



Phased Approach to High Temperature CO₂ Power Cycle Pilot Test Facility

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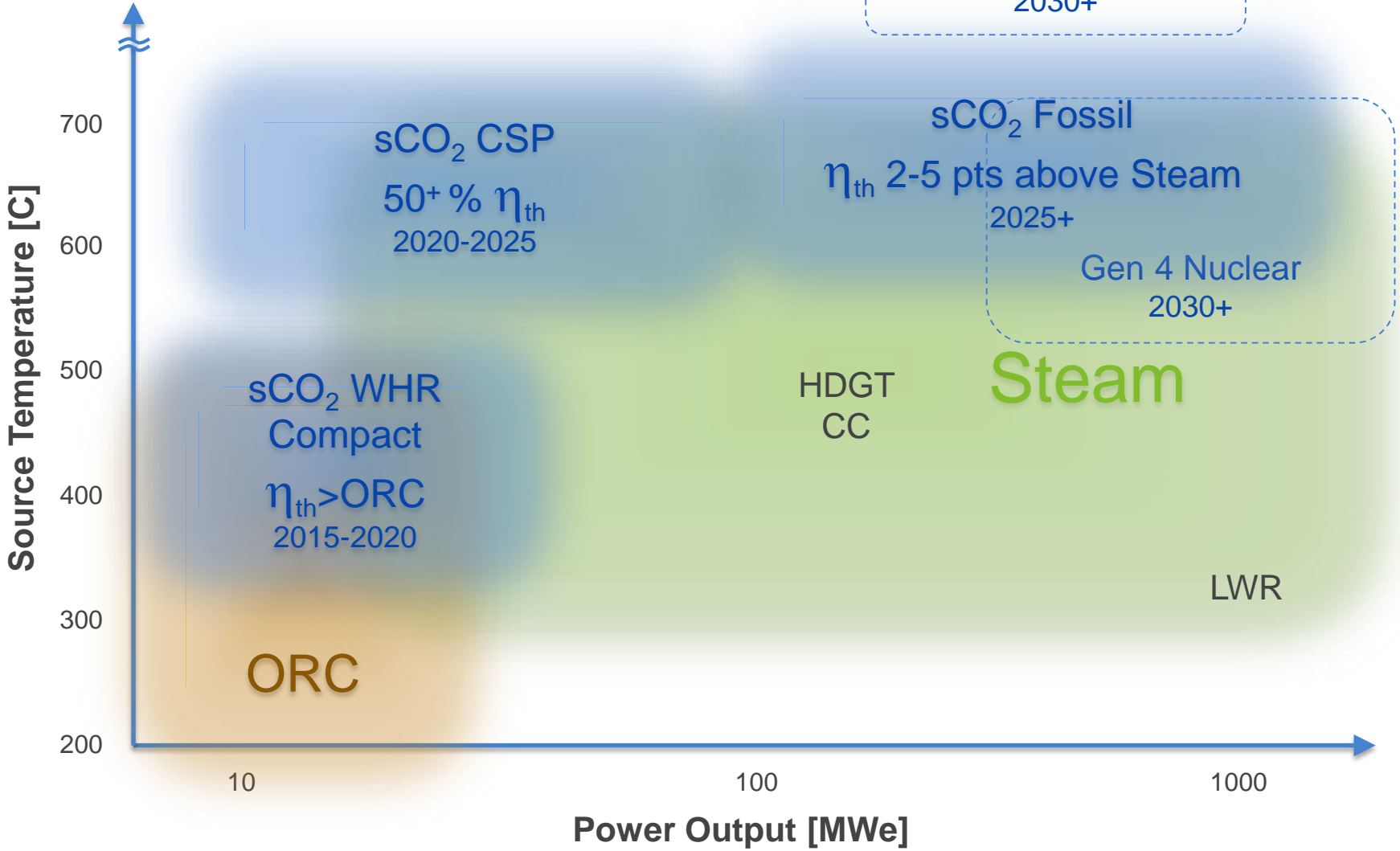


10 MWe Class Turbine
Developed by GE/SwRI
Under DOE SunShot
program

Imagination at work.

