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Supercritical from heat to power

CARBOSOLA - the german R&D initiative on carbon dioxide (sCO2) as an alternative working fluid for waste heat recovery

TECHNISCHE UNIVERSITÄT DRESDEN

HZDR
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DLR

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Agenda

1. Technology potentials
2. Market view
3. International R&D activities
4. Technical & scientific challenges
5. CARBOSOLA - the german R&D initiative on sCO2 as an alternative working fluid for waste heat recovery
6. Horizon 2020 – project idea
7. Summary

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Technology Potentials - Overview

Technology potential of supercritical CO_2 (sCO_2)-cycles:

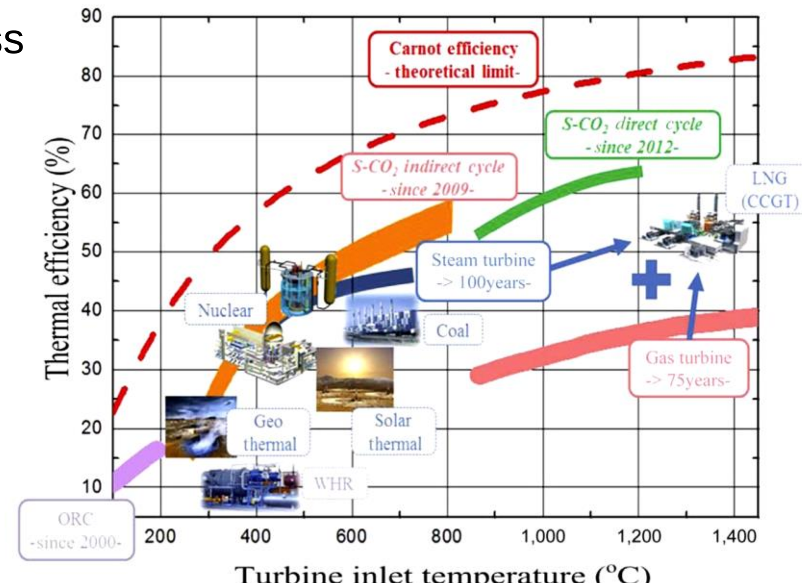
- higher efficiency = higher primary energy utilization
  - → reduced emissions from heat from thermochemical conversion
  - → reduced heat release into the atmosphere

  } **lower footprint**
- smaller component size, lower costs, higher operating flexibility
- Lower water consumption in the power plant process

Steam Turbine

sCO_2-Turbine

Gampe (2016)



Ahn et al. (2015)

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Technology Potentials - Overview

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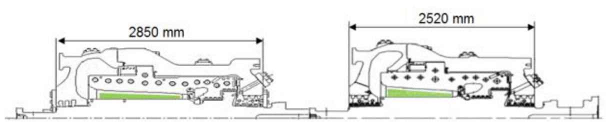
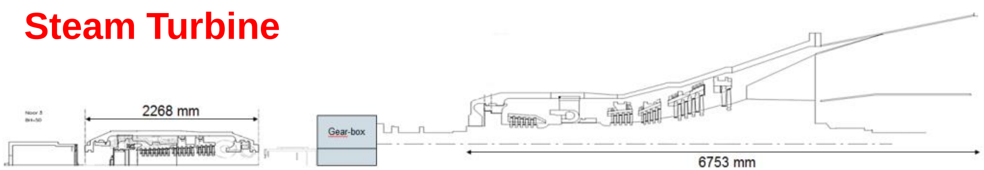
- higher efficiency compared to water/steam
  → reduced emissions & reduced heat release into the atmosphere
- Less complex cycle layout, smaller component size, lower cost
- Lower water consumption in the power plant process
- non-hazardous fluid (not flammable/explosive/toxic)

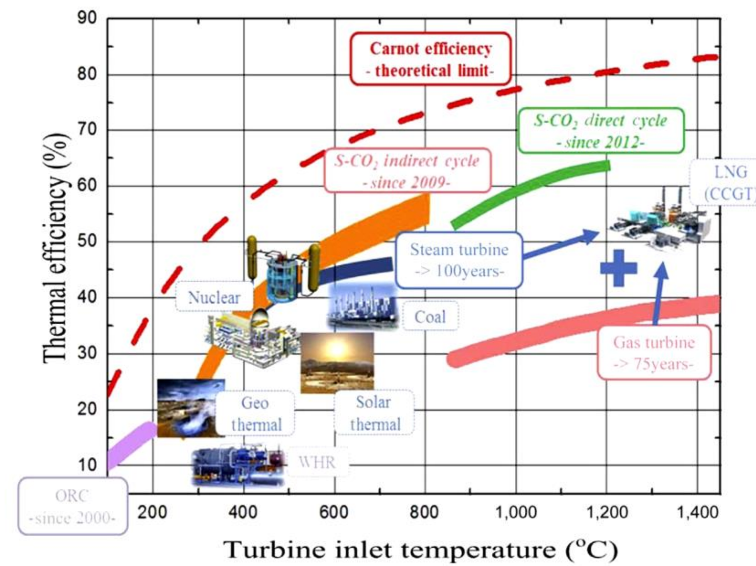
sCO_2-Turbine



Steam Turbine



Glos et al. (2017)



Ahn et al. (2015)

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Technology Potentials –
Bottoming Processes / Secondary Heat Sources

