Advanced gas turbine cycles: new solutions for the near future needs

Giuseppe Messina
ENEA, Sustainable Combustion Processes Laboratory
Roma, 24 June 2015

Sustainable Combustion
& Processes Laboratory

Outline

- Solar eclipse: a real "stress test"
- Flexibility from power generation
- S-CO2 Power Cycles

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Solar Eclipse: a real “stress test”

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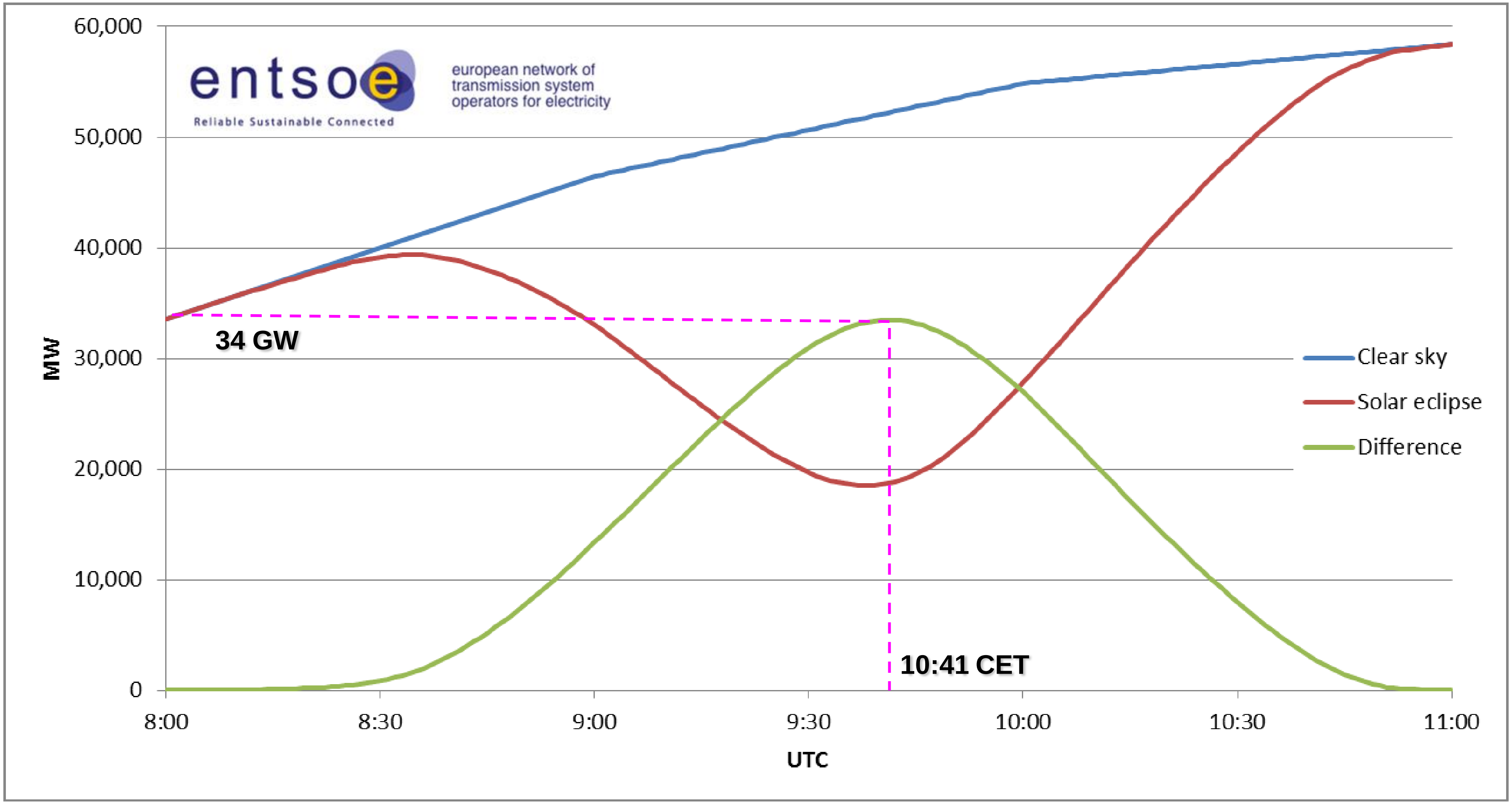
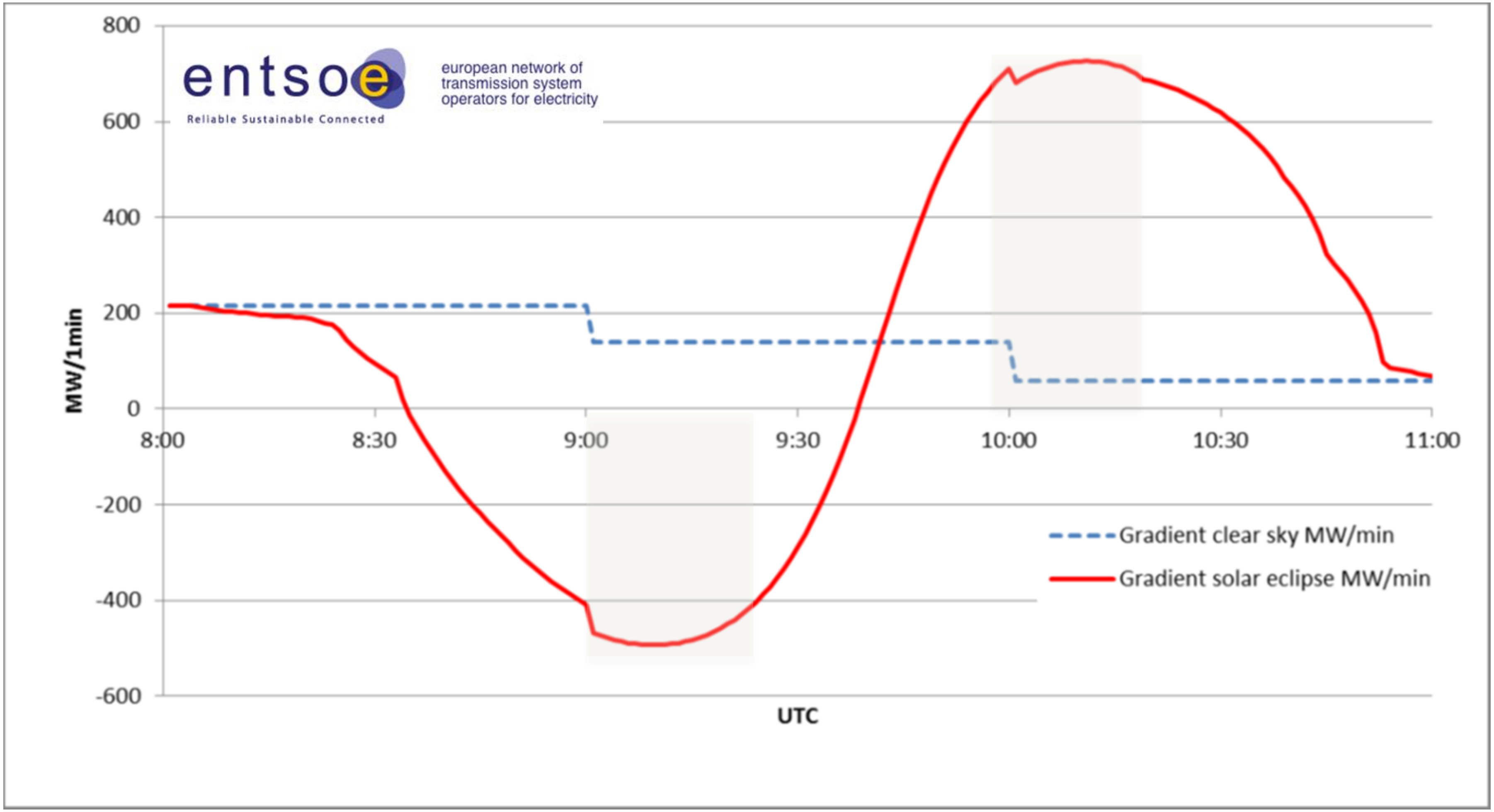
People watch as a solar eclipse begins over the Eden Project near St Austell in Cornwall, England, March 20, 2015.
Ben Birchall / AP Photo
From: abcnews.go.com

