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

RICERCA DI SISTEMA ELETTRICO

MINISTERO DELLO SVILUPPO ECONOMICO

Accordo di Programma MiSE-ENEA

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

Sustainable Combustion & Processes Laboratory

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

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Solar Eclipse: a real “stress-test”

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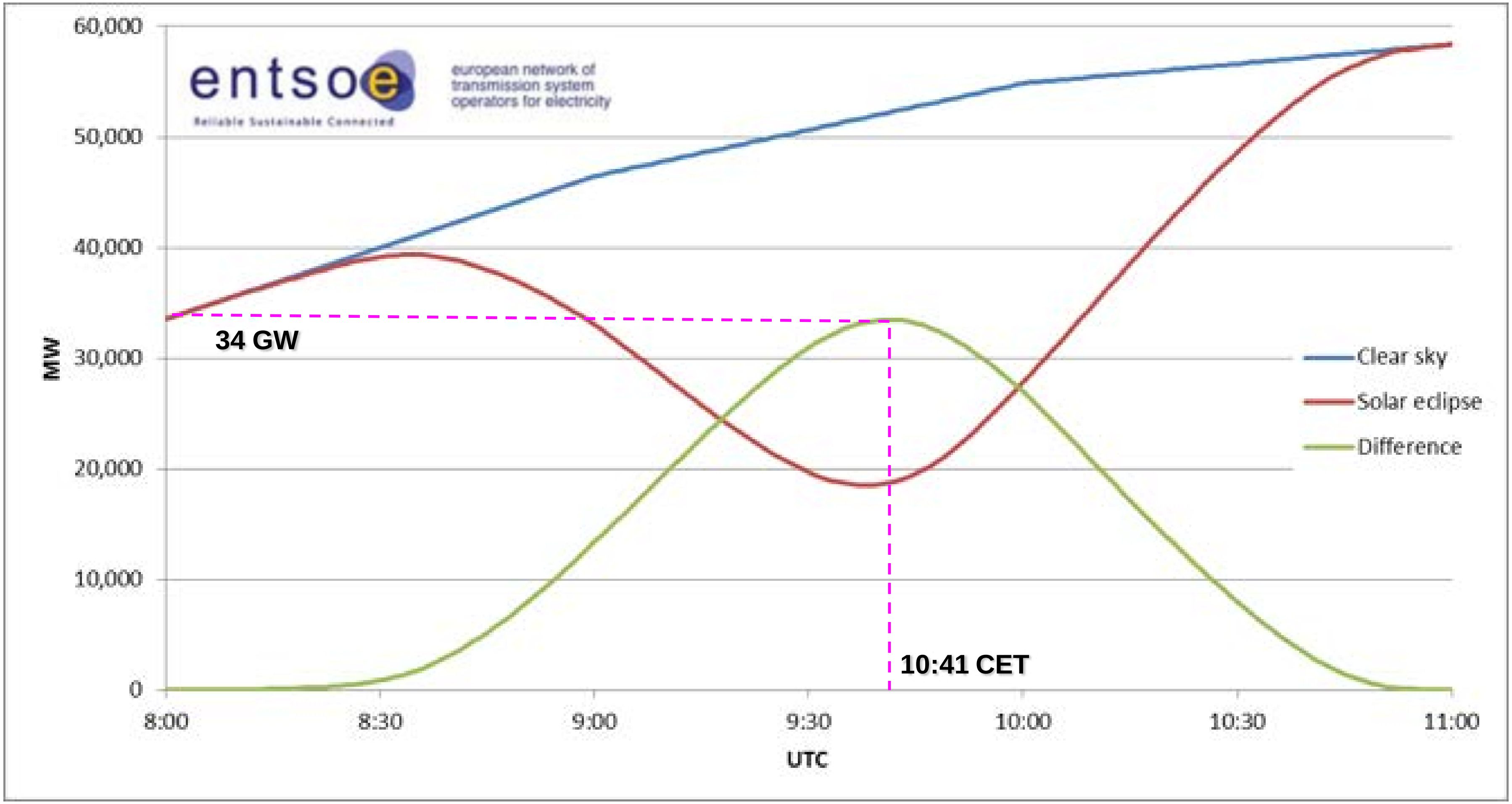

From: ENTSOE - Solar Eclipse 2015 - Impact Analysis, 19 February 2015

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Solar Eclipse: a real “stress-test”

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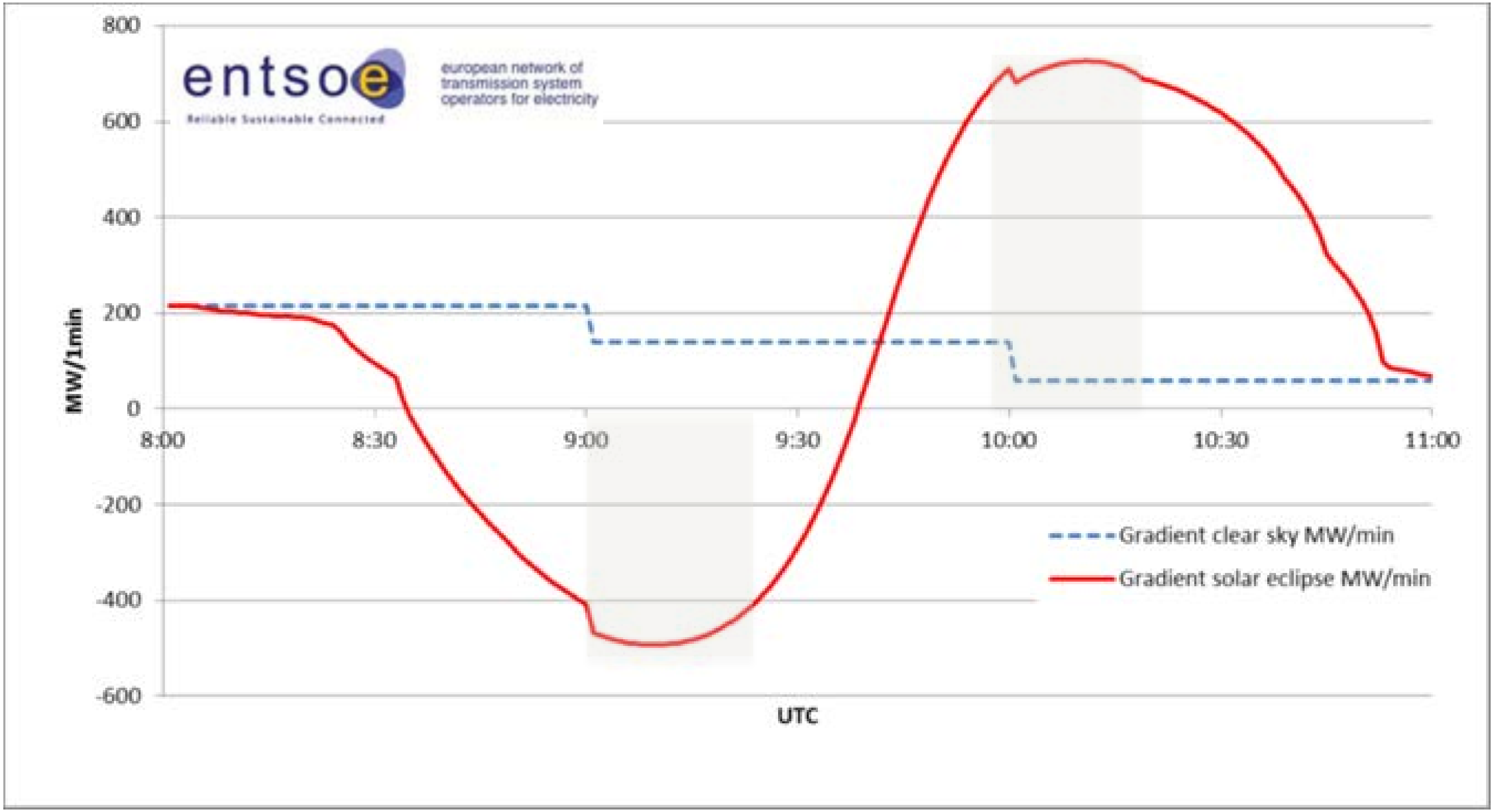

