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Research on the Development of a Small-scale Supercritical Carbon Dioxide Power Cycle Experimental Test Loop

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Daejeon, South Korea

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Outline

GLOBAL KIER TECHNOLOGIES

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Chapter 01

Introduction of KIER's S-CO2 R&D

The KIER, a global energy innovator, does its best in pursuing its mission to invent world-class energy technologies based on open innovation, life-cycle research quality assurance, participatory and open communication. Therefore the KIER will become the best energy technology R&D institute in the world, contributing to the creation of wealth and improvement of quality of life for the people.

KIER S-CO2 Project Overview

- 2013-2014 : 10 kWe test loop
- 2014 : 1 kWe test loop

- 2015-2019 : 5 years project
- Vision : Substitution of the steam system
  (particularly in fossil fuel application)
- Mid-term goal : WHR market
- Budget : $2M/yr
- Project Leader : Young-Jin Baik, Ph.D.
  Chief of Thermal Energy Conversion Laboratory at KIER
- Performance targets for 2020
  TIT : 500℃
  capacity : several hundreds kWe

Brief history of S-CO2 R&D in KIER

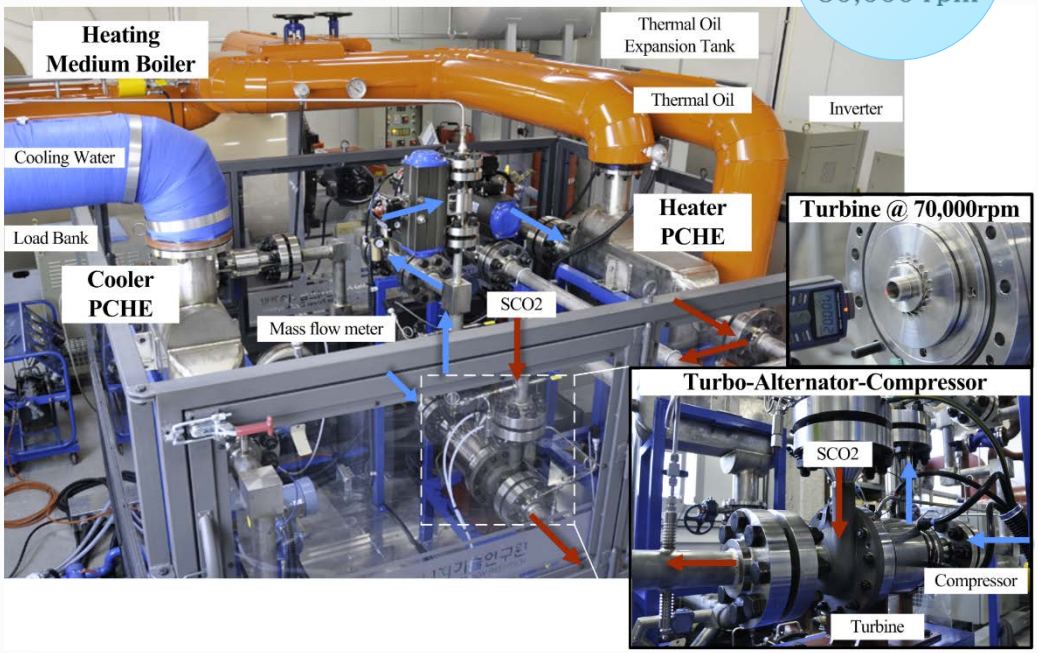
Final Goal(2019)

- Design Capacity >100 kWe, Max.P/T : 130 bar/500 °C , Operation >50 kWe , 2 hours

1

10 kWe Test Loop (2013-2014)

Supercritical Region 30,000 rpm



2

1 kWe Test Loop (2014)

Cold-run 140,000rpm

Brief history of S-CO2 R&D in KIER

3

80 kWe Test Loop (2015-2016)

2016 Target

135 bar
500 ℃
Test Loop

1st target

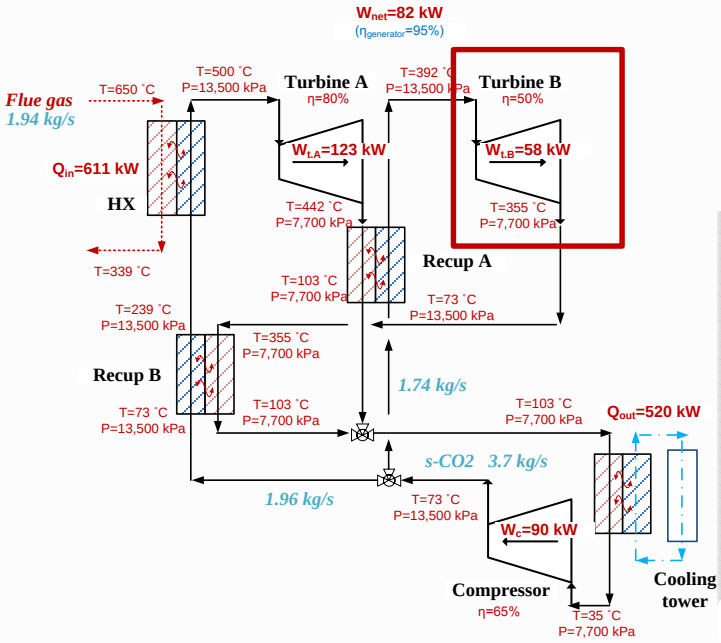
200 ℃
Power
Generation

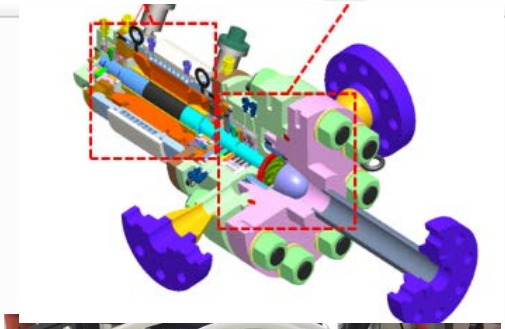
Ready to Operation

Turbine B

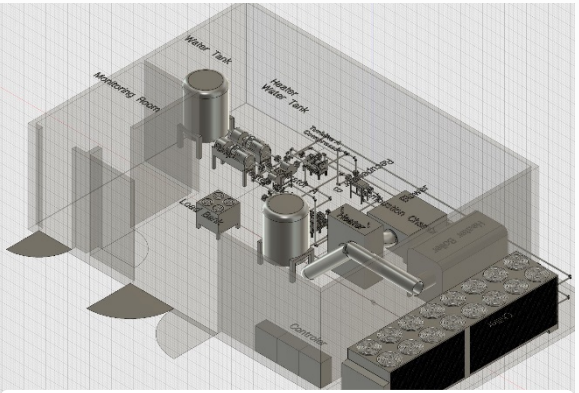
Modifying Test Loop

200 ℃ off-design operation

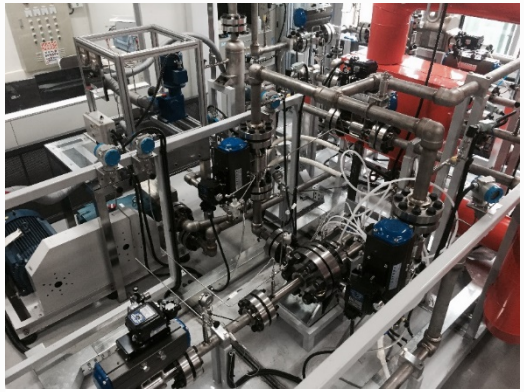




Turbo-generator



Full test loop (expected)



Test loop

Test Loop Summary

	10 kWe-class (2013-2014)	1 kWe-class (2014)	80 kWe-class (2015-2016)
Purpose	Feasibility test	Control, Operation	Power generation
Status	Tested @ 30,000RPM Modified to the 80 kWe test loop	Manufactured Cold-run test @ 140,000RPM	Designed/1 turbo-generator was manufactured, cold-run test @ 43,000RPM
Design Capacity (kWe)	12	1	80
TIT (℃)	180	200	500
Cycle type	Simple Un-Recuperated Closed Brayton	Transcritical & Simple recuperated	Dual Brayton
Turbomachinery	1 Turbo-Alternator-Compressor	1 Turbo-generator	1 Turbo-Alternator-Compressor (design) 1 Turbo-generator (manufactured)
Compressor type	Centrifugal, Shrouded	Positive displacement Pump	Centrifugal
Turbine type	**Radial, Shrouded**	**Radial w/ Partial admission nozzle**	**Axial impulse w/ Partial admission nozzle***
Bearing	**Gas foil journal/thrust**	**Angular contact ball (Oil lubrication)**	**Tilting-pad* (Oil lubrication)**
Rotational speed (RPM)	70,000	200,000	45,000*
Heater Recuperator	LNG fired Thermal Oil Boiler none	Immersion electric heater PCHE	LNG fired flue gas heater PCHE