Solar Eclipse: a real "stress-test"



From: ENTSOE - Solar Eclipse 2015 - Impact Analysis, 19 February 2015

Solar Eclipse: a real "stress-test"



From: ENTSOE - Solar Eclipse 2015 - Impact Analysis, 19 February 2015

Renewables growth

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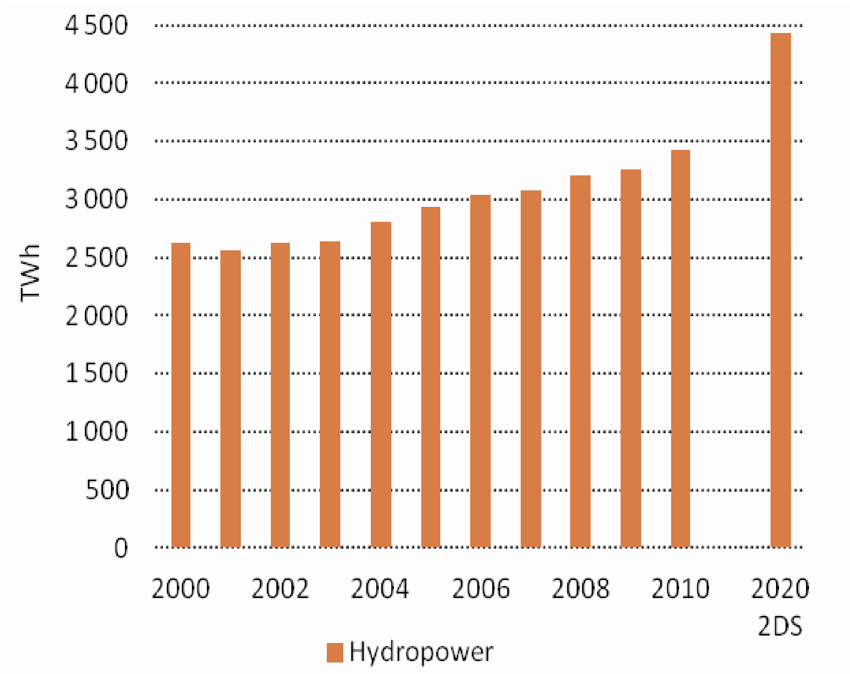
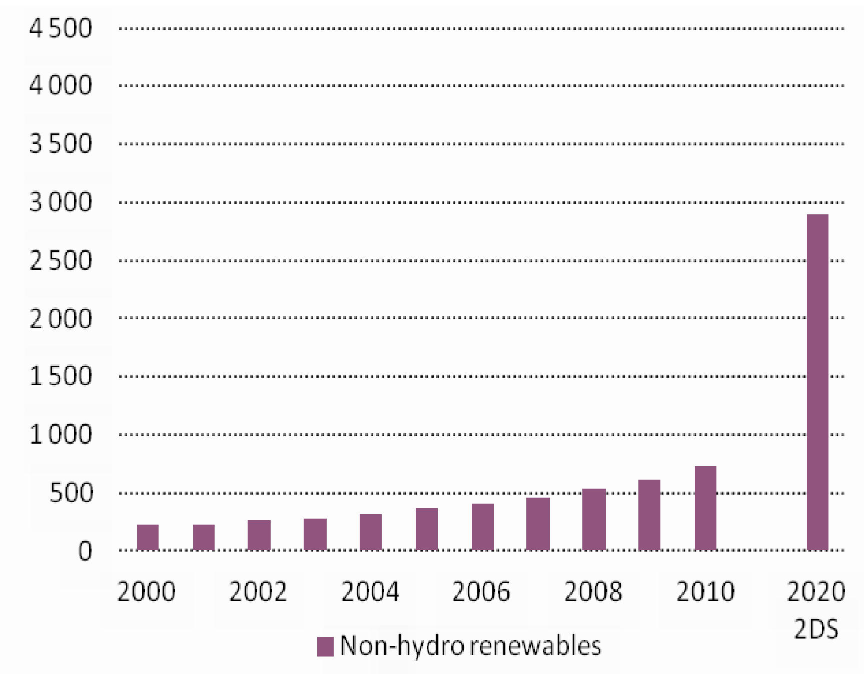




42%

Average annual growth in Solar PV

75%

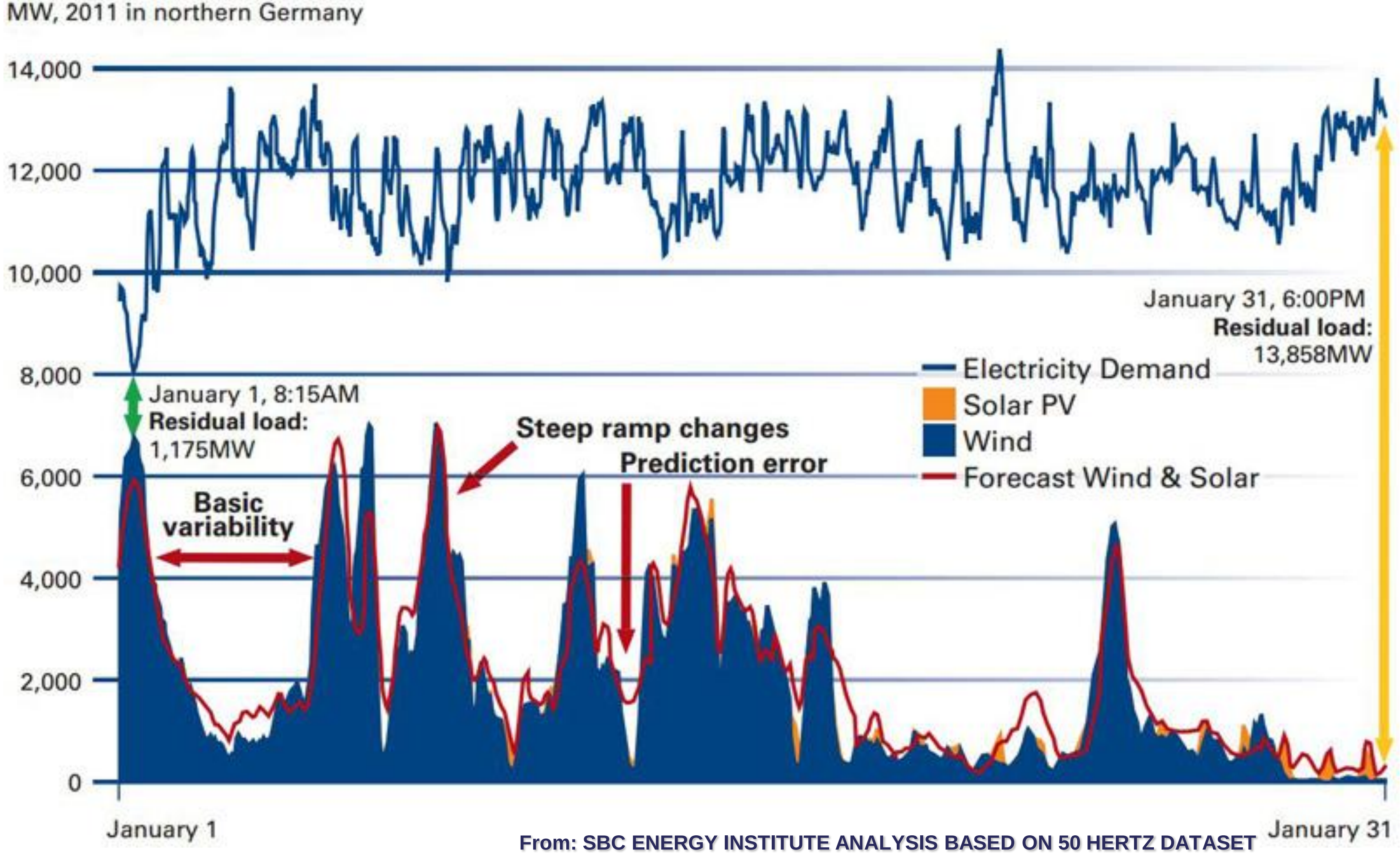
Cost reductions in Solar PV in just three years in some countries

