Phased Approach to High Temperature CO_2 Power Cycle Pilot Test Facility

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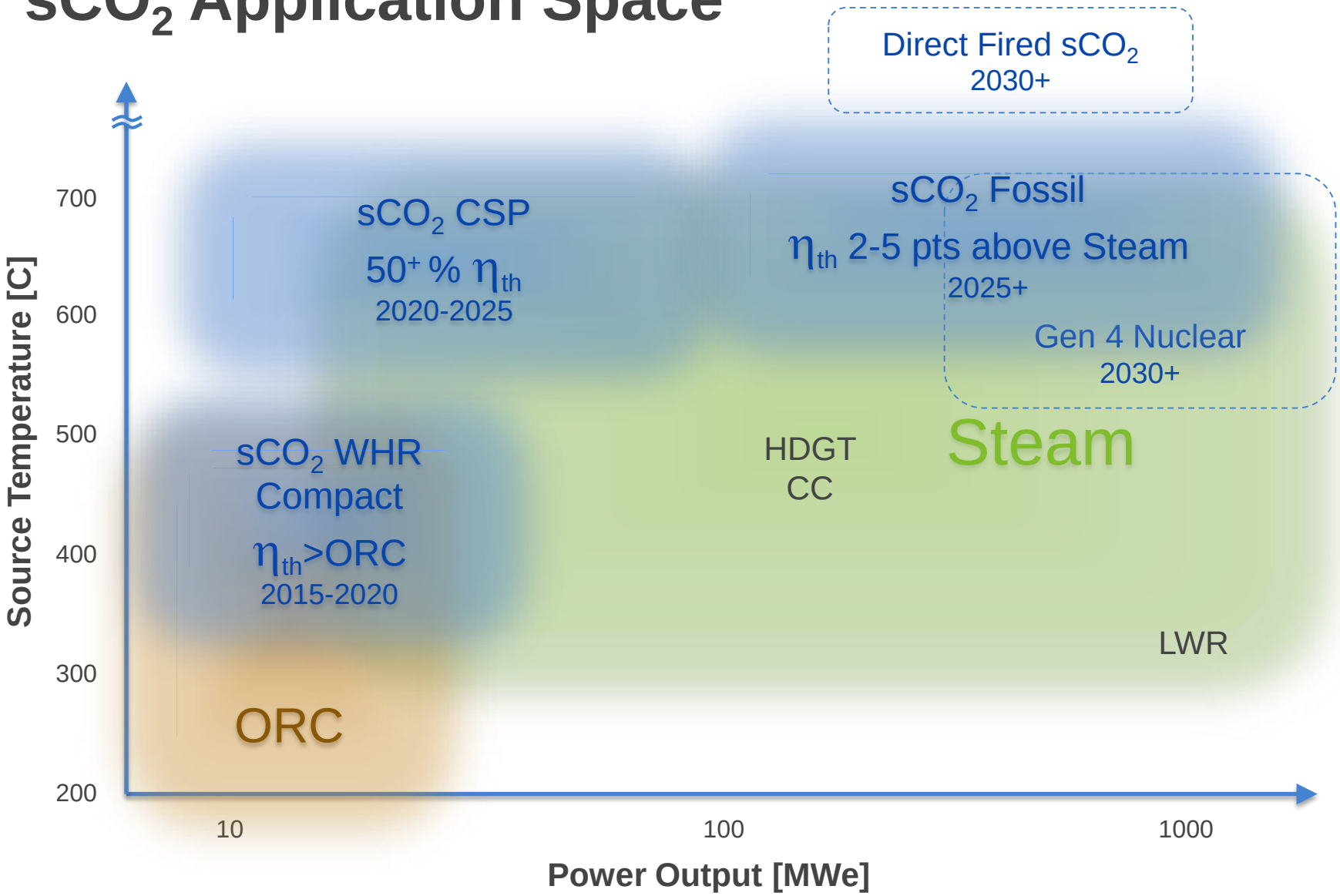
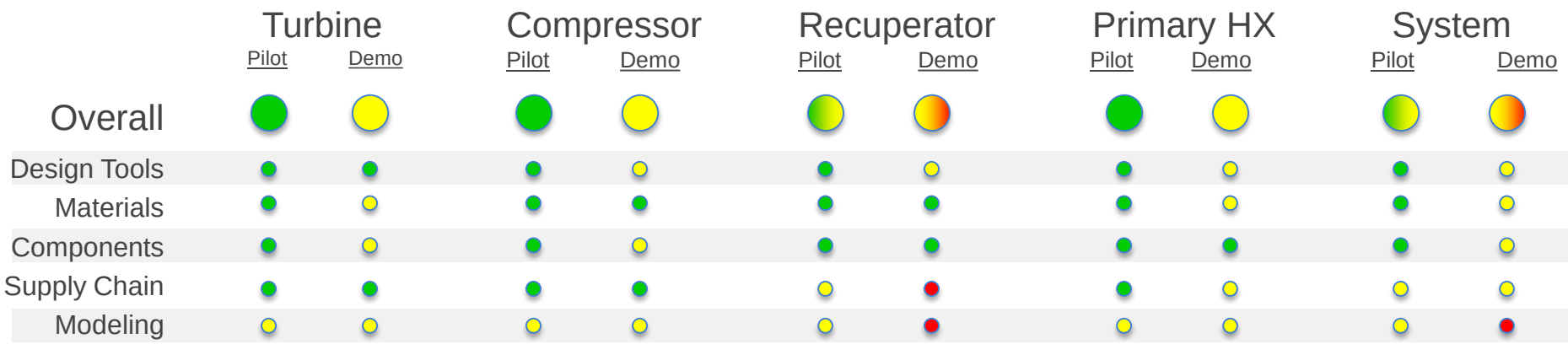
10 MWe Class Turbine Developed by GE/SwRI Under DOE SunShot program