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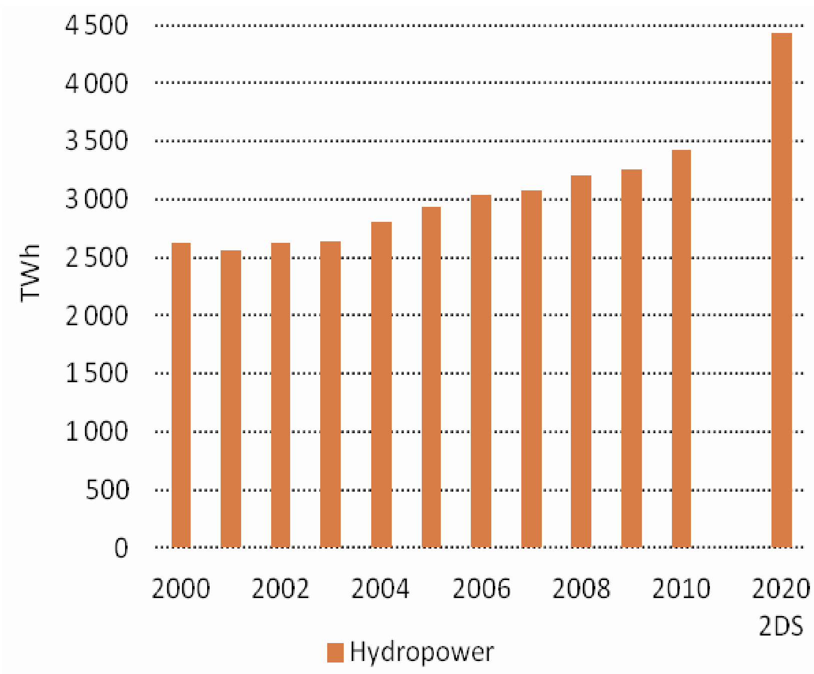
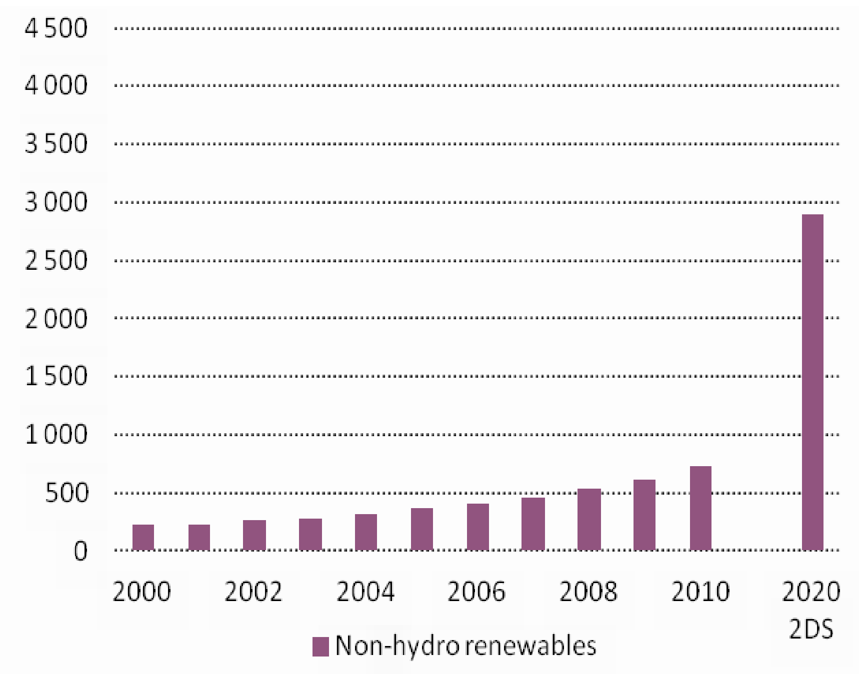
Renewables growth





42%

Average annual growth in Solar PV

75%

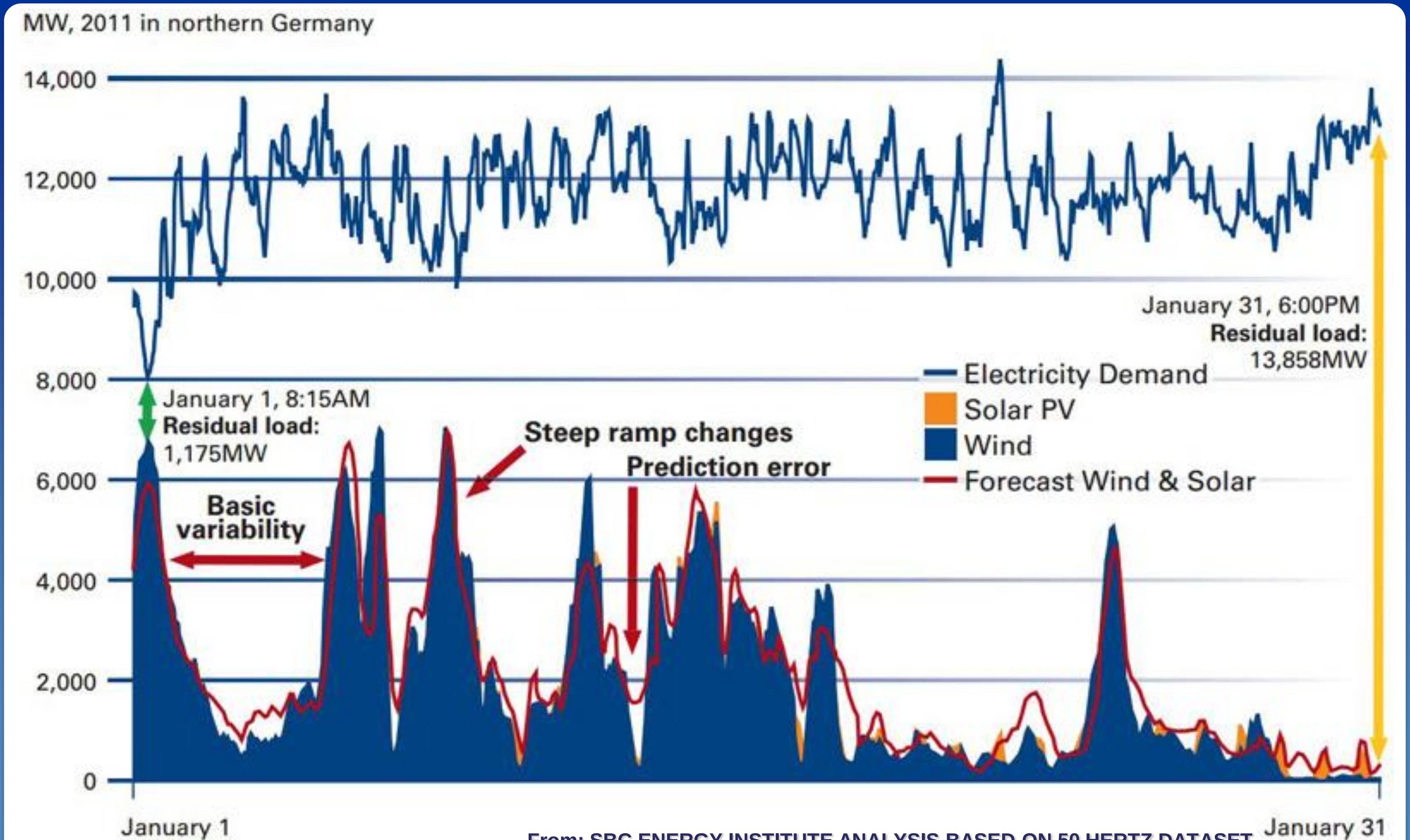
Cost reductions in Solar PV in just three years in some countries

