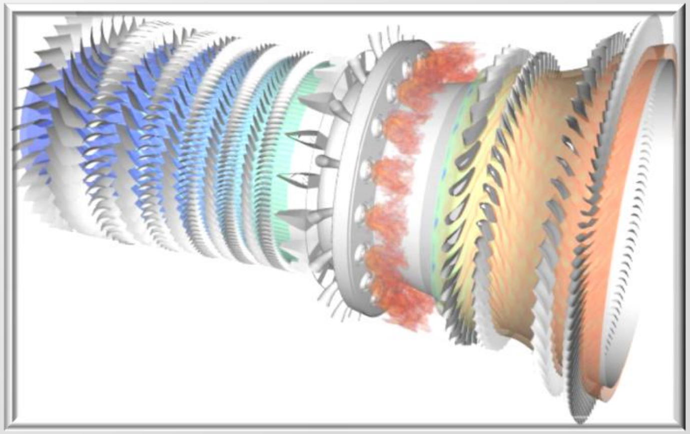
RICERCA DI SISTEMA ELETTRICO

MINISTERO DELLO SVILUPPO ECONOMICO

Accordo di Programma MiSE-ENEA

ENEA AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBILE

Flexibility and Combustion Stability in the Near Future Scenario of Gas Turbines



Eugenio Giacomazzi

ENEA, Sustainable Combustion Processes Laboratory

Roma, 24 June 2015

Sustainable Combustion Processes Laboratory

Outline

- Power generation scenario
  - CO_2 emissions, European energy policy and our research topics
- "Combustion Instabilities"
  - What they are and what they cause
  - Fuel flexibility: practical examples from GT users
- "Advanced Supercritical CO_2 Cycles"
  - Load flexibility: practical examples from GT users
  - Why do we need S-CO_2 cycles?
  - Panorama of S-CO_2 projects funded by DOE in US
- ENEA's activities in Europe and in AdP-PAR2014
- Conclusions

Present Global CO_2 Emission Scenario

- In 2014 the global emission of CO_2 did not rise for the first time in 40 years [Faith Birol, IEA chief economist, March 2015].
  - Quite remarkable since the global economy grew by 3%.
  - This reduction is mainly due to:
    - a lower energy consumption in China;
    - a major shift from coal to natural gas in the US;
    - an increased overall use of natural gas in Asia;
    - an increased LNG demand in Asia over the last decade as a result of economic growth and the need to curb air pollution.

- But in Europe …

Power Generation Future Scenario

- EU Energy Roadmaps and its Drawbacks -

CO_2 Reduction
40%* by 2030
80-95% by 2050

≠

Increased GT Emissions

- More CO_2: 8% / MWh
- More CO
- More NO_x

- ❑ Increasing Share of Renewables
- ❑ Low or Carbon Free Fuels
- ❑ CCUS

↓

- ❑ Stability of the Electrical Grid
- ❑ Gas-Fired Power Capacity at Risk
- ❑ Combustion Dynamics

Unpredictable load variations (2013 data)
- Spain: 13 GW (daily)
- Germany: 25 GW (daily)
- National load ramps of 5 GW/h

Idled or closed plants (2013/14 data)
- 14% (24.7 GW) of EU installed capacity idled, closed or at risk in 2013
- Up to 50 GW may be closed by 2015/16 [CEDIGAZ, 2014]

Failures and unexpected overhauls
- Mainly due to fuel-variation

*Compared to 1990

DMSP/OLS

ENEA

Needs Upon This Scenario and Motivation of Our Research Topics

"Dynamics, Monitoring and Control of Combustion Instabilities"

operational flexibility

- Increase fuel- and load- flexibility of present GT power plants, and thus their efficiency, maintaining safe and reliable operation with low pollutant emission.

- Integrate renewable and GT back-up power plants.

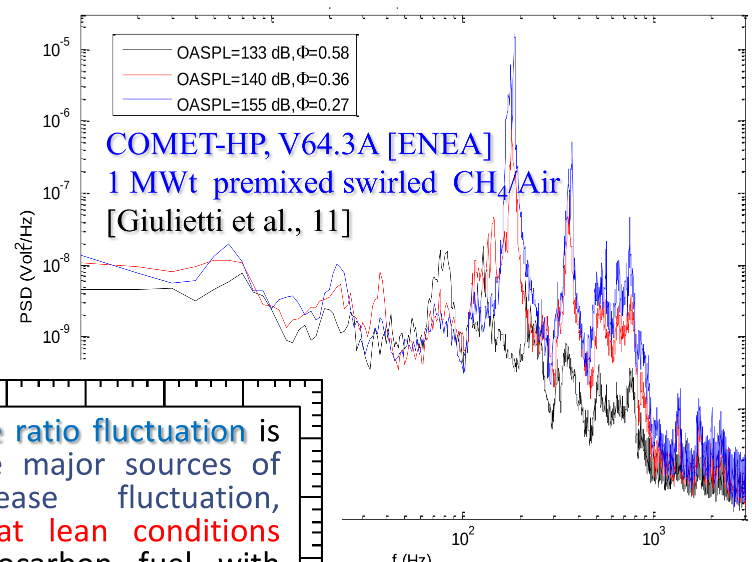
- Identify new more flexible GT cycles including highly integrated and cost effective CCS.

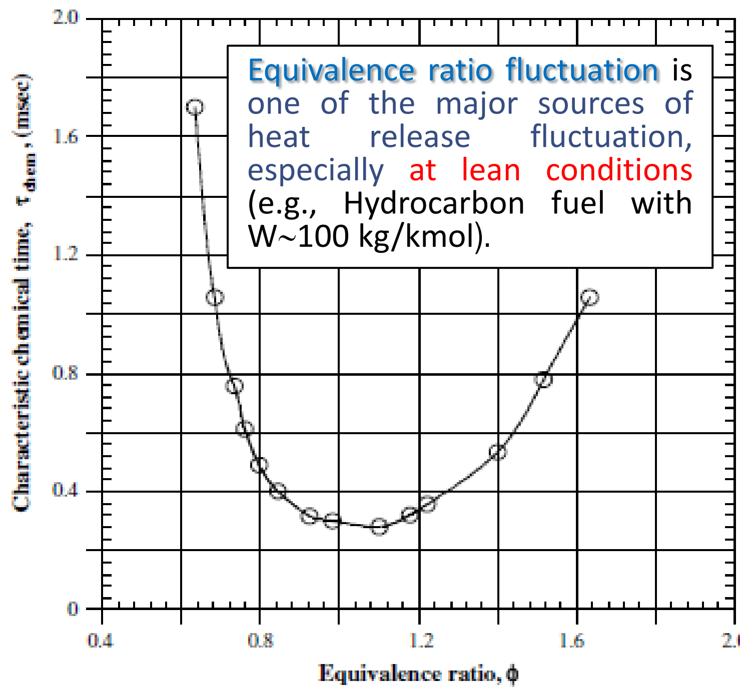
"Advanced Supercritical-CO_2 Cycles"