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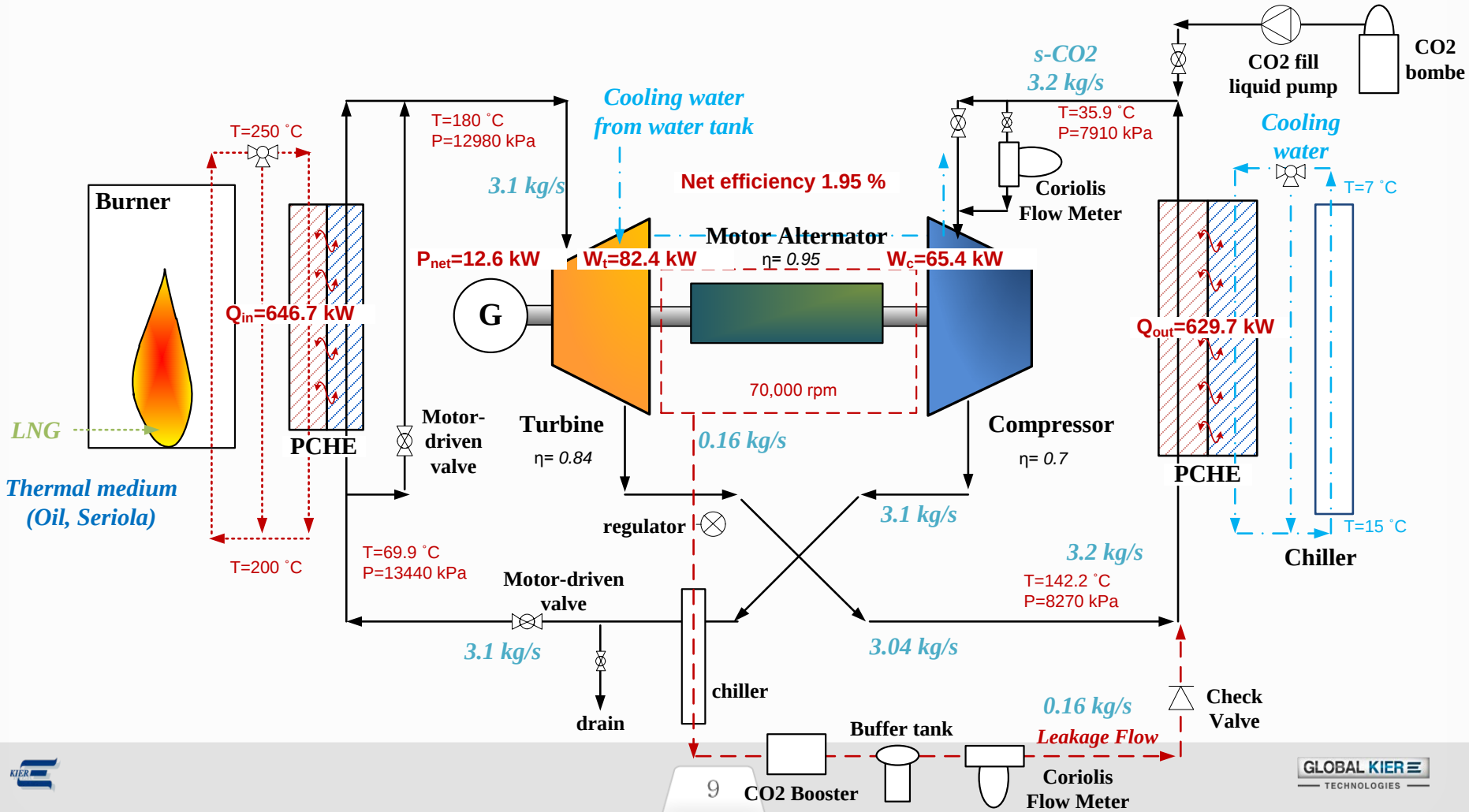
Chapter 02

10 kWe Test Loop (2013-2014)

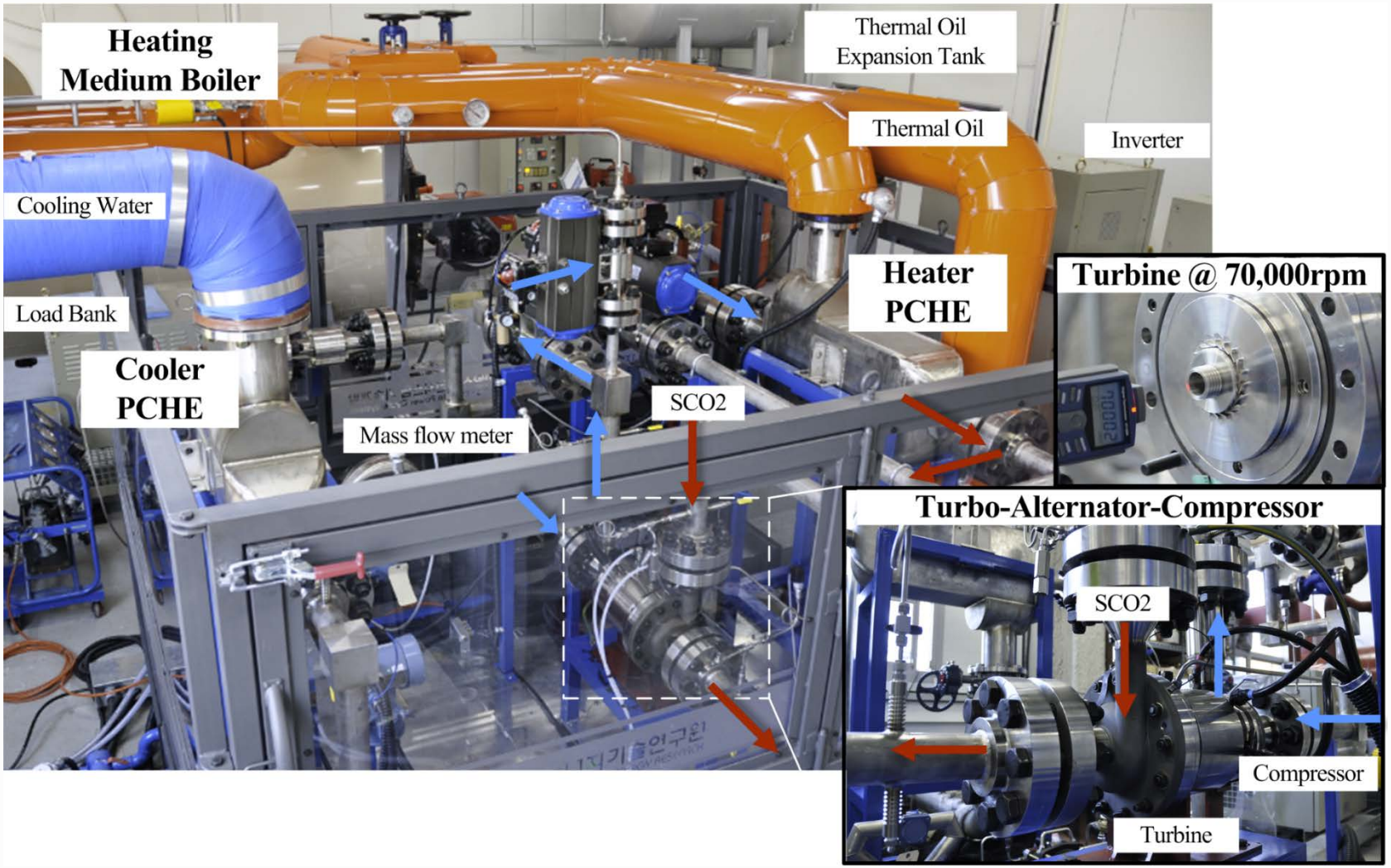
The KIER, a global energy innovator, does its best in pursuing its mission to invent world-class energy technologies based on open innovation, life-cycle research quality assurance, participatory and open communication. Therefore the KIER will become the best energy technology R&D institute in the world, contributing to the creation of wealth and improvement of quality of life for the people.