27%

Average annual growth in wind

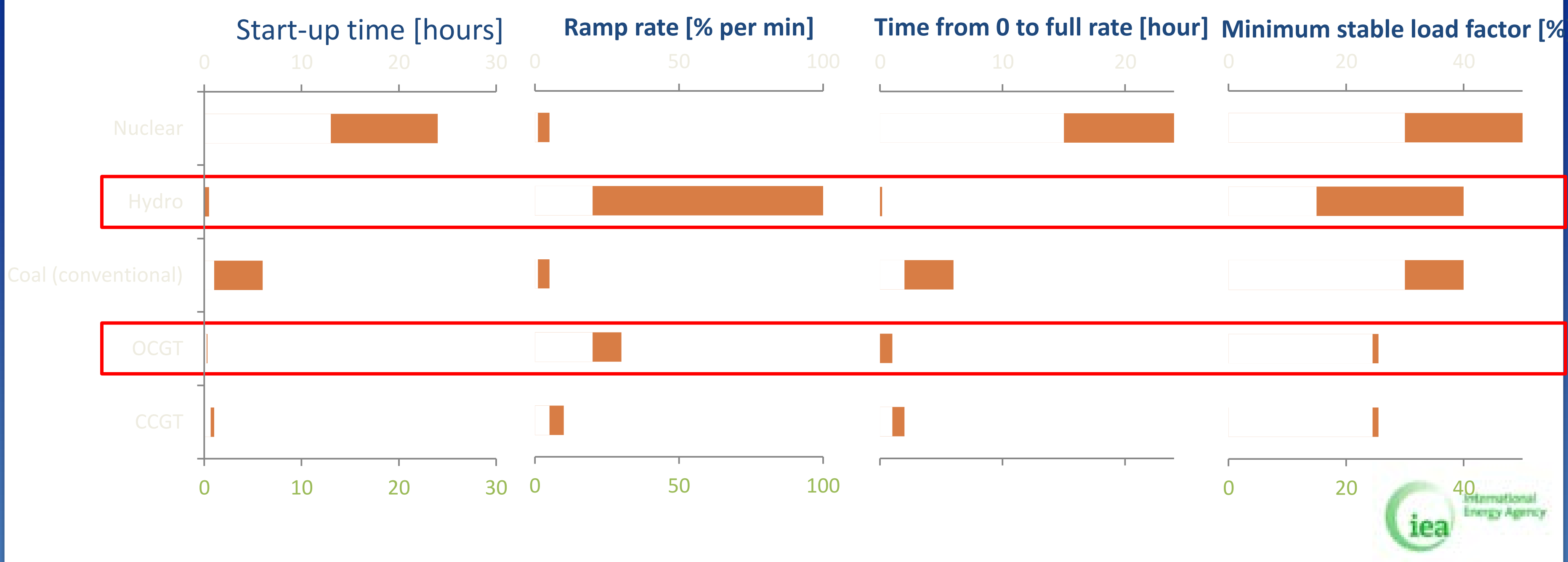
From: IEA – Energy Technology Perspectives 2012

Renewables growth...and load-flexibility



From: SBC ENERGY INSTITUTE ANALYSIS BASED ON 50 HERTZ DATASET

Flexibility from Power Generation



- 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

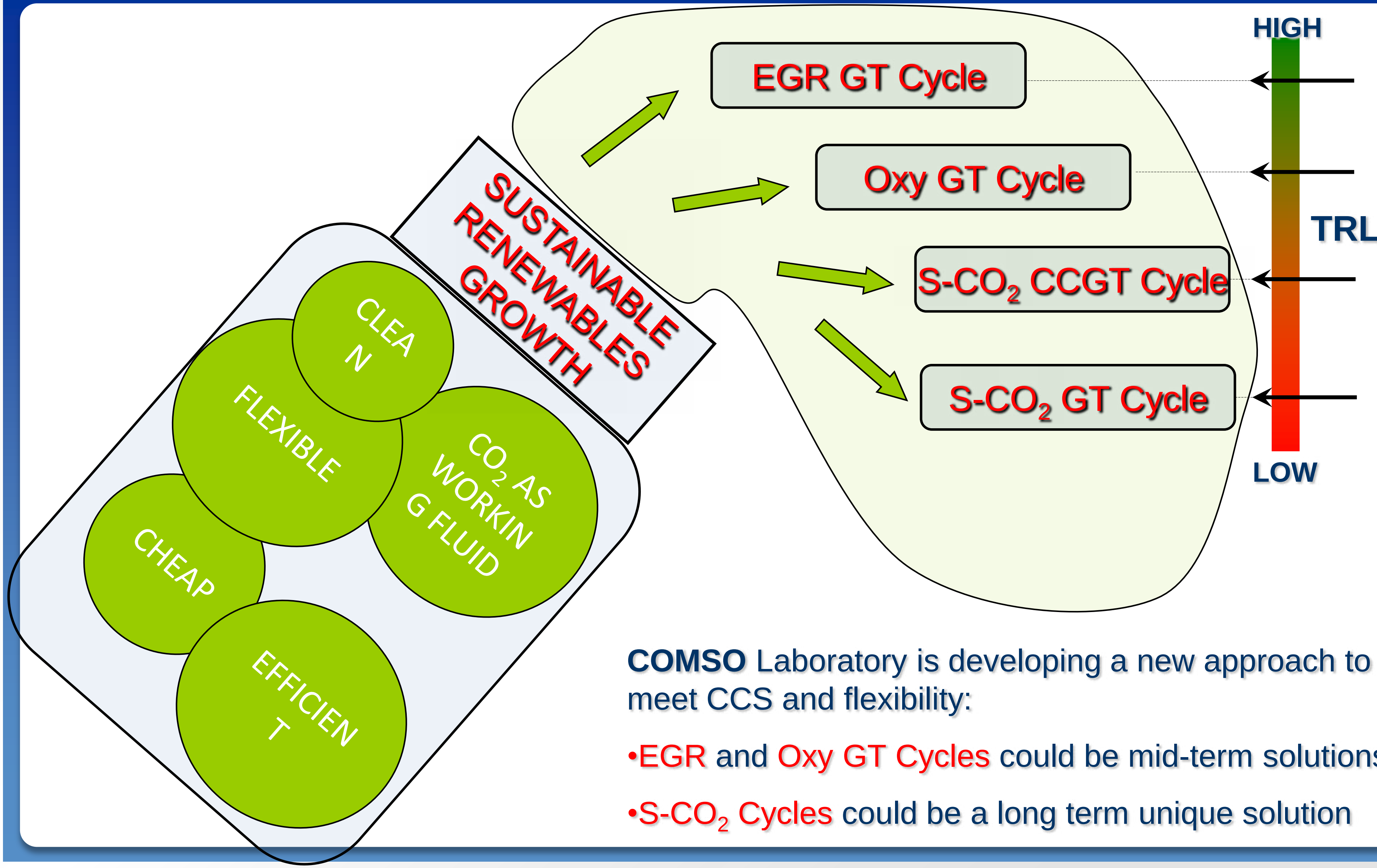
OCGT **without** CCS still continue to be a viable cost-effective option for peak load