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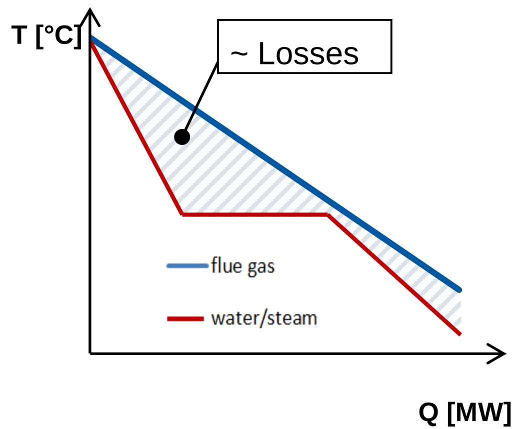
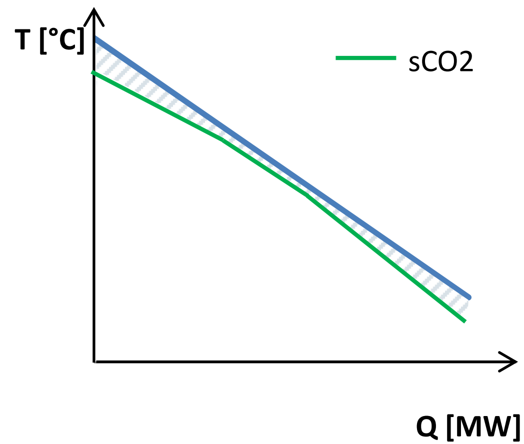
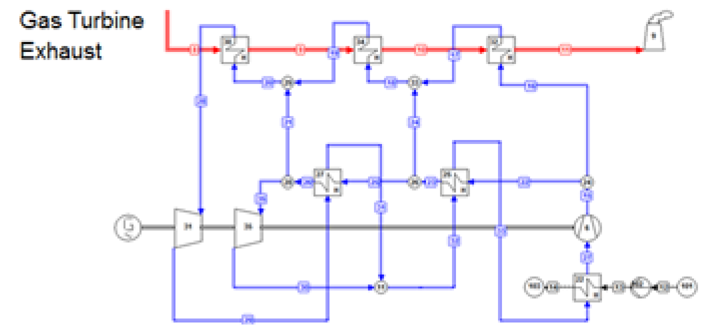
Water/Steam



sCO2





Cascaded sCO_2 cycle for waste heat recovery

→ Better thermal coupling in the steam generator leads to higher efficiency

→ Optimization through cascaded sCO2 cycles for waste heat recovery

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Optimization potential for w/s depending on flue gas temperatures

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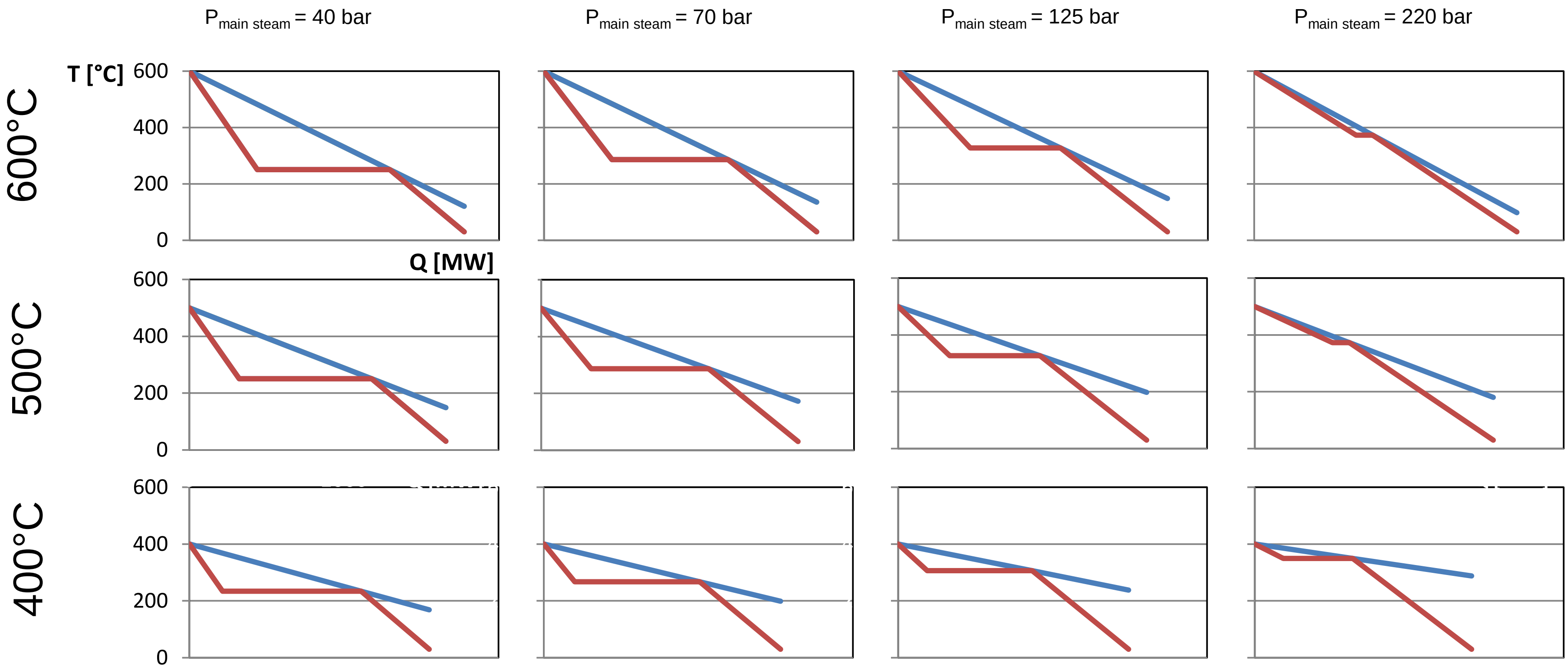