Dynamics, Monitoring and Control
of
Combustion Instabilities in Gas Turbines

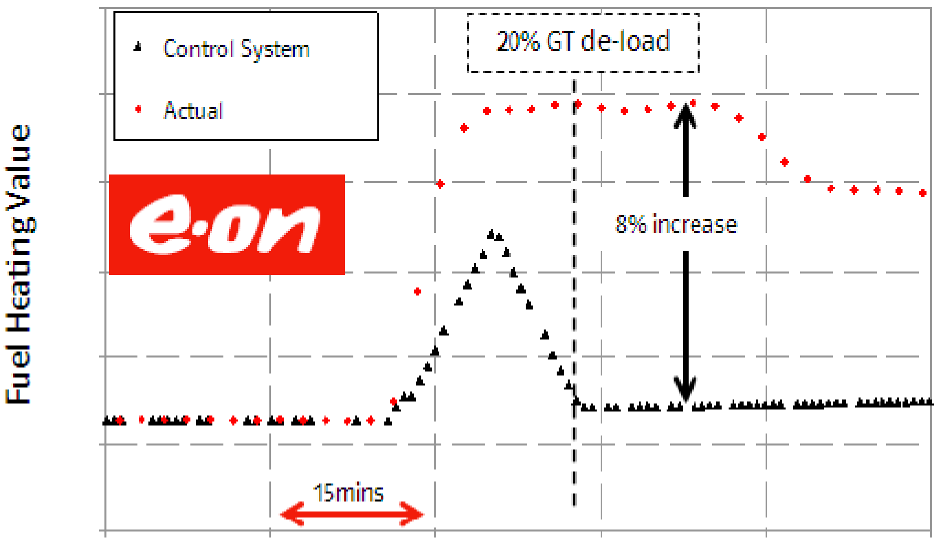
Lean Premixed Combustion and Its Drawbacks

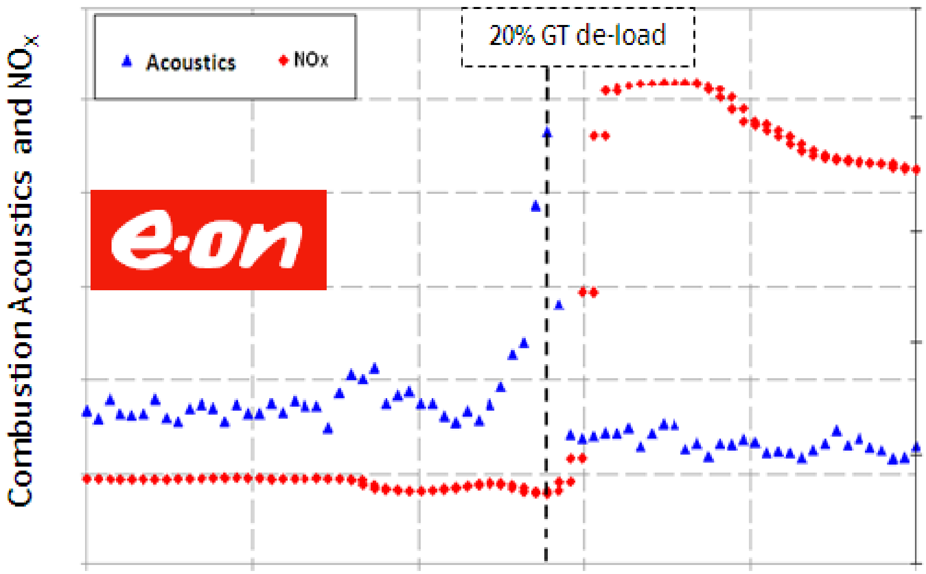
- Lean-PreMixed (LPM) and Lean-Premixed-Prevaporized (LPP) combustion: state-of-the-art technologies in stationary GTs for highly efficient low emission power generation.
- Drawbacks: noisy large amplitude pressure fluctuations (>1-10% P_c, mean chamber pressure), known as thermo-acoustic (operational) combustion instabilities.
  - Interference with engine operation (flashback and Lean Blow Out).
  - Vibrations in mechanical components.
  - Failure of the system, due to cyclic mechanical and thermal loads to the walls and turbine blades.
- Due to resonance of heat release oscillations with the combustion chamber acoustics.





Effect of Fuel Composition Changes



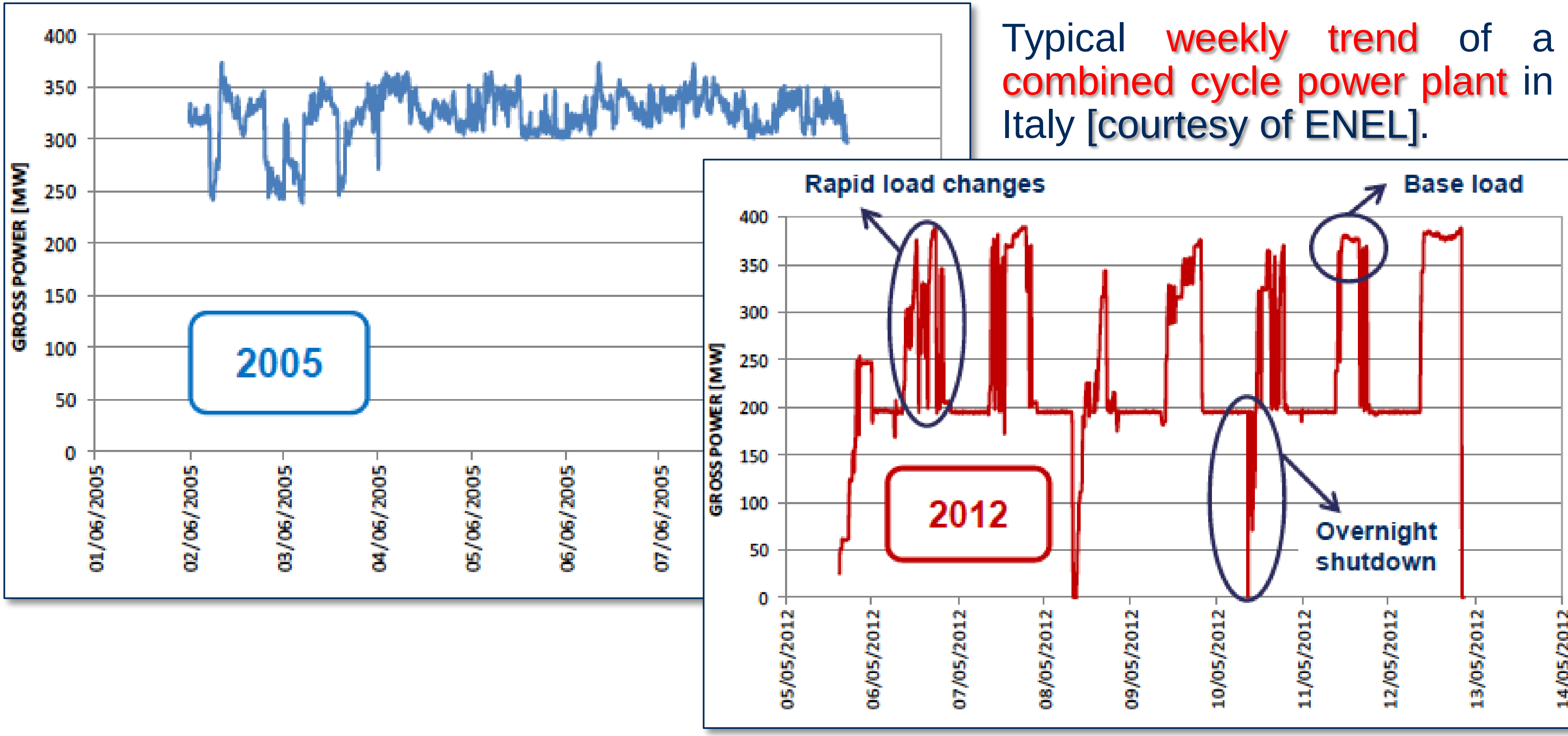


Aero derivative GT in a Combined Heat & Power application

- Several de-loads/trips: large variations in fuel composition, probably due to the close proximity to a gas storage facility.
- Rapid (<8 min) 8% increase in the measured fuel heating value.
- Control system: reversed to default, causing incorrect fuel splits.
  - 90% noise increase.
- 20% de-load: imposed by the control system due to the high dynamics.
  - Strong NO_x increase due to incorrect fuel splits.
- Mitigation: change of the control constants.

