Development of an experimental s-CO2 loop for bottoming cycle applications

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1st European Seminar on Supercritical CO2 (sCO2) Power Systems

28 to 30 September 2016, Vienna, Austria

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Development of an experimental s-CO_2 loop for bottoming cycle applications

- Introduction
  - Review of the project
  - Aim and objectives
  - S-CO_2 waste heat recovery system
- Rig test development
  - Expected outcomes of this research
  - Risks identified
  - Proposed configurations
  - Rig test definition & design vector
- Summary of progress
- Next steps
  - Roadmap

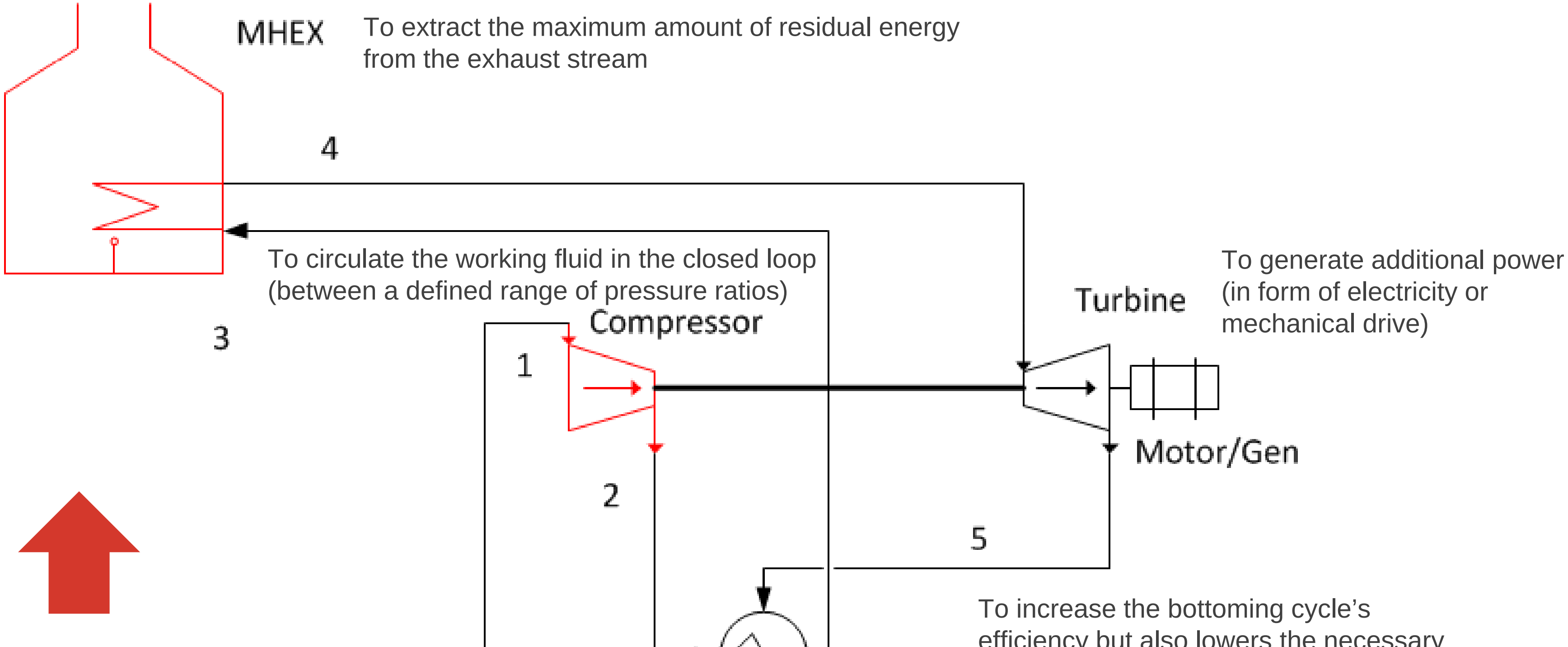
Aim of the project

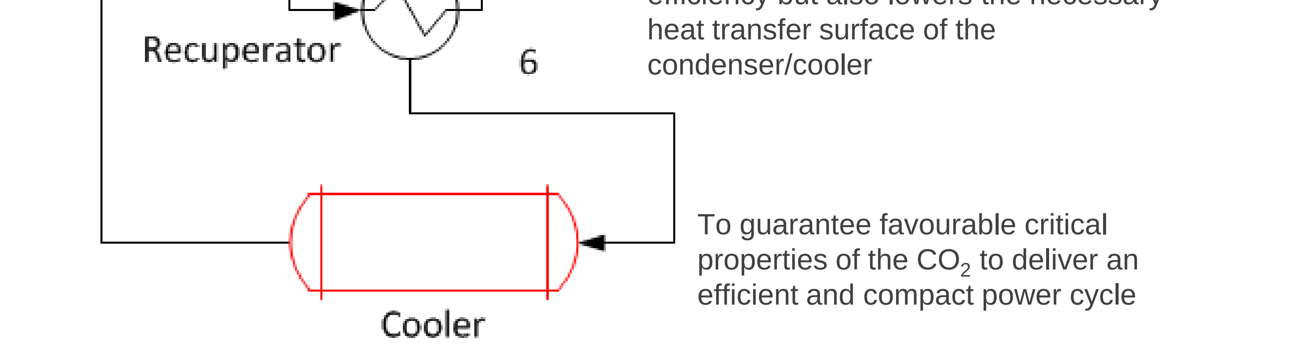
Design, build and commission a closed loop s-CO_2 system to enable critical component testing and whole cycle demonstration of a representative waste heat recovery system

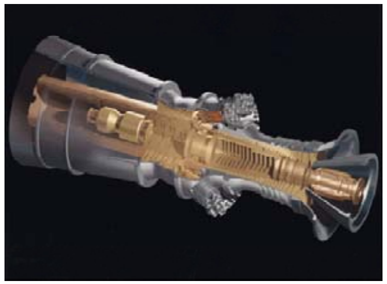
Objectives

- Develop tools for the design of s-CO_2 power cycles for waste heat recovery
- De-risk a proof-of-the-concept
- Identify critical components and key requirements for rig testing
- Design & commission a s-CO_2 closed loop test facility