→Lower optimization potential of main steam pressure with lower flue gas temperature

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Technology Potentials - Secondary Heat Sources

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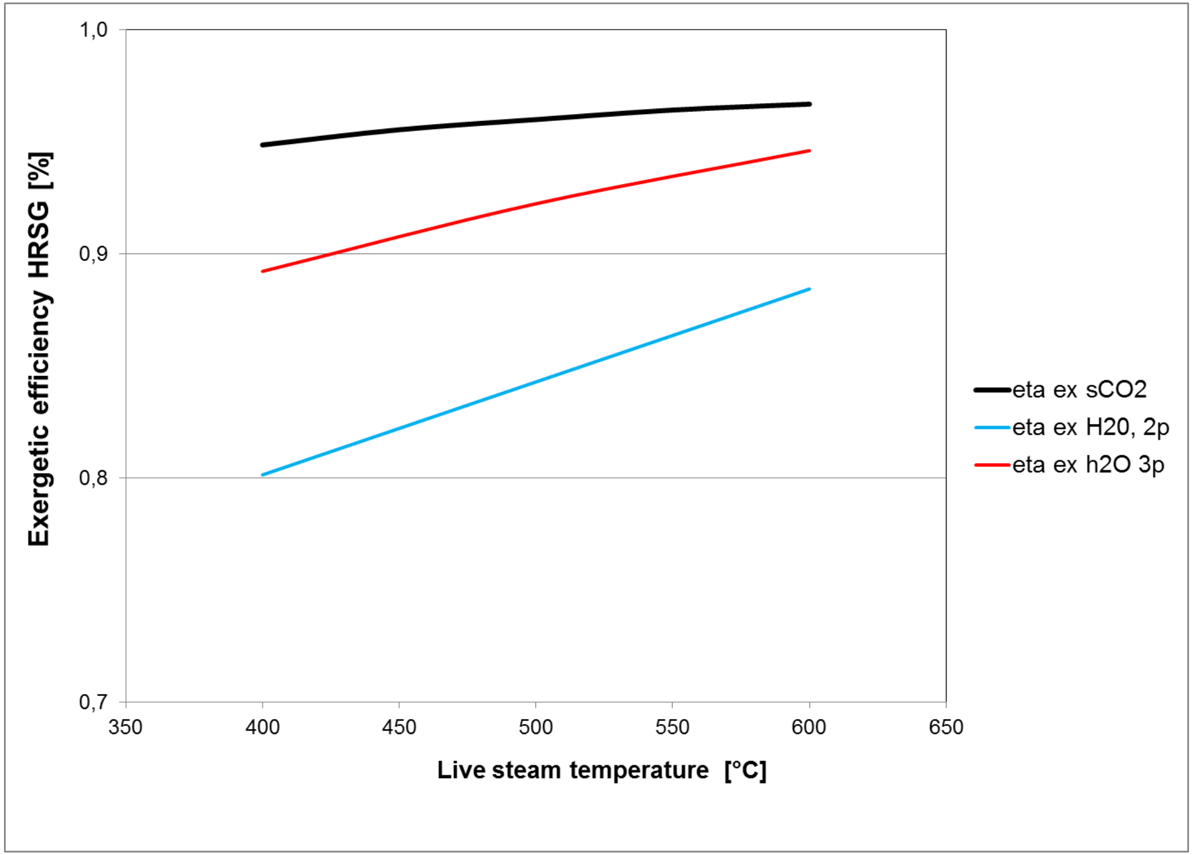

$$\eta_{Ex} = \frac{\dot{E}_{working\ fluid}}{\dot{E}_{flue\ gas}}$$

→ Higher potential for sCO2 at lower waste heat temperatures

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International R&D activities

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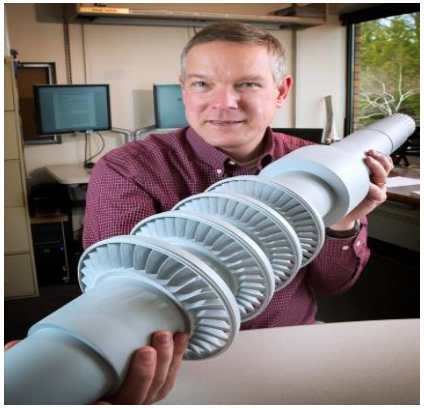

ENERGY

This Is What We Call Ecomagination: GE Is Building A CO2-Powered Turbine That Generates 10 Megawatts And Fits On A Table

Shouhang IHW signed agreement with EDF on supercritical CO2 Brayton cycle coupled with Concentrated Solar Power plant

On, Dec 28, 2017, Shouhang IHW signed an agreement on technology cooperation of supercritical CO2 Brayton cycle coupled with CSP plant with EDF.

World's First

Hyundai Heavy, KEPCO Develops Source Technology for Supercritical CO2 Turbine

Hyundai Heavy Industries Co. and Korea Electric Power Corp (KEPCO) have developed an tion emission-free steam generating technology using fuel waste for the first time in the world.

EPS100 HEAT RECOVERY SOLUTION

8MW NAMEPLATE CAPACITY

sCO_2flex

Increasing coal and lignite power plants' flexibility

The **Supercritical CO_2 Cycle for Flexible & Sustainable Support to the Electricity System** (sCO_2-Flex) **aims to adapt fossil-fuel power plants to the future energy system requirements**.

