The future of sCO_2 POWER CYCLE TECHNOLOGY - EU Perspective

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6th International Supercritical CO_2 Power Cycles Symposium
28th March 2018

A JUMP IN THE PAST

1965 . . .

In Europe,

Italy,

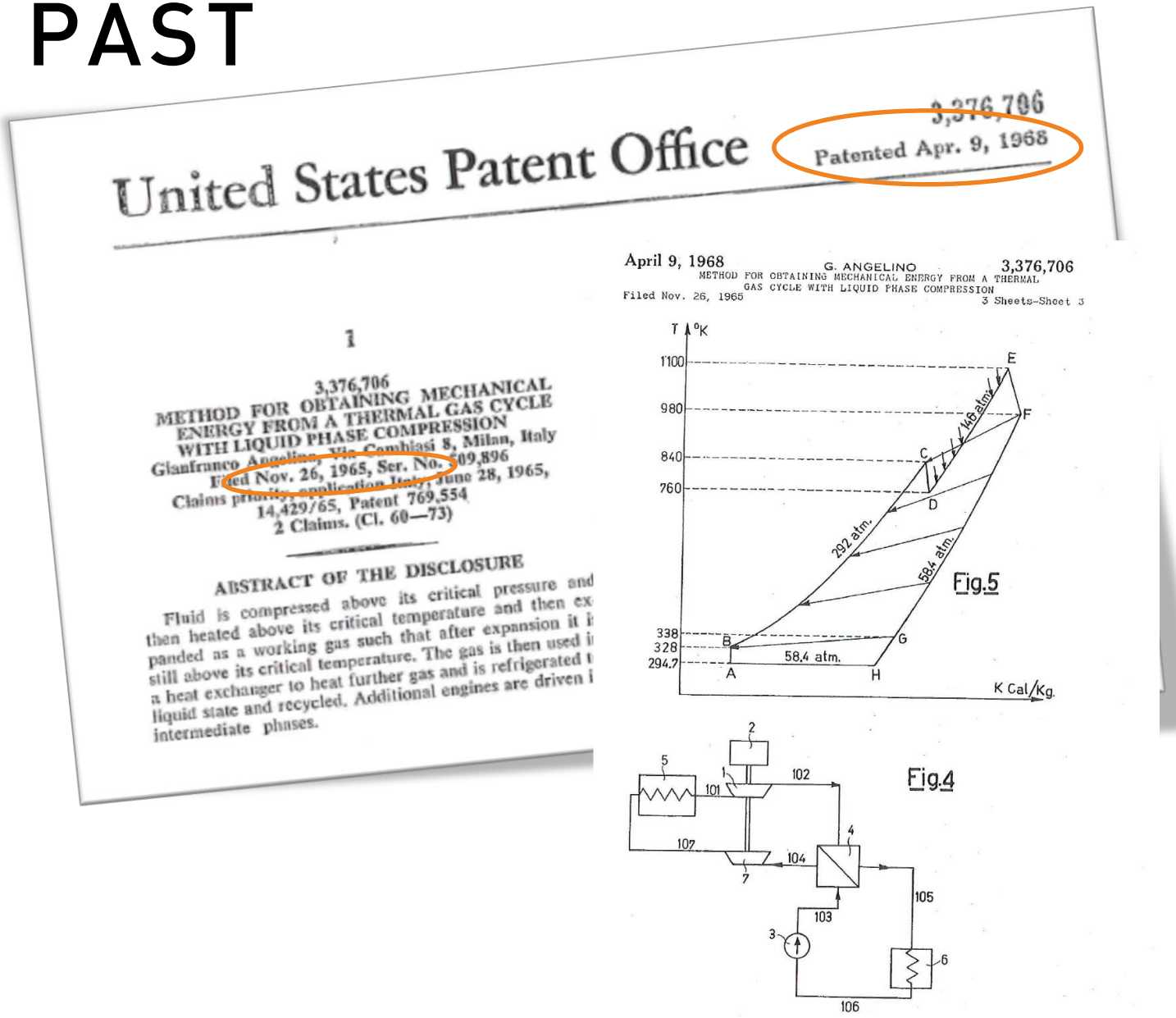
Politecnico of Milan

POLITECNICO
MILANO 1863

A JUMP IN THE PAST

- Back in early 60s, at the Politecnico of Milan, Prof. G. Angelino was already very active on sCO_2 Power Cycles. In 1965 he filed a patent on supercritical power cycles using CO_2 as working fluid. The patent for his idea was granted
- **30 YEARS LATER** I discussed my Thesis on **real gas cycles using organic fluid and CO_2** with Prof. Angelino as my Supervisor.

.... here dates back my first interest in the subject of supercrital CO_2 cycles.



United States Patent Office

3,376,706

Patented Apr. 9, 1968

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3,376,706

METHOD FOR OBTAINING MECHANICAL ENERGY FROM A THERMAL GAS CYCLE WITH LIQUID PHASE COMPRESSION

Gianfranco Angelino, Via Cambiasi 8, Milan, Italy

Filed Nov. 26, 1965, Ser. No. 509,896

Claims priority, application Italy, June 28, 1965, 14,429/65, Patent 769,554

2 Claims. (Cl. 60—73)

ABSTRACT OF THE DISCLOSURE

Fluid is compressed above its critical pressure and then heated above its critical temperature and then expanded as a working gas such that after expansion it is still above its critical temperature. The gas is then used in a heat exchanger to heat further gas and is refrigerated to liquid state and recycled. Additional engines are driven in intermediate phases.