10 kWe Test Loop (Un-recuperated Simple Closed Brayton)

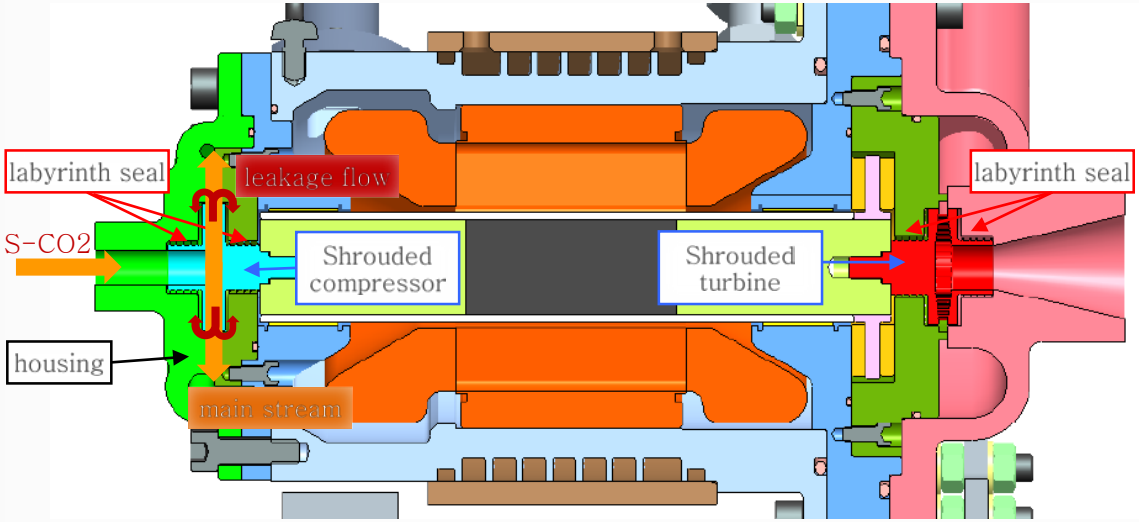
- Target power : 12.6 kWe @ 70,000 rpm, 180°C/13 MPa
- A hermetic Turbine-Alternator-Compressor (TAC) unit

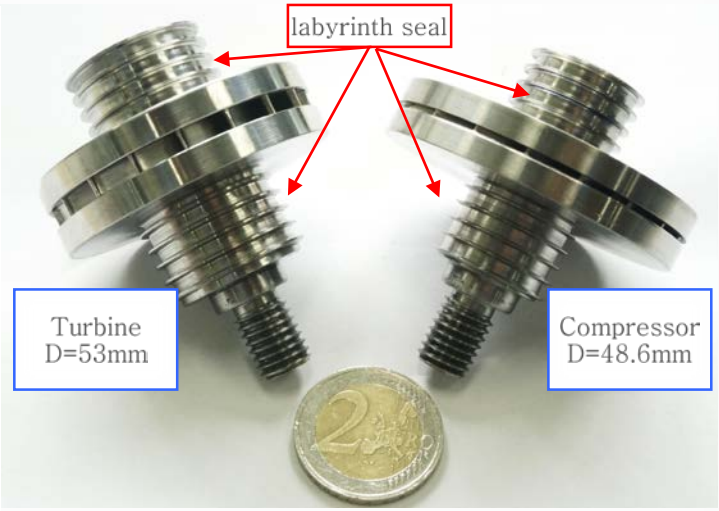


10 kWe Test Loop (Un-recuperated Simple Closed Brayton)



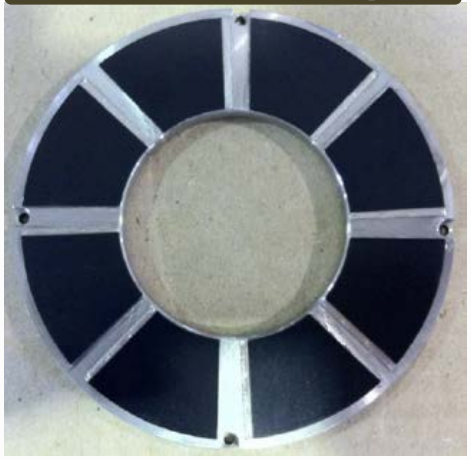
KIER Shrouded compressor / turbine





Gas Foil Journal Bearing

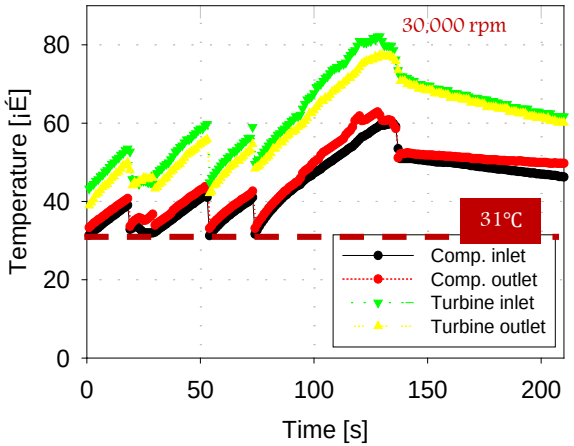
Gas Foil Thrust Bearing

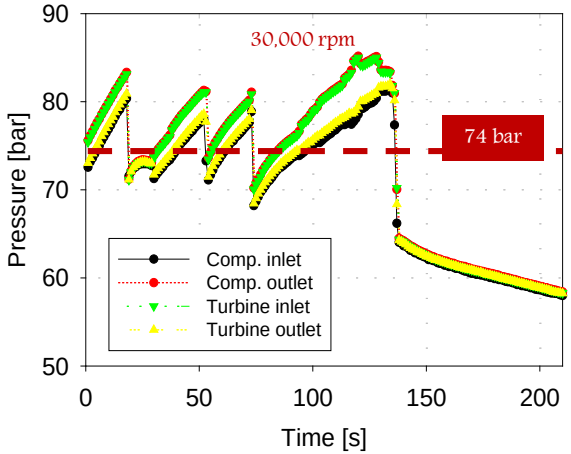


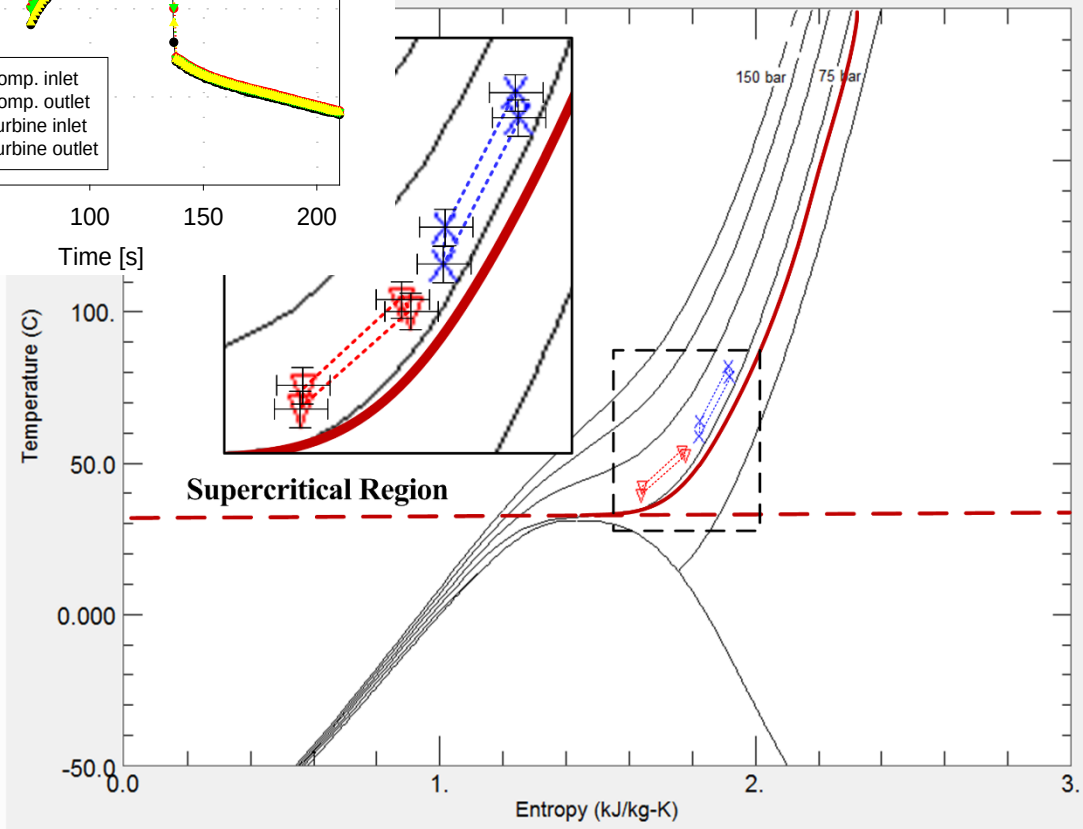
Turbine Nozzle

Test run of the 10 kWe-class test loop

30,000rpm, 85bar, 83℃ (Supercritical Region)