BRIEF

Toshiba ships turbine for NET Power supercritical CO2 carbon capture plant

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Heat Market

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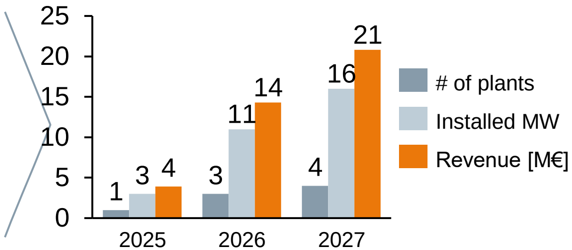
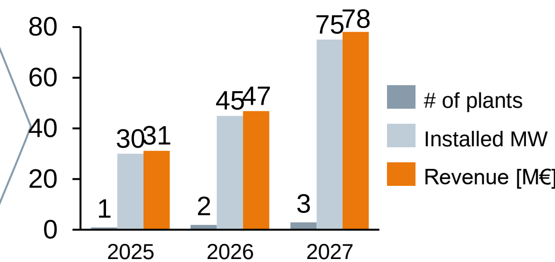
	Currently addressed by	CO2 Advantages	Market Potential
Industrial WHR	• ORC; technology not yet established • Water/Steam cycle	• Δη + 2.1%pts compared to Water/steam (depending on heat source temp.) • Better usage of low temperature levels • no special medium as for ORC	• **Overall > 28 GW_{el} or** • **~2900 retrofits** • 9 GW_{el} (US only) *Temperature range: 100 – 600 ℃*
AGT bottoming cycle	• ORC; technology not yet established • Water/Steam cycle	• Δη + 2.1%pts compared to Water/steam • no special medium as for ORC	• Existing AGT fleet: > **7000 engines**
Next Level Geothermal (CPG)	• Unique technology • Conventional hydrothermal geothermal with W/S cycle or ORC	• Power output 3x higher compared to hydrothermal geothermal • > 10x more sites usable compared to hydrothermal geothermal	• **8 GW_{el} /a** market potential for Co2 based geothermal power production • Overall technical potential**: 2000 GW_{el}**

Forecast

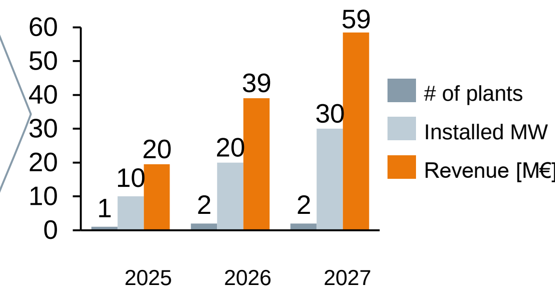
Industrial WHR:



AGT bottoming cycle:



Next Level Geothermal (CPG):



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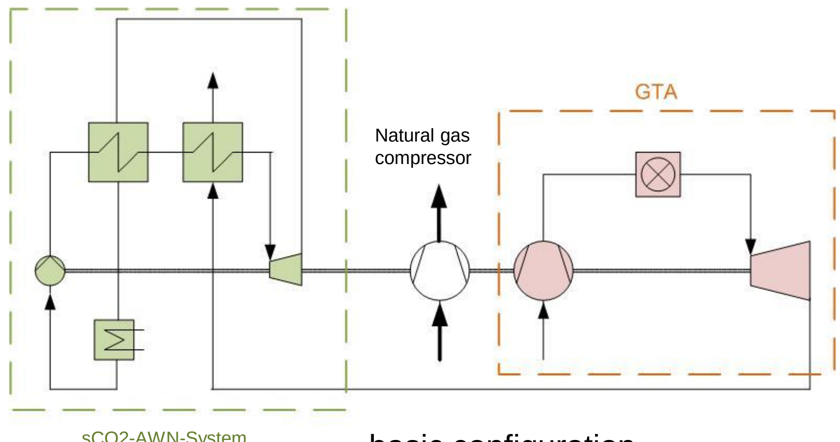
Technology Potentials - Secondary Heat Sources

Example - sCO2 secondary process for GT in natural gas compressor stations

- High impact: Large number, **auxilary power requirements at full load about 1% of the transported quantity per 250 km**
- Most of the compressor drive turbines consist without waste heat recovery, waste heat recovery concepts based on STIG (e.g. Aquarius-GT), downstream DTA with power generation (e.g. GVS Weitendorf of the Trans-Austria gas pipeline)
- Completely new application for sCO2 technology in GT for mechanical drive and variable speed
  In contrast to the sCO2 applications currently considered for power generation (generator drive, constant speed), the sCO2 turbine can also be imagined as a booster for the natural gas compressor drive.
  The variable speed is a new challenge.



basic configuration

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Heat Market

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Industrial WHR

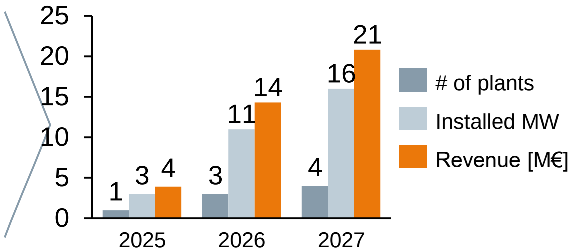
Currently addressed by
- ORC; technology not yet established
- Water/Steam cycle

CO2 Advantages
- Δη + 2.1%pts compared to Water/steam (depending on heat source temp.)
- Better usage of low temperature levels
- no special medium as for ORC