$S\text{-}CO_2$ Waste heat recovery system





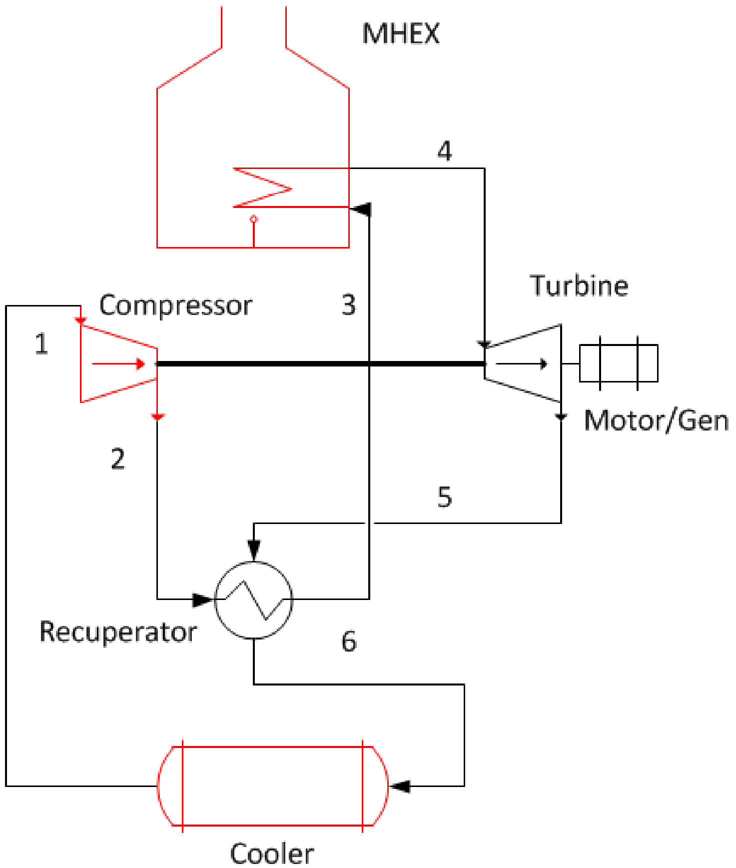


http://www.netl.doe.gov/scng/projects/end-use/at/images/at31176

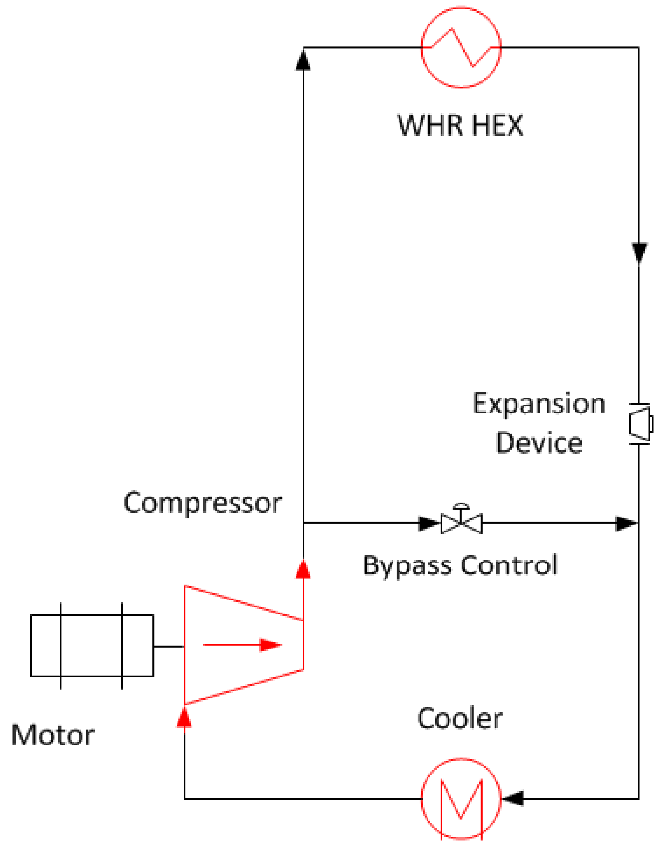
Expected outcomes of this research

- Component validation (TRL 4)
  - Waste heat recovery system (main heat exchanger)
  - Supervision and control system
  - Compressor characterisation
- Feasibility evaluation of the concept (TRL 3)
- Development of analytical models to predict (TRL 3)