27%

Average annual growth in wind

From: IEA – Energy Technology Perspectives 2012

Renewables growth...and load-flexibility



From: SBC ENERGY INSTITUTE ANALYSIS BASED ON 50 HERTZ DATASET

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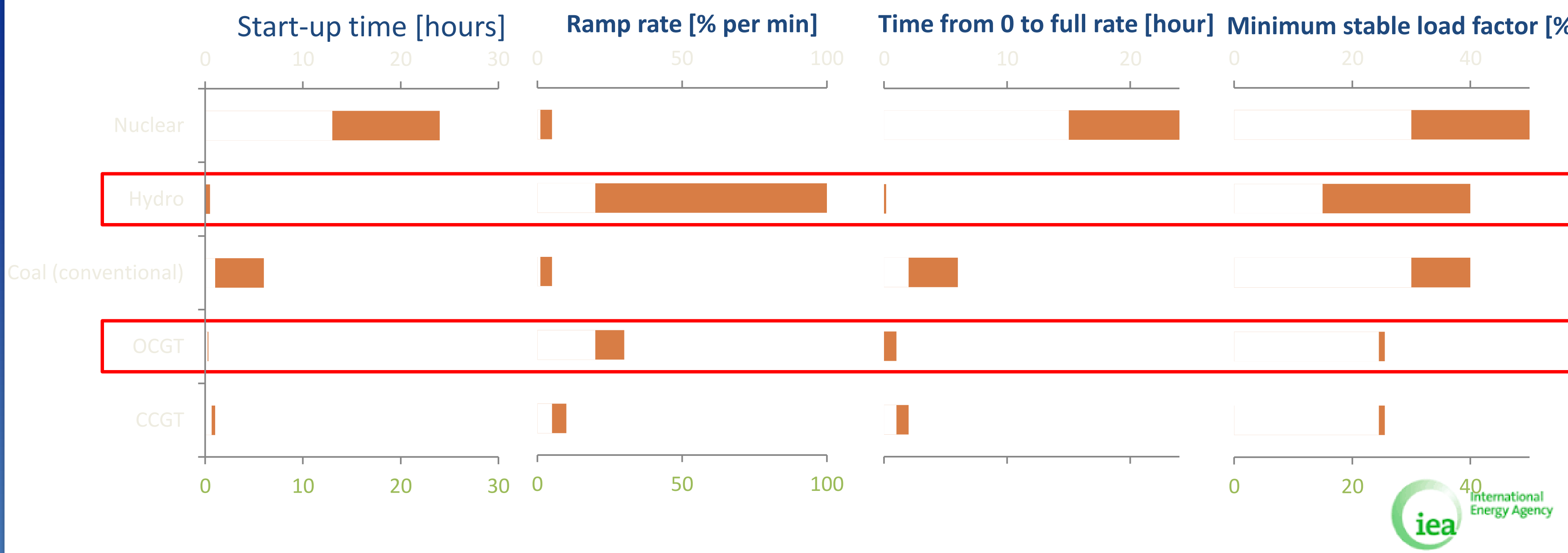
Flexibility from Power Generation

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



- Hydro generation can respond more quickly than other technologies, but the resource is geographically limited
- Open Cycle Gas Turbines are therefore very often considered
- For the traditional base load power plants, a change in operation would translate into reduced load factors, while maintenance cost increase and thus lower financial revenue

From: IEA – Energy Technology Perspectives 2012

Flexibility from Power Generation

and...with CCS?

New operational constraints
Larger start-up time
Higher CAPEX and OPEX

Results:

CCS can meet the future flexibility requirements

OCGT **without** CCS still continue to be a viable cost-effective option for peak load

	Turndown	Cycling capability: Start-up to full load	Ramp rates	Part load efficiency
NGCC	Low load operation: 15-25% CC load (10-20% GT load) Min. environmental Load: 40-50% CC NPO (30-40% GT load)	Hot start-up: 45-55 min Warm start-up: 120 min Cold start-up: 180 min	35 - 50 MW/minute max Hot start-up load change rate: - 0-40% GT load: 3-5%/min - HRSG press.: 1-2%/min - 40-85% GT load: 4-6%/min - 85-100% GT load: 2-3%/min	Approx. constant efficiency down to 85% GT load; 2-3 percentage points less @ 60% CC load
with CCS	Post-combustion unit min. load: 30% CO_2 compressor min. efficient load: 70%	Regenerator preheating: - hot start-up: 1-2 h - warm start-up: 3-4 h	Same as plant w/o CCS	Same as plant w/o CCS
IGCC	Min. env. GT Load: 60% PO. Process unit /air separation unit (ASU) cold box min. load: 50% ASU compr. min. load: 70%	Cold start-up: 80-90 h Gasification hot start-up: 6-8 h ASU hot start-up: 6 h	Gasification ramp rate: 3-5%/min ASU ramp rate: 3%/min	Gross electrical efficiency: 2 percentage points less @ 70% CC load
with CCS	CO_2 compressor min. efficient load: 70%	Same as plant w/o CCS	Same as plant w/o CCS	Same as plant w/o CCS
USC PC	Min. boiler load: 25-30%	Very hot start-up: < 1h Hot start-up: 1.5-2.5 h Warm start-up: 3-5 h Cold start-up: 6-7 h	30-50% load: 2-3%/min 50-90% load: 4-8%/min 90-100% load: 3-5%/min	Subcritical boiler: -4 perc. point @ 75% load Supercritical boiler:- 2 perc. point @ 75% load
with CCS	Post-combustion unit min. load: 30% CO_2 compressor min. efficient load: 70%	Regenerator preheating: - hot start-up: 1-2 h - warm start-up: 3-4 h	Same as plant w/o CCS	Same as plant w/o CCS
Oxy fuel				
Air-firing mode	Min. boiler load: 25-30%	Very hot start-up: < 1h Hot start-up: 1.5-2.5 h Warm start-up: 3-5 h Cold start-up: 6-7 h	30-50% load: 2-3%/min 50-90% load: 4-8%/min 90-100% load: 3-5%/min	Subcritical boiler: -4 perc. point @ 75% load Supercritical boiler: -2 perc. point @ 75% load
Oxy-firing mode	Cold box min. load: 40-50%. ASU compressor min. efficient load: 70% CO_2 compressor min. efficient load: 70%	Start-up in air-firing mode, ASU start-up completed in approx. 36 h	ASU ramp rate: 3%/min	Same as plant in air-firing mode

