POLITECNICO DI MILANO

CO_2 CAPTURE FROM NATURAL GAS COMBINED CYCLES

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Purpose of the study

- Devoted to natural gas combined cycles
  - Coal is the reference fuel, but natural gas offers
    - Simpler configurations, lower technological risks
    - Repowering issues for Italian NGCC fleet
- Near-mid term solutions excluding unproven components
- 'Classic' techniques for CO_2 capture
  - Post-combustion with amine capture
  - Pre-combustion, with reforming, shift and MDEA capture
  - Oxy-combustion, with semi-closed H_2O-CO_2 power cycle
- Detailed thermodynamic analysis and optimization
- Performance, emissions and economic assessment

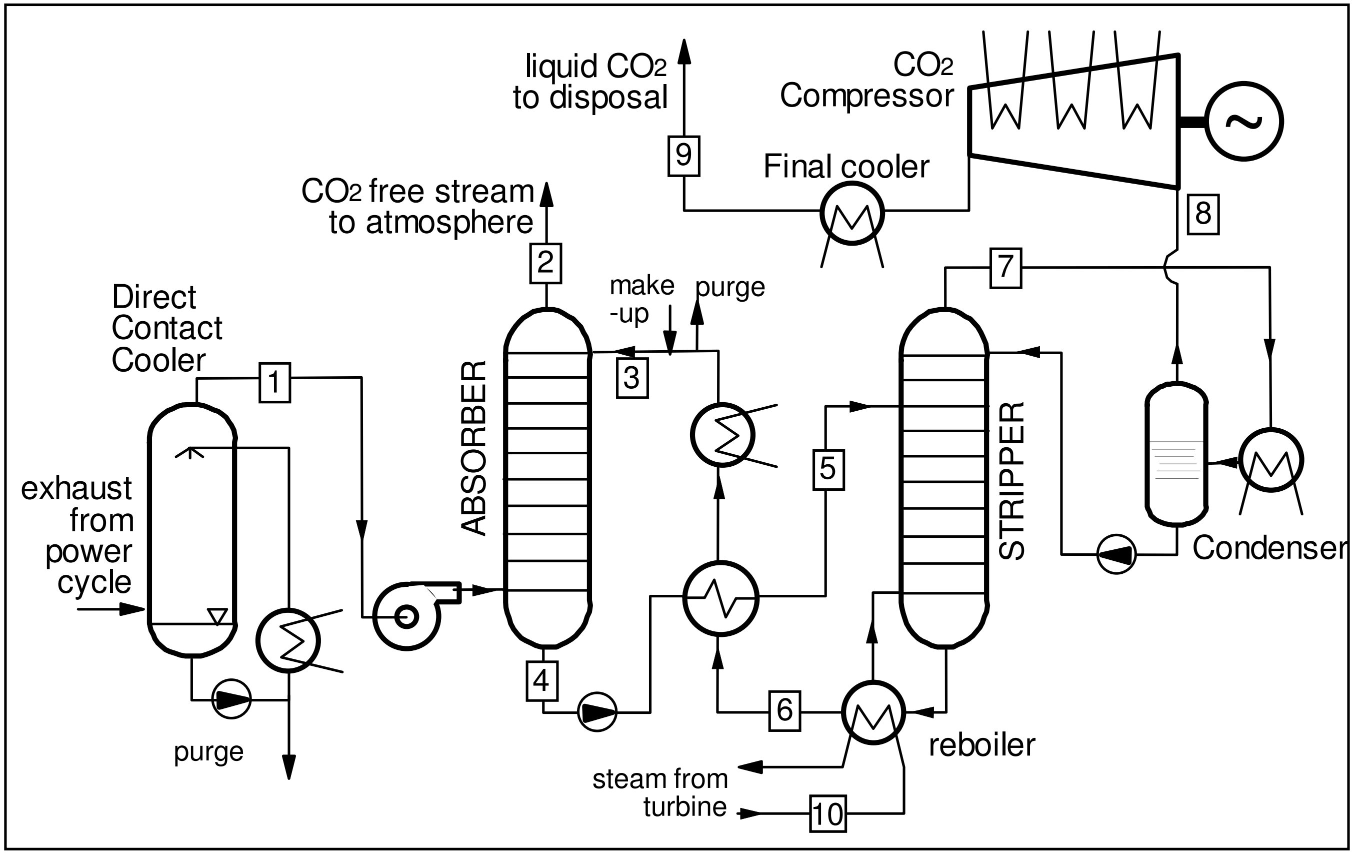
The reference case

- A modern combined cycle based on a GE Fr.9FB gas turbine
- Data supplied by Edison, supporting the present study
- Calculations by means GS code, developed in our Department and used for power plant on-design performance prediction