  - Part load performance
  - Transient response

Rig test development



Simple Recuperated Brayton



Scaled components rig test

Risks identified through rig test development

Precise instrumentation required

Accurate time response for off-design / transient

Novel component

High shaft speeds

High pressure and density (sealing, bearings, windage)

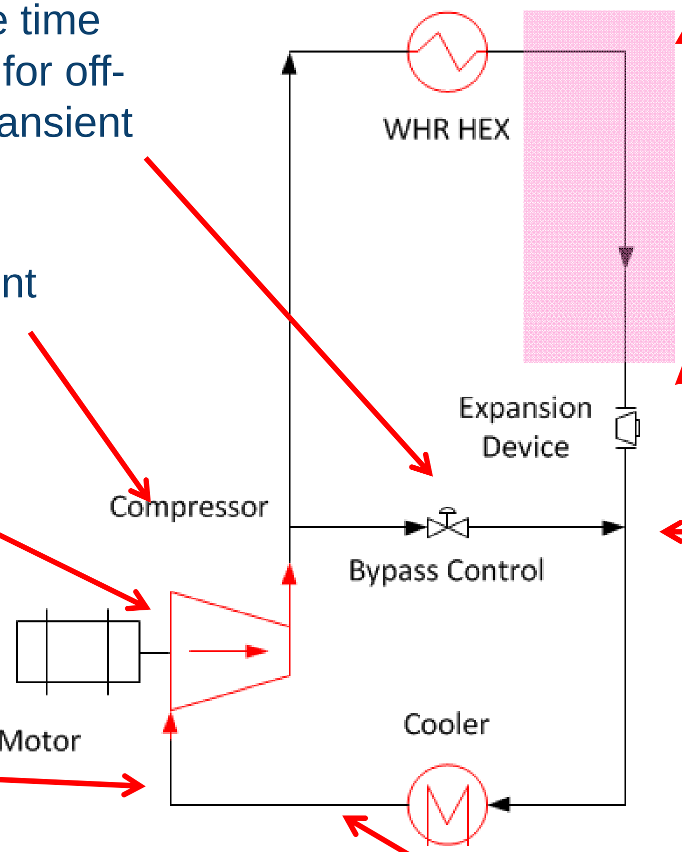
Novel component

High pressure and temperature (material selection)