R. Domenichini et Al, Operating Flexibility of Power Plants with Carbon Capture and Storage (CCS), Energy Procedia, 2013

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Flexibility from Power Generation

The COMSO Laboratory approach

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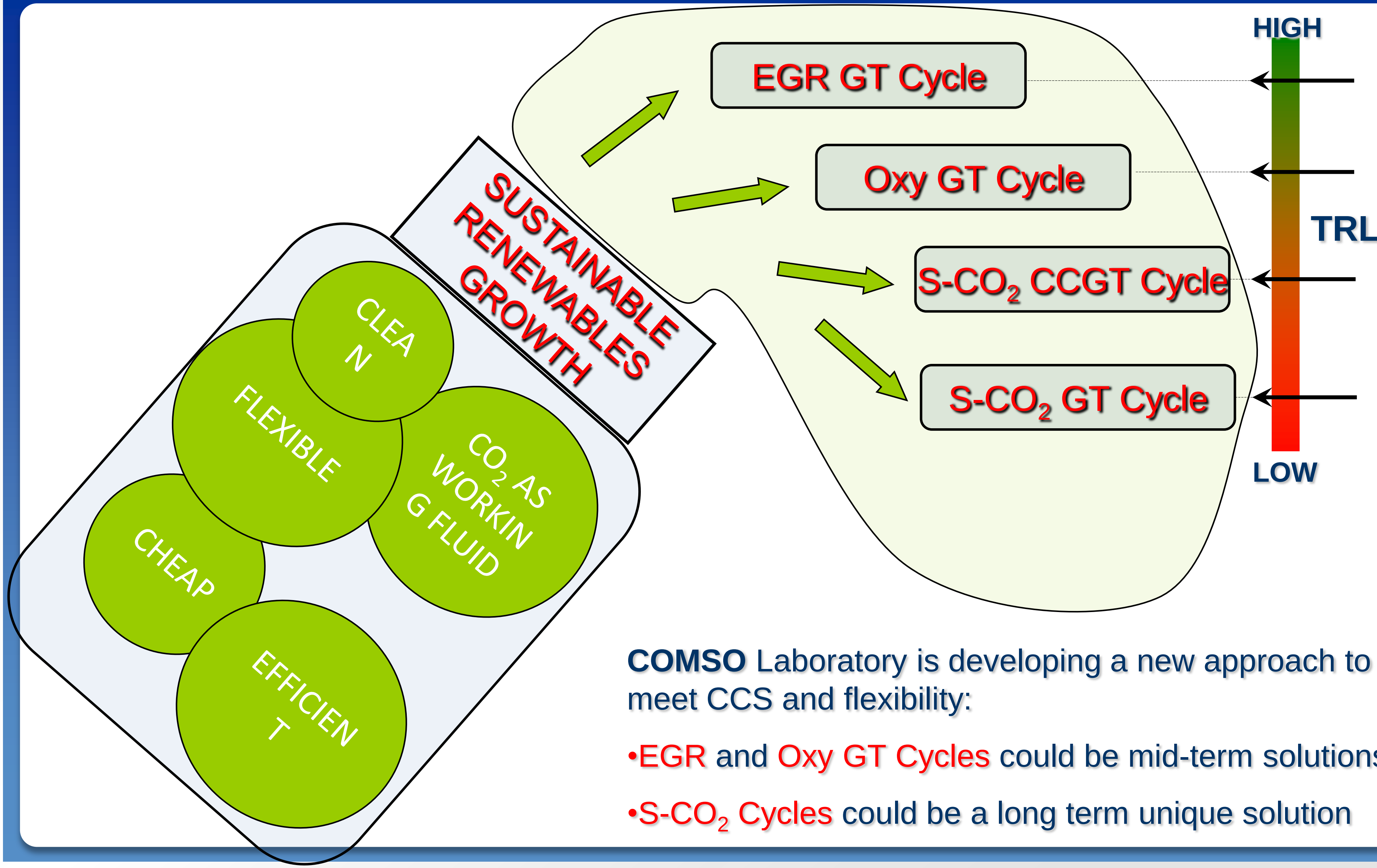


COMSO Laboratory is developing a new approach to meet CCS and flexibility:

•EGR and Oxy GT Cycles could be mid-term solutions

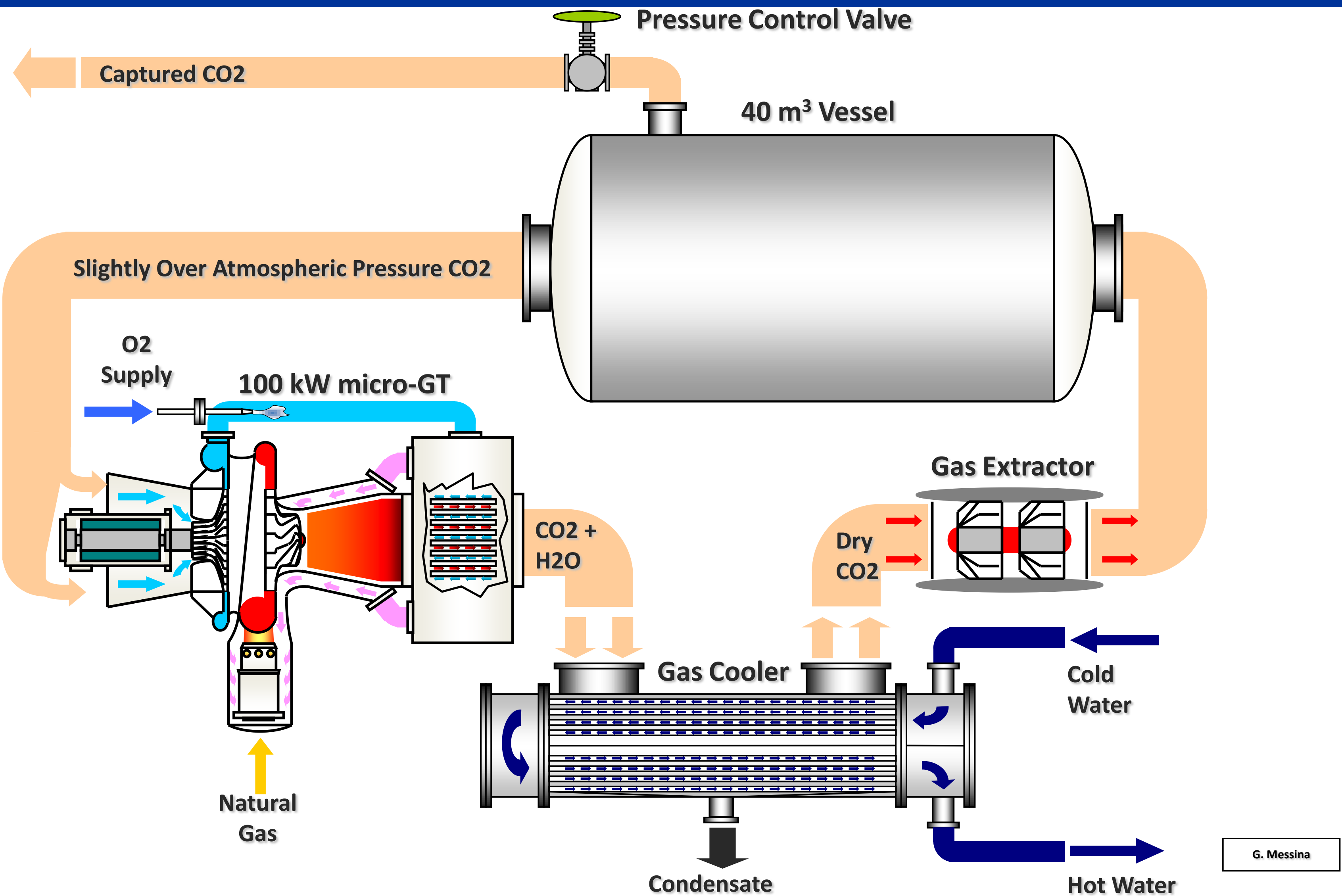
•S-CO_2 Cycles could be a long term unique solution