Market Potential
- **Overall > 28 GW_{el} or**
- **~2900 retrofits**
- 9 GW_{el} (US only)

Temperature range: 100 – 600 ℃

Forecast



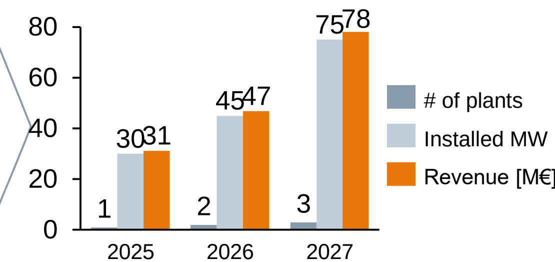
AGT bottoming cycle

Currently addressed by
- ORC; technology not yet established
- Water/Steam cycle

CO2 Advantages
- Δη + 2.1%pts compared to Water/steam
- no special medium as for ORC

Market Potential
- Existing AGT fleet: > **7000 engines**

Forecast



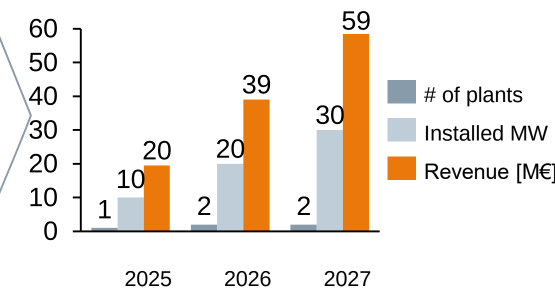
Next Level Geothermal (CPG)

Currently addressed by
- Unique technology
- Conventional hydrothermal geothermal with W/S cycle or ORC

CO2 Advantages
- Power output 3x higher compared to hydrothermal geothermal
- > 10x more sites usable compared to hydrothermal geothermal

Market Potential
- **8 GW_{el} /a** market potential for Co2 based geothermal power production
- Overall technical potential**: 2000 GW_{el}**

Forecast



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Innovative idea:
CO_2-based geothermal power generation

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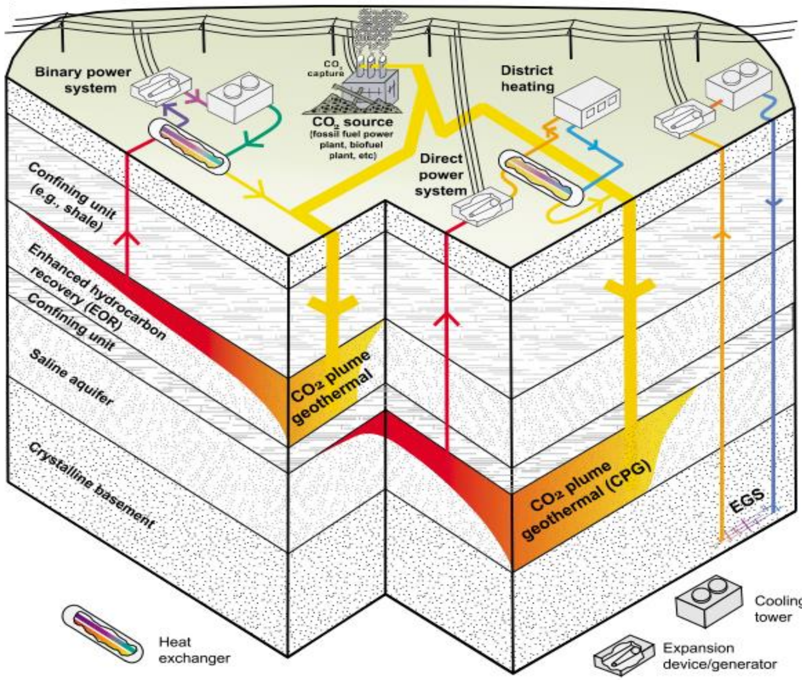
CO2-based geothermal energy



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journal homepage: www.elsevier.com/locate/apenergy

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A comparison of electric power output of CO_2 Plume Geothermal (CPG) and brine geothermal systems for varying reservoir conditions

CrossMark

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[e] Department of Earth Sciences, ETH–Zürich, Sonneggstrasse 5, 8092 Zürich, Switzerland

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CO_2-based geothermal power generation Basic Concept

Characteristics & benefits

- Density varies with temperature

  →Self circulating due to **thermosiphon**
- 2 to 5 lower viscosity of sCO_2 compared to brine