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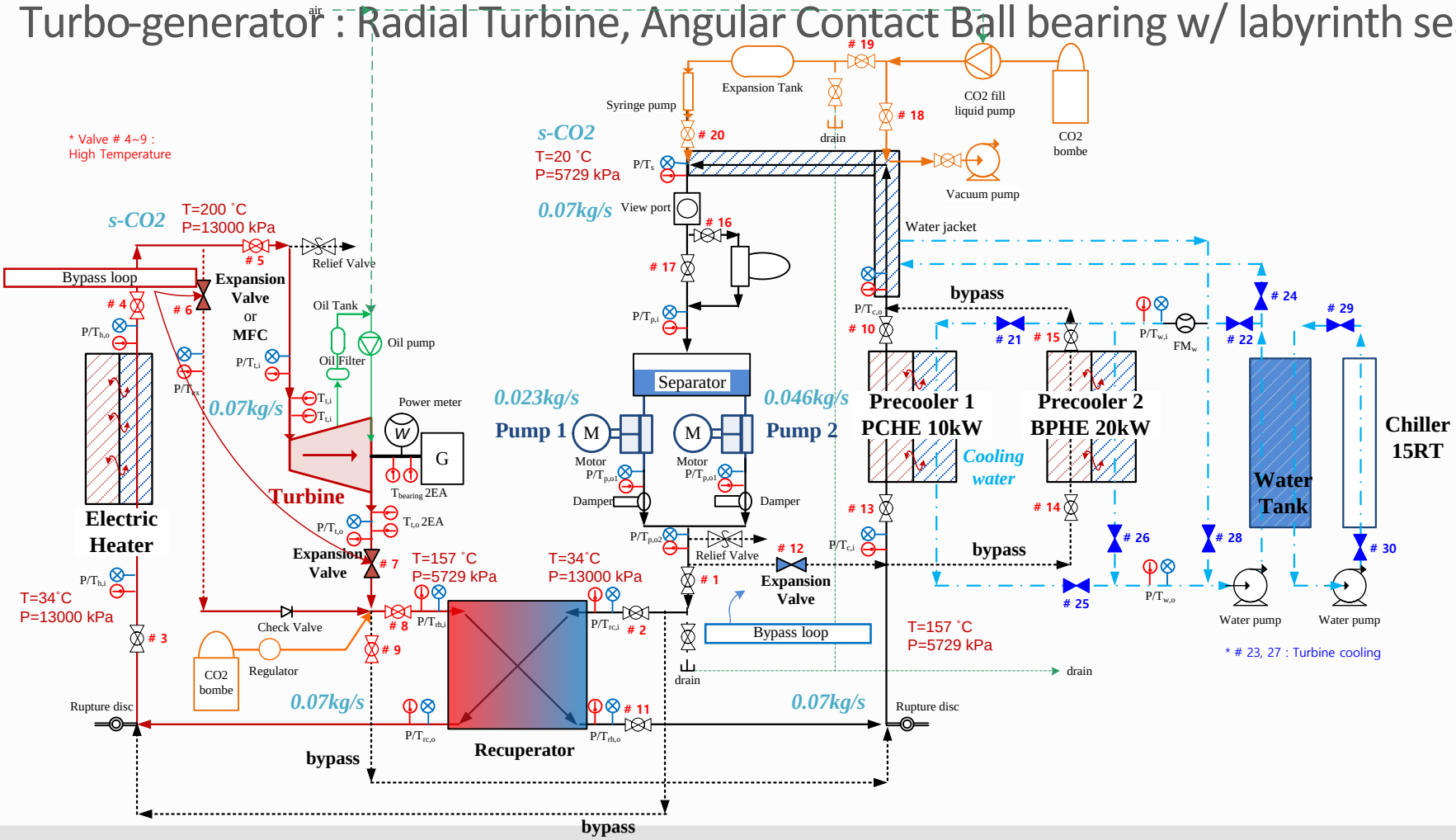
1 kWe Test Loop (2014)

Chapter 04

The KIER, a global energy innovator, does its best in pursuing its mission to invent world-class energy technologies based on open innovation, life-cycle research quality assurance, participatory and open communication. Therefore the KIER will become the best energy technology R&D institute in the world, contributing to the creation of wealth and improvement of quality of life for the people.

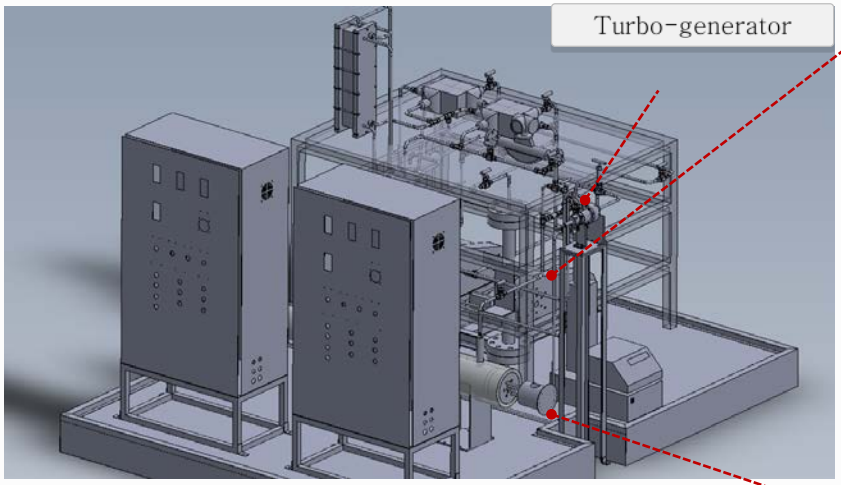
Multi-purpose 1 kWe-class test loop (Transcritical)

- Target power : 1 kWe @ 200,000 rpm, 200℃/13 MPa
- Turbo-generator : Radial Turbine, Angular Contact Ball bearing w/ labyrinth seals

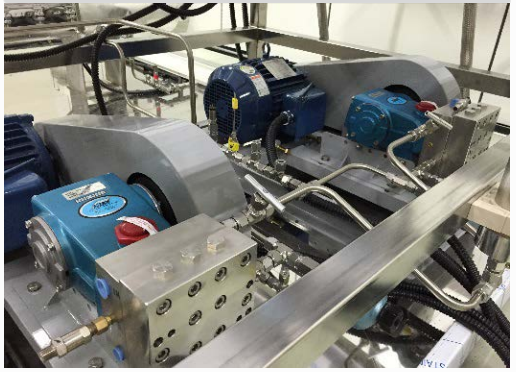


1 kWe-class test loop (Transcritical)