AGATUR

Advanced GAs TUrbines Rising

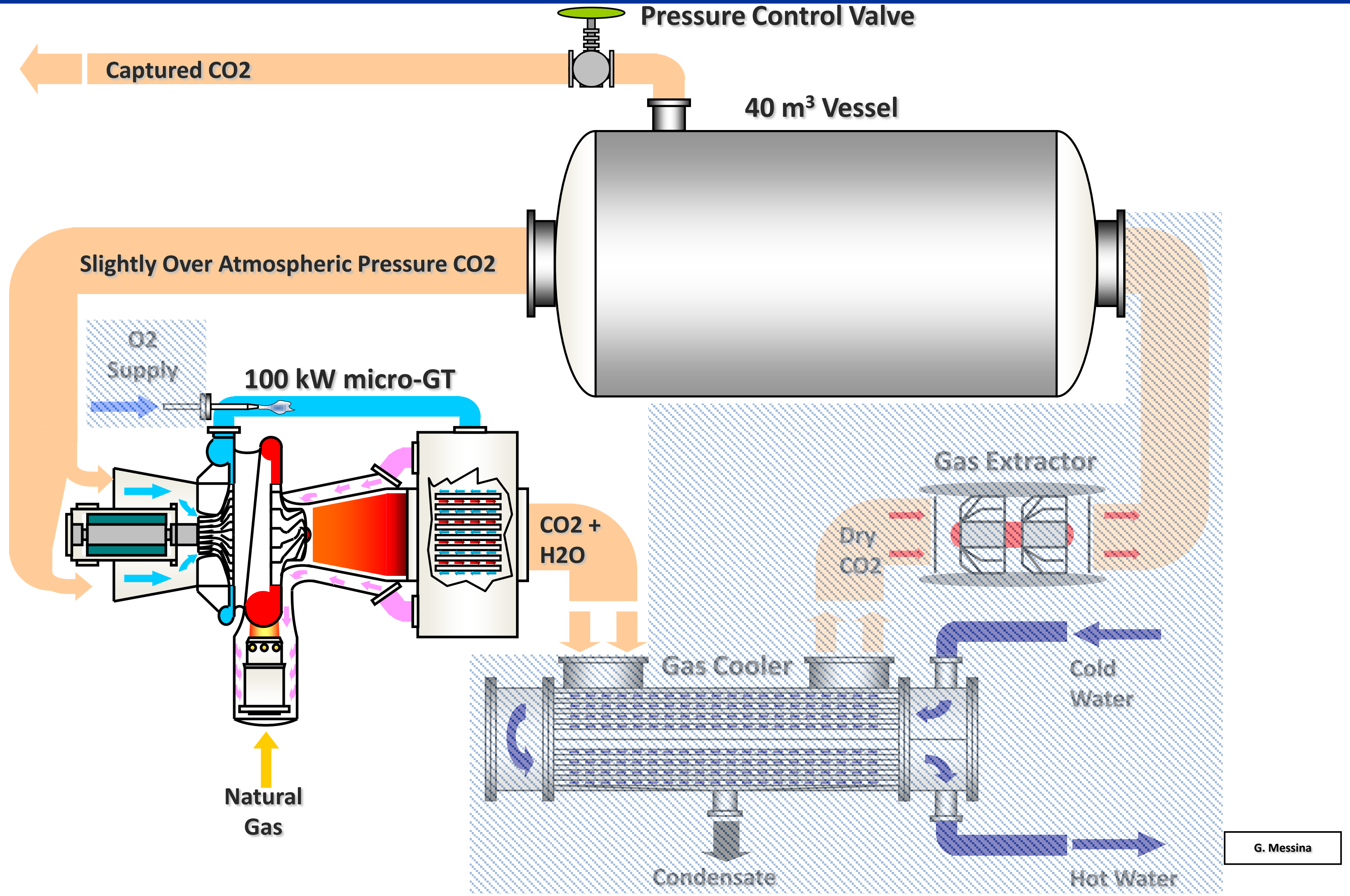
COMSO Experimental Activities

EGR Cycle implementation on AGATUR facility



COMSO Experimental Activities

EGR Cycle implementation on AGATUR facility

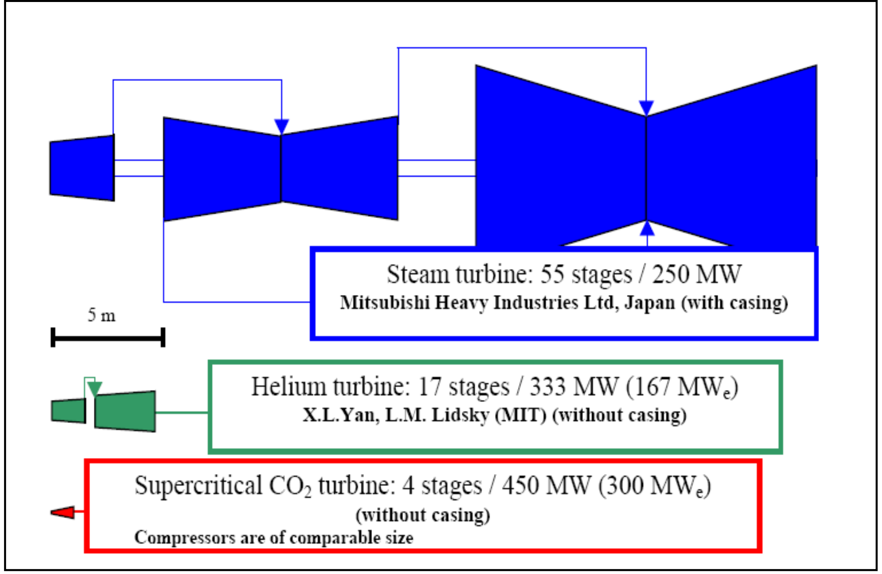


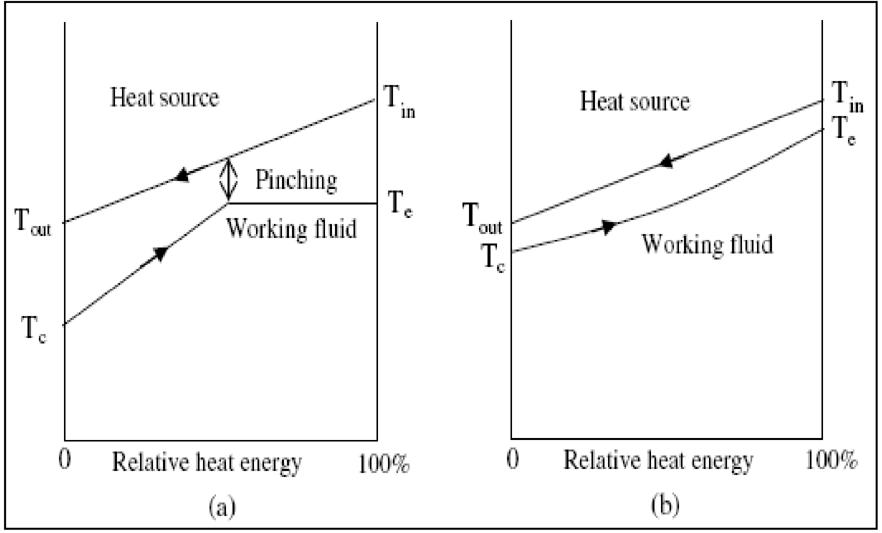
S-CO_2 Peculiarities

Characteristics of an ideal power cycle

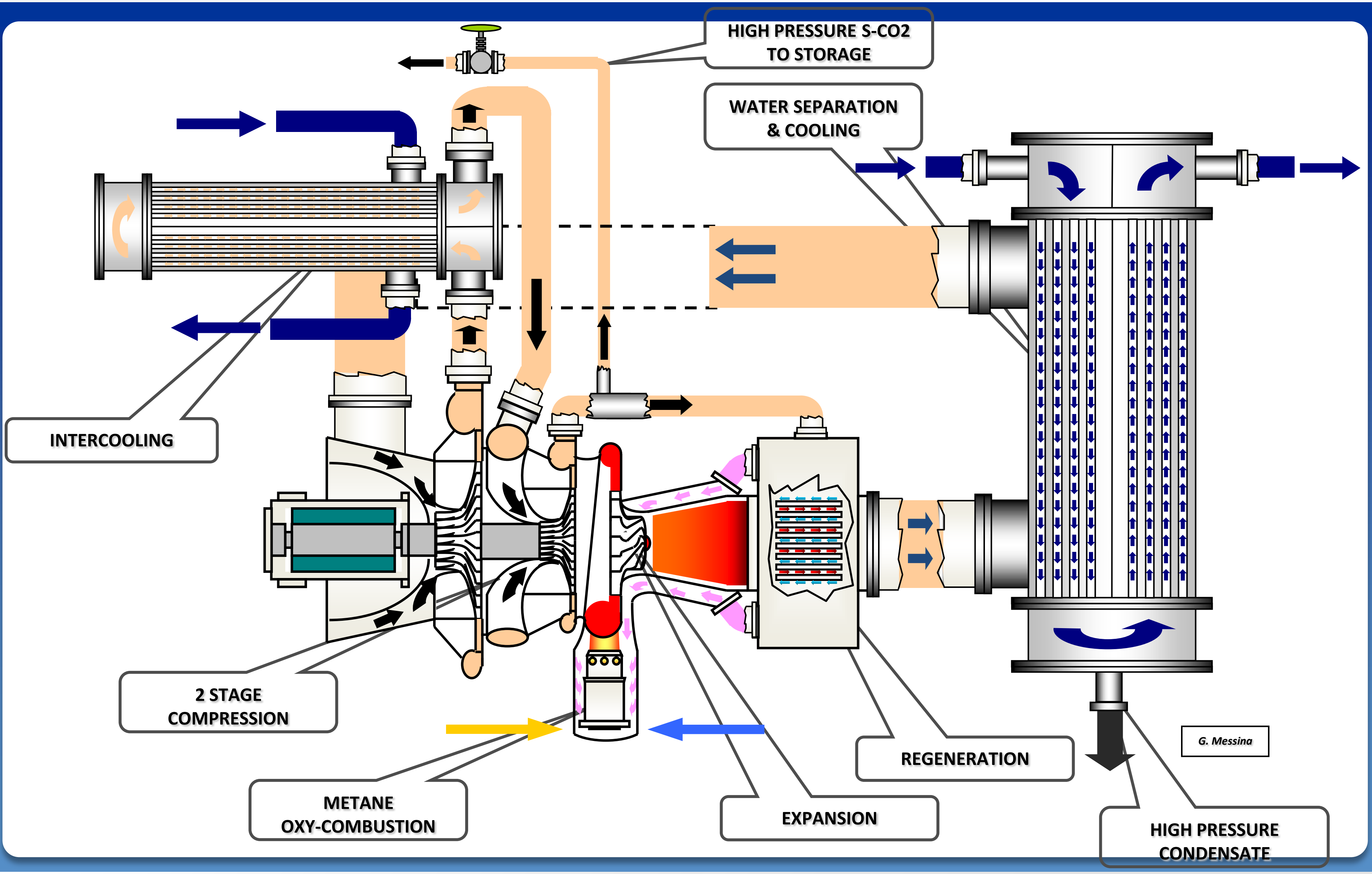
- Good utilization of available heat
  - High expansion, low compression work
  - Direct coupling to heat source
- Benign working fluid
  - Non-corrosive, non-toxic, thermally stable