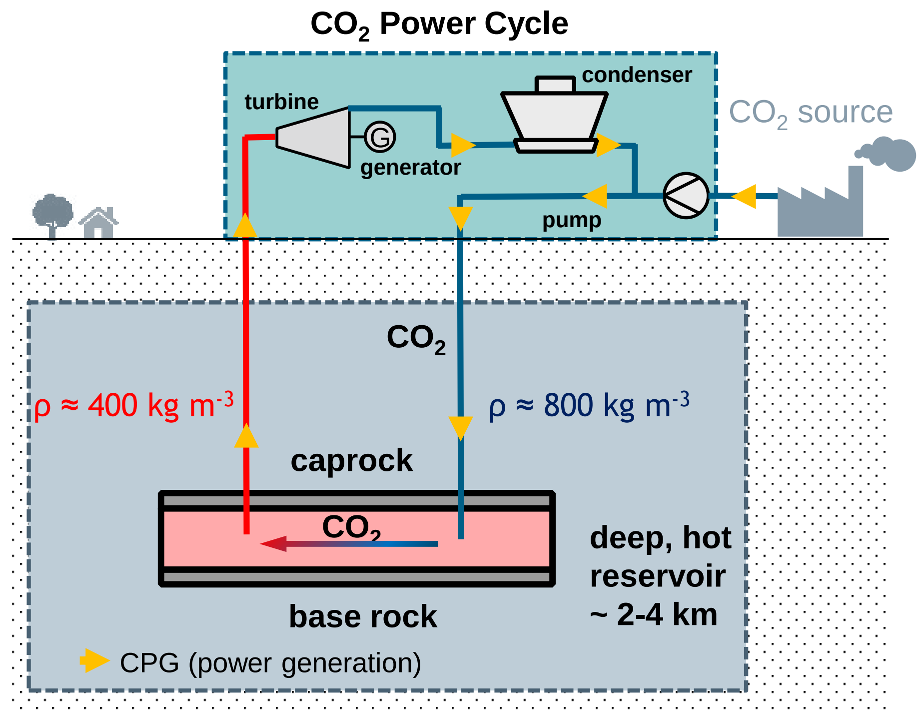
  →**higher mobility**

➢ **Efficient** use of geothermal energy at **lower temperatures**

➢ **More sites worldwide usable** e.g. exhausted oel and gas fields

➢ Direct cycle possible → easy cycle design, **less components**

➢ **Energy storage** of excess renewable power **(CPGES)**



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Agenda

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Technological and scientific challenges - excerpt

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Overall system/ Cycle:

- Conventional **operating and control concepts** cannot be adapted due to over- or near-critical process control and must be redeveloped on the basis of dynamic system modeling
- **Process architectures** must be optimized for the respective applications taking into account the influence of fluid purity and ambient conditions

Materials:

- **Unclear material** behaviour e.g. due to oxidation or carburisation → technical risk, **development of new materials may be necessary**
- **New model approaches** based on experimentally obtained data required for the evaluation of component **lifetime prediction**

Heat Exchanger:

- Suitable approaches for **modelling the heat transfer**, especially in the vicinity of the critical point, must be **identified and further developed** for the design of the internal and external heat exchangers.
- High demands on **heat exchangers** (high efficiency, high surface density, high process parameters) require **new concepts and production processes**.

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Technological and scientific challenges - excerpt

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Turbo machinery:

- **High-precision substance data models** for industrial requirements (processing time) required to adapt design and dimensioning methods for supercritical CO_2
- **New calculation models** for CO_2 specific loss correlations, leakage rates, etc. necessary → Need for experimental data
- **New sealing technologies** are absolutely necessary to increase efficiency potentials. This can necessitate the use of new materials and production technologies, and the influence on the overall system must be evaluated (mechanics, rotor dynamics)
- **New design concepts** must be developed for high thermodynamic performance, low pressure losses at low cost & footprint
- **Modelling of the heat transfer** of supercritical CO_2 necessary to evaluate the tangential operating behaviour

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Agenda

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German research project “CARBOSOLA”

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Objectives / Challenges

Objectives

- Detailed analysis of economic potentials and optimization
- Develop scientific fundamentals for design & simulation incl. CO_2 test rig
- Design of a sCO_2 demonstration plant CO2 cycle (TRL3) for a WHR application

Challanges

- Compressor design due to compression in the critical region of CO_2
- Cost effective heat exchanger due to large heat exchanger surfaces
- Overall plant layout and operational concept

Project data & schedule

Project budget: 3’5 EUR,

Project duration: 3 years

Submit of application: until 31. Jan. 2019

Scheduled project start: 01.Oct. 2019 (confirmation pending)

Development partner

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DLR

Work packages

WP 1
Potential study & optimization
sCO_2-CC (T_{max} < 550 °C)

Responsible: Siemens

WP 2
Potential study & optimization
sCO_2-CSP (T_{max} >6050 °C)

Responsible: DLR

WP 3
Scientific fundamentals for design and simulation of sCO_2-Technologie

Responsible: TUD

WP 4
Component and system design of a WHR demonstration plant

(T_{max} < 500 °C)
Responsible: Siemens

WP 5
Development of sCO2 test rig (>600 °C) for component tests and generic experiments

Responsible: HZDR

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Carbosola & Horizon 2020 as a part of the European sCO_2 Technology Roadmap