	Turndown	Cycling capability: Start-up to full load	Cycling capability: 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

Flexibility from Power Generation

The COMSO Laboratory approach



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

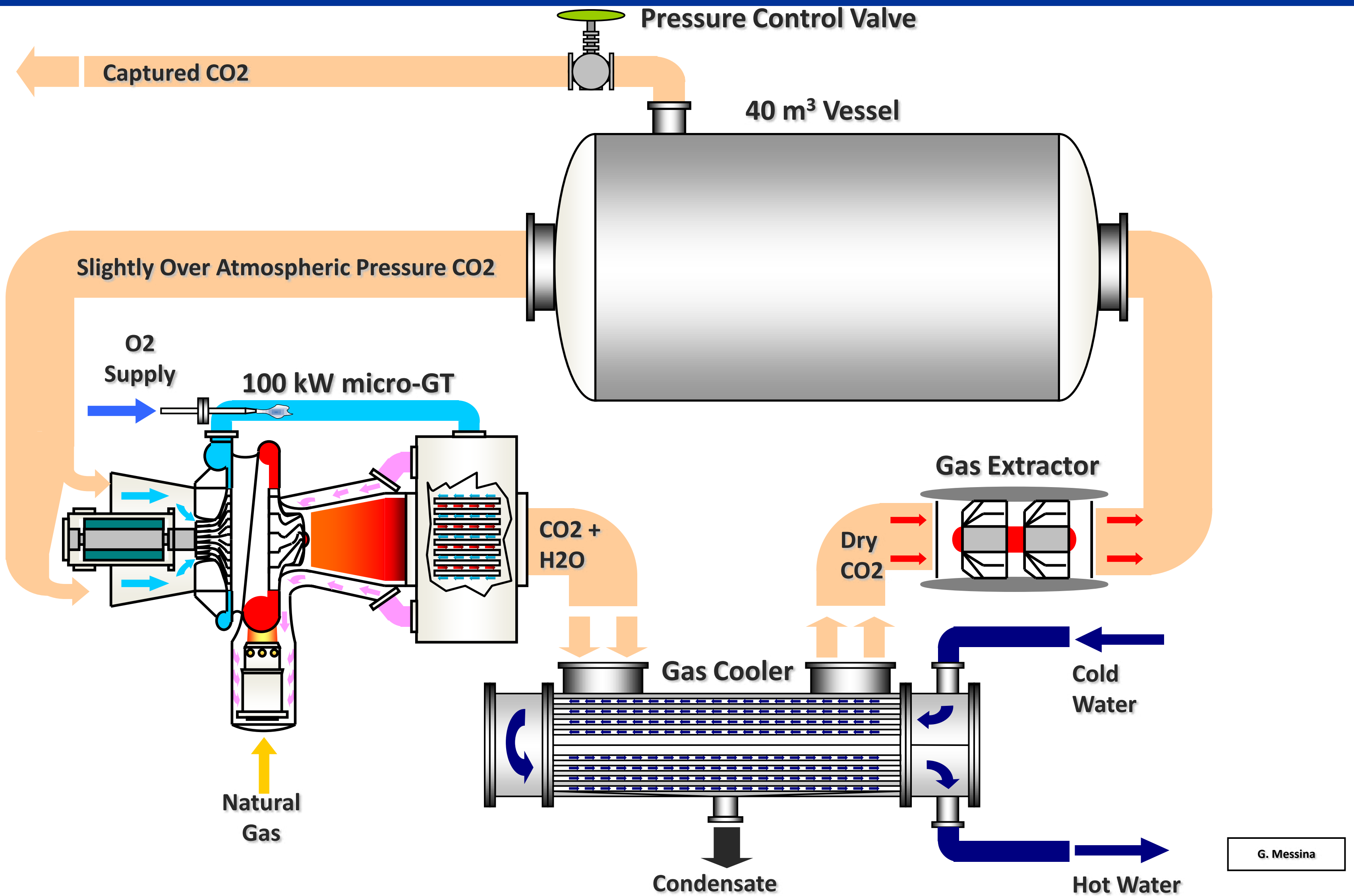
- EGR and Oxy GT Cycles could be mid-term solutions
- S-CO_2 Cycles could be a long term unique solution