April 9, 1968 G. ANGELINO 3,376,706

METHOD FOR OBTAINING MECHANICAL ENERGY FROM A THERMAL GAS CYCLE WITH LIQUID PHASE COMPRESSION

Filed Nov. 26, 1965 3 Sheets-Sheet 3

Fig.5

Fig.4

AND THEN?

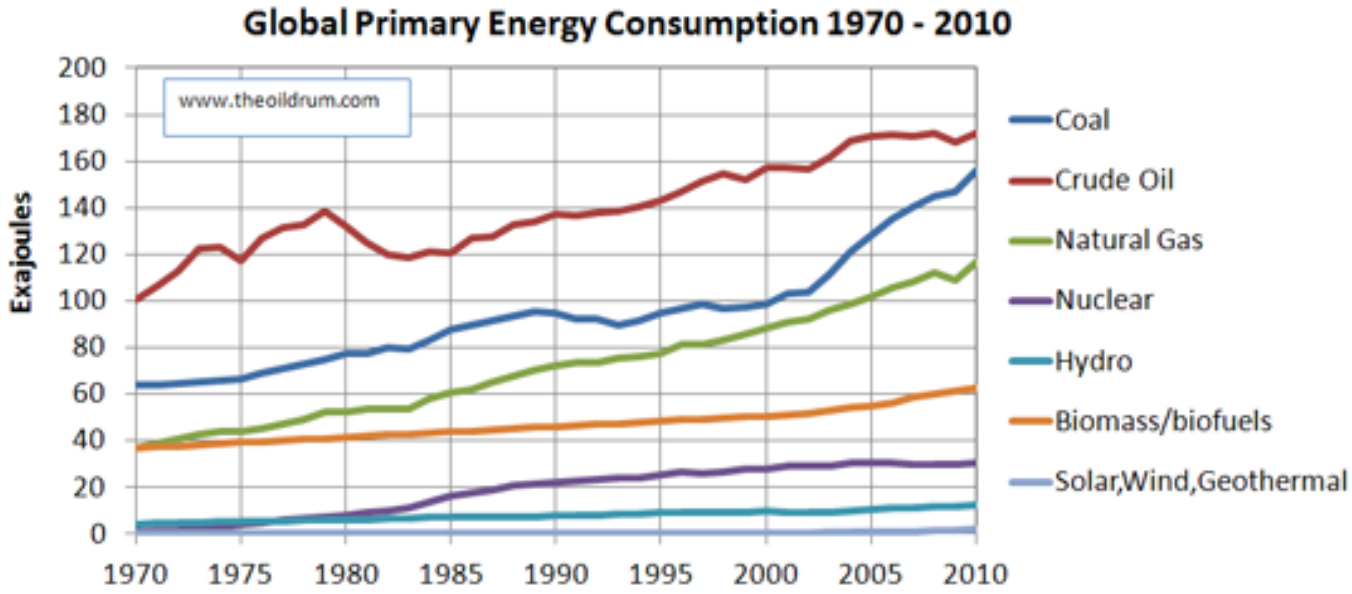
53 YEARS IN THE MIDDLE

1960s

In these years the investigations of Prof. Angelino and Others on the sCO_2 Power Cycles were driven by the interest in Nuclear Power

1970s 2000s

During the following 4 decades the '**Oil&Gas Energy Era**' dominated the market. There was not enough interest to develop a new challenging technology as the sCO_2 technology.



(source: theoildrum.com)

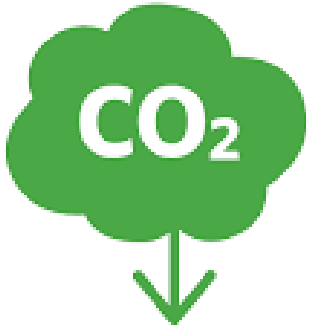
AND THEN?

53 YEARS IN THE MIDDLE

2000s - On

R&D activities on sCO_2 worldwide have been revitalized, with a focus on WHR, Nuclear and Oxy-Combustion and some pilot projects utilizing sCO_2 power cycles came to life.

WHY ?



The **climate change issue,** the increasing rate of **global carbon dioxide emissions** force governments and global Oil & Gas industry to focus attention on new ways for more efficient, **sustainable** and **cleaner power generation**. The sCO_2 power cycle technology can contribute to the solution of the problem. Features like **High Efficiency**, **Compactness** and **reduced Capex** are the potential drivers to make sCO_2 power cycle attractive for many applications**.**

sCO_2 PROJECT IN EUROPE

- In Europe there are much less sCO_2 cycles/engines R&D and Develpment project then in USA and Asia;
- There are a number of small project in the Universities and some project with Industrial players financed by the program Horizon 2020 (like sCO_2-FLEX) , but not big enuogh to build a pilot plant with reasonable scale;