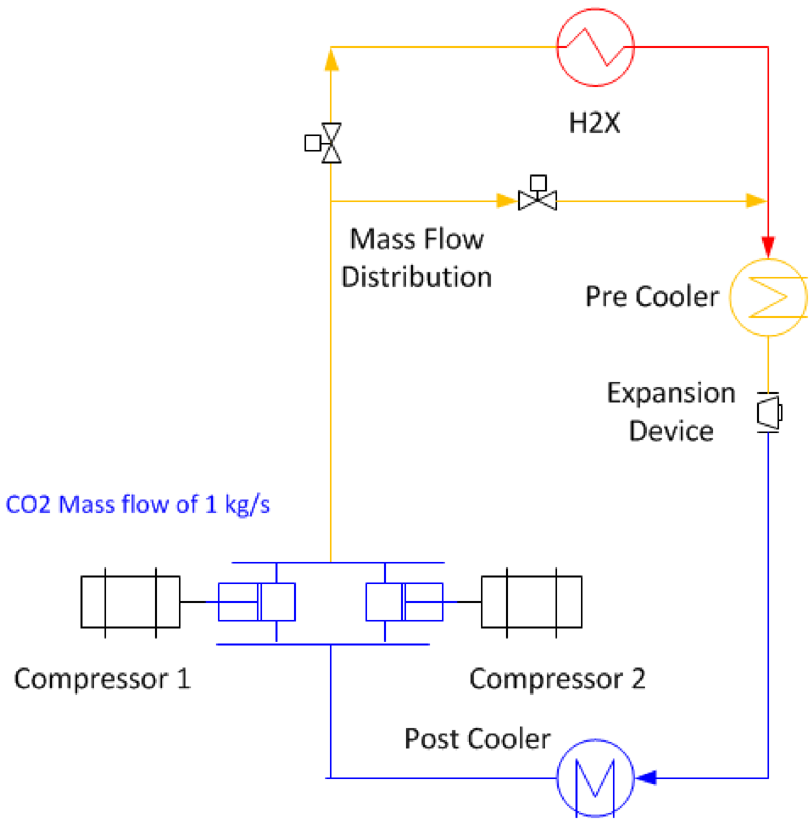
Limited supplier options

Mixing streams should be monitored

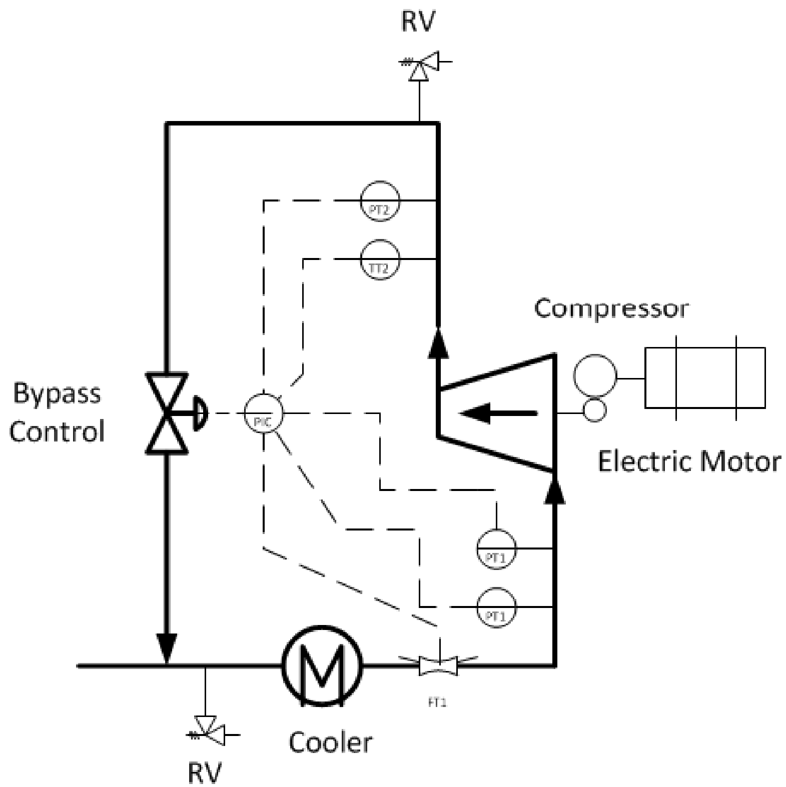
Refined control to guarantee supercritical flow



Schematic of the envisaged s-CO_2 rig test



Scaled components rig test (Stage 1+)