AGATUR

Advanced GAs TUrbines Rising

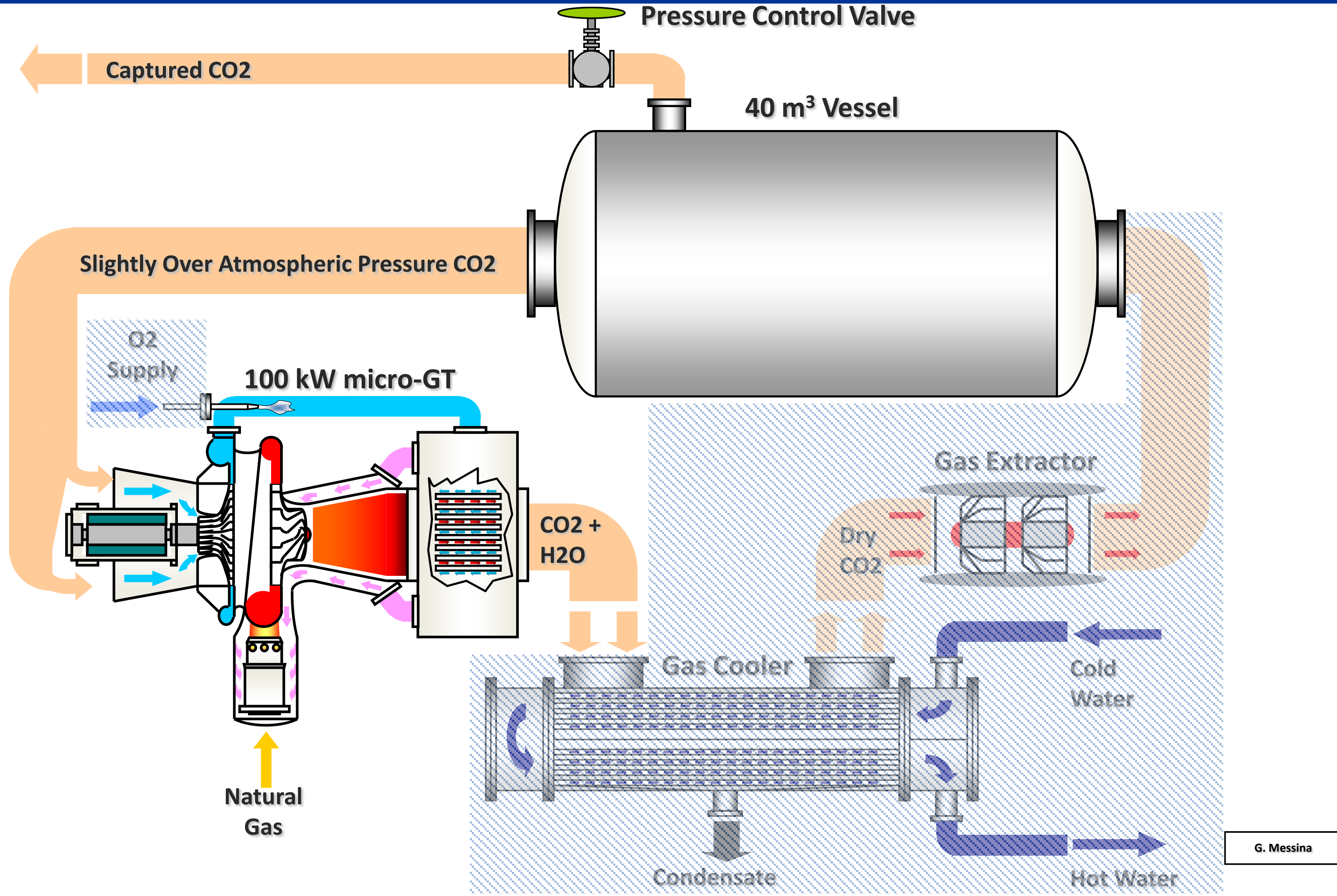
COMSO Experimental Activities

EGR Cycle implementation on AGATUR facility



COMSO Experimental Activities

EGR Cycle implementation on AGATUR facility

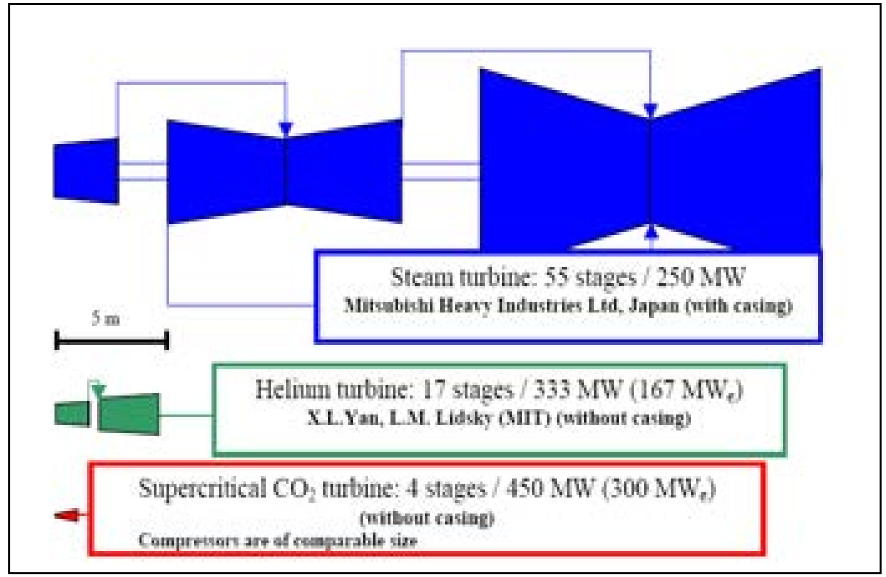


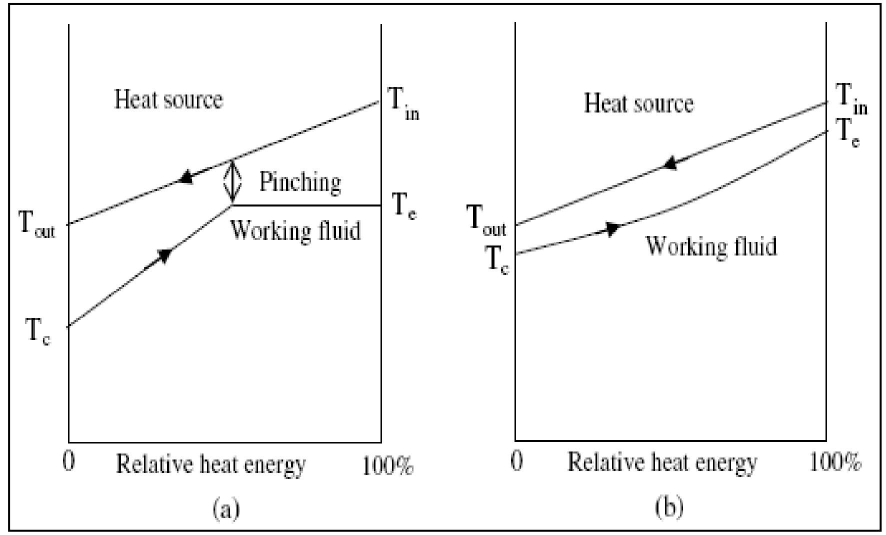
S-CO_2 Peculiarities

Characteristics of an ideal power cycle

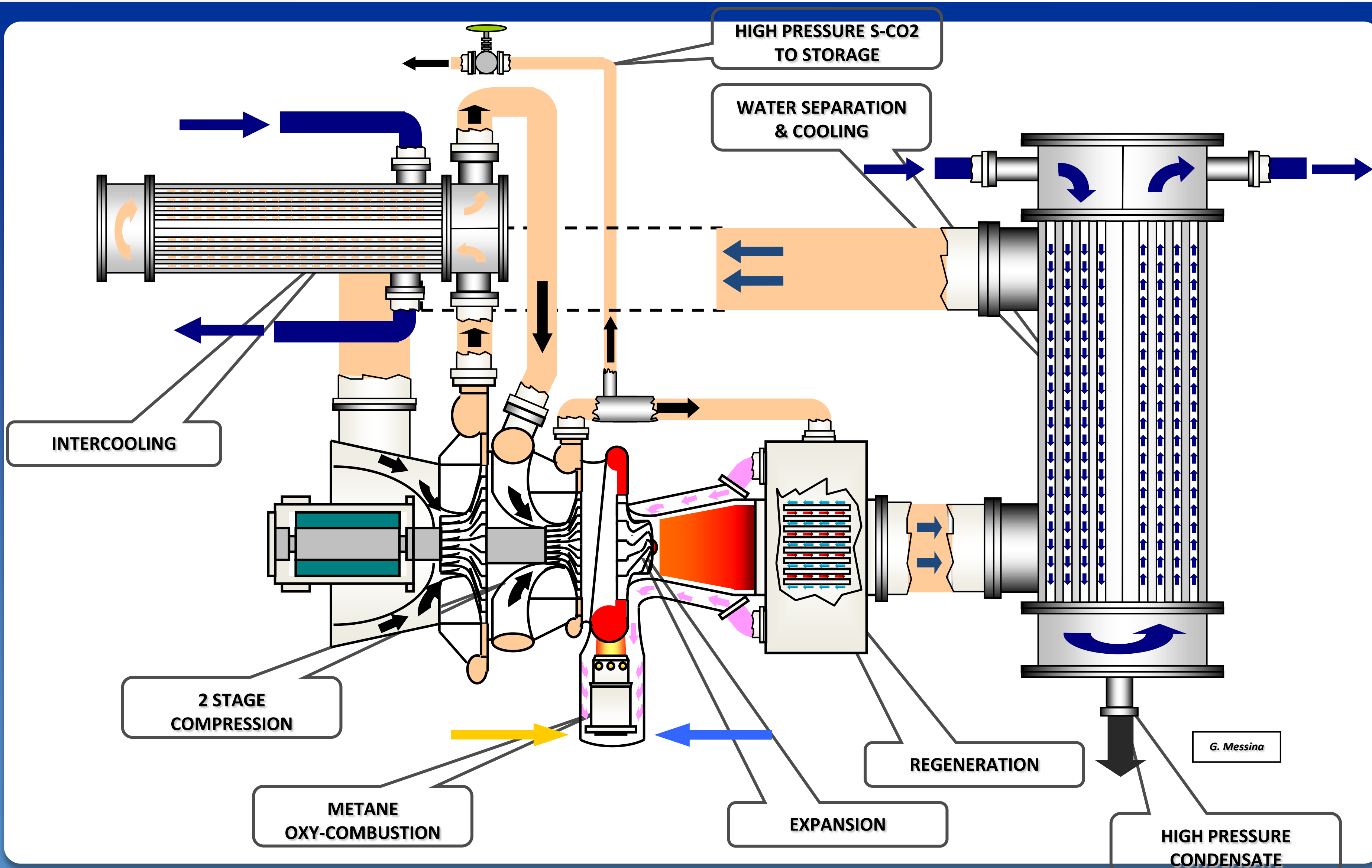
- Good utilization of available heat
  - High expansion, low compression work
  - Direct coupling to heat source
- Benign working fluid
  - Non-corrosive, non-toxic, thermally stable
  - Dry expansion to avoid erosion
- Low capital cost
- Low operation & maintenance (O&M) costs

Supercritical CO_2 meets these characteristics



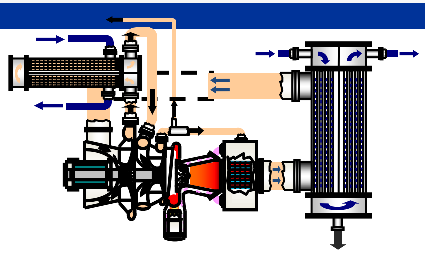


OXY S-CO_2 Cycle: plant layout