  - Dry expansion to avoid erosion
- Low capital cost
- Low operation & maintenance (O&M) costs

Supercritical CO_2 meets these characteristics



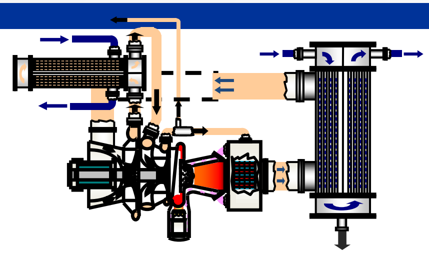


OXY S-CO_2 Cycle: plant layout



OXY S-CO_2 Cycle: simulation results

ETN

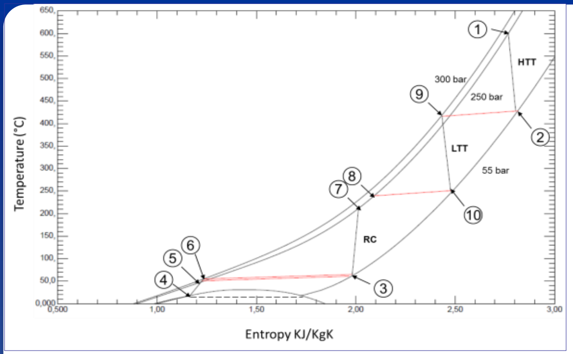


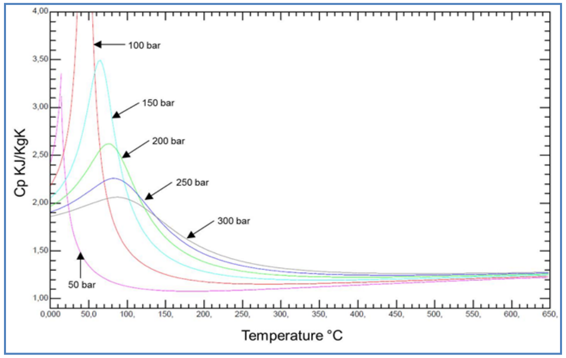
Fuel kg/s	LHV kJ/kg	HCOMPR kW	LCOMPR kW	TURB kW	TIT C	TOT C	TOR C	Oxygen kg/s	Oxygen kJ/kg	EFF
0,01443	50010	32	80	-540	1151	781	702	0,058	42	**0,535**
0,01392	50010	36	83	-526	1100	734	659	0,058	42	**0,525**
0,01354	50010	35	83	-505	1050	696	613	0,056	40	**0,511**