Gas turbine – GE 9FB	Manufacturer's data	Calculated value	Perc. variation
Natural gas flow, kg/s (air flow imposed)	16.187	16.198	0.07%
Gross electric power output, MWe	272.6	272.44	-0.06%
Gross electric efficiency, %	38.18	38.11	-0.07 points
Turbine outlet temperature, °C	622.8	622.7	-0.1°C

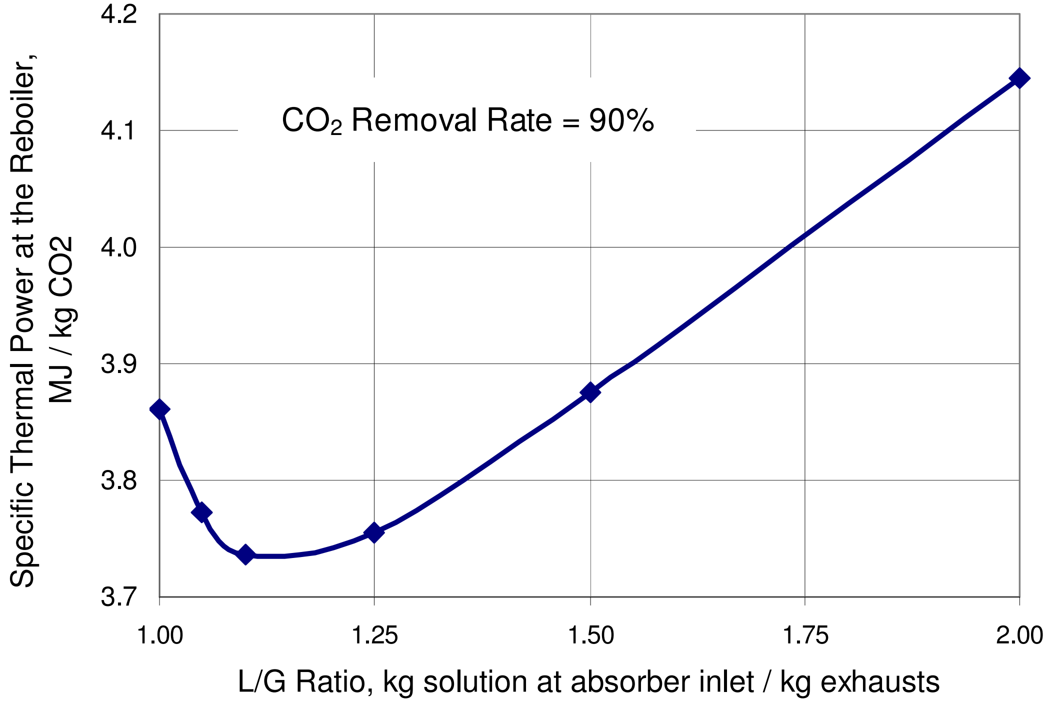
Combined cycle	Manufacturer's data	Calculated value	Perc. variation
HP steam flow, kg/s	167.00	167.27	0.16%
IP steam flow, kg/s	20.83	20.88	0.24%
LP steam flow, kg/s	20.39	20.24	-0.74%
Exhaust gas temperature at stack, °C	89	88.6	-0.4°C
Steam turbine gross electric power, MWe	299.70	299.29	-0.14%
Net electric power, combined cycle, MWe	822.10	821.37	-0.09%
Net electric efficiency, combined cycle, %	57.60	57.45	-0.15 points