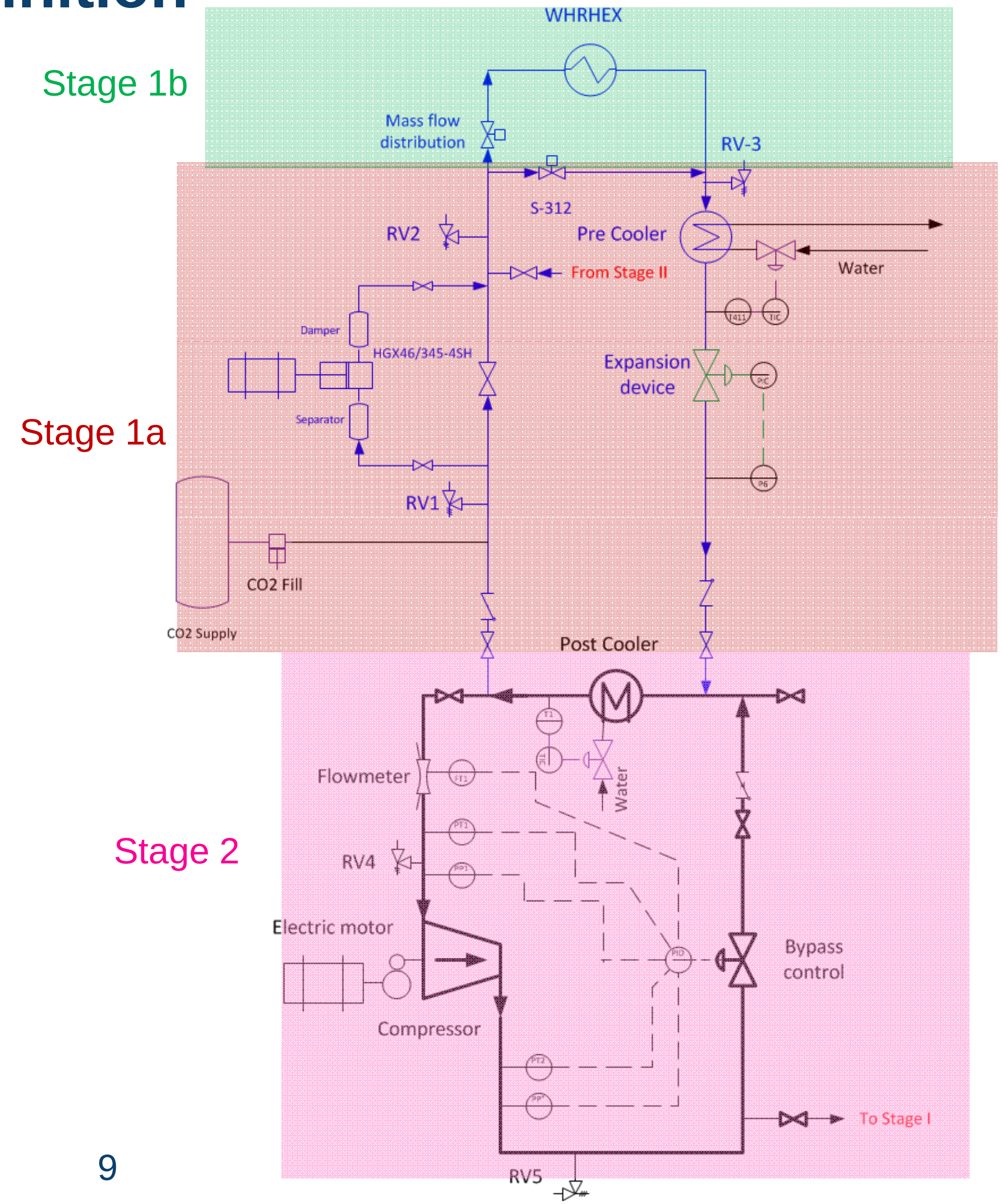


Scaled components rig test (Stage 2)

$s\text{-}CO_2$ Rig test definition

This interface allows:

- Independent testing of each major equipment
- Progressive investment on sophisticated measurement techniques
- Lessons learned from Stage 1+ → Stage 2
- De-risk future component testing
- Identify technology limitations
- Stand-alone development of sub-systems:
  - Cooling tower
  - Electric supply
  - Combustor
  - Gearbox train and lube
  - Scavenging system
- Split control system development
- Define third party support



s-CO_2 Rig test: Proposed design vector

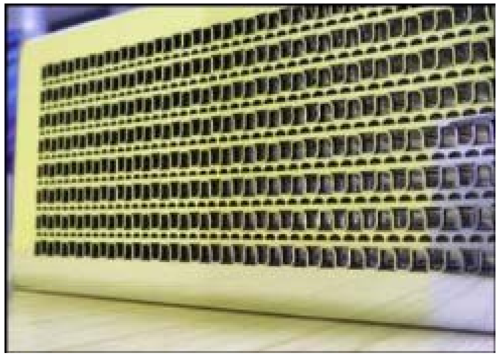
Parameter	Stages: 1a & 1b	Stage 2
Overall Pressure Ratio	2.66	1.95
Top pressure [MPa]	12	15
Top temperature [K]	450 / 820	820
Bottom pressure [MPa]	4.5	7.7
Bottom temperature [K]	> 284	NA
Inlet compressor [K]	294	305
CO_2 cycle mass flow [kg/s]	1	5
CO_2 to MHEX [kg/s]	0.3	

- Ambient Temperature: 288 [K]
- Air mass flow < 2 [kg/s]
- Water mass flow < 16 [kg/s]
- Polytropic efficiency: 70%
- Max temperature for returning cooling tower 310 [K]
- Max temperature before expansion 370 [K]
- Pinch point heat exchangers: 5 [K]

Summary of progress

- Modelling of cycles at design point well developed
  - Analytical tools have been tuned and validated
- Development of transient models of rig test stage 1a well advanced
- Rig test baseline layout in final stages
- Tuning of tools for centrifugal compressor design in progress
  - First prototype of centrifugal compressor completed
- Rig component costing exercise complete for key components

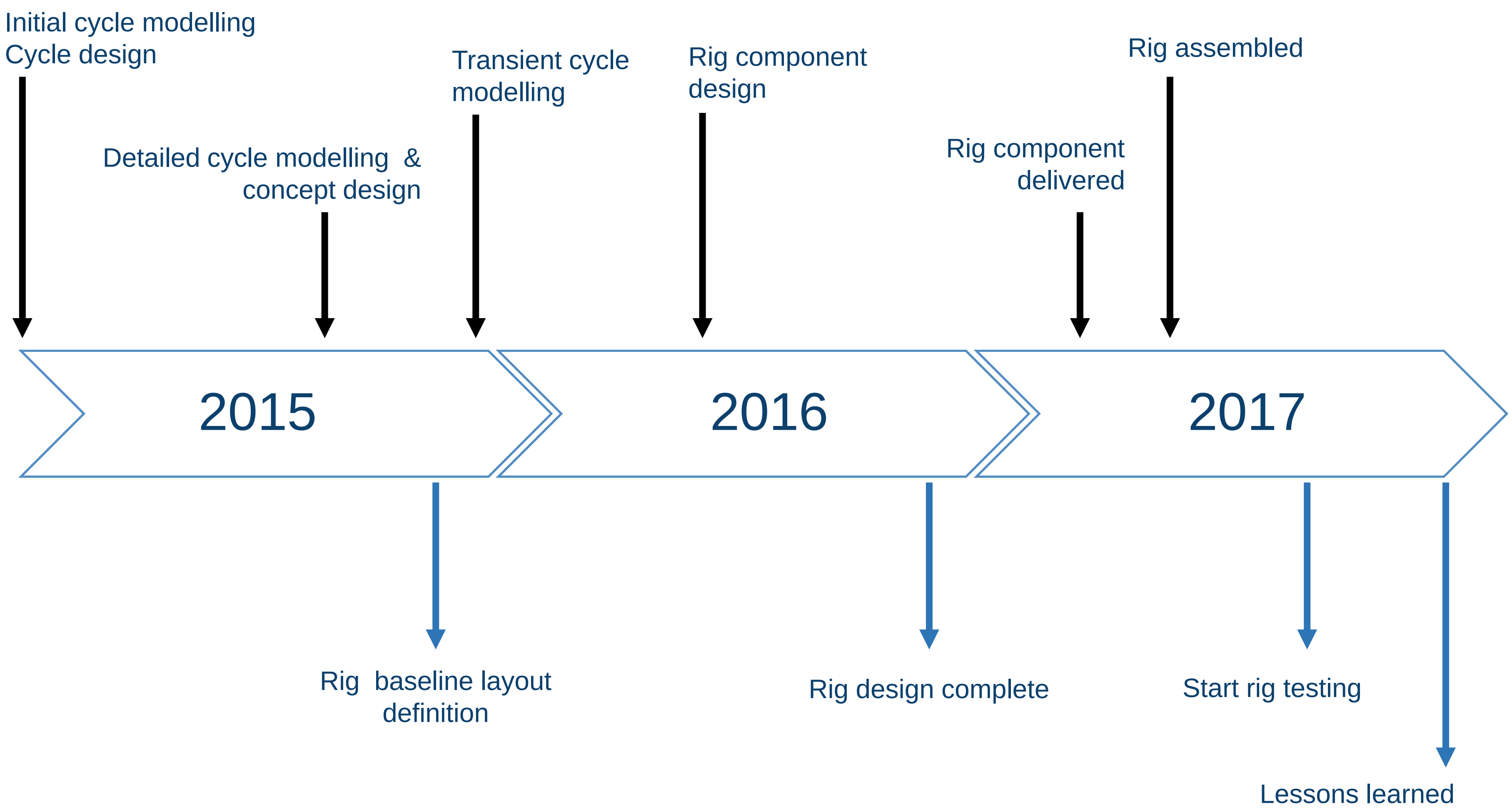
Preliminary compressor (stage 2) mechanical design study completed