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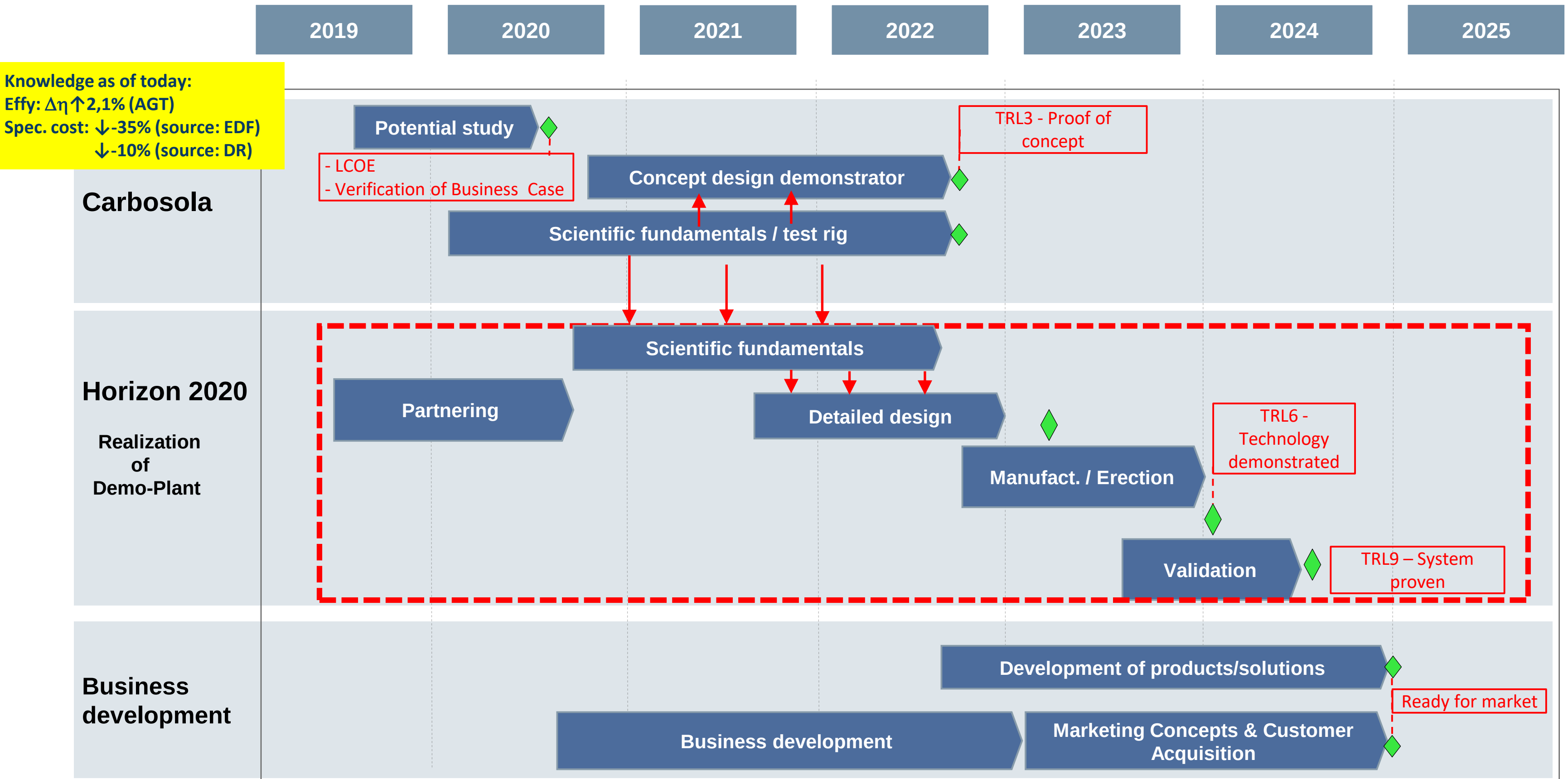

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Horizon 2020
Project Idea Description

Goal: The operation of a sCO_2 demonstration plant

- validates the operability of waste heat cycle,
- verifies the performance of components and
- demonstrates the potential to produce a low LCOE

R&D Activities:

- Turbine and compressor concepts, enhanced design tools, new sealing technologies, advanced blade technology
- High pressure low cost heat exchangers, waste heat recovery units considering limited space, limited pressure drop, harsh fluids and gases
- Process architectures, operational concepts, I&C technology

Budget estimation:

- Starting point TRL3, (results from CARBOSOLA project, applied for at BMWI)
- TRL3-6: 5 M€
- TRL 7-9: 35 M€ (approx. 15 MW)

Partner: …

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Summary

Technology potential	Challenges
• Simple & compact cycle structure • Potential for lower power plant cost • Potential for better performance compared to w/s	• Turbine and compressor concepts including advanced sealing technologies • Optimized cycle architectures considering specific fluid properties • High-performance, high-temperature heat exchangers essential • Operational concept

Next steps

- Provide scientific technological fundamentals
- Develop concept for a sCO2 demonstration plant

CARBOSOLA

- Find partners for cooperation (technical cooperation & financing)
- Generate ideas for potential applications
- Proof of concept / Realization of CPG demonstrator

HORIZON 2020

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Back up

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Next Level Geothermal Power (NLGP)