Advanced Supercritical CO_2 Cycles

CCGT Operation
in the Current Renewable-Dominated Scenario

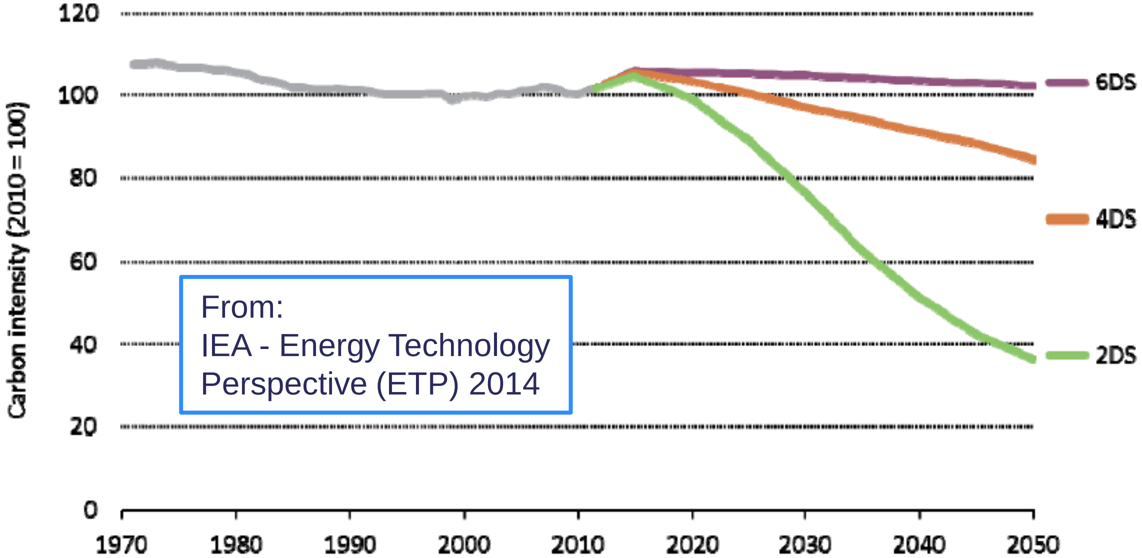


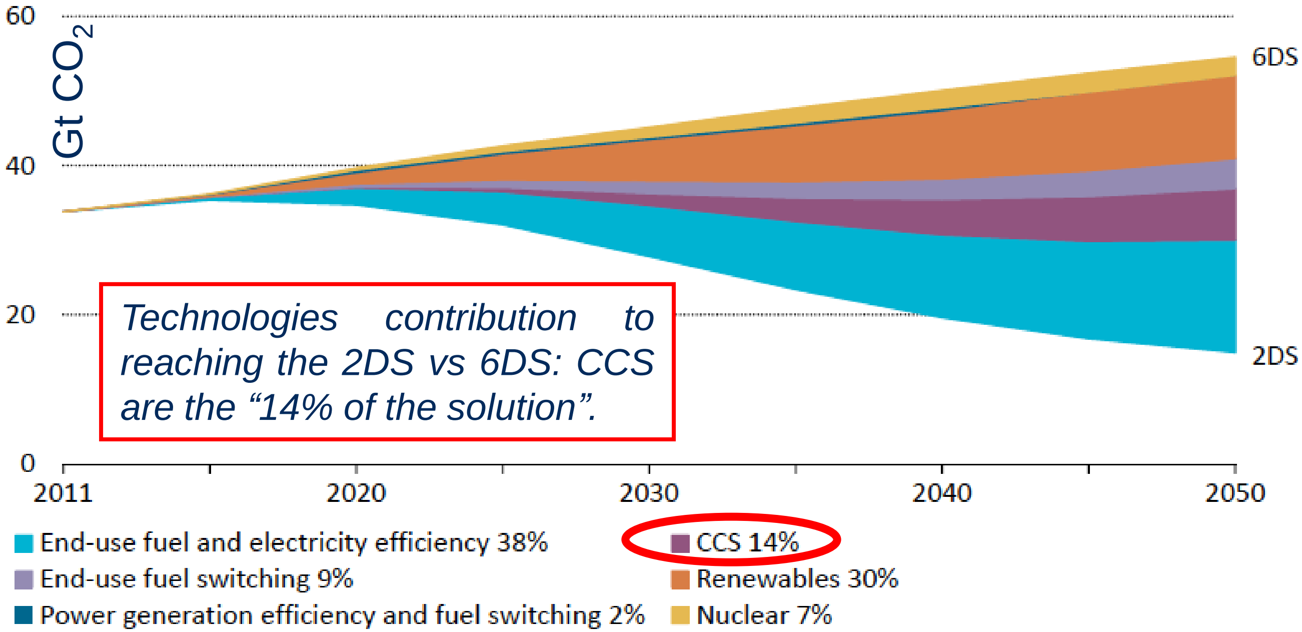
Typical weekly trend of a combined cycle power plant in Italy [courtesy of ENEL].

- Power plant operation in 2012, with respect to 2005, shows an increased number of start-up / shutdown cycles, reduced operation at base load, and operation at minimum environmental load during night time.
- The scenario would be worst if weakly flexible CCS were implemented.