OXY S-CO_2 Cycle: simulation results

ETN

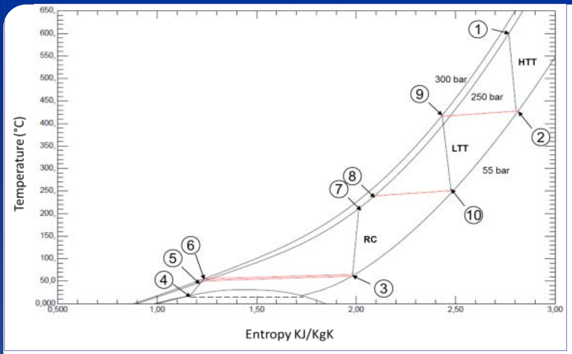


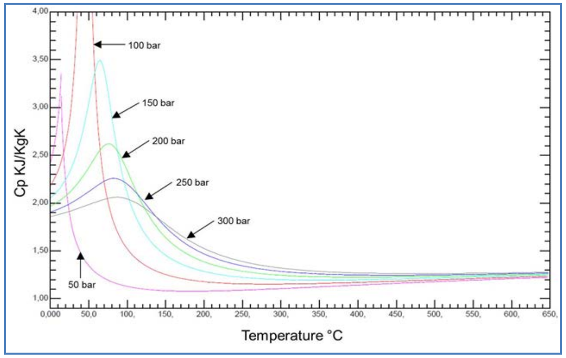
Fuel kg/s	LHV kJ/kg	HCOMPR kW	LCOMPR kW	TURB kW	TIT C	TOT C	TOR C	Oxygen kg/s	Oxygen kJ/kg	EFF
0,01443	50010	32	80	-540	1151	781	702	0,058	42	**0,535**
0,01392	50010	36	83	-526	1100	734	659	0,058	42	**0,525**
0,01354	50010	35	83	-505	1050	696	613	0,056	40	**0,511**

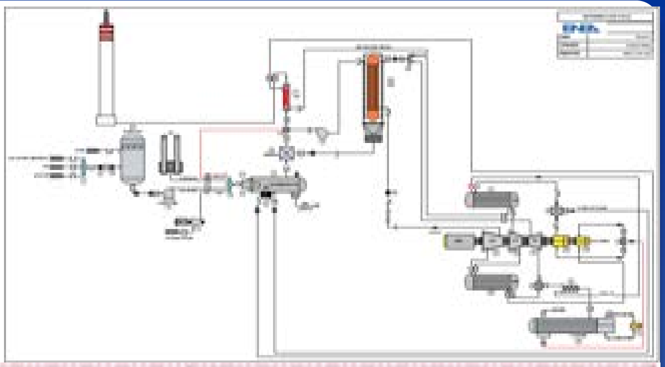
- Regenerator cold side outlet temperature is a key parameter on cycle performance, because of both direct and indirect impact through the TIT limitation.
- A rough sensitivity study was performed by varying TIT, in order to evaluate the “Technological level” on the cycle performance.
- The first principle 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”.