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sCO₂ Application Space



Technology Readiness and Gaps @ 550C

	Turbine		Compressor		Recuperator		Primary HX		System	
	Pilot	Demo	Pilot	Demo	Pilot	Demo	Pilot	Demo	Pilot	Demo
Overall										
Design Tools										
Materials										
Components										
Supply Chain										
Modeling										

Technology Gaps

Long term materials data in CO₂
 Codes & Standards
 Erosion resistance
 Advanced seals
 Off-design/transient modeling
 Hermetic turbo-alternator

Designs for operation near CO₂ critical pt
 Advanced seals
 Internal bearings
 Off-design/transient modeling
 Hermetic turbo-compressor

Diversified vendor base – capacity/cost
 Technologies to reduce cost
 Off-design/transient modeling

Long term materials data in CO₂
 Codes & Standards
 Erosion resistance
 Off-design/transient modeling

Long term materials data in CO₂
 Codes & Standards
 Transient operability including upsets
 System modeling transient/off-design
 Starting systems
 Leakage gas recompression



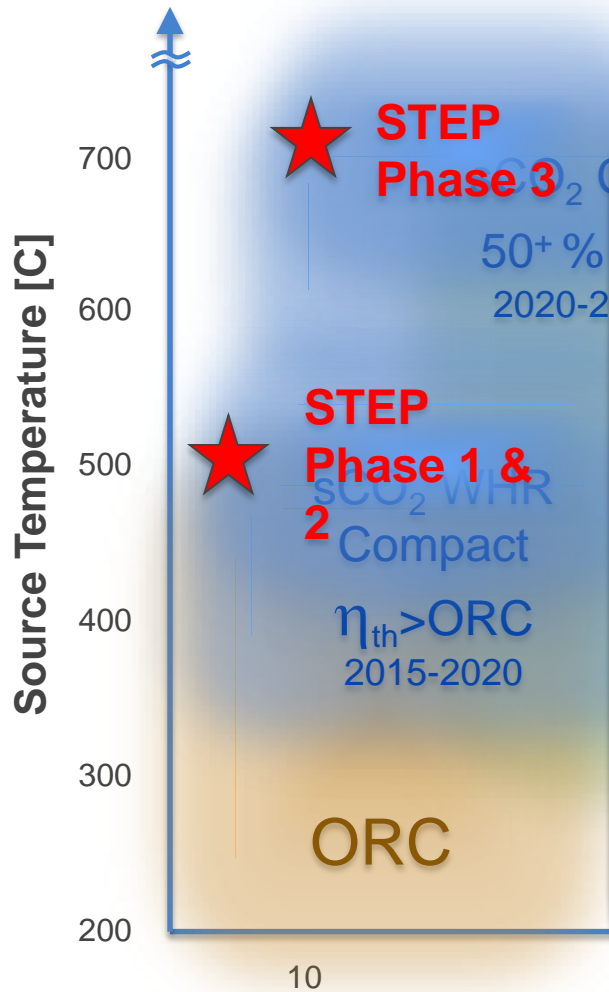
Technology Readiness and Gaps @ 700+C

	Turbine		Compressor		Recuperator		Primary HX		System	
	Pilot	Demo	Pilot	Demo	Pilot	Demo	Pilot	Demo	Pilot	Demo
550 C										
700 C										
Additional 700 C Technology Gaps	Long term superalloy materials data in CO ₂		Operation and control of parallel compressors for recompression cycle		Long term materials data in CO ₂		Long term superalloy materials data in CO ₂		Long term superalloy materials data in CO ₂	
	Codes & Standards				Diversified vendor base – capacity/cost		Codes & Standards		Codes & Standards	
	Thermal management						Furnace designs for low ΔT of primary fluid (air side recuperation)		Transient operability including upsets for complex recompression cycles	
	High temperature seals and bearings						Materials availability			

Technology readiness sufficient for development of 550 C prototype
 Challenges for all components at 700 C – paced by primary HX
 Additional data and experience needed to enable commercialization



sCO₂ Application Space



Direct Fired sCO₂

STEP Facility

Specific Goals:

1. Steady state and transient operation of complex cycles with automatic control logic
2. Demonstrate SOA component performance in a configuration scalable to > 50 MW
3. Path to power block thermal efficiency > 50% for high temperature recompression cycle