The Importance of CCS in Current CO_2 Scenarios

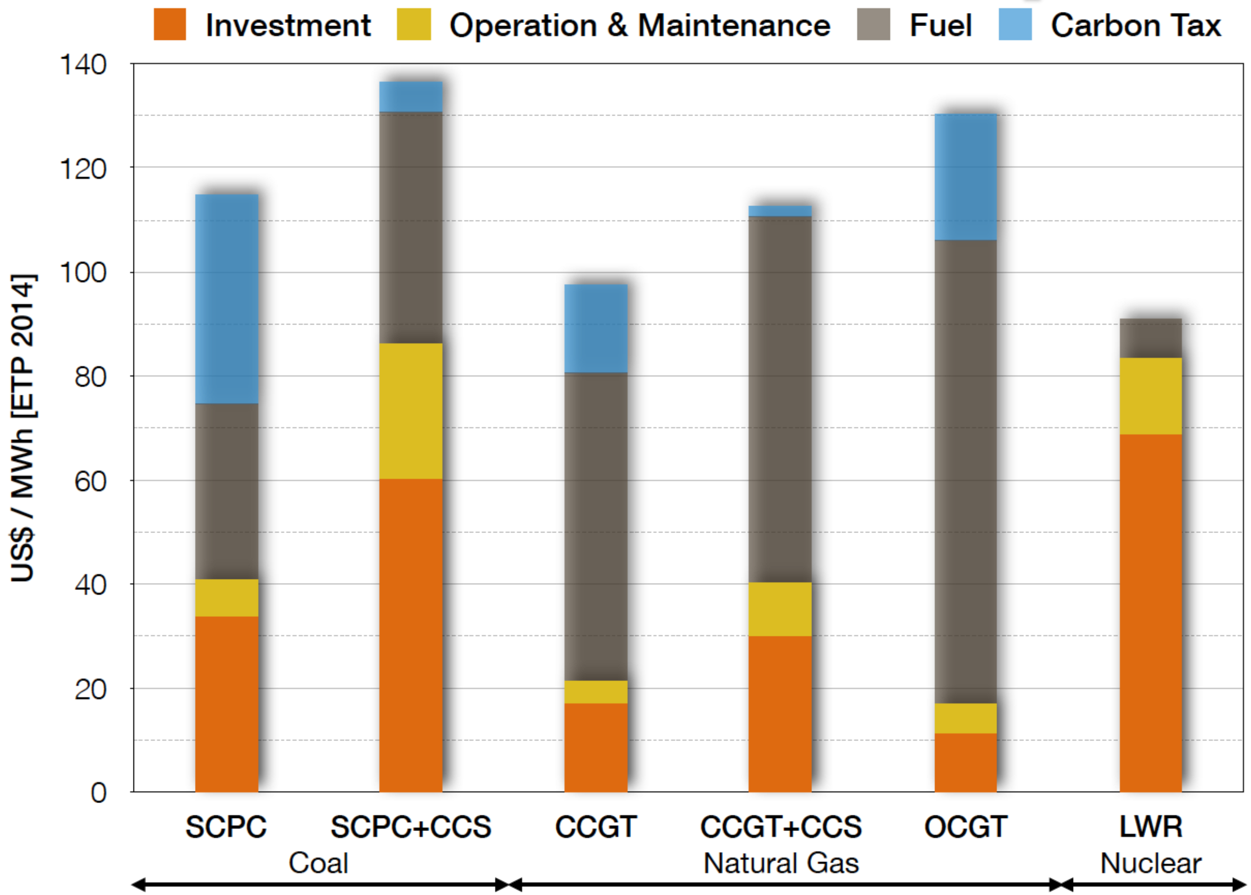
- From 2009 to 2050 global final **electricity demand** nearly doubles.
- Both conventional and unconventional **natural gas** continue to play an important role in power generation until 2050.





- **CCS** is a **key technology** to make sustainable the energy demand from fossil fuels.
- CCS **deployment** is occurring **too slowly** due to high costs and a lack of political and financial commitment.

CCS and Current Power Plants [ETP 2013/14]



- From the point of view of the final cost of electricity (assuming a carbon tax), CCGT are more competitive than SCPC plants, with or without CCS [ETP 2014], …

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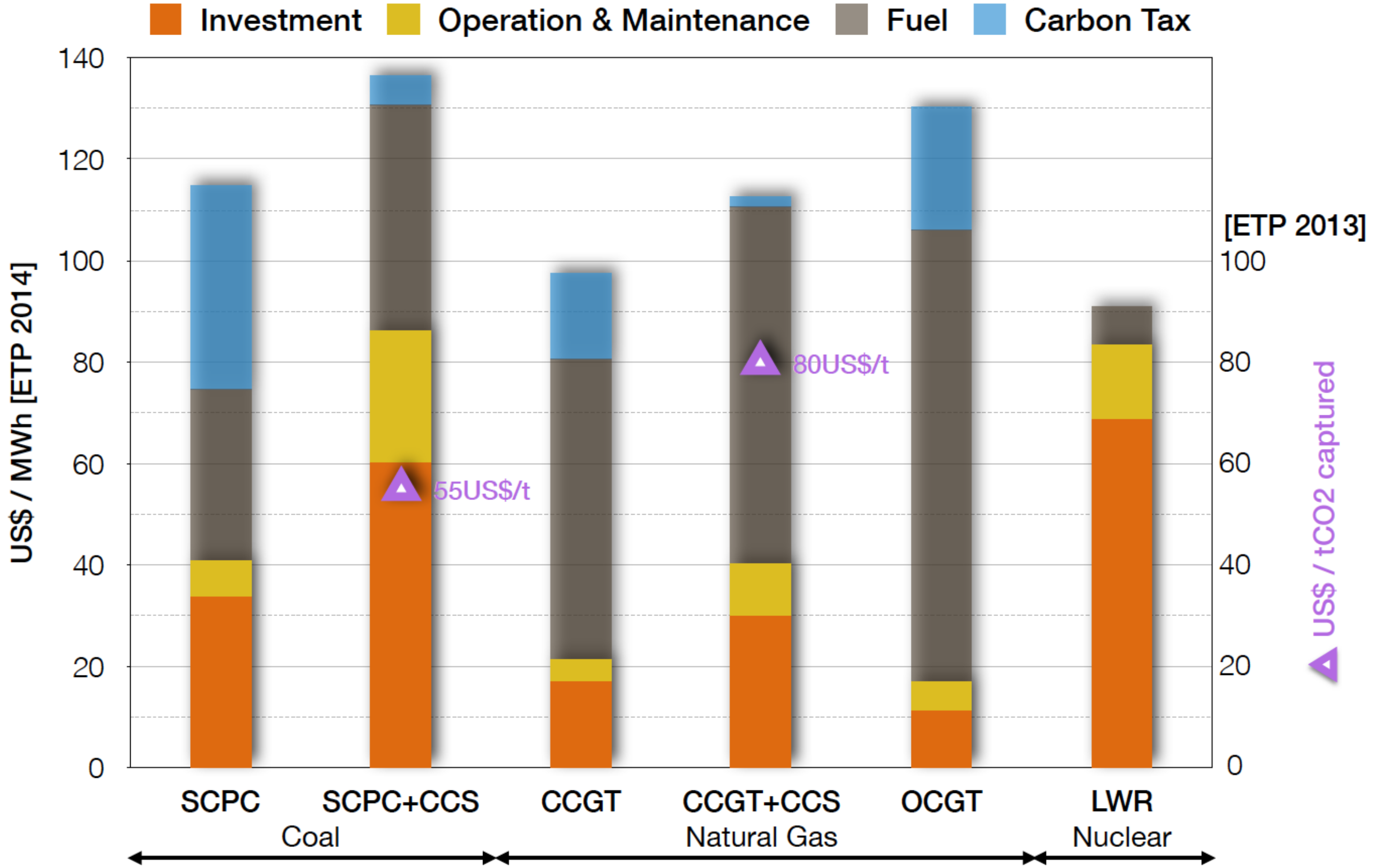