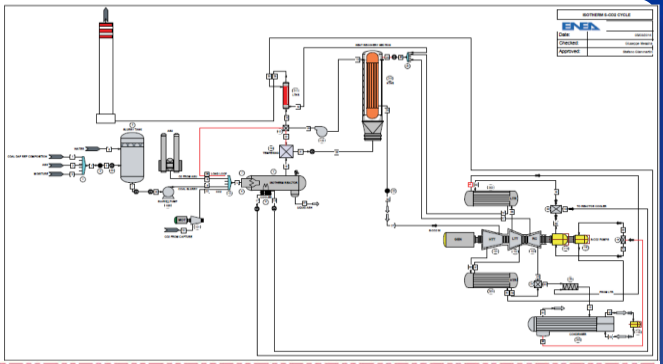
- Regenerator cold side outlet temperature is a key parameter on cycle performance, because of both direct and indirect impact through the TIT limitation.
- A rough sensitivity study was performed by varying TIT, in order to evaluate the "Technological level" on the cycle performance.
- The first principle efficiency LHV basis, is always more than 50%, also with a "state-of-the-art" temperature setting. Energy consumption for oxygen production was included (720 kJ/kg).
- Beside of mechanical energy, other cycle products are a stream of "pipeline ready" CO_2 (300 bar) and a water stream at 30 bar.
- The cycle is virtually "zero emission".

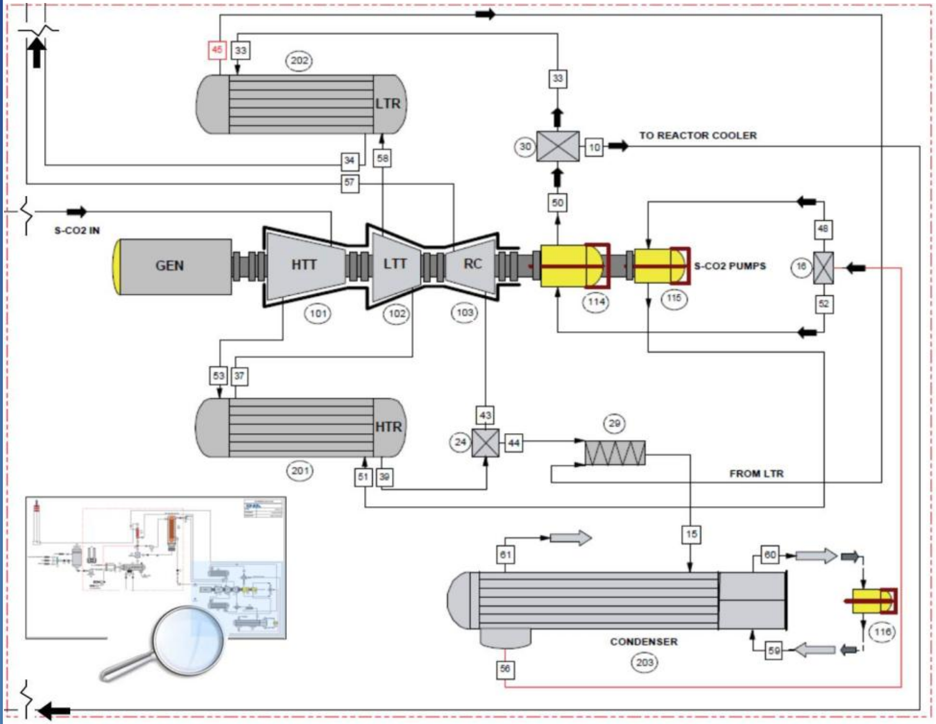
Giuseppe Messina, "Supercritical Carbon Dioxide Power Cycle", presentation to European Turbine Network, London, 2013