Imagination at work.

sCO_2 Application Space



Technology Readiness and Gaps @ 550C



Technology Gaps

Turbine

- Long term materials data in CO_2
- Codes & Standards
- Erosion resistance
- Advanced seals
- Off-design/transient modeling
- Hermetic turbo-alternator

Compressor

- Designs for operation near CO_2 critical pt
- Advanced seals
- Internal bearings
- Off-design/transient modeling
- Hermetic turbo-compressor

Recuperator

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

Primary HX

- Long term materials data in CO_2
- Codes & Standards
- Erosion resistance
- Off-design/transient modeling

System

- Long term materials data in CO_2
- Codes & Standards
- Transient operability including upsets
- System modeling transient/off-design
- Starting systems
- Leakage gas recompression

Technology Readiness and Gaps @ 700+C

Additional 700 C Technology Gaps

Turbine

- Long term superalloy materials data in CO_2
- Codes & Standards
- Thermal management
- High temperature seals and bearings

Compressor

- Operation and control of parallel compressors for recompression cycle

Recuperator

- Long term materials data in CO_2
- Diversified vendor base – capacity/cost

Primary HX

- Long term superalloy materials data in CO_2
- Codes & Standards
- Furnace designs for low ΔT of primary fluid (air side recuperation)
- Materials availability

System

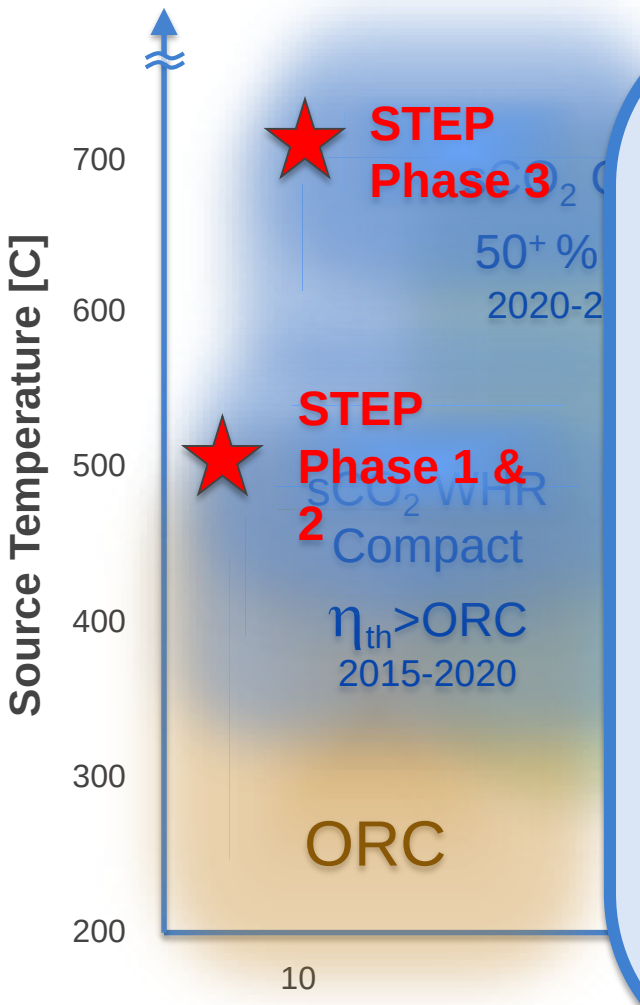
- Long term superalloy materials data in CO_2
- Codes & Standards
- Transient operability including upsets for complex recompression cycles