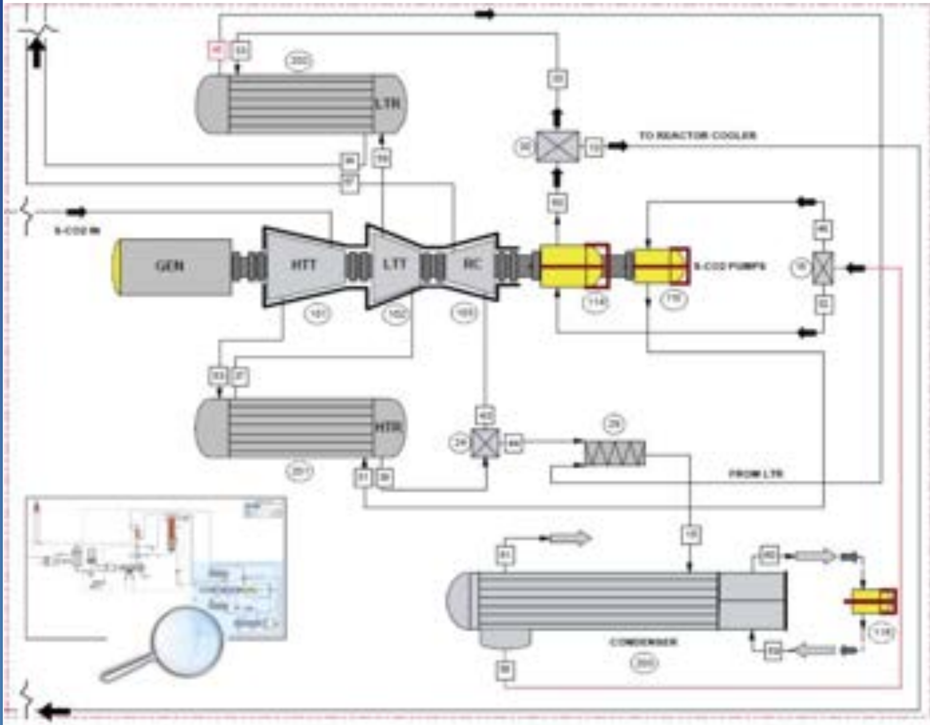
Giuseppe Messina, “Supercritical Carbon Dioxide Power Cycle”, presentation to European Turbine Network, London, 2013