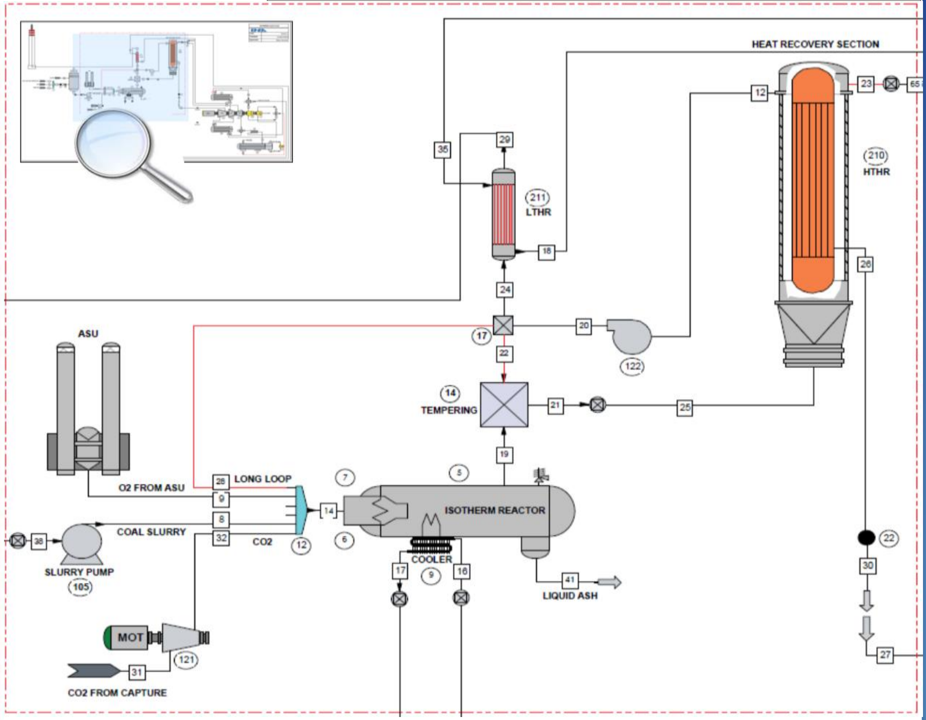
OXYCoal fired S-CO2 Closed Cycle





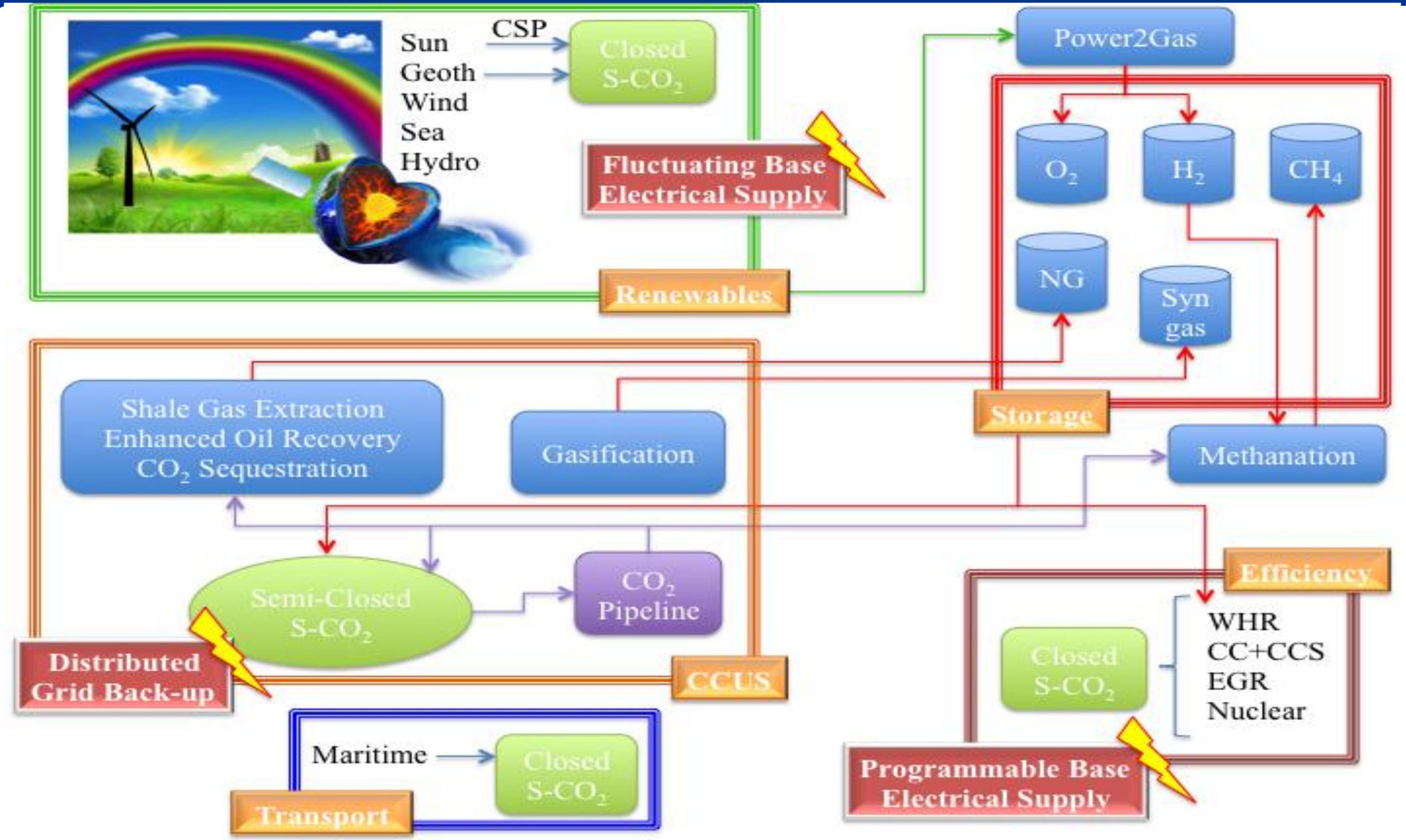






G.Messina, E. Giacomazzi, "Modellazione di un Ciclo di Potenza a CO2 Supercrtica da 48 MWt alimentato dal Loop ISOTHERM PWR", Ricerca di Sistema Elettrico, PAR 2013.

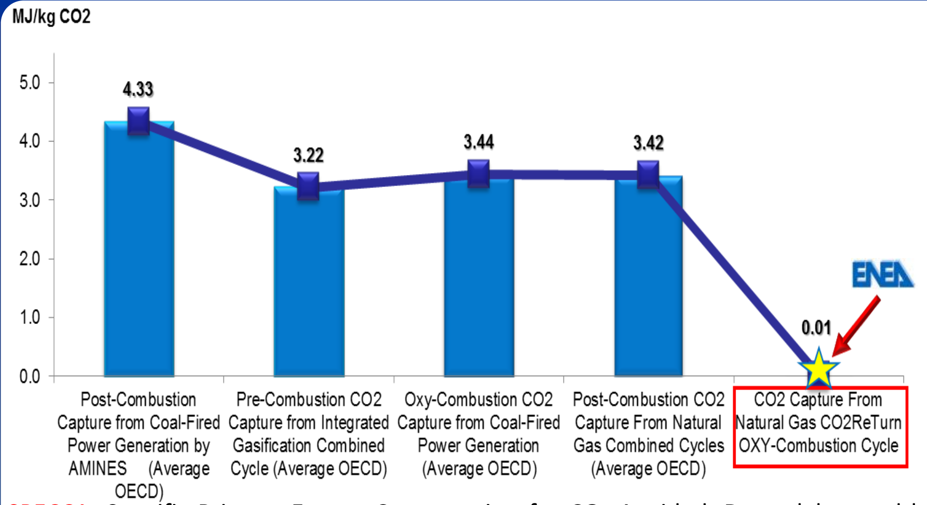
An Holistic Solution

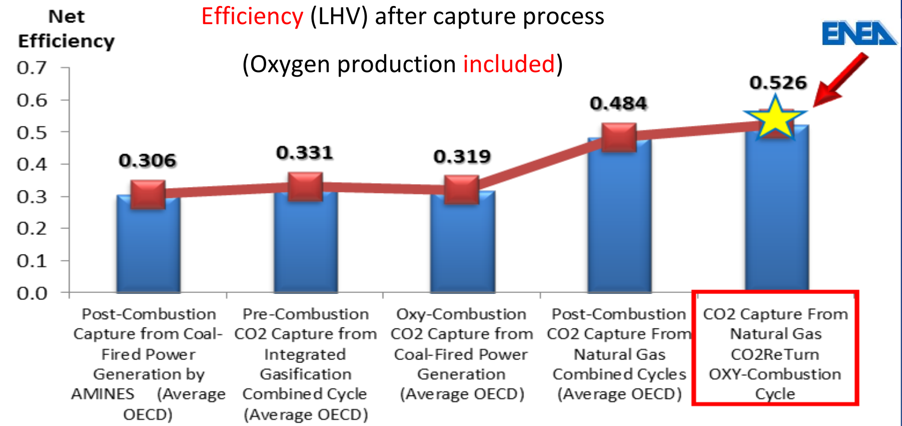


E. Giacomazzi and G. Messina, Exploitation of Supercritical CO2 Properties – An Holistic Solution for the 21st Century Power Generation, Impiantistica Italiana, 2015

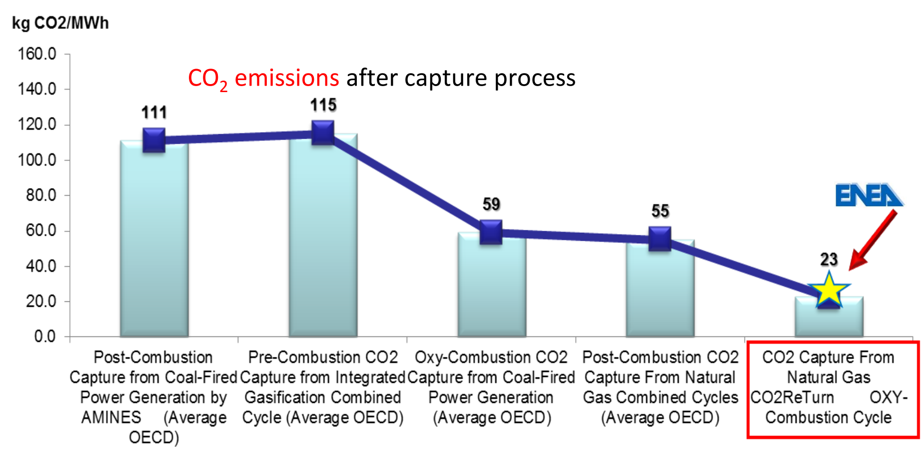
S-CO_2 ALBA Cycle

the COMSO Laboratory proposal in figures





SPECCA: Specific Primary Energy Consumption for CO_2 Avoided. Data elaborated by ENEA from: 1) Rahul Anantharaman et al. "European Best Practice Guidelines for Assessment of CO_2 Capture Technologies", CAESAR Project – FP7, 2011; 2) Matthias Finkenrath, "Cost and Performance of Carbon Dioxide Capture from Power Generation", IEA, 2011.



S-CO2 Advanced Liquid compression BrAyton Cycle

Patenting procedure in progress

**ITALIAN NATIONAL AGENCY
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SUSTAINABLE ECONOMIC DEVELOPMENT**

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