TODAY CONTEXT FOR sCO2

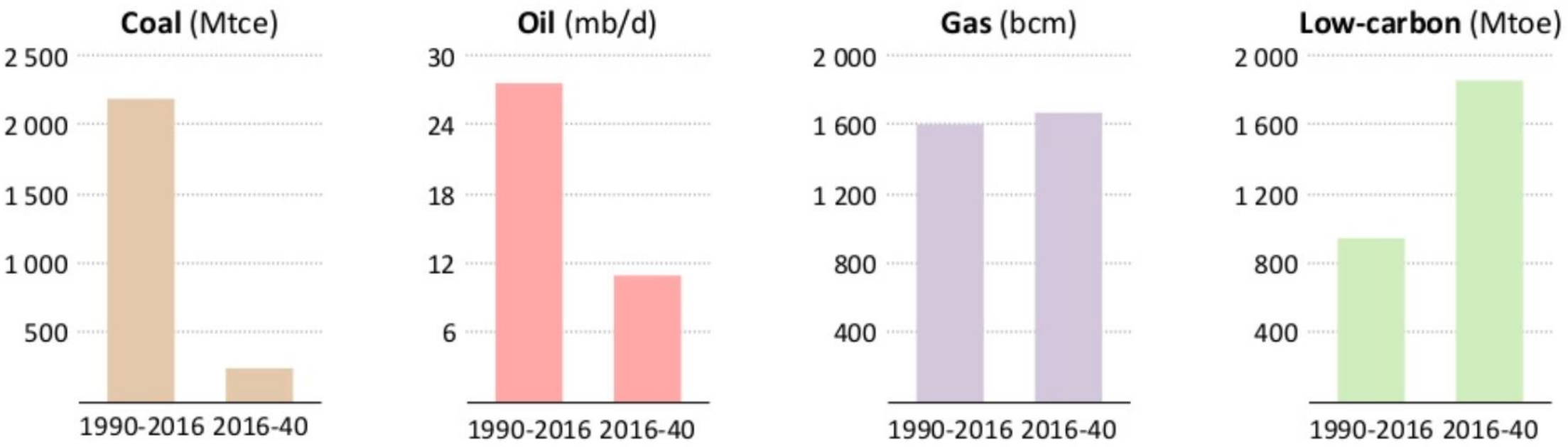
A NEW GLOBAL ENERGY SCENARIO

“ We had the carbon era, we had the oil era, now we are experiencing a new era, the Era of Energy DIVERSIFICATION”