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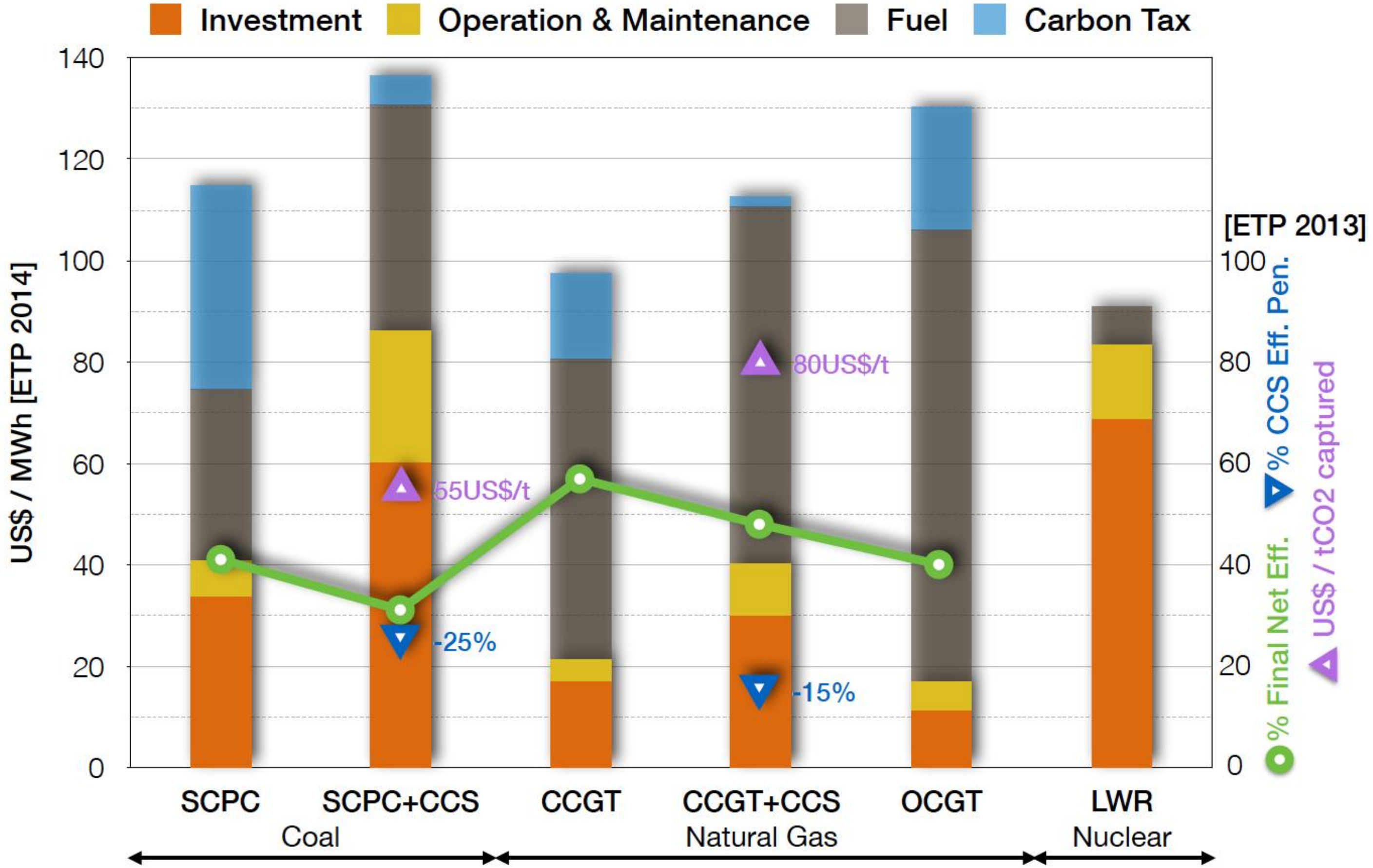

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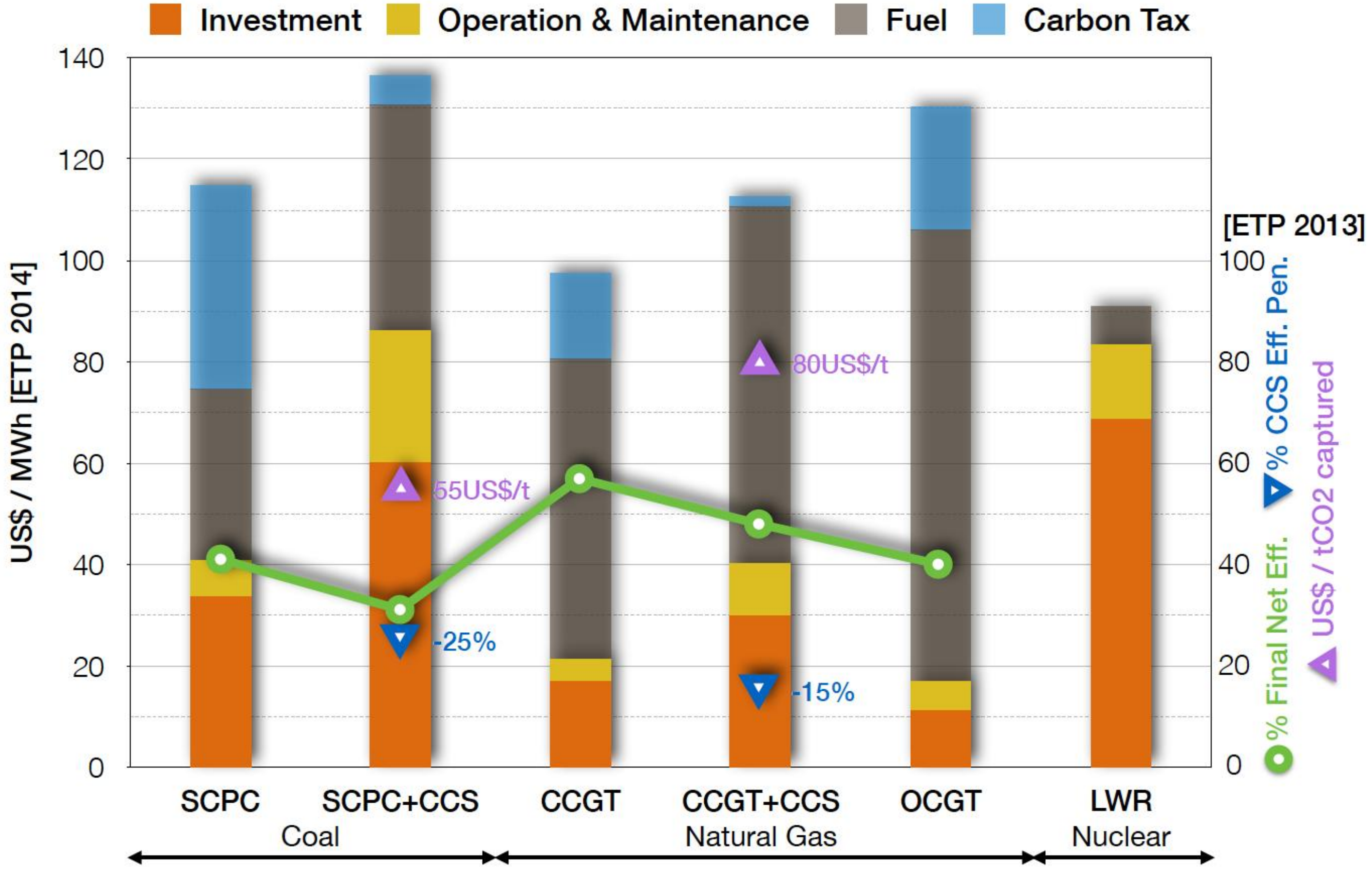
- … although the cost of CO_2 captured (US$/t$CO_2$) is lower for coal plants.
- This since both the relative net efficiency penalty due to CCS (%) and the final net efficiency with capture (LHV, %) favour CCGT [ETP 2013, OECD countries].