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

sCO_2 Application Space



Direct Fired sCO_2

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

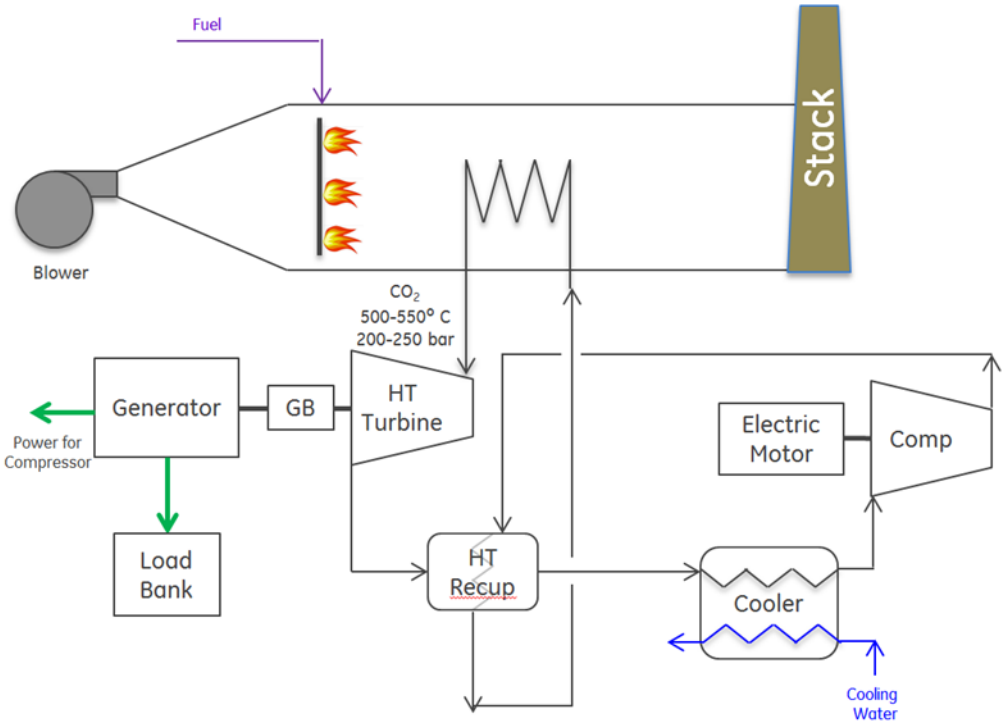
Phase 1 & 2– Low Temperature WHR

- 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

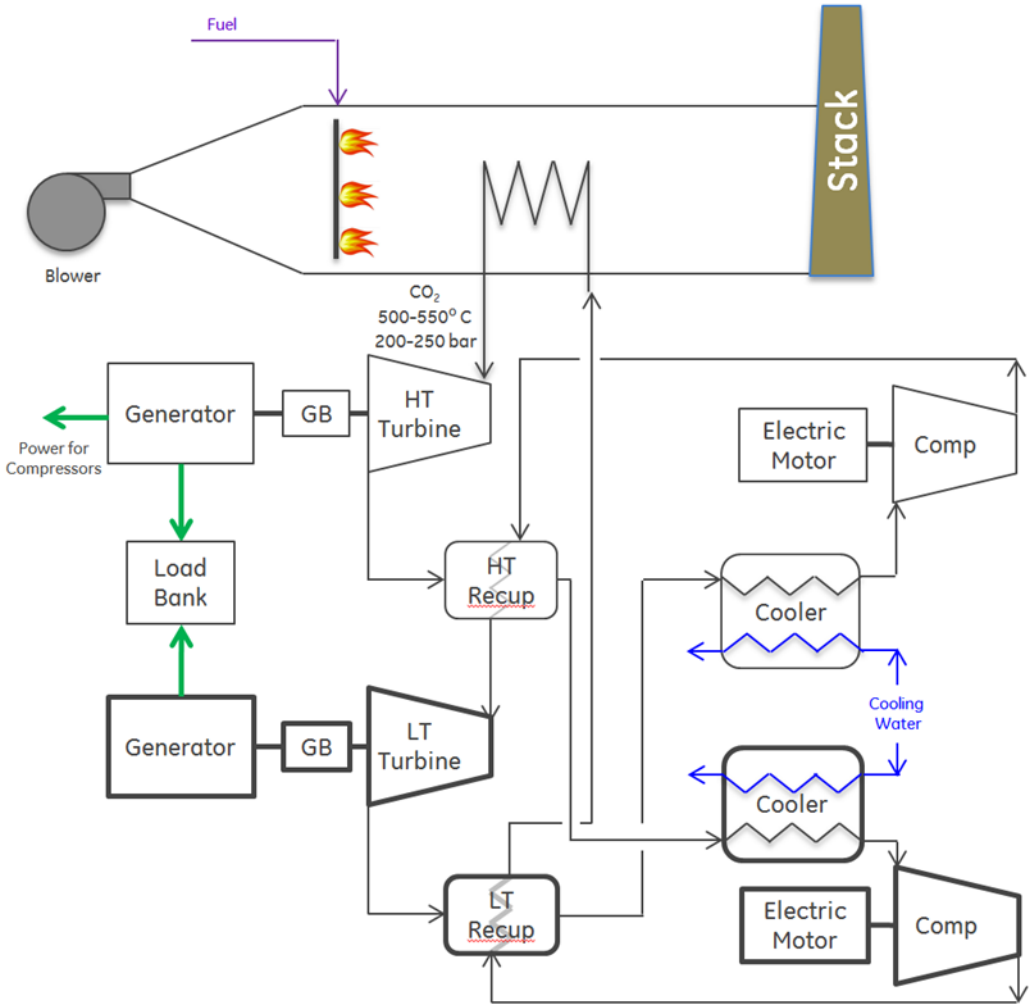
STEP Facility – Phase 1



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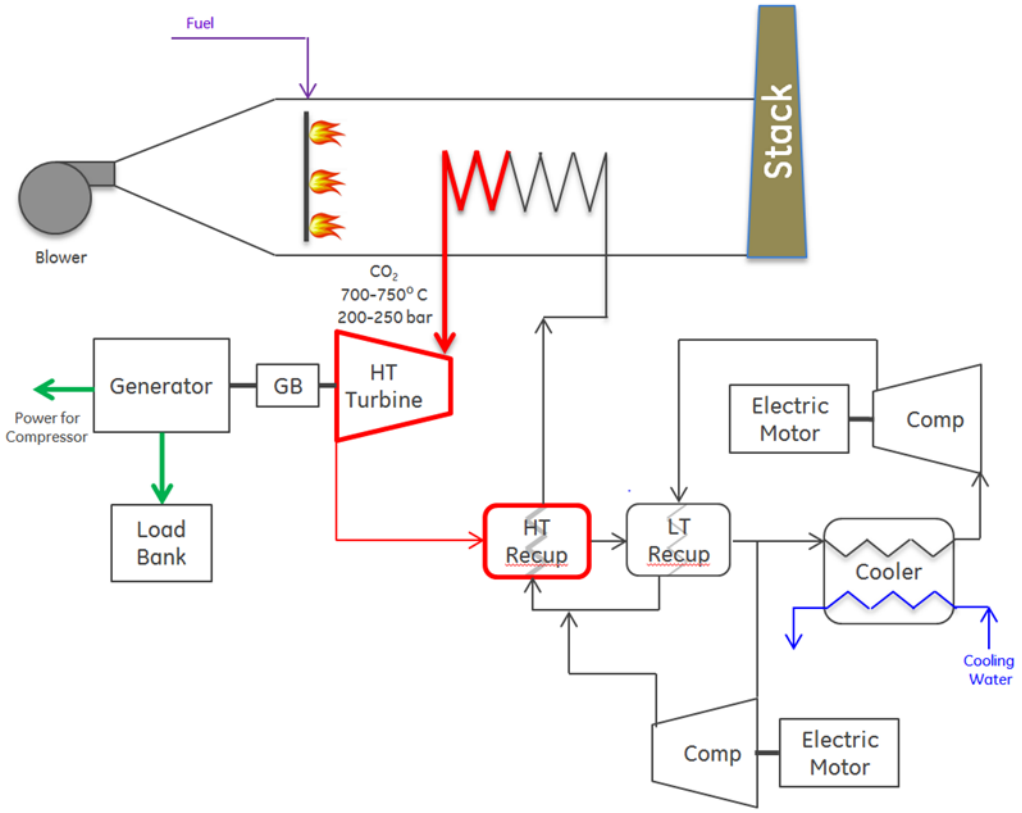
- **Complex cycle**
- **Dual compressor control**
- **Dual turbine control**
- **Compressor operability**
- **Inventory management**
- **Starting transients**

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

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

STEP Facility – Component Reuse

Component	Design Basis	Phase 1	Phase 2	Phase 3
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.