Fatih Birol,
Executive director of the IEA

TODAY CONTEXT FOR sCO2

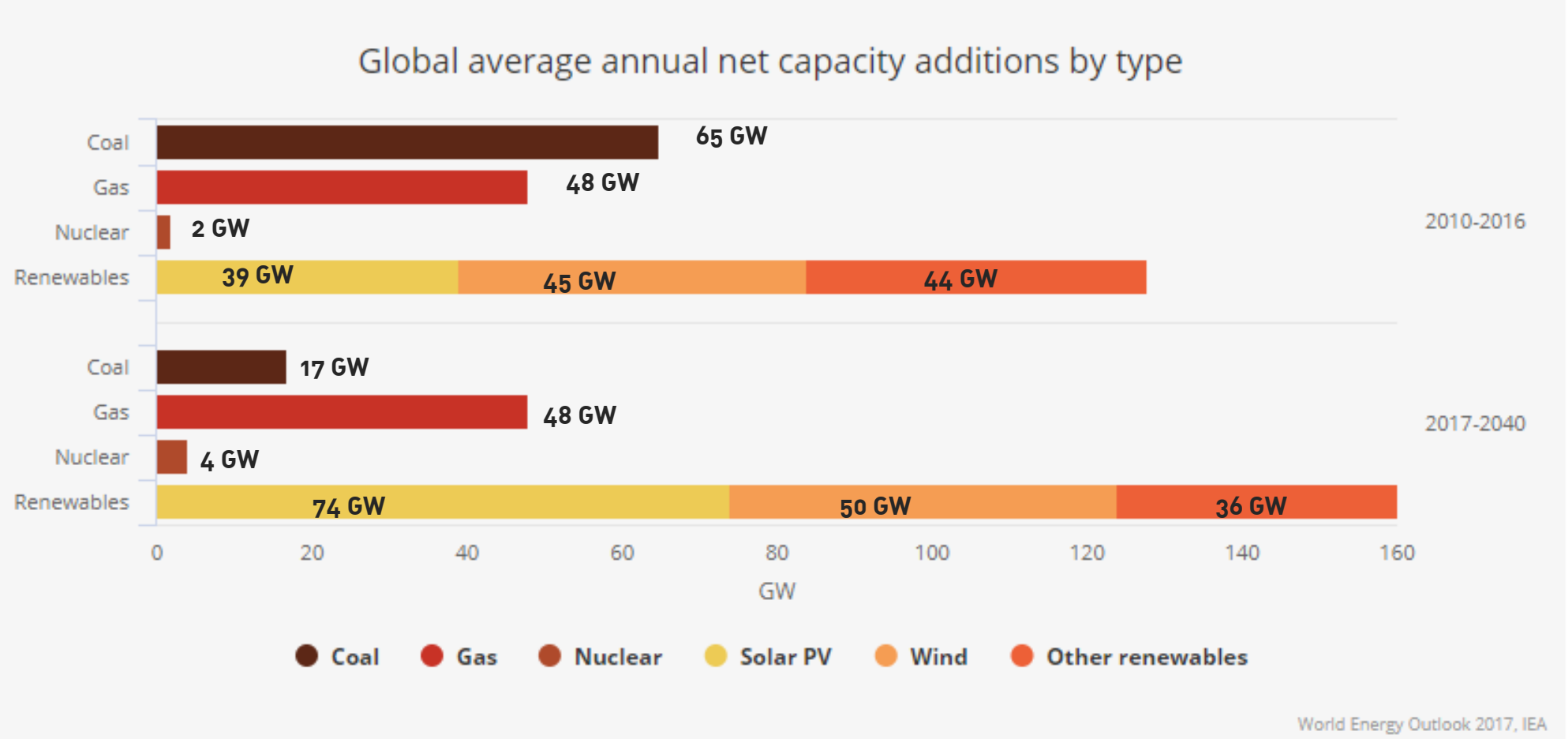
Change in World Primary Energy Demand



(source: World Energy Outlook 2017 - IEA)

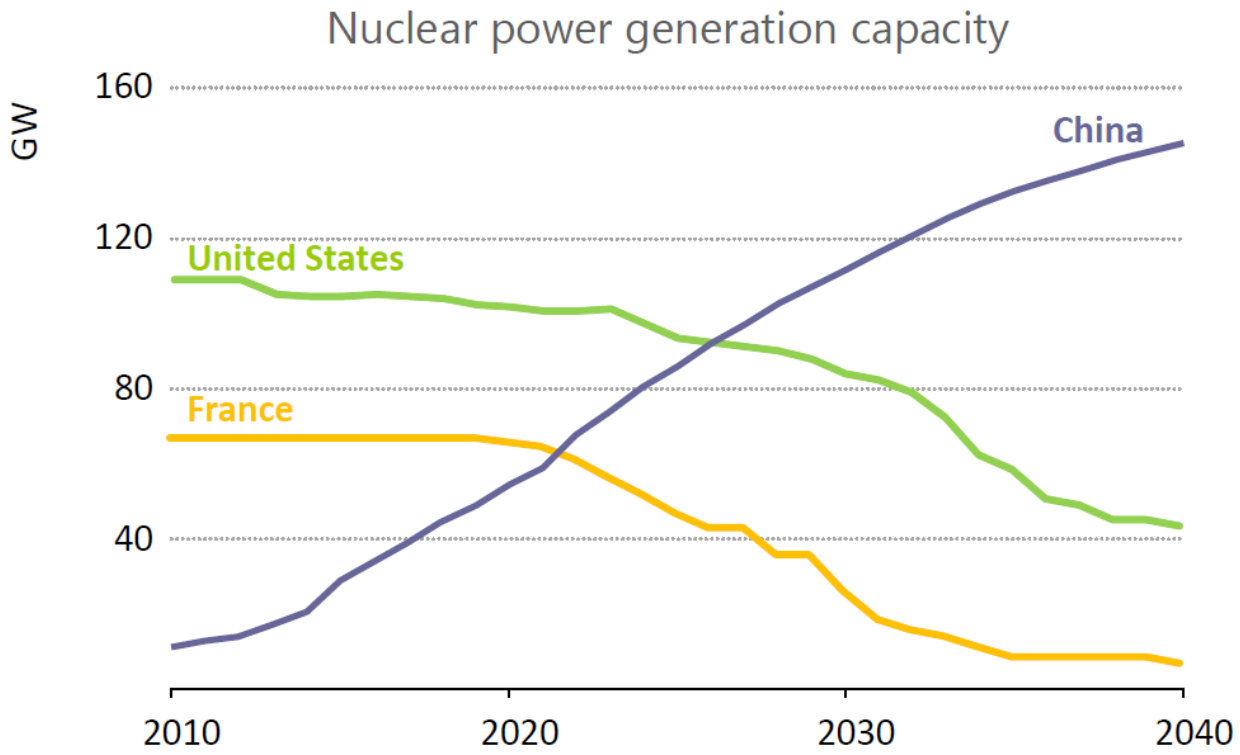
Coal decling, **Oil** decreasing**, Natural gas** and **renewables** will lead the way of the future energy scenario

TODAY CONTEXT FOR sCO2



Natural gas and **renewables** will represent most of the annual capacity addition to the energy system in the coming years