Phase 1 & 2– Low Temperature WHR

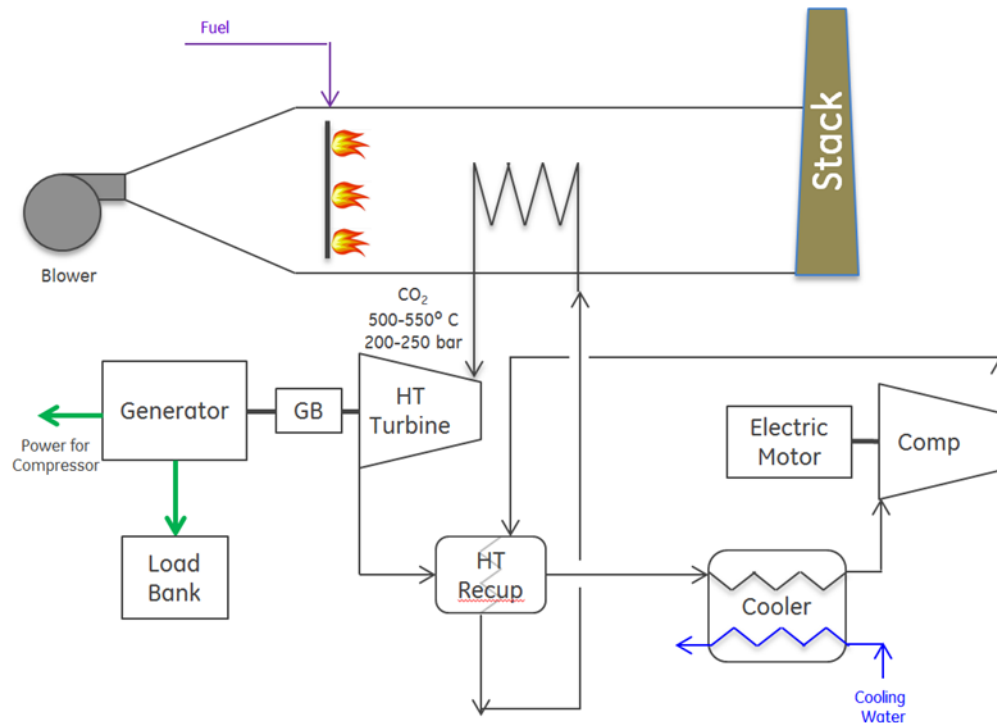
- Fast Implementation
- Operability and Controls
- Component Performance

Phase 3 – High Temperature Recompression

- Build on Phase 1 & 2 learning
- Demonstrate component and cycle efficiency at/above current SOA



STEP Facility – Phase 1

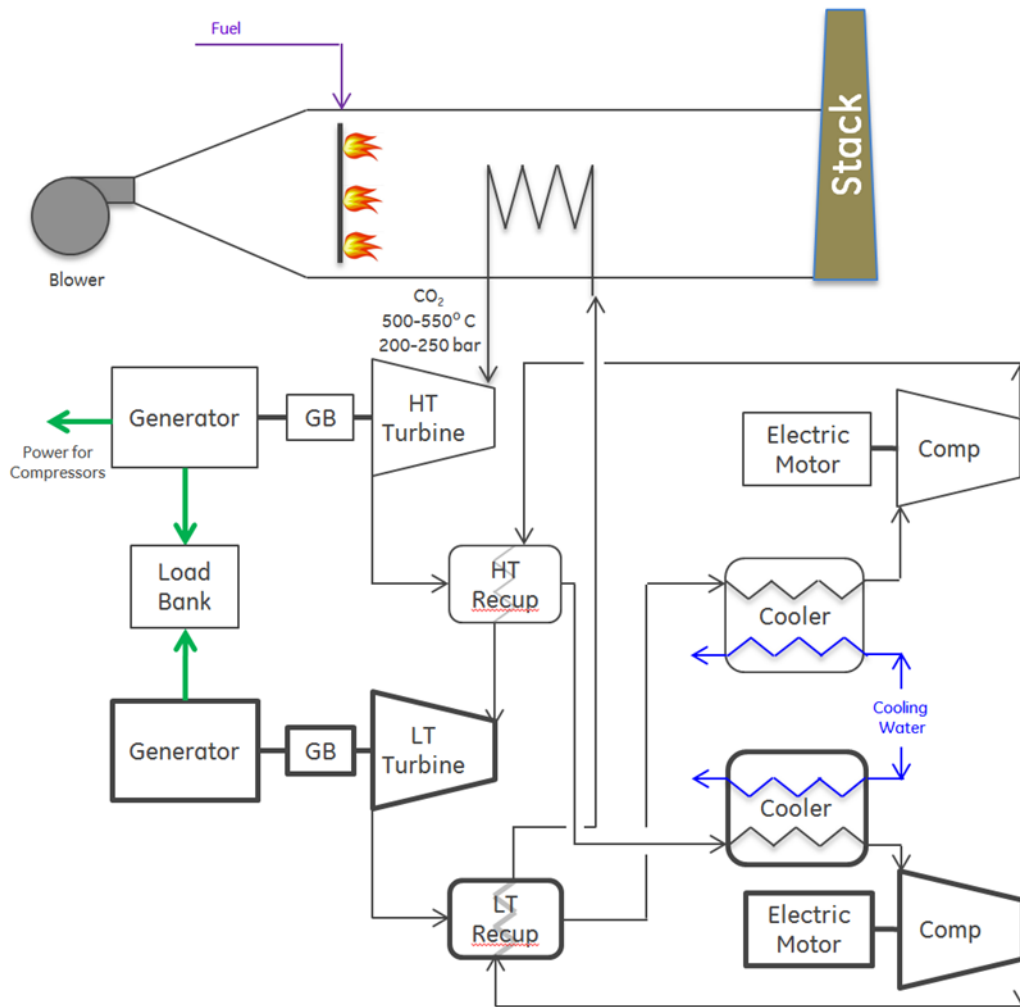


Simple Cycle

- Shortest time to initial data
- Controls & Safety
- Component performance
- Steady & Transient cycle data