CCS and Current Power Plants [ETP 2013/14]

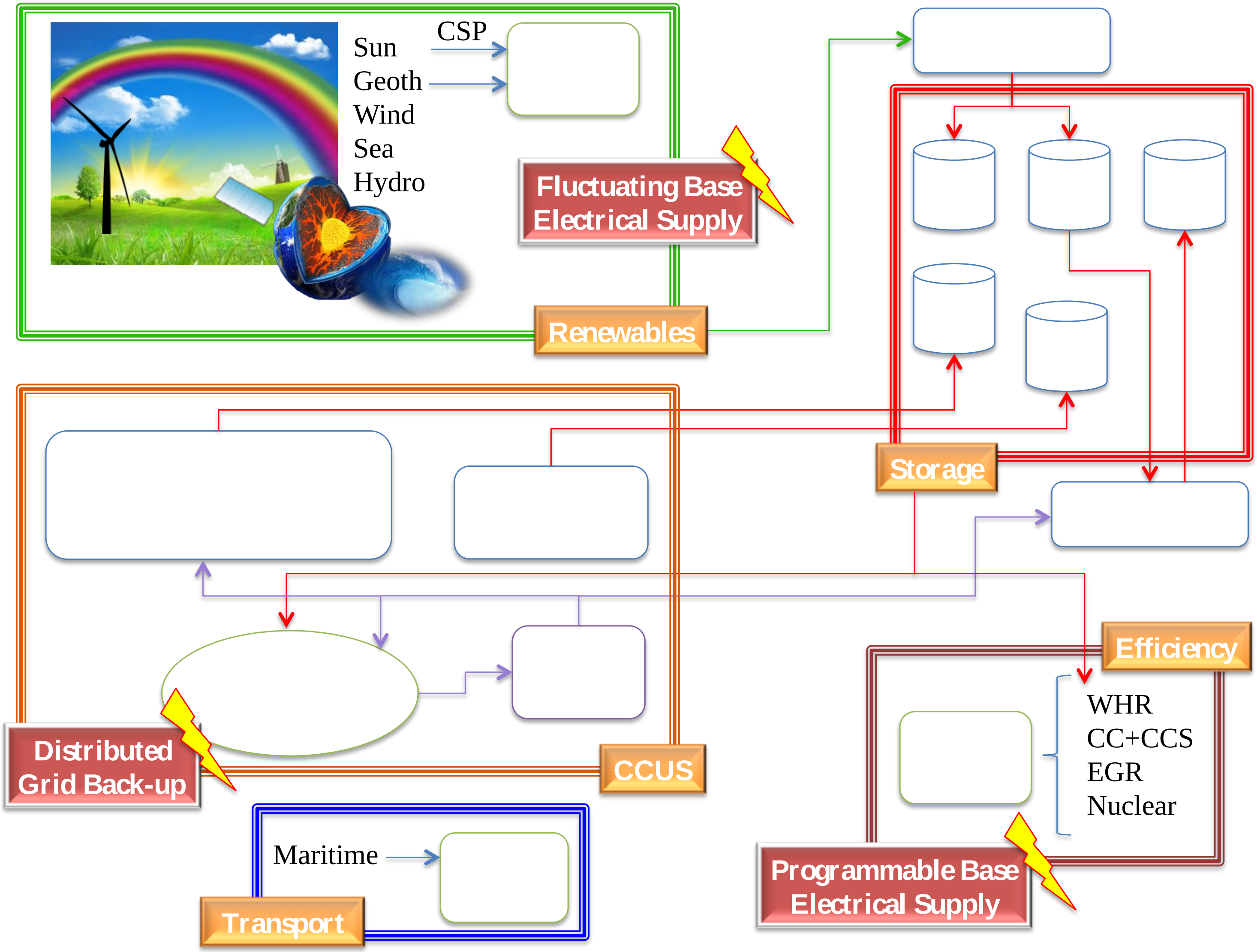


- Hence,
  - Invest in CCGT plants with CCS (trying to reduce the 80US$/t CO_2).
  - Could there be some new, more competitive and flexible technologies? We really believe in YES!

Why S-CO_2 Turbine Cycles?

- **Concept**: load-flexible, compact and efficient GTs using S-CO_2 as working fluid.
  - Semi-closed cycles with oxy-combustion
    - ✓ Near-zero emission GT back-up power plants.
    - ✓ High base-load efficiency (>50%), including a highly integrated and cost effective CO_2 capture strategy, oxygen production and pressure losses.
    - ✓ "Pipeline ready" CO_2 stream: sequestration, enhanced oil/gas recovery.
    - ✓ Efficiently operated at partial load by lowering both the fuel mass flow rate and operative pressures.
    - ✓ More efficient and flexible partial load operation, not any longer related to environment constrains.
  - Closed cycles
    - ✓ Adaptable for Waste Heat Recovery (e.g., in nuclear), Concentrated Solar Power and geothermal applications.
    - ✓ Useful to enhance the flexibility and efficiency of current CCGT power plants, by replacing their steam section.
- **Integrated vision**: Power to Gas, methanation, water free shale-gas extraction.

S-CO_2 Exploitation in Our Integrated Vision



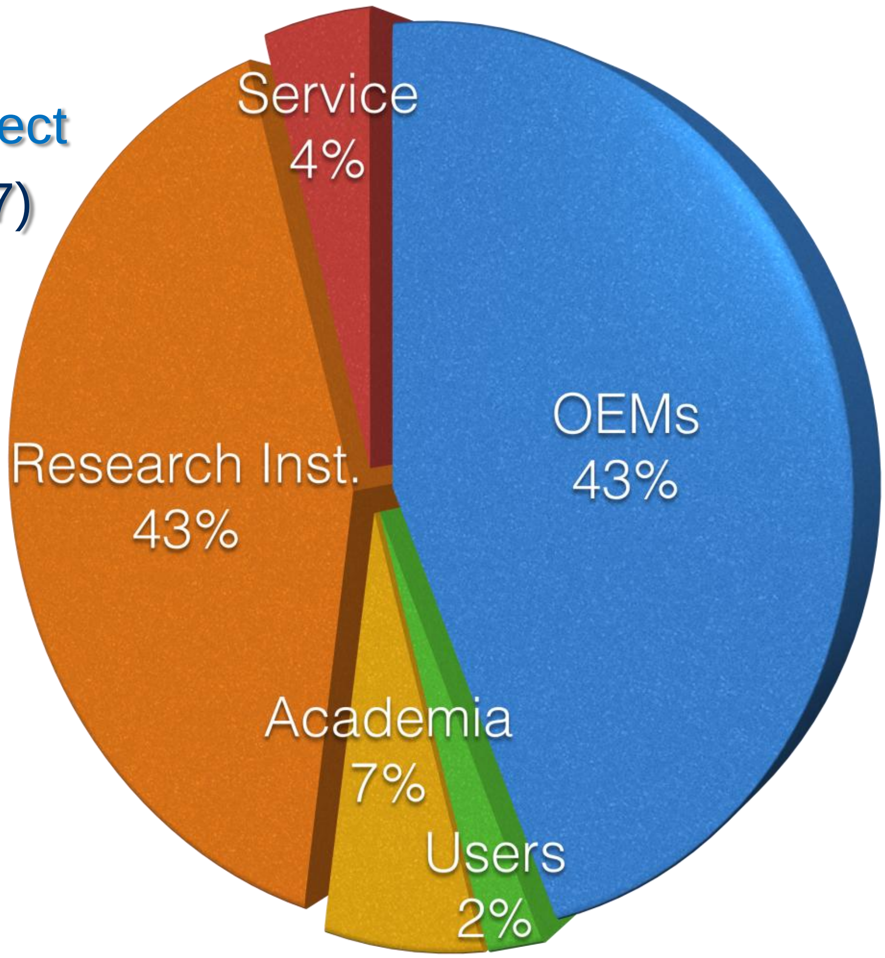
DOE [US] Projects on Indirectly and Directly Heated S-CO_2 Gas Turbine Cycles for Efficient Power Generation