TODAY CONTEXT FOR sCO2



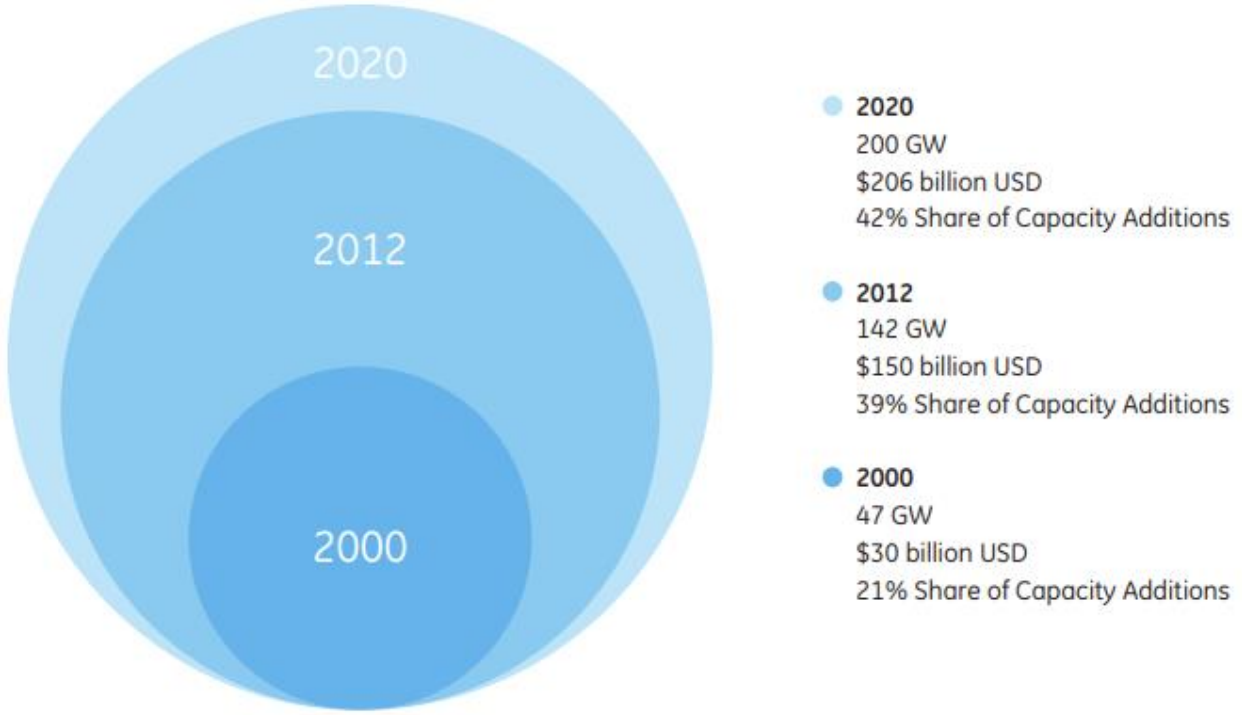
(source: World Energy Outlook 2017)

Nuclear faces significant decline with only China growing and overtaking the US as leader

TODAY CONTEXT FOR sCO2

- In the new era of energy **diversification** there will not be a dominant source for power generation
- Technology needs to **adapt** and be more **flexible** to different sources and conditions
- Flexibility calls for the use of **smaller**, more **efficient** and **less costly** power systems

Trends in distributed power installations and investments



(source: "The rise of Distributed Power" by General Electric Company)

Hence the rise in the last decades of distributed power systems

sCO2 POWER CYCLE FUTURE SCENARIO

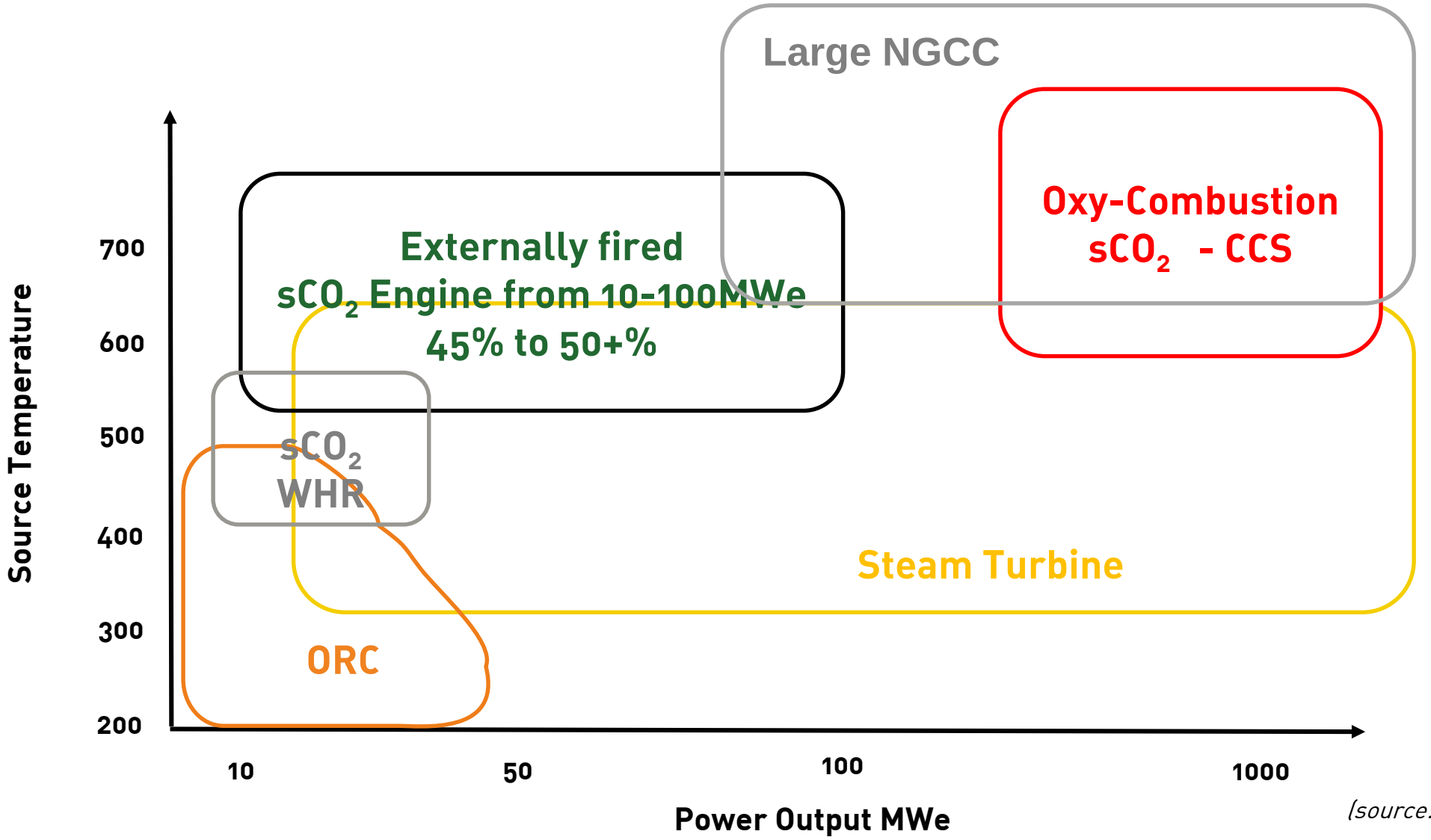
In this context (diversification and more distributed power) sCO_2 power cycle have to take the challenge to be the:

- more **flexible;**
- more **competitive** (higher efficiency, lower capex, lower LCOE);
- **Cleaner** (externally fired with more emissions control)

To play a significant role for **small-medium power plant, required in the market primarily for Natural Gas, but also for biomass, waste, CSP, Flaring, WHR, etc…**

Besides that, another opportunity are the **Oxy-Combustion sCO_2 cycles** with the challenge to make the Carbon Capture and Sequestration technology competitive in term of **LCOE,** and become a solution for utility scale new / substitution plants.

sCO2 POWER CYCLE FUTURE SCENARIO



(source: General Electric)

sCO2 POWER CYCLE FUTURE SCENARIO

In coherence with this scenario sCO_2 technology will have more chances for success in the near future for some applications and not for others.

YES

- WHR (gas turbines)
- Externally fired sCO_2 Engines, with natural gas & other fossil fuel, biomass, CSP, flaring, etc..

NO

- Geothermal

MAYBE

- Utility scale application for fossil fuel with CCS (i.e. Oxy-combustion)
- Nuclear

sCO2 POWER CYCLE FUTURE DEVELOPMENTS

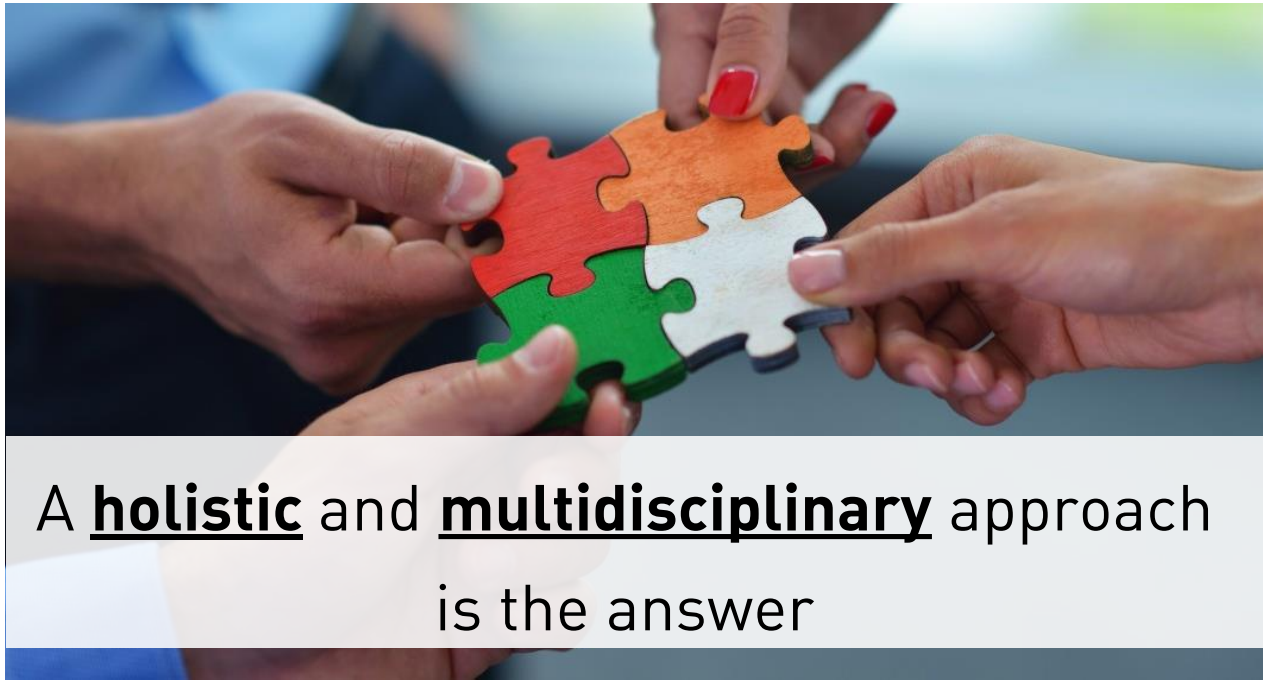
In accordance with the context previously described, in our view next challenge for sCO_2 power cycle technology will be to respond to the market need for:

An externally fired machine for power generation via a sCO2 Closed Brayton Cycle

- In the range **10-100 MWe**
- **↑ 45-50+%** η_e
- **Capex ↓ 0,9$/kW$_e$**
- **Compact** and **flexible** and **Clean**

sCO2 POWER CYCLE FUTURE DEVELOPMENTS

WHAT IS THE WINNING STRATEGY FOR THIS CHALLENGE?