STEP Facility – Phase 2



Cascaded Cycle

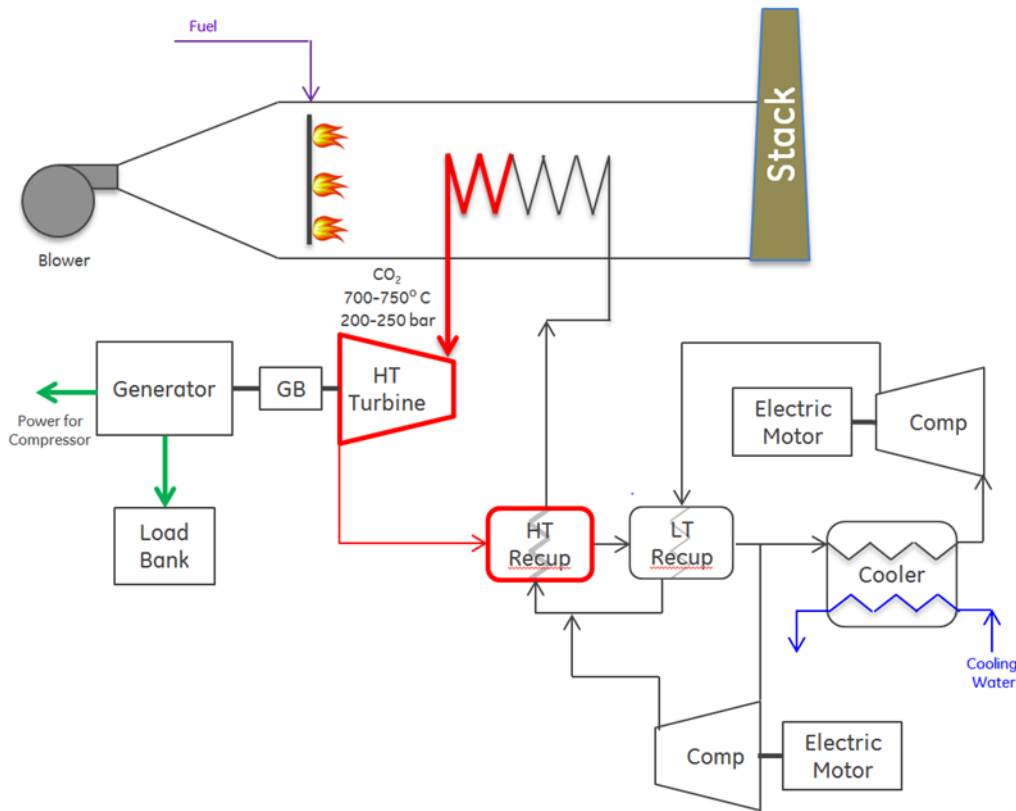
- Shortest time to initial data
- Controls & Safety
- Component performance
- Steady & Transient cycle data

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- **Complex cycle**
- **Dual compressor control**
- **Dual turbine control**
- **Compressor operability**
- **Inventory management**
- **Starting transients**



STEP Facility – Phase 3



Recompression Cycle

- Shortest time to initial data
- Controls & Safety
- Component performance
- Steady & Transient cycle data

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- Complex cycle
- Dual compressor control
- Dual turbine control
- Compressor operability
- Inventory management
- Starting transients

+

- **Highly complex cycle**
- **Parallel compressor control**
- **SOA component efficiencies**
- **Cycle efficiency > 50%**



STEP Facility – Component Reuse

<u>Component</u>	<u>Design Basis</u>	<u>Phase 1</u>	<u>Phase 2</u>	<u>Phase 3</u>
High Temperature Turbine	SunShot	○	○	●
Main Compressor	Apollo	○	○	●
Bypass Compressor	GE Product Line			●
Re-bladed Bypass Compressor	Apollo/GE Prod Line		●	
Low Temperature Turbine	SunShot		●	
Primary Heater	Vendor	○	○	●
High Temperature Recuperator	Vendor	○	○	●
Low Temperature Recuperator	Vendor	○	○	●
Heat Rejection Cooler	Vendor	○	○	●

● = Optimized
○ = Re-used off design

All components optimized for Phase 3 conditions

Minimal additional hardware → LT Turbine + re-bladed compressor



Summary

GE believes there is a market for sCO₂ power cycles in WHR applications.

Market for high temperature, high efficiency cycles will be paced by primary heat exchanger and heat source demand.

Technology exists for development of a pilot at 550C. Testing of cascaded cycle will enable commercialization to gain long-duration experience.

Higher temperature pilot paced by availability of high temperature materials for primary heater and valves.

Phased approach meets multiple objectives with single test facility. Allows for risk retirements with simpler cycles at lower cost.