- DOE Share: 44M US$
- Performers Share: 10M US$
- Number of Projects: 29
- Time: 2014-2016
- Sponsoring Organisations: NETL, DOE ARPA-E, EERE, SANDIA

- Applications:
  - (fossil, renewable, nuclear) electrical generation
  - naval transport
- Indirect Heating: waste heat recovery, solar, nuclear
- Direct Heating: oxy-combustion (gaseous fossil fuel and coal)
- Efficiency: higher than 52% including CCS

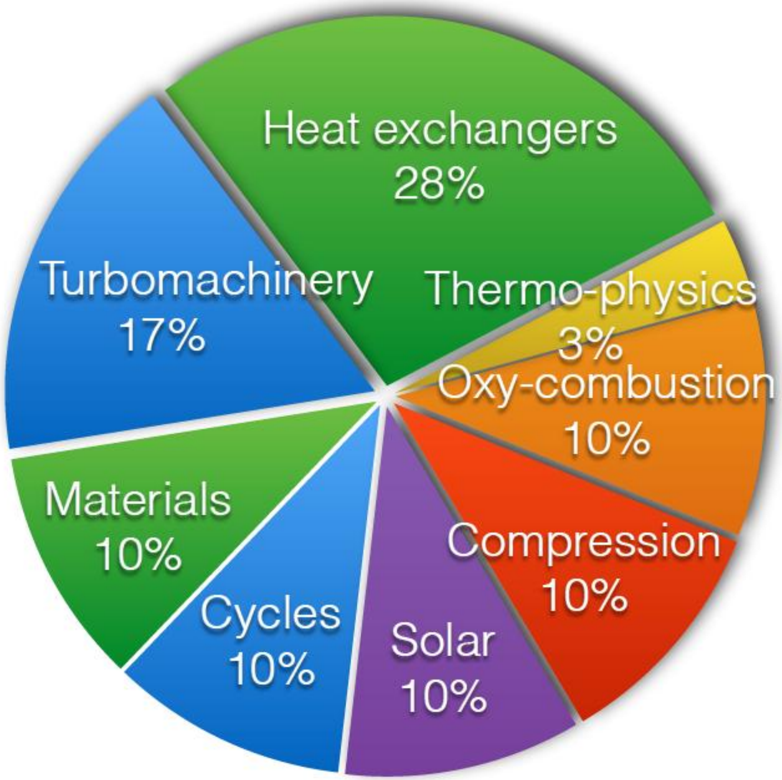
DOE [US] Projects on Indirectly and Directly Heated S-CO_2 Gas Turbine Cycles for Efficient Power Generation

- Performers with More than One Project
  1. Southwest Research Institute (7)
  2. Sandia National Lab (7)
  3. Aerojet Rocketdyne (4)
  4. General Electric (3)
  5. Thar Energy (3)
  6. Brayton Energy (2)
  7. NREL (2)
  8. Oregon State University (2)

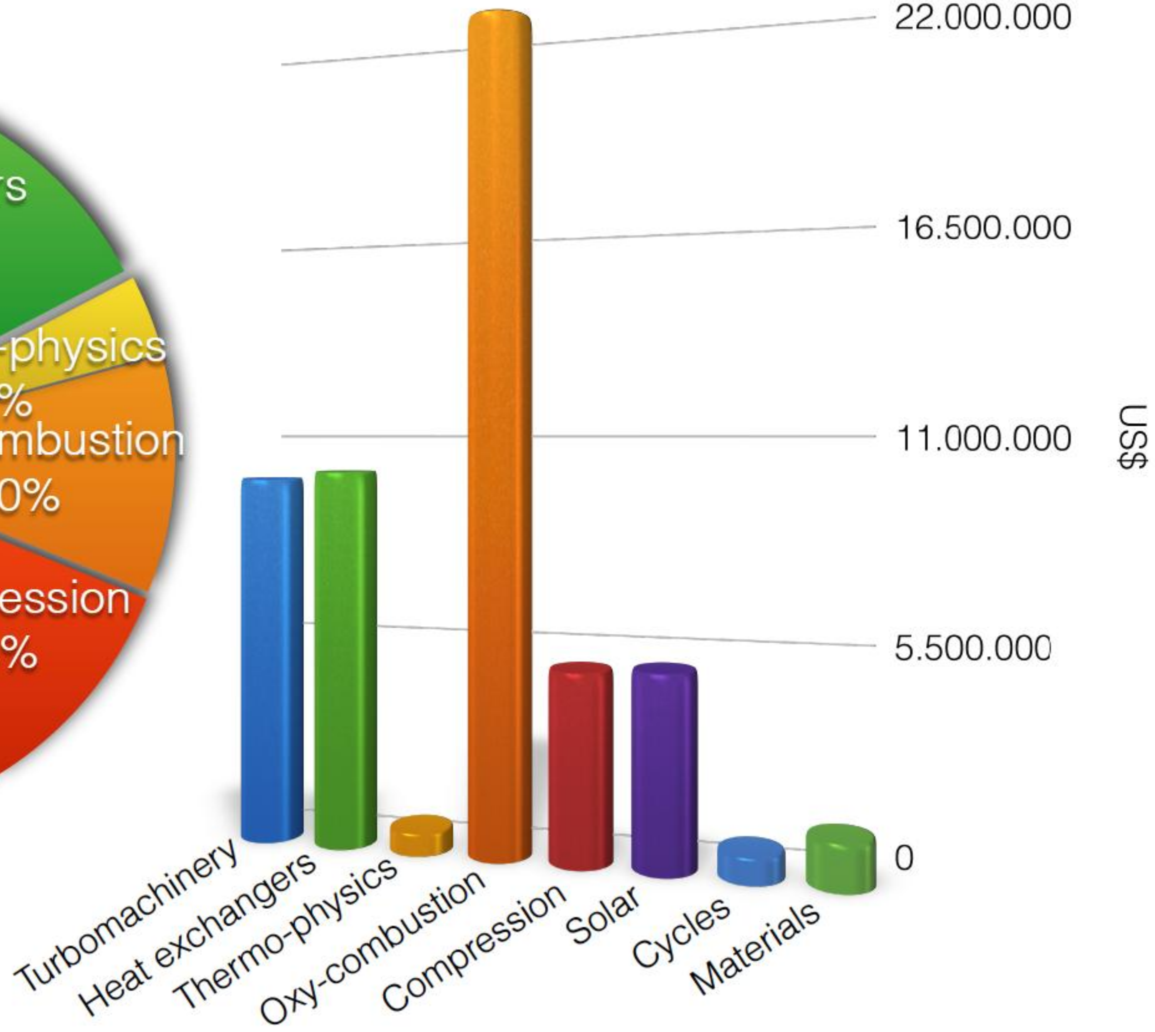


% based on number of participated projects

DOE [US] Projects on Indirectly and Directly Heated S-CO_2 Gas Turbine Cycles for Efficient Power Generation