1. While components vendors will keep their attention on the R&D for **single components** of the cycle
2. **sCO2 Engine** Manufactures should **focus** on **the machine** as **a whole**
3. **follow** the **evolutionary path** of other technologies in the power market (i.e. Gas turbine) from **complex plants** to **single compact machines**.

sCO2 POWER CYCLE FUTURE DEVELOPMENTS

EXAMPLE – EVOLUTION OF MACHINE TECHNOLOGY

Drawing of first gas turbine on the market: a set of separate components

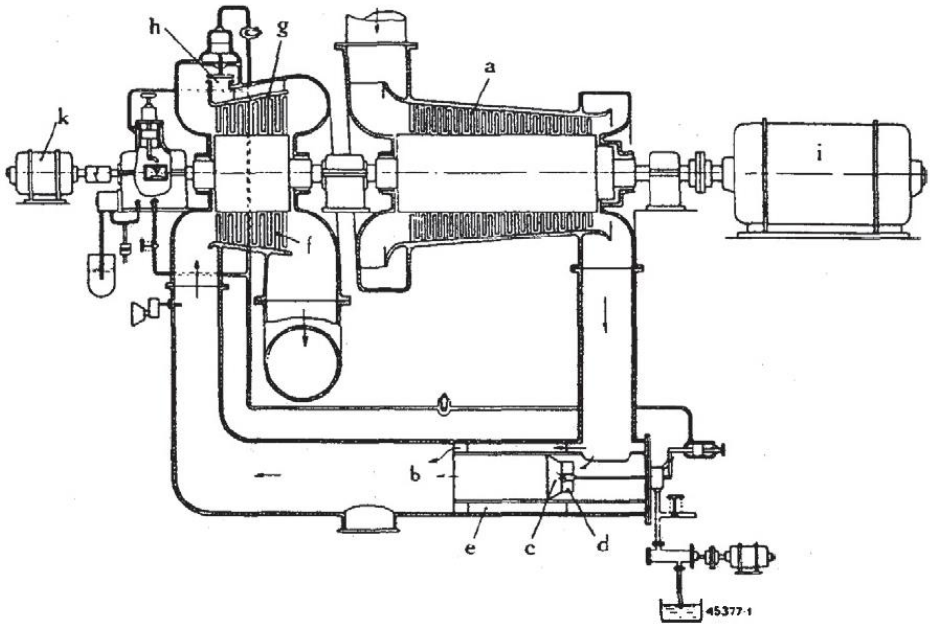


Fig. 3. Diagram of the simplest form of combustion turbine plant. With reaction type gas turbine and axial compressor for oil fuel, and with excess air cooling.

a. Axial compressor
b. Combustion chamber
c. Combustion nozzle
d. Burner
e. Cooling-air jacket
f. Gas-turbine blading
g. Gas turbine
h. Safety valve
i. Generator
j. Starting motor

Source: Alstom - The world first Industrial Gas Turbine set at Neuchâtel (1939)

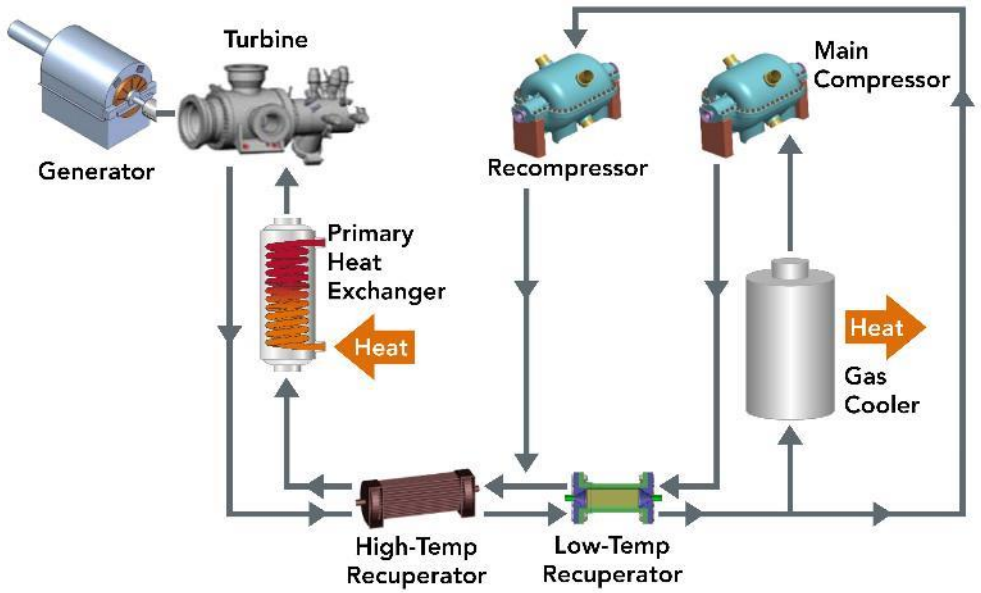
A modern gas turbine : all components are integrated in a single compact machine

