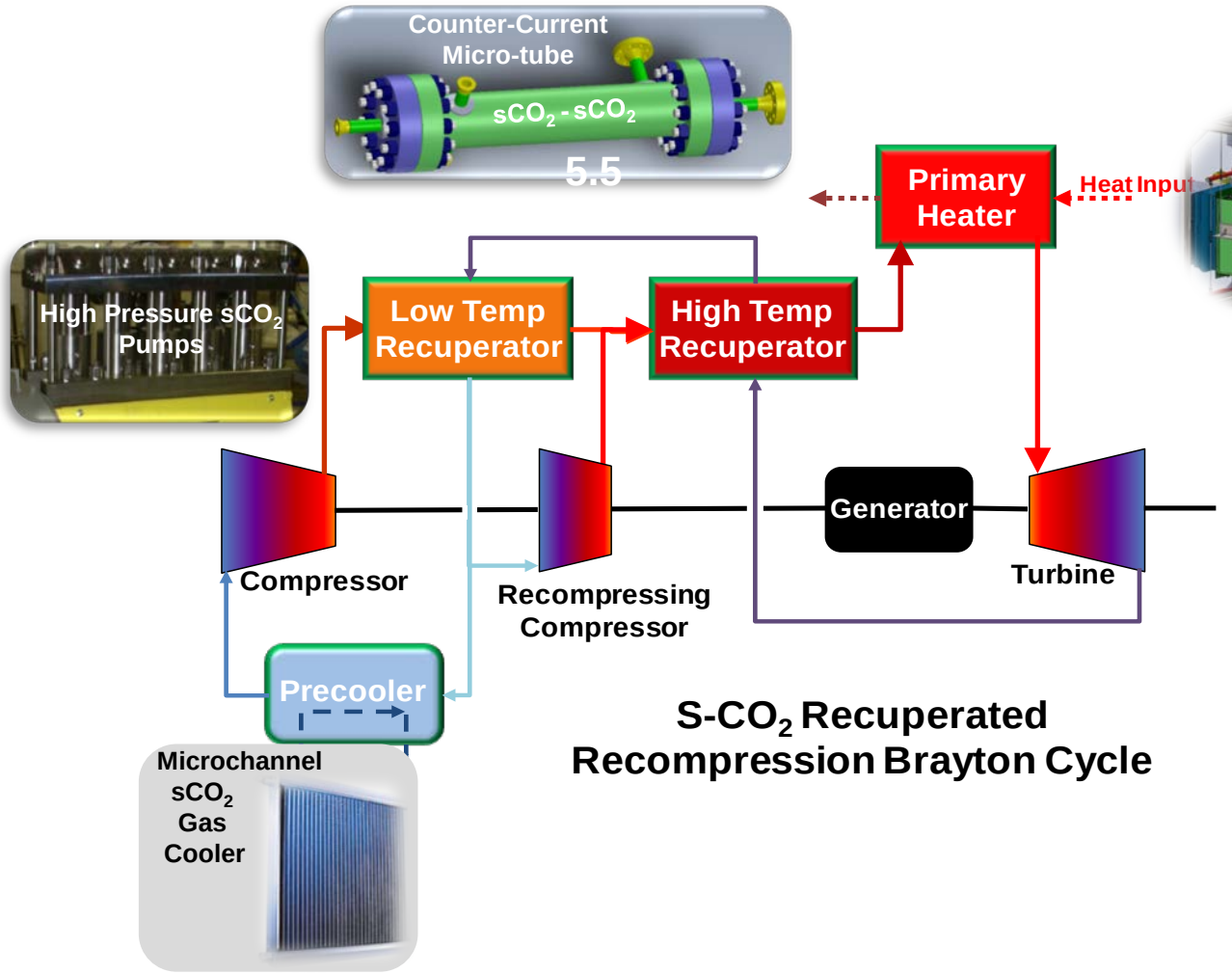
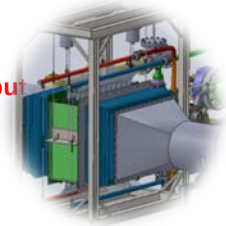