% based on 29 projects



ENEA’s Activities in Europe
and
in AdP-PAR2014

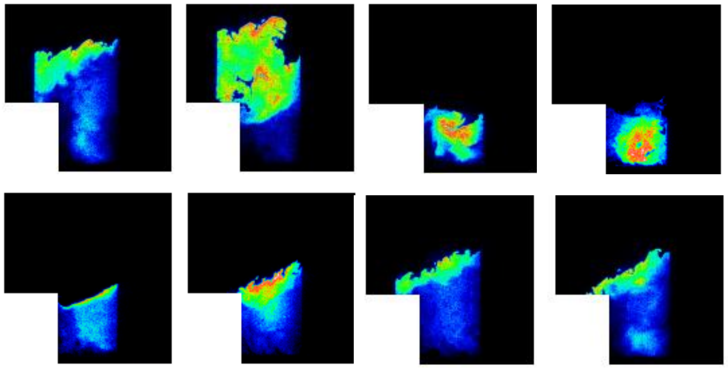
Dynamics, Monitoring and Control of Combustion Instabilities in Gas Turbines

- Actions, Activities and Next Steps -

- Actions
  - "Understanding": Marie Curie, ERC or other instruments in H-2020.
- Activities
  - ENEA-ASEN: real-time monitoring in a V94.3A GT (20 bar).
  - COFIRE-HNG (Marie Curie, ITN): 91.4/100 NOT FUNDED [7 ETN members].
  - HyBurn (ERC): submitted in March [DLR-ENEA].
  - Ph.D. (U. Roma Tre): 1. statistical vs chaotic analysis; 2. temperature vs heat release dynamics.
- Next Steps
  - Looking for a suitable call where combustion dynamics can be at least one of the work packages.

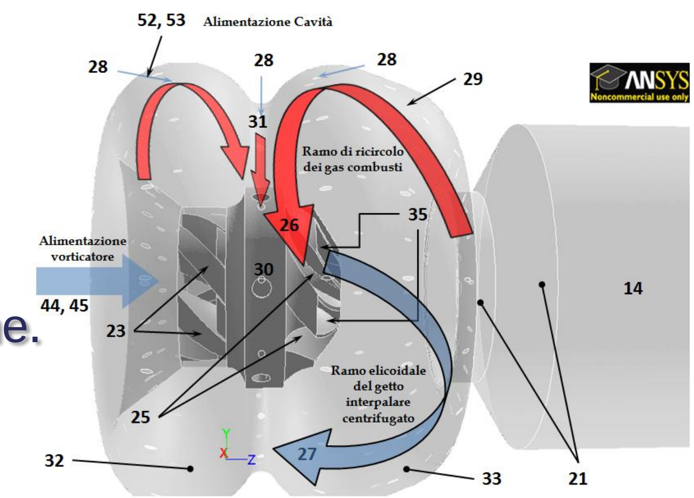
ENEA's Activities in PAR2014

- Combustion dynamics simulation
  - ONERA test case with flashback.



- Optical Diagnostics of Combustion
  - Instability precursor identification: statistical vs chaotic analysis.

- Development of advanced burners
  - Operation in the distributed combustion regime.

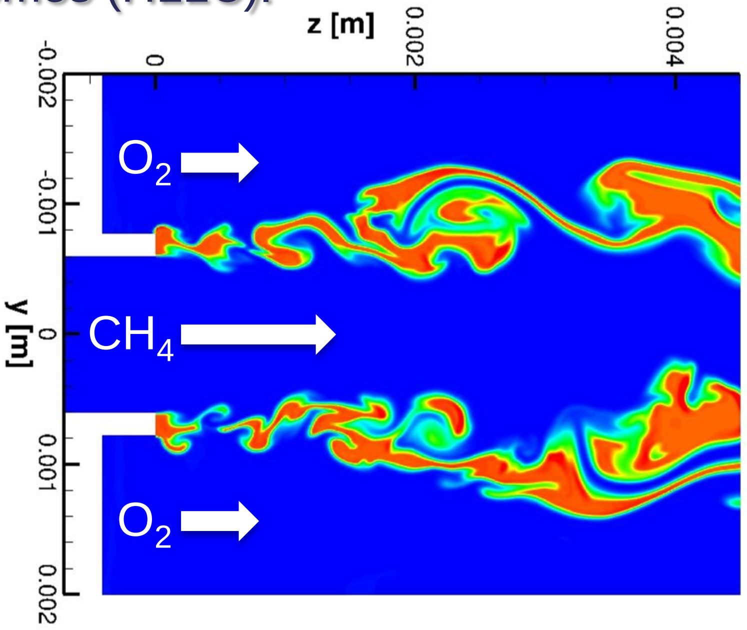


Advanced Supercritical CO_2 Cycles
- Actions, Activities and Next Steps -

- Actions
  - Strong relationship and collaboration with Cranfield University.
  - Discussions with GE-GRC (NDA), ALSTOM, NETPOWER.
  - SETPLAN 2014 poster: presentation of S-CO_2 topic and ENEA's vision to high-level EU DGs (Energy) and National Contact Points.
- Activities
  - H2020 Projects submitted:
    - LCE1-2014 (CO_2ReTurn consortium): phase 1 not passed.
    - Invited to join submission of other projects.
  - Italian National projects: PNR proposal (National Research Plan).
- Next steps
  - Patent: ALBA cycle (G. Messina).
  - Position Paper: within ETN (ENEA / CRANFIELD U. / ALSTOM).
  - ENERGY-2015-16 calls review: LCE 28 - 2017 identified.

ENEA's Activities in PAR2014

- High-pressure oxy-combustion simulation by using the HeaRT code
  - Implementation of real gas equation of state (GERG2004/Peng-Robinson).
  - Implementation of real gas transport coefficients.
  - Implementation of required numerical schemes (HLLC).



- ROMULUS
  - Effects of CO_2 dilution in combustion.
- AGATUR
  - Plant upgrade towards EGR and development of S-CO_2 plant start-up strategies.

How Our Topics Fit in the EU Energy Policy

- The Four Pillars of the EU Energy Policy -

Decarbonisation

- Clean and efficient power generation
- Increasing share of renewables
- Highly cycle-integrated CCS
- Low or carbon free fuels
- Low minimum environmental load

Security of energy supply

- Safe operation
- Availability and reliability
- Fuel- and load-flexibility
- Energy storage
- Grid-integration of renewable and back-up power plants

Sustainability

- Exploitation in different fields
- CCUS (CCS+Utilisation)
- Affordable technologies

Competitiveness

- Lower electricity cost
- Cost-competitive CCS
- Innovative cycles

✓ Conclusion: integration of advanced fossil power generation and renewables for their own sustainability.

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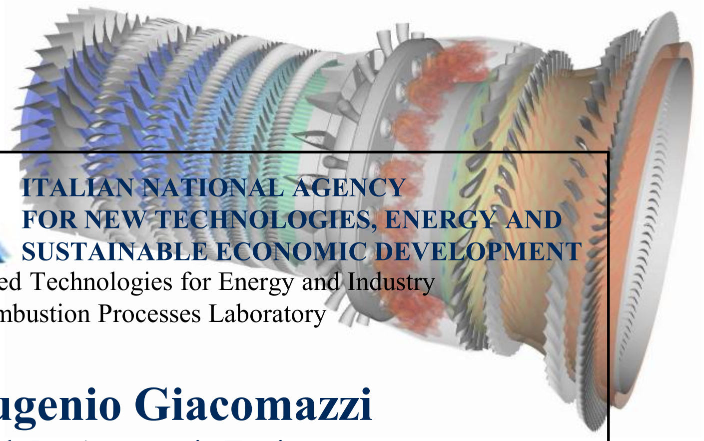

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COMSO

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