Life Cycle Scheme of Oil & Gas (O&G) Fields

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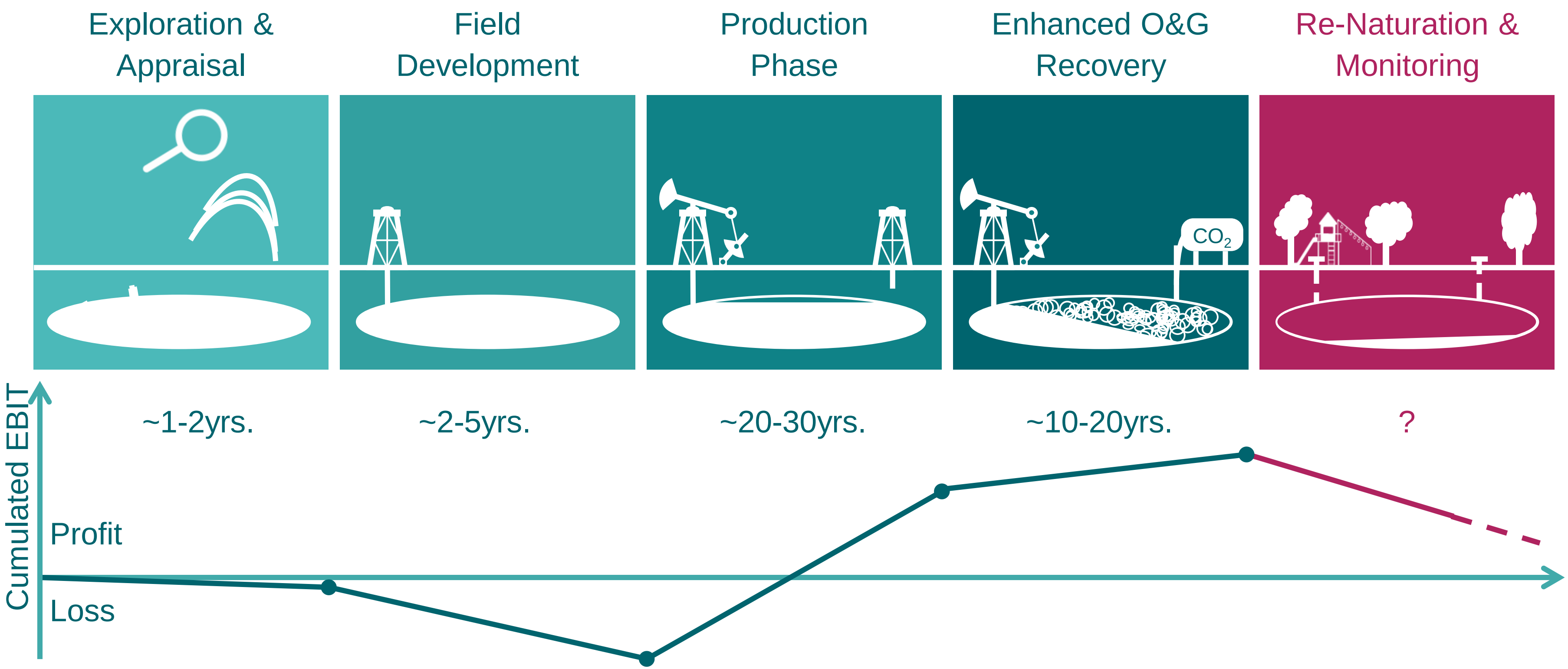

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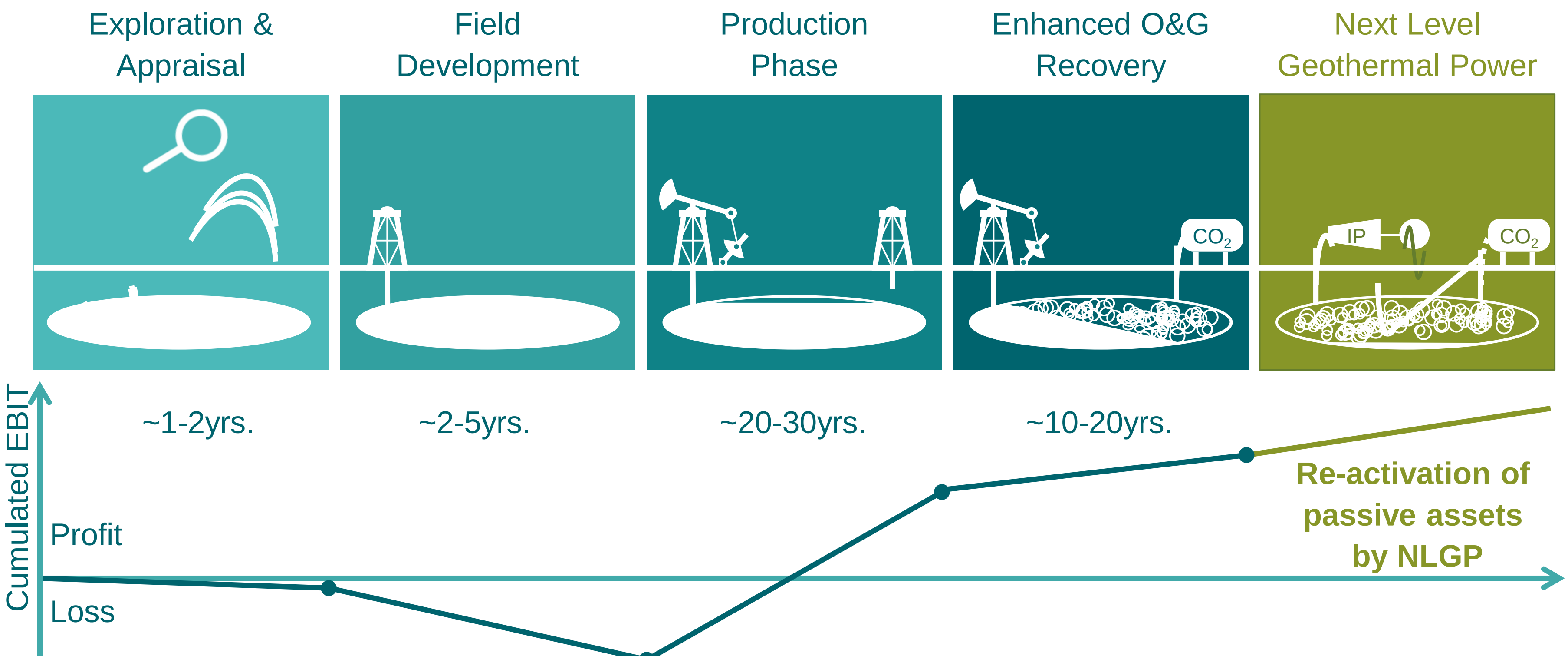
Next Level Geothermal Power (NLGP)
Life Cycle Scheme of Oil & Gas (O&G) Fields



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