S-CO_2 Recuperated Recompression Brayton Cycle



Inconel 740H
Hot Air–sCO_2 HX

Major Components

- 2 Recuperators
- 1 Primary Heater
- 1 Condensor
- 2 Compressors
- 1 Expander

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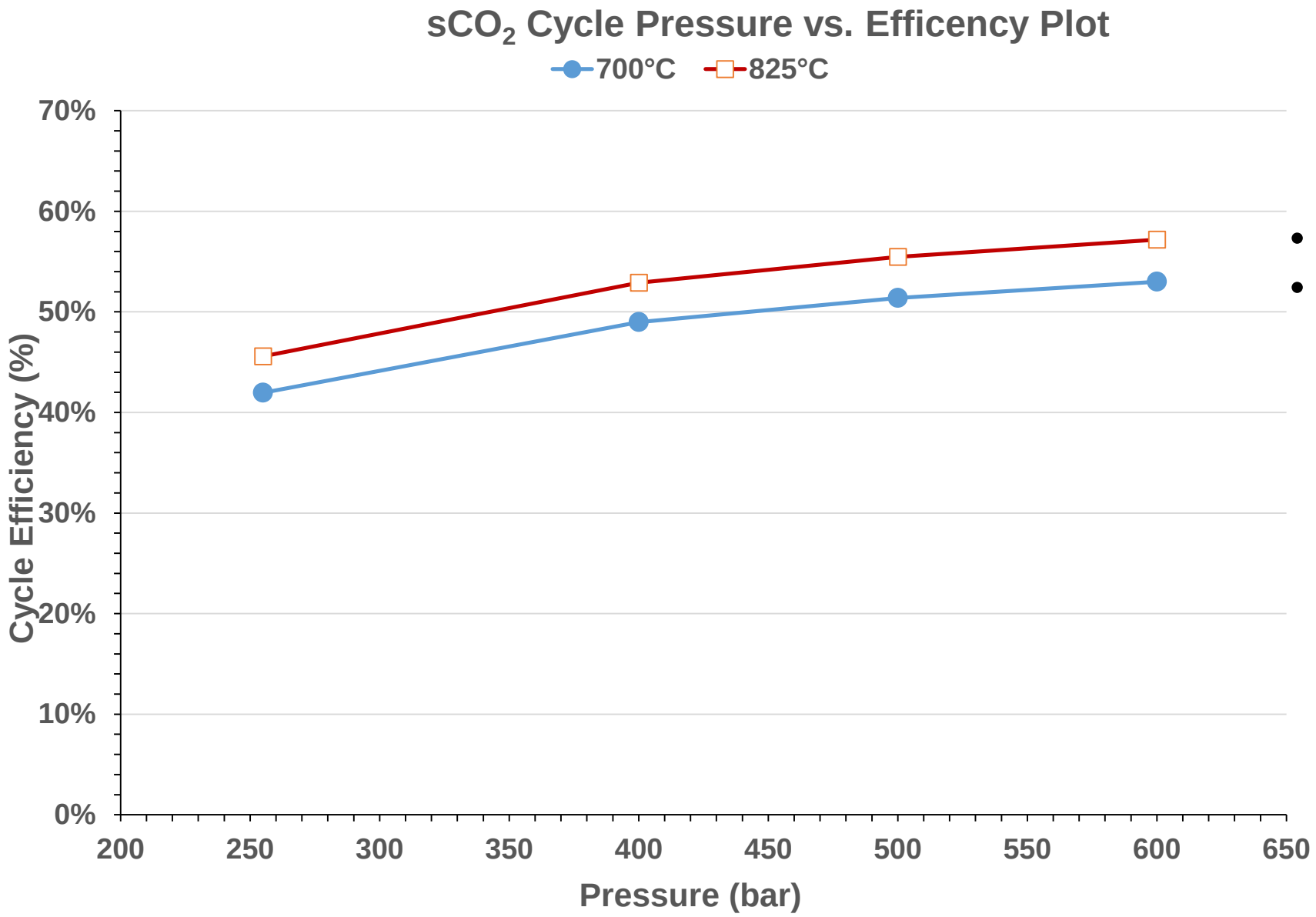
Optimization $/kW



- Small System < 5 MW
- Fabrication cost > material cost

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Major Components

	$/kWe	
Compressor	125	
Recompressor	75	
HTR	125	
LTR	50	
Cooler	25	
Heater	100	
Turbine	100	
Generator	50	
Tubing, valves, etc	75	
Controls	75	
Skid	25	
Labor, Overheads	75	
	900	