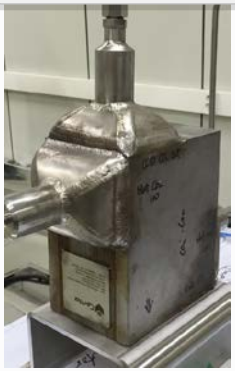
~ 1 kWe @ 200,000 rpm, 200℃ / 130 bar

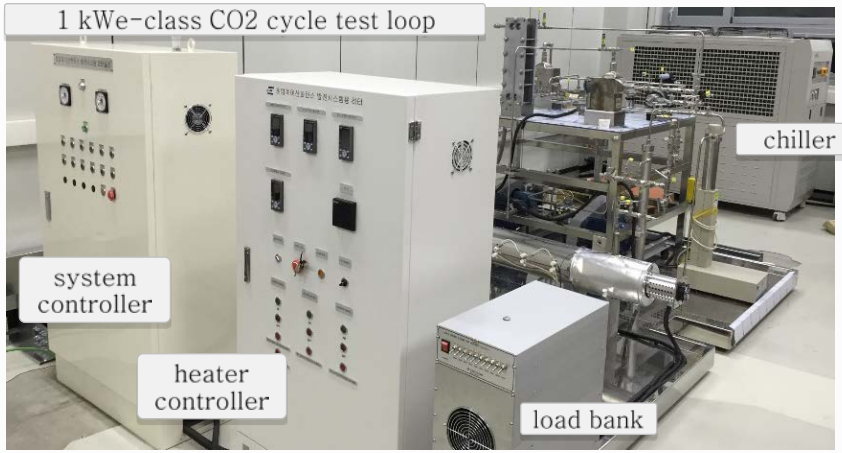


CO2 Pump

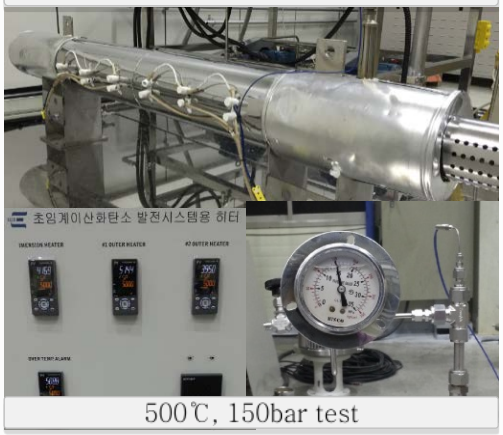


10 kW Recuperator
PCHE CO2-CO2





Immersion electric heater

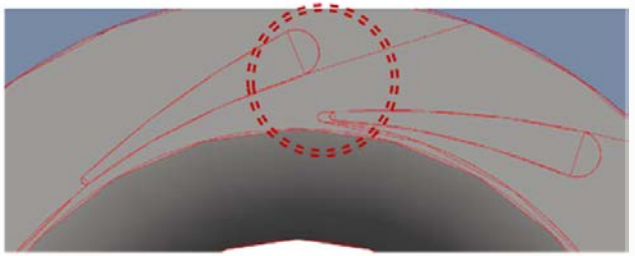


10 kW Precooler
PCHE CO2-Coolant

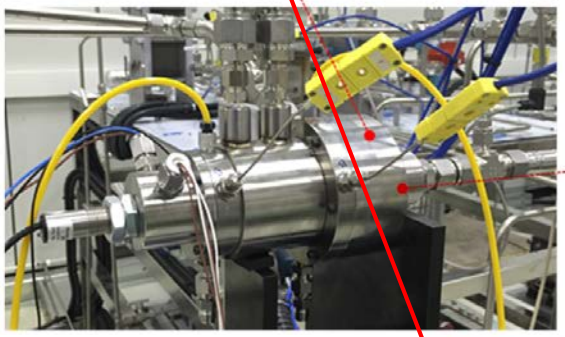
1 kWe-class test loop - Turbo-generator

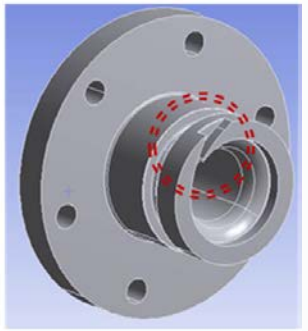
Radial Turbine (D=22.6mm)

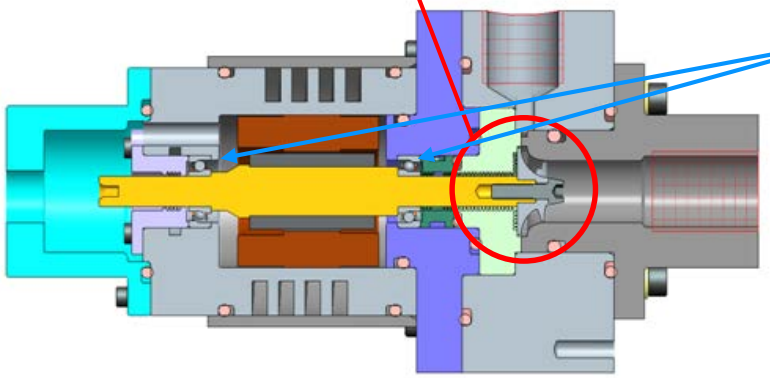
Partial Admission Nozzle



800,000 RPM
-> 200,000 RPM

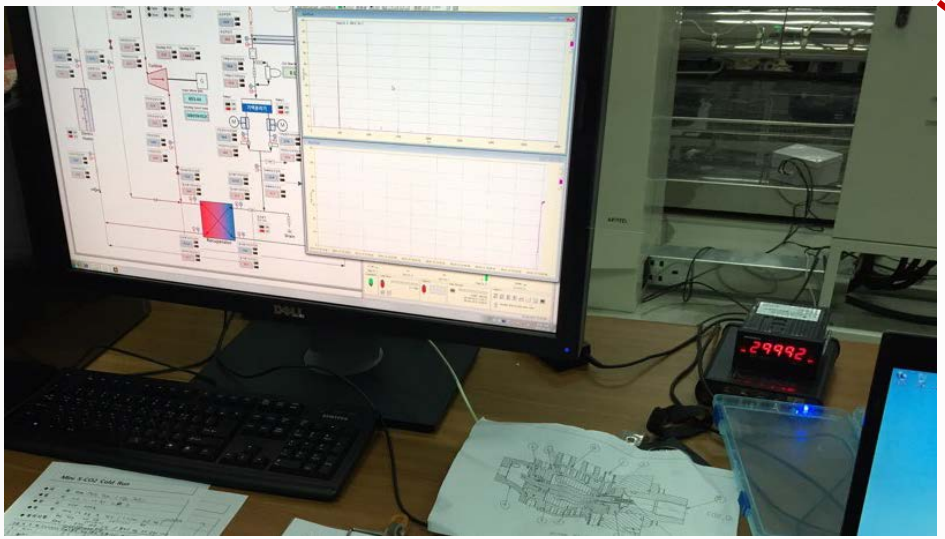


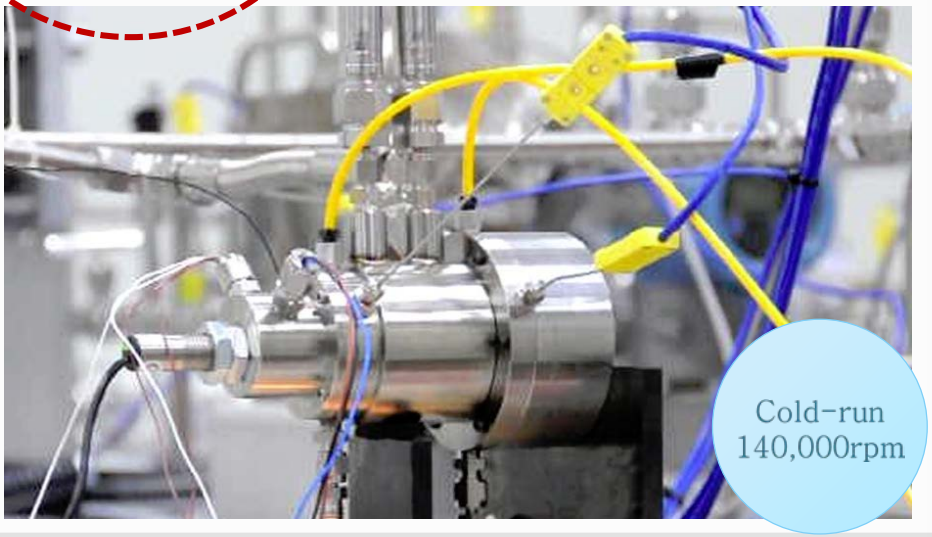




Angular contact
Ball Bearing

1 kWe-class test loop (Transcritical)





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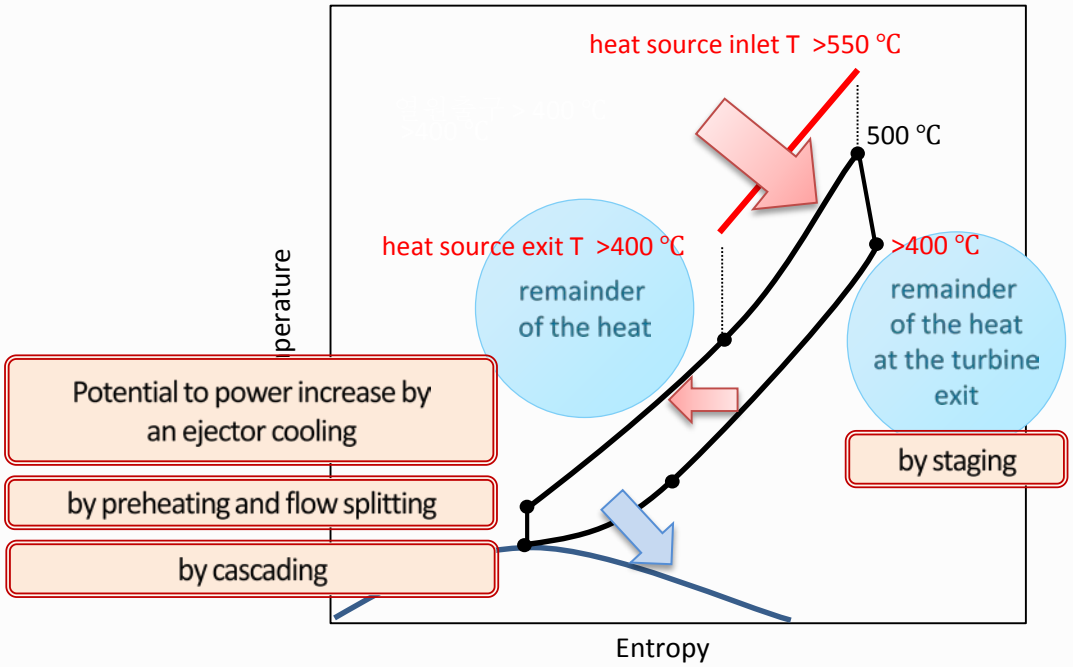
80 kWe Test Loop (2015-2017)

The KIER, a global energy innovator, does its best in pursuing its mission to invent world-class energy technologies based on open innovation, life-cycle research quality assurance, participatory and open communication. Therefore the KIER will become the best energy technology R&D institute in the world, contributing to the creation of wealth and improvement of quality of life for the people.