Post-Combustion Capture



Typical chemical absorption process
with Mono-Ethanol-Amine

Post-Combustion Capture: influence of L/G

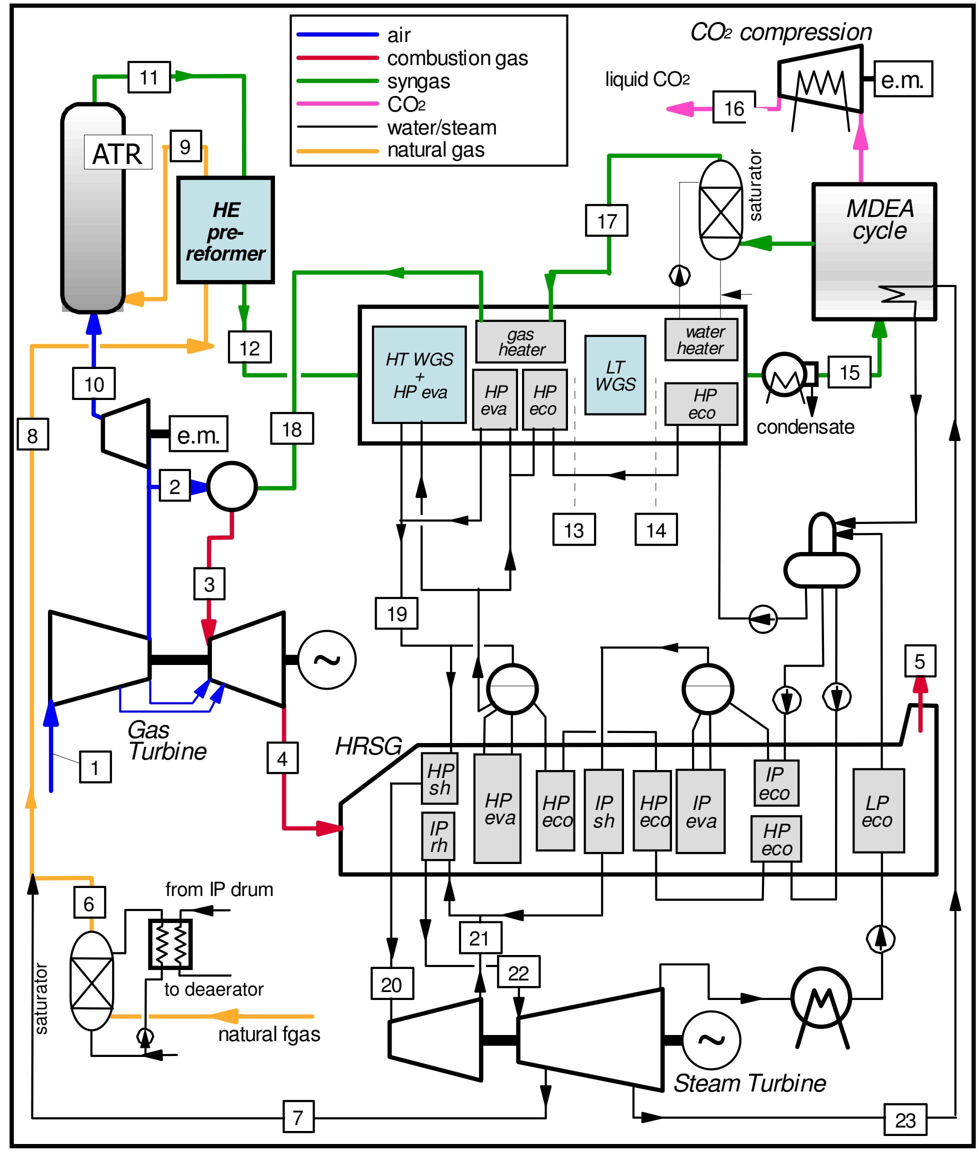


L/G ratio, kg/kg	1.00	1.05	1.10	1.25	1.50	2.00
Solution flow rate at absorber inlet, kg/s	653.34	686.01	718.68	816.68	980.01	1306.6
Lean solution loading, molCO_2 / molMEA	0.23	0.24	0.25	0.28	0.31	0.35
Rich solution loading, molCO_2 / molMEA	0.50	0.50	0.50	0.49	0.49	0.49
Cooling duty, MW	163.29	161.09	160.85	165.47	177.96	207.13
Recuperator duty, MW	166.26	173.81	181.18	202.33	234.78	292.54
Reboiler thermal power,MW	143.00	139.80	138.40	139.10	143.60	153.60