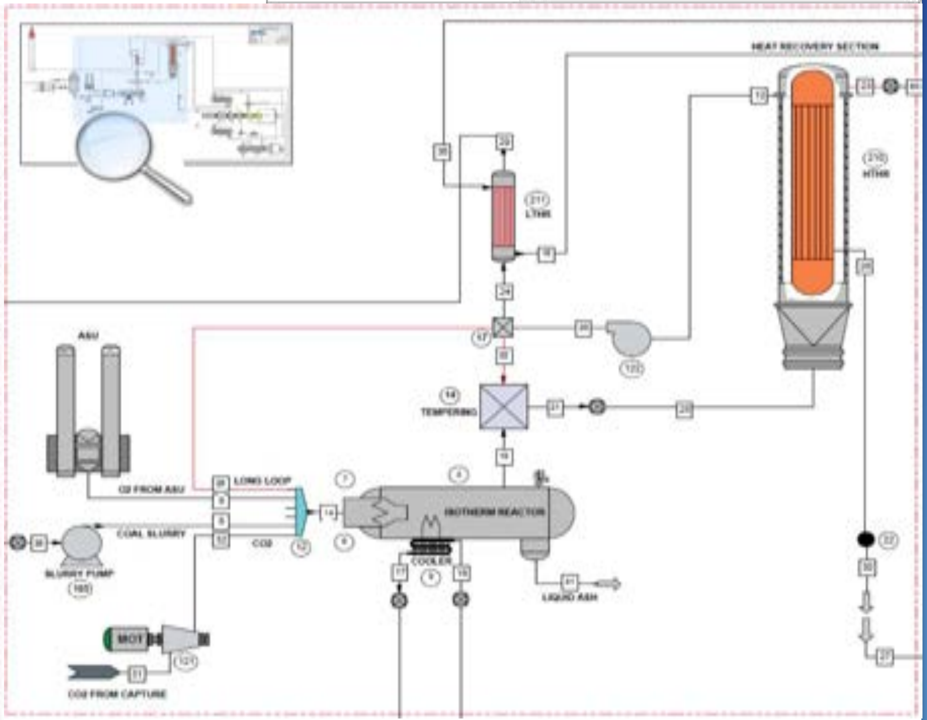
OXYCoal fired S-CO2 Closed Cycle





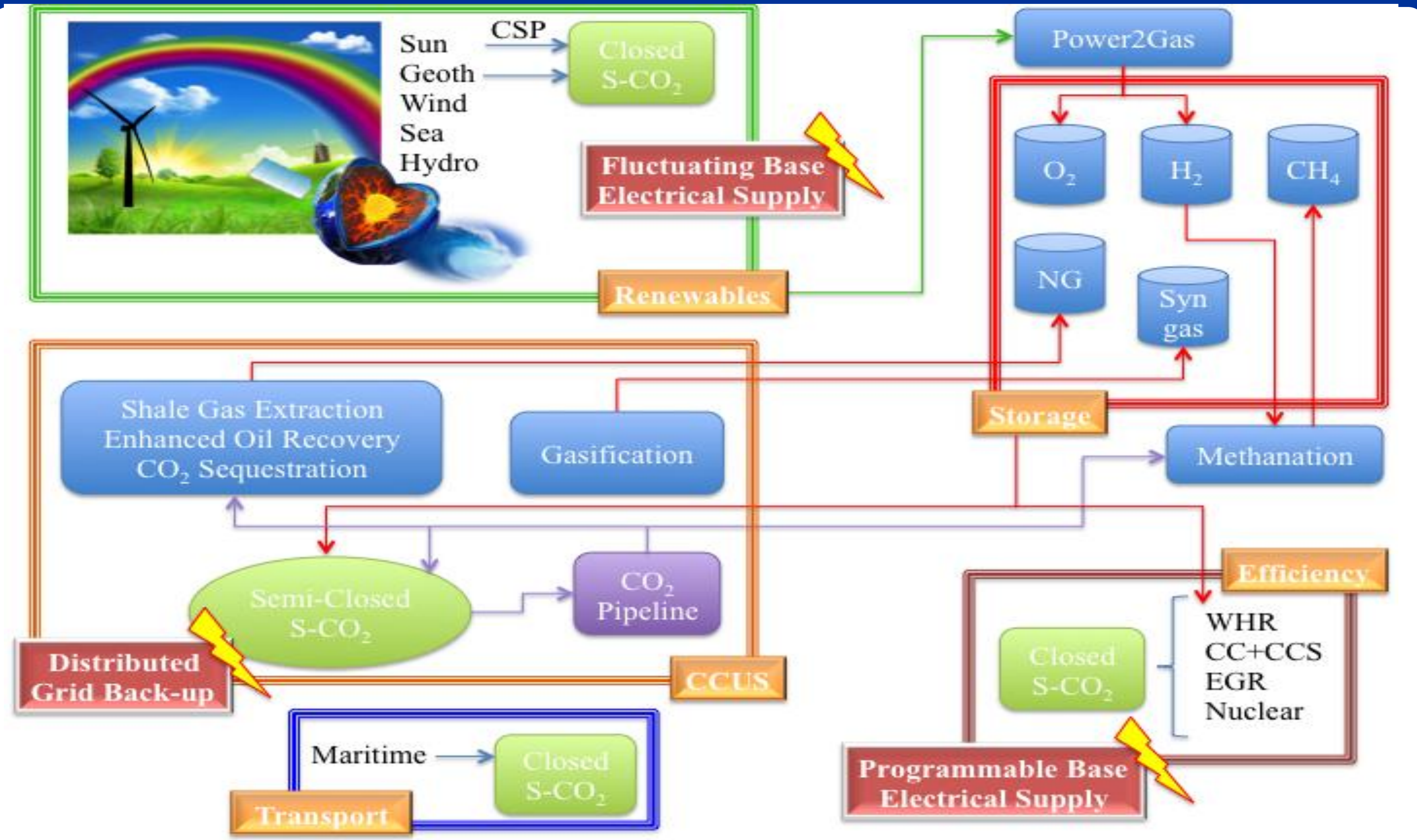






G.Messina, E. Giacomazzi, "Modellazione di un Ciclo di Potenza a CO2 Supercrtica da 48 MWt alimentato dal Loop ISOTHERM PWR", Ricerca di Sistema Elettrico, PAR 2013.

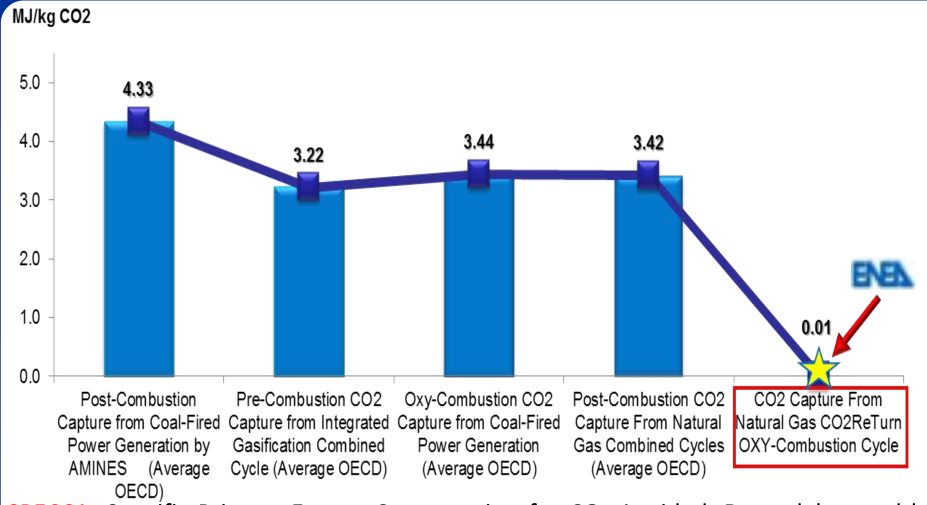
An Holistic Solution



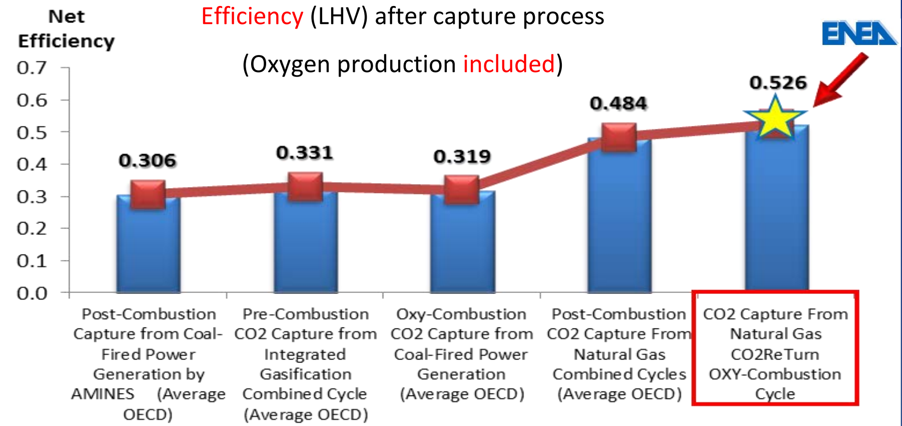
E. Giacomazzi and G. Messina, Exploitation of Supercritical CO2 Properties – An Holistic Solution for the 21st Century Power Generation, Impiantistica Italiana,2015

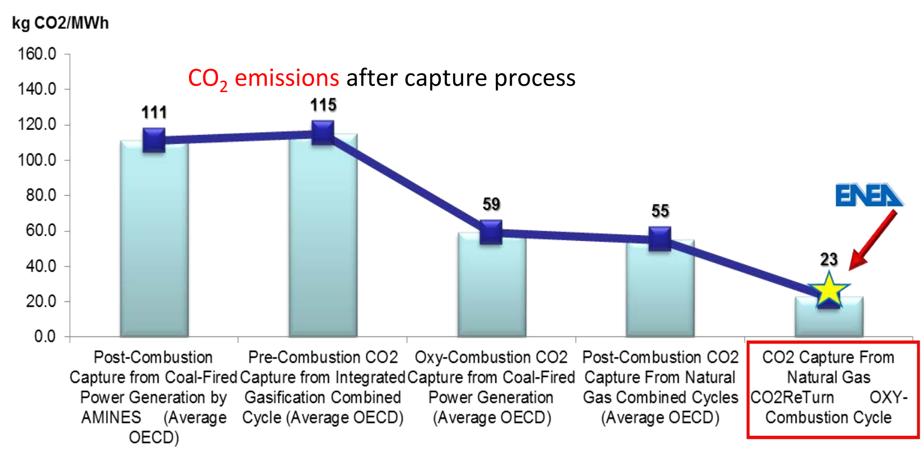
S-CO_2 ALBA Cycle

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 Combustion & Processes Laboratory

Eugenio Giacomazzi
Ph.D., Aeronautic Engineer
Researcher

ENEA – C.R. Casaccia, UTTEI-COMSO, S.P. 081
Via Anguillarese, 301
00123 – S. M. Galeria, ROMA – ITALY

Tel.: +39.063048.4649 / 4690 – Fax: +39.063048.4811
Mobile Phone: +39.3383461449
E-Mail: eugenio.giacomazzi@enea.it

Giuseppe Messina
Mechanical Engineer

ENEA – C.R. Casaccia, UTTEI-COMSO, S.P. 081
Via Anguillarese, 301
00123 – S. M. Galeria, ROMA – ITALY

Tel.: +39.063048.6762 – Fax: +39.063048.4811
Mobile Phone: +39.3338617051
E-Mail: giuseppe.messina@casaccia.enea.it

Thanks for your attention!

Express your interest sending an e-mail to:

Giuseppe.Messina.Cas@ENEA.it
Eugenio.Giacomazzi@ENEA.it