Where is a chance ?

❖ **We are looking for an opportunity to increase power in WHR area.**

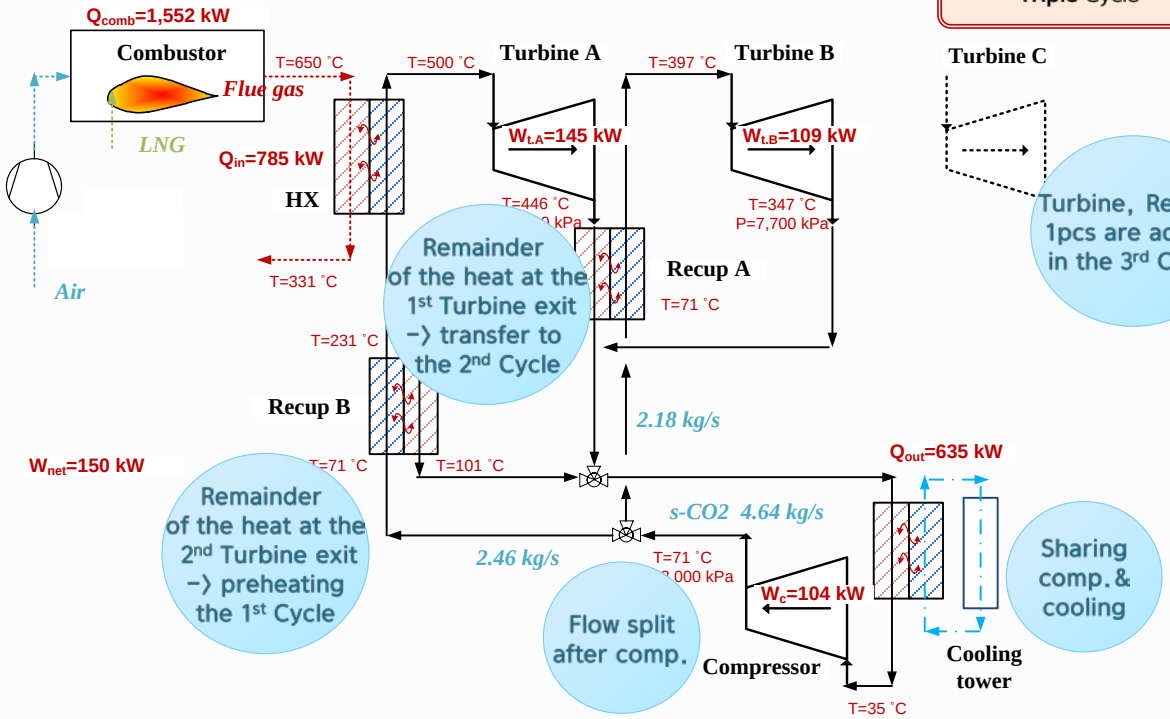
- ✓ Characteristics of the SCO2 Brayton cycle
- ✓ Evaluation on a couple of strategies by modeling and simulation
- ✓ How to increase power of the cycle? **'Power'** is more important than **'efficiency'** in WHR



Potential to power increase by staging : dual cycle

Dual Cycle

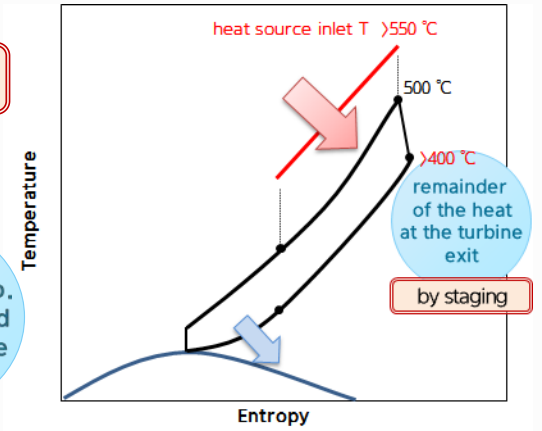
Remainder of the heat at the turbine exit is transferred to the 2nd cycle instead of recuperation
Remainder of the heat at the 2nd turbine exit preheats the 1st cycle

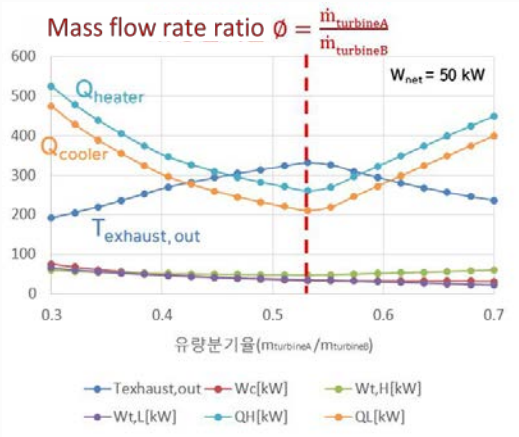


Triple Cycle

Turbine C

Turbine, Recup. 1pcs are added in the 3rd Cycle



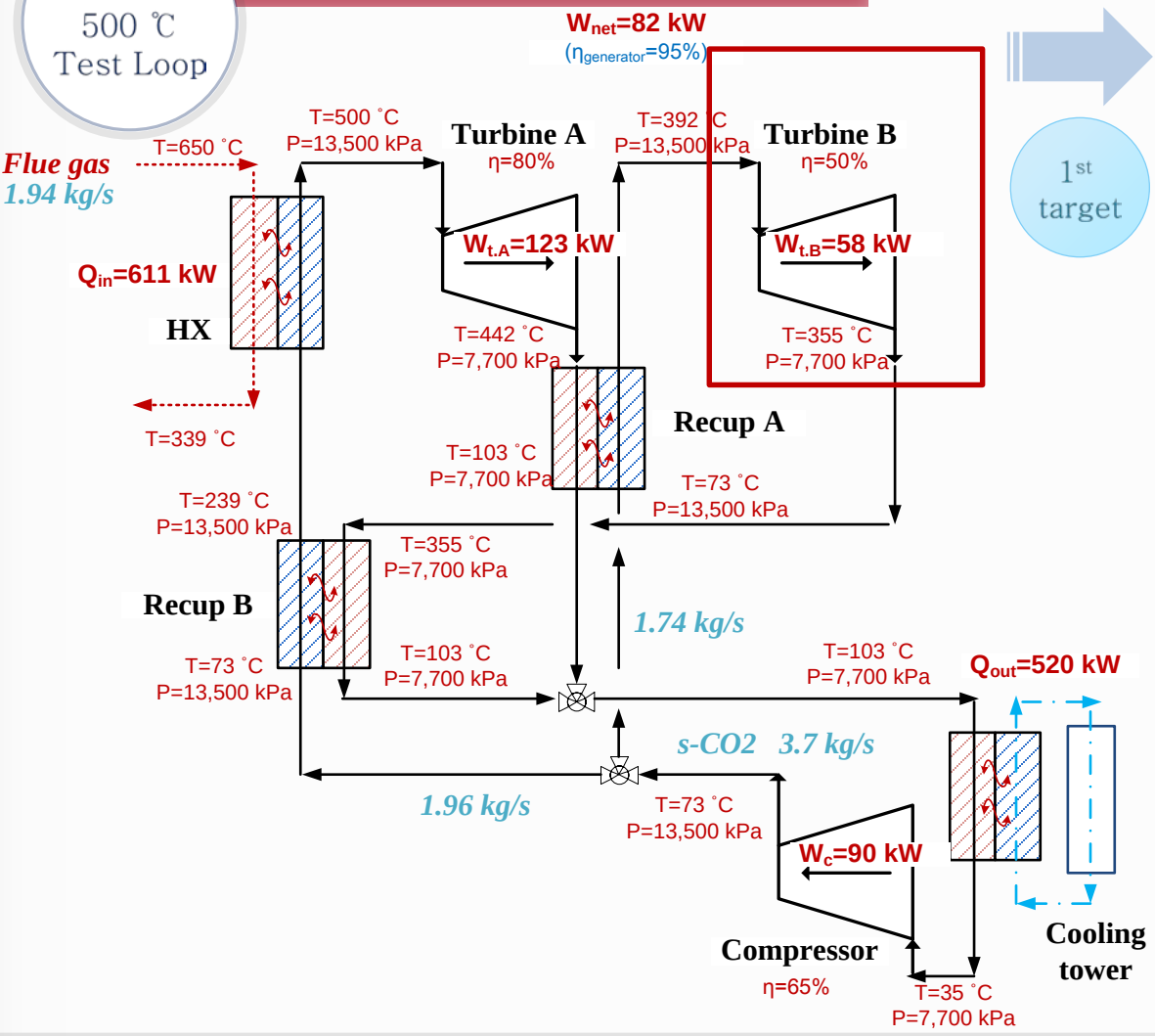


- We have confirmed that there exists an optimum mass flow rate ratio that maximizes the power.