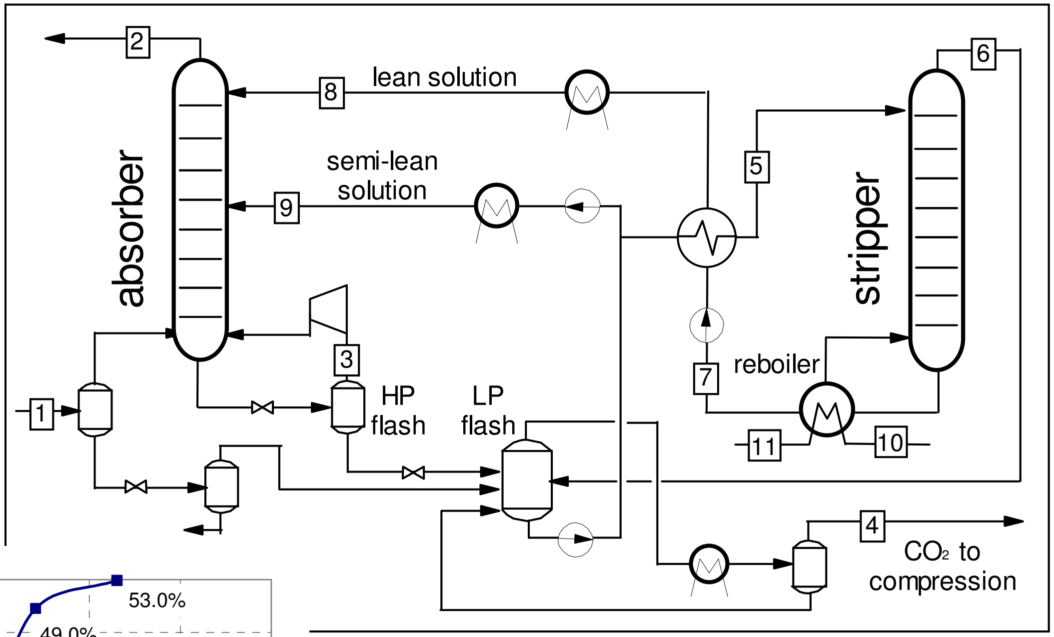
Pre-combustion Capture: plant scheme

The chemical section includes:

- A pre-reformer (heated by raw syngas)
- Air-blown auto-thermal reformer (1050°C, S/C=1.5)
- Two-stage shift reactors
- Absorption process with Methyl-Diethanol-Amine (mixed physical-chemical)

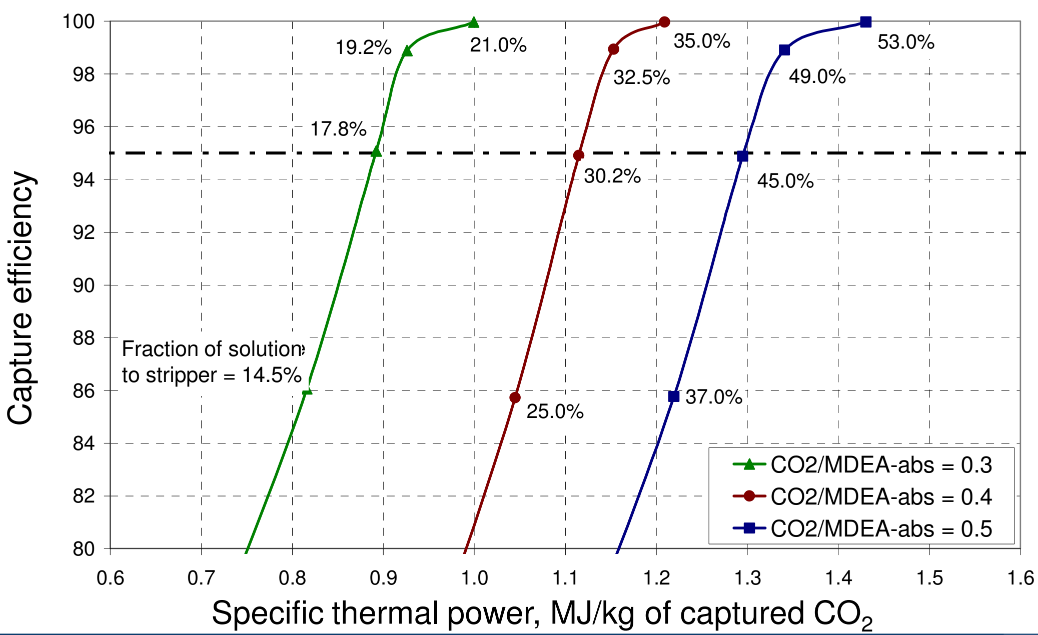


Pre-combustion Capture: plant scheme



MDEA cycle:

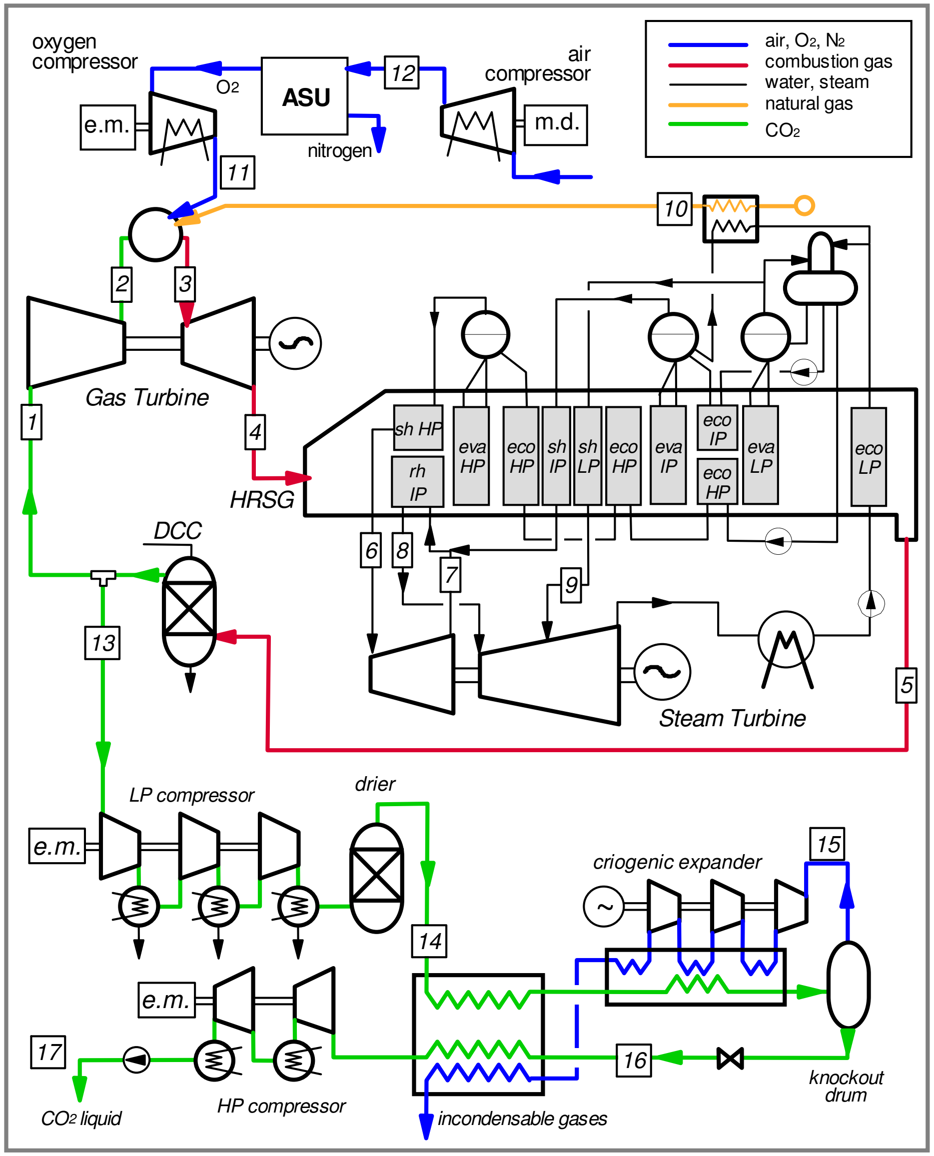
Optimizing the fraction of solution to stripping and the loading (CO_2/MDEA) in the absorber



Oxy-combustion: plant scheme

The Joule cycle is re-design for operations with CO_2-H_2O:

- Larger pressure ratio (44) to have similar temperatures of conventional GTs
- Blade cooling more demanding
- High-purity oxygen (98.5%)
- CO_2 purification section to remove incondensable gases such as N_2,O_2,Ar