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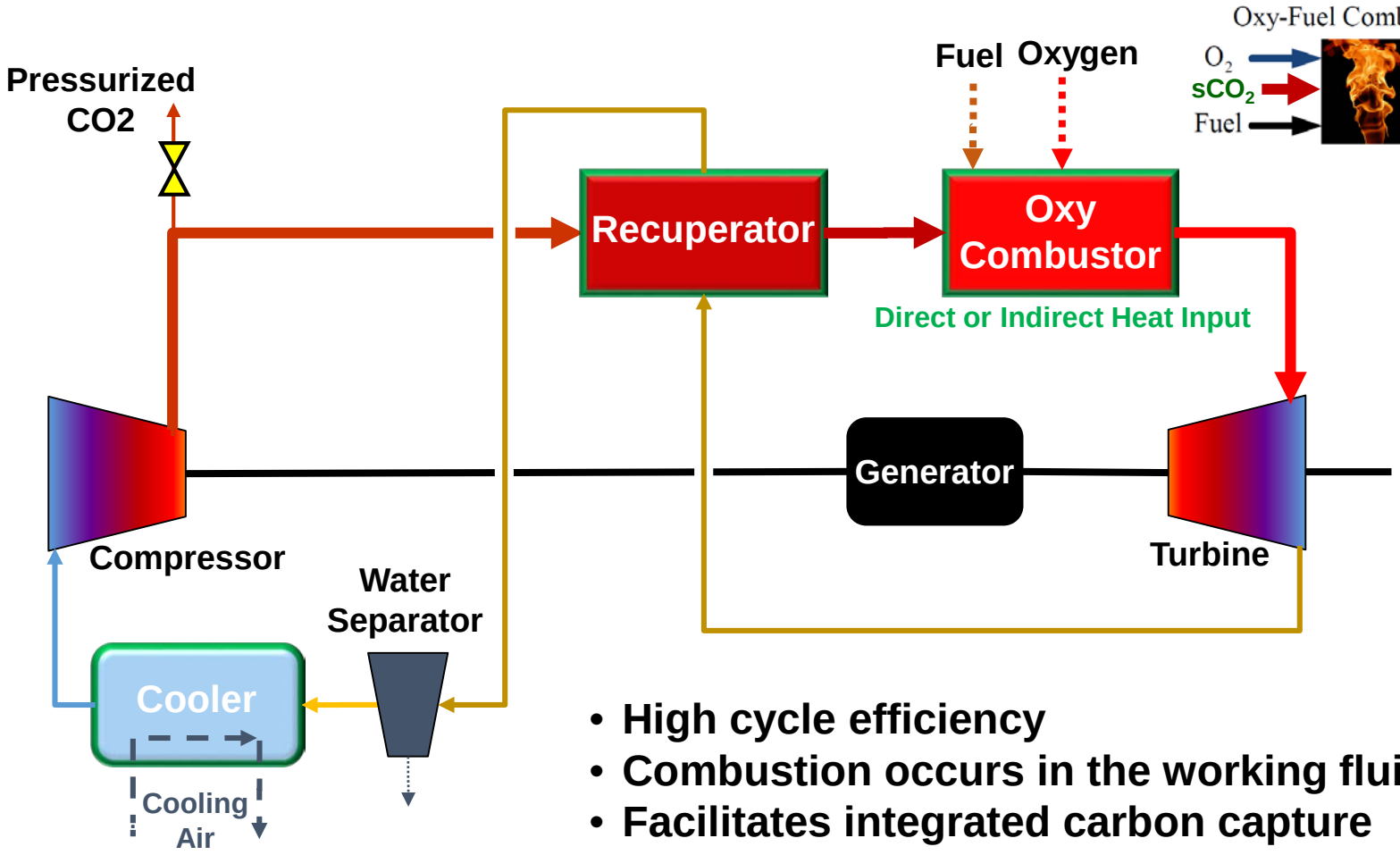
Multiple By-Products



- High cycle efficiency
- Combustion occurs in the working fluid
- Facilitates integrated carbon capture

- CO2 Uses
  - EOR
  - Industrial uses
  - Convert it into plastics

- **Allows for Higher Capital Costs**

Conclusion

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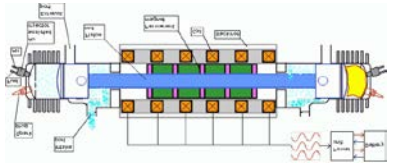
Multi-Tens of Billions Market Opportunity
Only way to achieve it: Drive down Cost $/kW

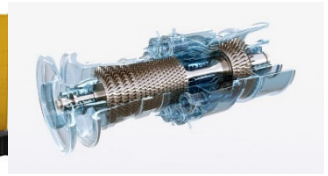
Natural Gas Portable Genset
1-5 kW



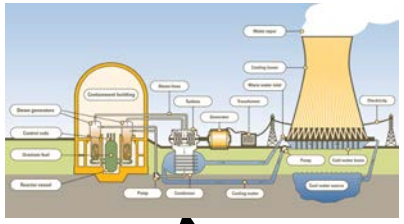
Solar Thermal Power
10-200 kW

Natural Gas Genset
500-5000 kW

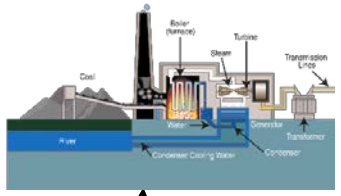
Waste Heat Recovery Airplane
500-2000kW



Nuclear Power Plant
50-200 MW



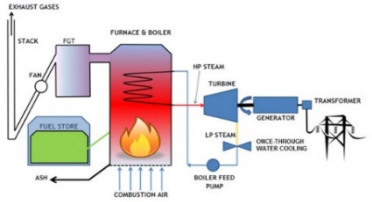
Coal Power Plant
100-500 MW



1 kW

500 MW

Natural Gas Genset
10-200 kW



Biomass Thermal Power
10-5000 kW

Waste Heat Recovery
Gas Turbines
Cement Plants
Steel Plants
Ships
1-25 MW

Natural Gas Power Plant
50-500 MW

Oxy Combustion
200-500 MW

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Mt. Washington
Duquesne Incline

Phipps Conservatory
Carnegie Museum

PNC Park
Heinz Field

Lalit Chordia, Ph.D
Thar

Nature and Parks
Museums
Universities
Churches

Hippest localities in the country
E. Liberty and Lawrenceville

Our 75,000 Sq. Ft Facility in Pittsburgh