Test of medium scale main heat exchanger completed

Le Pierres, R. *et. al*. “Impact of mechanical design issues on PCHE”, 2011

Next steps


Initial cycle modelling
Cycle design
Detailed cycle modelling & concept design
Transient cycle modelling
Rig component design
Rig component delivered
Rig assembled
2015
2016
2017
Rig baseline layout definition
Rig design complete
Start rig testing
Lessons learned

Roadmap of the rig test development

Stage	Components	Outcomes
1a	Circulation compressor, expansion valve, pre cooler	- De-risk SCO_2 loop. - Demonstrate component/rig robustness and proof of concept. - Demonstrate pressure and temperature acquisition data at supercritical state.
1b	MHEX, combustor, pre and post cooler, circulation compressor, expansion valve	- Test MHEX performance. - Demonstrate pressure and temperature control cooling system.
2	Stage 1 + centrifugal compressor, expansion valve	- De-risk compressor installation. - Demonstrate pressure and temperature control at supercritical state. - Demonstrate compressor performance at representative PR. - Demonstrate representative uncoupled rig control.
3	Stage 1 + centrifugal compressor, turbine - uncoupled	- De-risk turbine installation. - Demonstrate uncoupled design point performance and control. - Demonstrate part load/transient
4	Stage 1 + centrifugal compressor, turbine - coupled	- Demonstrate coupled design point performance and control. - Demonstrate start-up & shut-down process of representative cycle.