80 kWe-class test loop (Dual)

135 bar
500 ℃
Test Loop

80 kWe Test Loop (2015-2016)

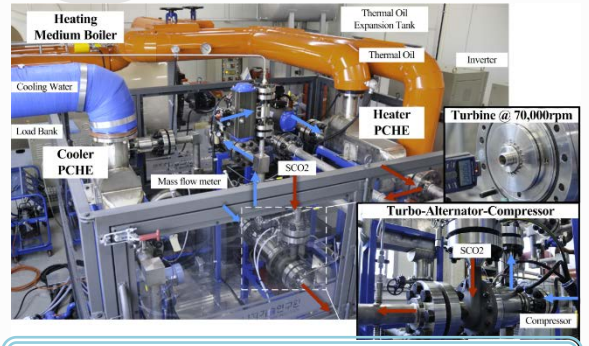


1st target

200 ℃ Power Generation

Turbine B

200 ℃ off-design operation



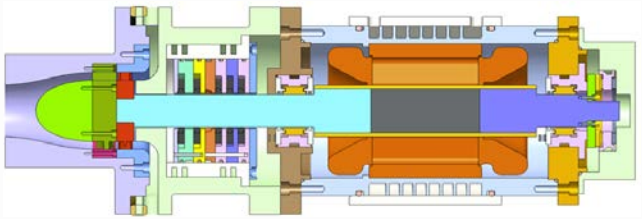
Modifying 10 kWe Test Loop Facility

Test Loop(Transcritical)

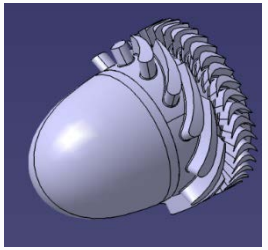
Turbo-generator design

✓ Power turbine nozzle and rotor design

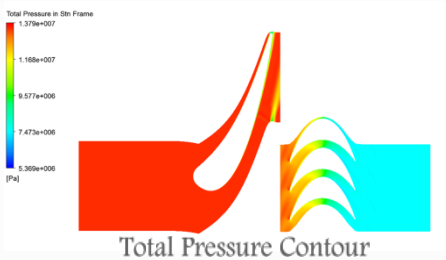
- **Main challenges**
  - how to reduce a spin speed, which helps rotor dynamics, bearing, and windage problem to be easier, at a quite small flow rate .
  - how to handle a large amount of axial force.
- Axial type, impulse turbine
- 25% partial admission operation
- Inlet design for partial admission
- Exit design
- Turbine Main Spec.
  - Mass Flow Rate: 1.74kg/s
  - Speed : 45,000rpm
  - Size : Dia. 80mm
  - Intel total pressure/ total temp. : 13,000kPa/ 392degC
  - Exit total pressure/ total temp. : 7,700kPa/ 338 degC