Source: Rolls Royce

sCO2 POWER CYCLE FUTURE DEVELOPMENTS

EXAMPLE – EVOLUTION OF sCO2 TECHNOLOGY

sCO_2 power cycle system is made up by different separated machine



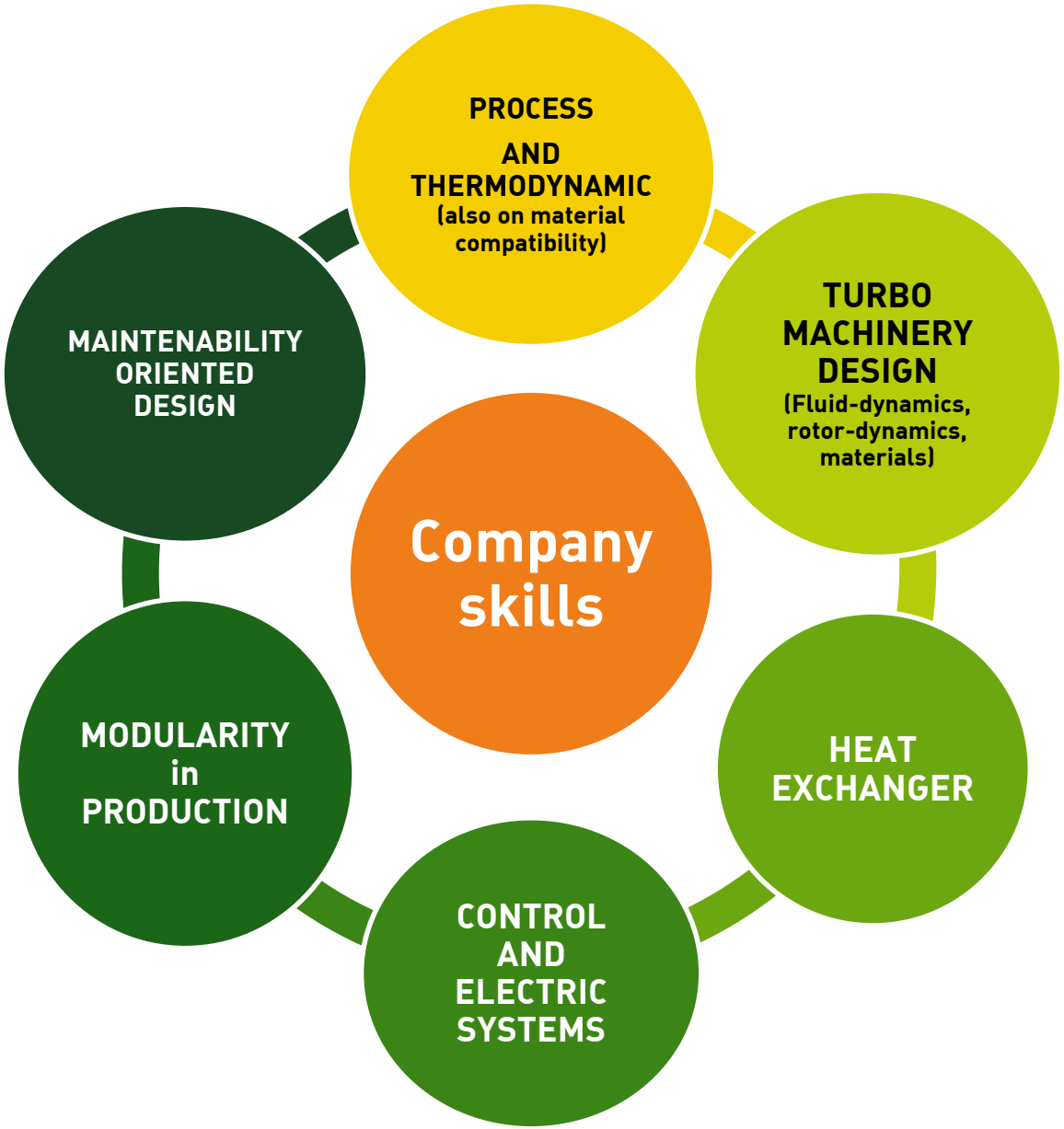
The technological evolution should be able to integrate all the cycle components in a single designed machine

sCO2 POWER CYCLE FUTURE DEVELOPMENTS

WHAT ARE THE CONDITIONS TO SUCCEED IN APPLYING THIS APPROACH?

- **Flexible approach** and **vision**, with **Multidisciplinary know how** and **comprehensive** technical and organizational **skills** inside the company

In-House competencies and resources are crucial for quick and flexible approach to product development



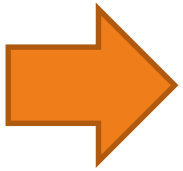
CONCLUSIONS

IF

- Focus on the applications with more chance for success
- Apply the right approach to the development of the machine, having in-house know how and skills;
- More investment will be available to the sCO_2 power cycle development

CONCLUSIONS

THEN ..



even in this Energy Diversification Era , sCO_2 Power Cycle could become the technology replacing **steam, internal combustion engines** and **small combined cycle gas turbines** finding application in:

- **fossil distributed power systems**
- **biomass and waste**
- **naval transport power systems**

GREEN POWER
THROUGH INNOVATION

THANK YOU !

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