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…. Thank you

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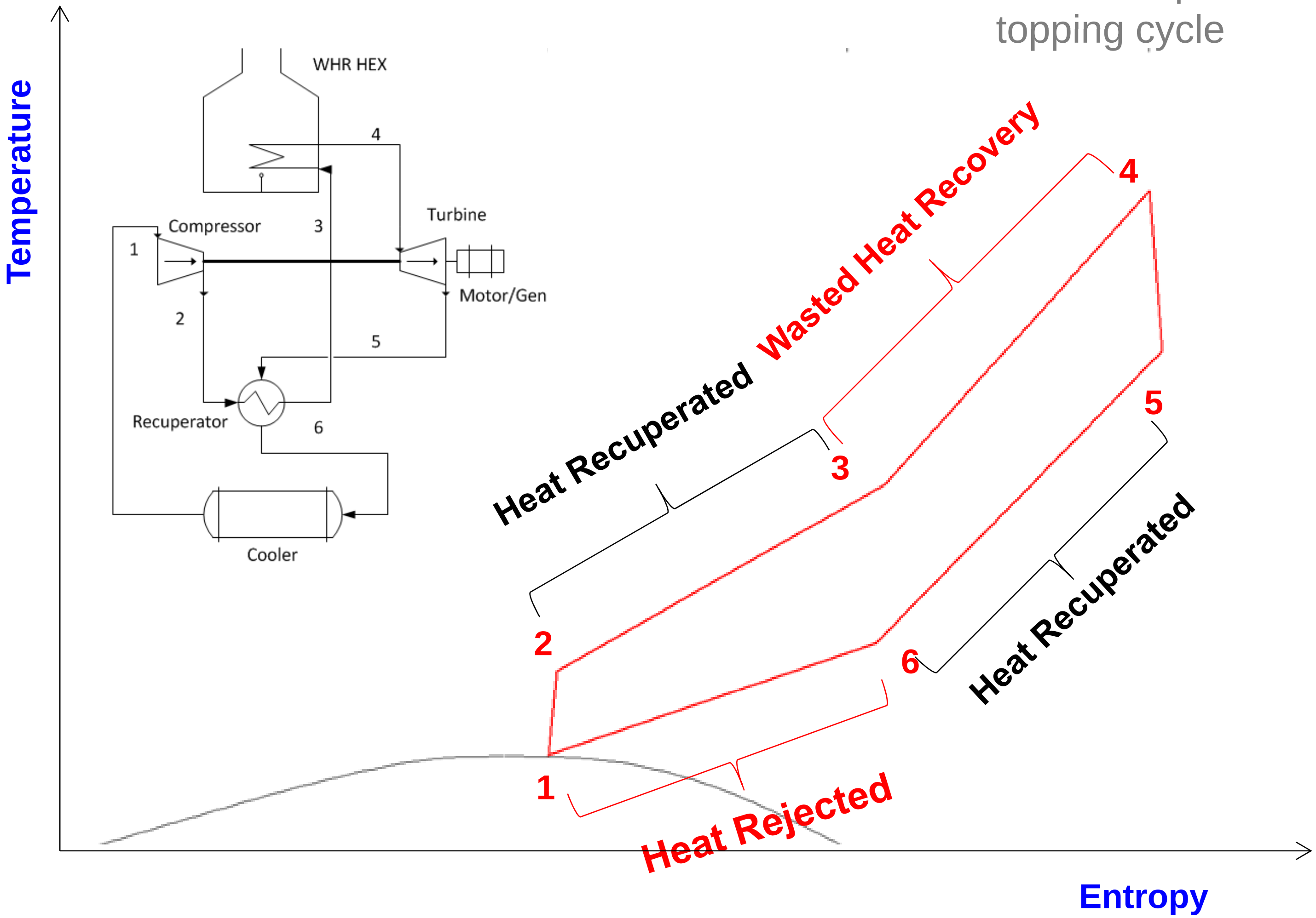
Current learning milestone: Simple Recuperated Brayton Cycle

Could offer 1/3 of additional power to the topping cycle



Review of similar projects

5 years experience | **More than 10 years experience**

Concept development

Nuclear Power Institute of China (NPIC) – 2011

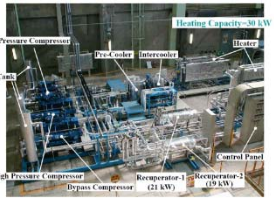
Others
Indian Institute of Science (India) – 2012

Research Centre Rez (Czech Republic) – 2013

Topics
- Fluid behaviour
- Safety implications
- Analysis codes
- Material behaviour
- Specifications

Small scale system and component test

SNL Compressor Loop Test (USA) – 2007

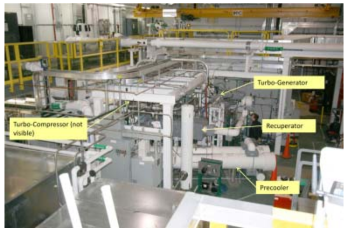


Tokyo Institute of Technology (Japan) – 2012

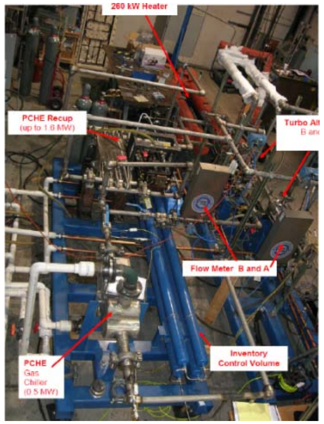
Others
SCIEL Korea Atomic Energy Research Institute (Korea) – 2012

Topics
- Turbomachinery performance
- Bearing & seals
- Heat Exchanger performance
- Operational test

Integrated system test



IST Bechtel Marine Propulsion Corporation & Bettis Atomic Power Laboratory – 2007



SNL & Barber Nichols – Brayton Recompressed (USA) – 2007

Topics
- Test loop control
- Validation design tools
- Plant concept development

Large component development and system test

EPS 100 – Echogen Power Systems & Dresser Rand

Sunshot – Southwest Research Institute / General Electric / Thar Energy

Topics
- Commercial development
- Chemistry control
- Operational control

Source: SCO2 Power Cycle Symposium