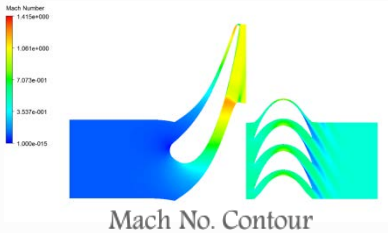
Power turbine layout



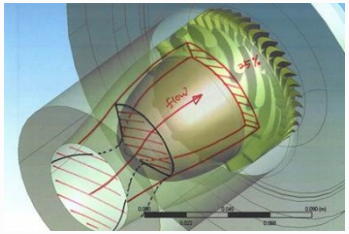
Turbine Geometry



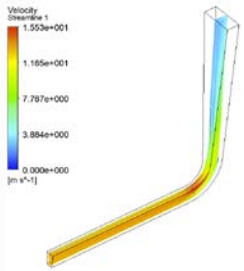
Total Pressure Contour



Mach No. Contour

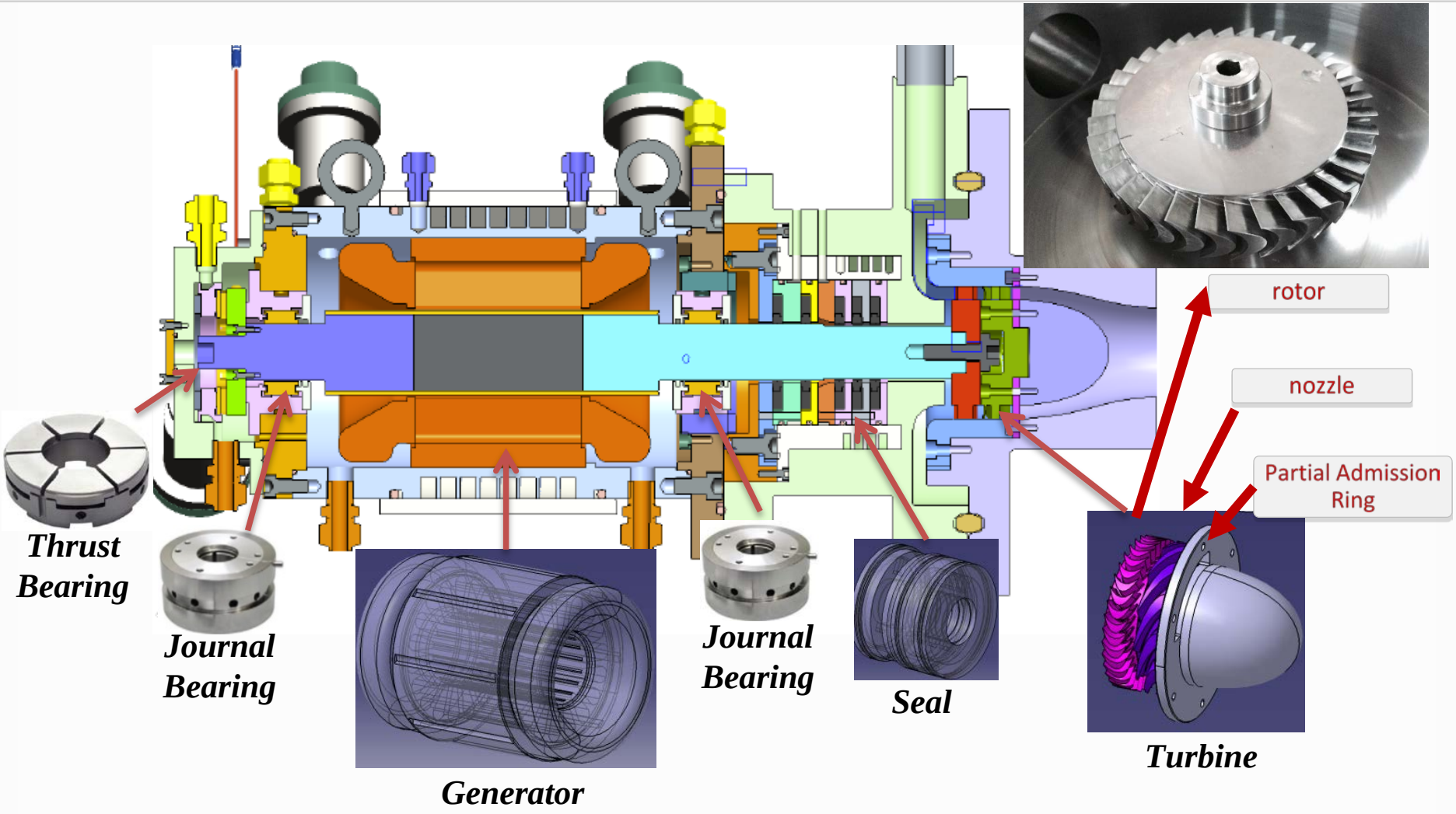


Inlet Geometry

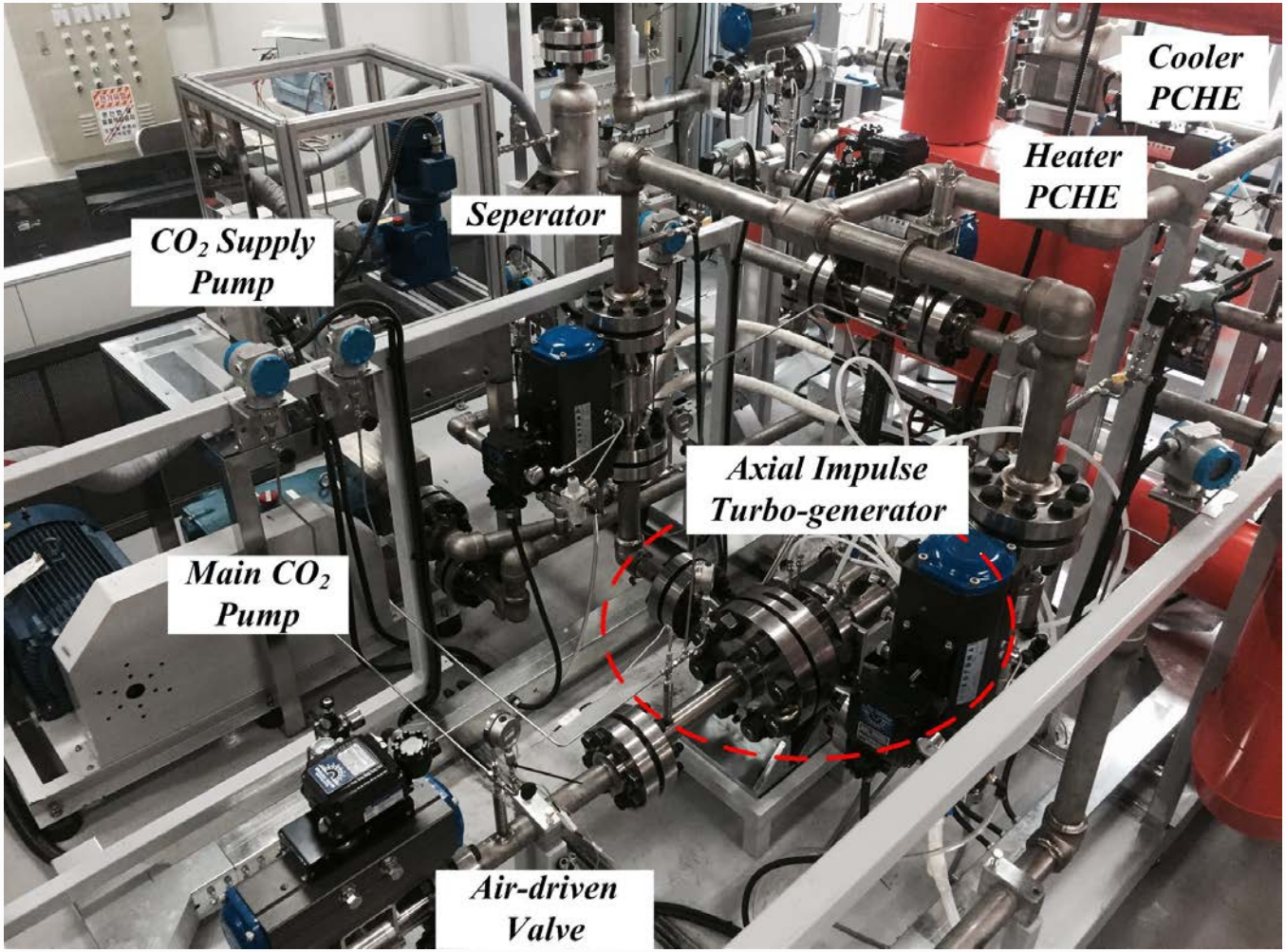


Exit Vel. Contour

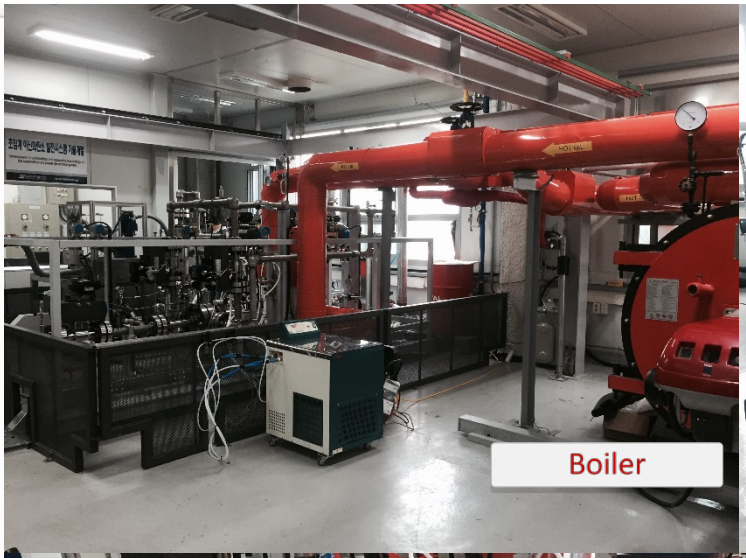
Turbo-generator layout design

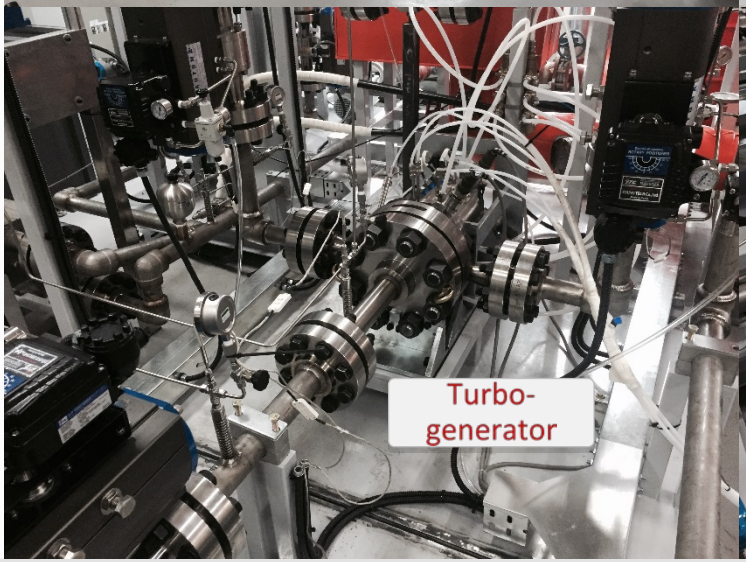


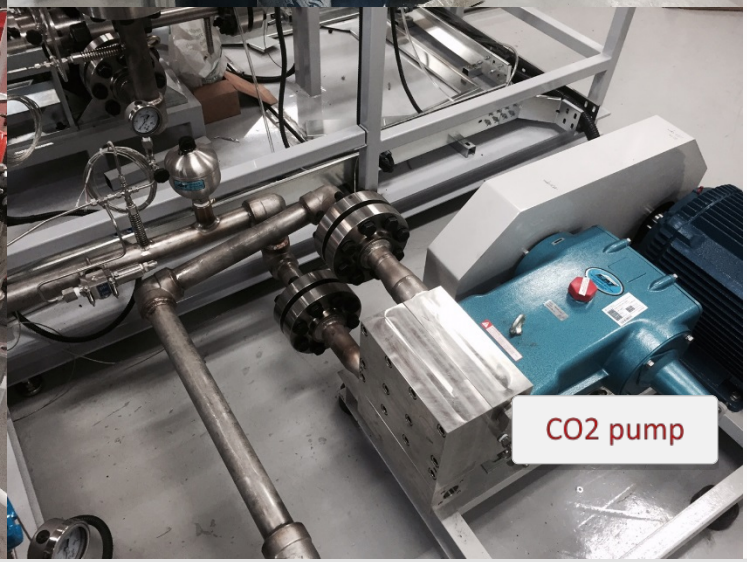
Test loop (Transcritical, Ready to Operation)



Test loop (Transcritial, Ready to Operation)







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Compressor type	Centrifugal, Shrouded	Positive displacement Pump	Centrifugal
Turbine type	**Radial, Shrouded**	**Radial w/ Partial admission nozzle**	**Axial impulse w/ Partial admission nozzle***
Bearing	**Gas foil journal/thrust**	**Angular contact ball (Oil lubrication)**	**Tilting-pad* (Oil lubrication)**
Rotational speed (RPM)	70,000	200,000	45,000*
Heater Recuperator	LNG fired Thermal Oil Boiler none	Immersion electric heater PCHE	LNG fired flue gas heater PCHE

Future Works (2016~2019)

- **Near-term goal (2016-2017) :**
  - An experimental implementation of a dual S-CO2 Brayton cycle of ~100 kWe for 500℃/13 MPa
- **Mid-term goal (2017-2019) :**
  - Development of an high-efficient novel S-CO2 cycle
  - An experimental implementation of KIER's unique S-CO2 cycle of several hundreds kWe
  - Target : WHR market

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GLOBAL KIER TECHNOLOGIES

Thank you for your attention

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