Results: Plant Performance

		No capture	Post-comb.	Pre-comb.	Oxy-fuel
Total net electric power, MW		821.4	728.6	808.2	660.1
Gas Turbine	x2	272.4	272.4	286.3	279.7
Steam Turbine		299.3	241.1	311.8	315.5
Auxiliaries, power cycle		22.8	16.3	25.6	16.5
Auxiliaries, heat rejection		-	8.8	8.1	12.9
Auxiliaries, MEA/MDEA cycle		-	3.7	2.5	-
Air and O_2 Compressors, ASU	x2	-	-	-	75.1
CO_2 Compressor	x2	-	12.4	15.1	17.6
Thermal power rejected, MW		459.9	588.8	537.0	861.9
Condenser		459.9	189.5	358.5	690.3
MEA/MDEA/ASU	x2	-	178.1	65.0	59.8
CO_2 Compressor	x2	-	21.5	25.6	26.0
Fuel thermal power LHV, MW		1429.7	1429.7	1625.0	1429.7
Net efficiency		0.5745	0.5096	0.4974	0.4617
CO_2 generated from fuel, kg/s		81.47	81.47	92.61	81.47
CO_2 captured, kg/s		-	73.91	84.77	78.96
Removal efficiency		-	0.9072	0.9154	0.9691
Specific emission, g CO_2 /kWh		357.09	37.36	34.88	13.72

Remarks: emissions

Carbon dioxide emissions:

- 90% reduction can be achieved by pre- and post-combustion
- Much better figures for oxy-fuels (99% feasible)

Nitrogen oxides emissions:

- Post-comb.: same as no capture
- Pre-comb.: due to the presence of hydrogen, no pre-mixed combustors available – syngas is nitrogen-diluted and saturated by steam to abate stoichiometric flame temperature, as for IGCCs
- Oxy-fuel: virtually zero-emissions

Remarks: technological developments

Post-combustion:

- No modifications to gas turbine
- Relevant modification to steam turbine (in case of retrofitting)
- Large volumes and weights of absorber/stripper
- MEA consumption and degradation

Pre-combustion:

- Relevant modifications to GT: air extraction, diffusive combustor
- Retrofitting is very questionable
- A complex chemical section for fuel conditioning

Oxy-combustion:

- GT must re-designed, using established know-how
- Large investment cost for ASU

Cost assessment

	No capture	Post-comb.	Pre-comb.	Oxy-fuel
1st year carrying charge	0.1450	0.1549	0.1549	0.1549
Overnight plant cost, €/kW	414	780	948	1004
Operating hours, h/year	7800	7800	7800	7800
Yearly average efficiency	0.5601	0.4969	0.4850	0.4502
COE investment, €/MWh	7.69	15.50	18.83	19.93
COE O&M, €/MWh	2.99	5.25	5.26	5.60
COE fuel, €/MWh	44.99	50.72	51.96	55.98
COE total, €/MWh	**55.67**	**71.46**	**76.05**	**81.51**
Cost of CO_2 captured, €/ton		42.16	52.64	58.51
Cost of CO_2 avoided (plant), €/ton		48.16	61.68	73.37
Cost of CO_2 avoided, including transport and final storage (7 €/ton)		**57.30**	**71.05**	**83.40**
Externalities NO_2, €/MWh	0.46	0.52	0.90	0.00
Externalities SO_2, €/MWh	0.02	0.02	0.00	0.00
Externalities NMVOC, €/MWh	0.00	0.01	0.00	0.00
Externalities CO_2, €/MWh	8.74	0.91	0.85	0.34
Total cost with externalities, €/MWh	**64.89**	**72.92**	**77.81**	**81.85**

Cost assumptions: Natural gas 7 €/GJ (0.19 €/Nmc);

Externalities: NO_2 3 €/kg, SO_2 3.4 €/kg, NMVOC 1.1 €/kg, CO_2 19 €/ton (from Extern-E, 2005)

Conclusions

Post-combustion seems the most interesting option in the near term:

- Minimum technological risk, no modifications to gas turbine
- Lowest predicted cost, better efficiency, operational flexibility

Pre-combustion (even if the winner for IGCCs) quite demanding

Oxy-combustion: an option for longer terms