Theoretical, Practical and Sustainable Exergetic Recovery of Energy Resources

A.A. Eftekhari and J. Bruining

TU Delft, Civil Engineering and Geosciences, Delft, the Netherlands
Stevinweg 1, 2628 CN, Delft, the Netherlands
a.a.eftekhari@tudelft.nl

Introduction

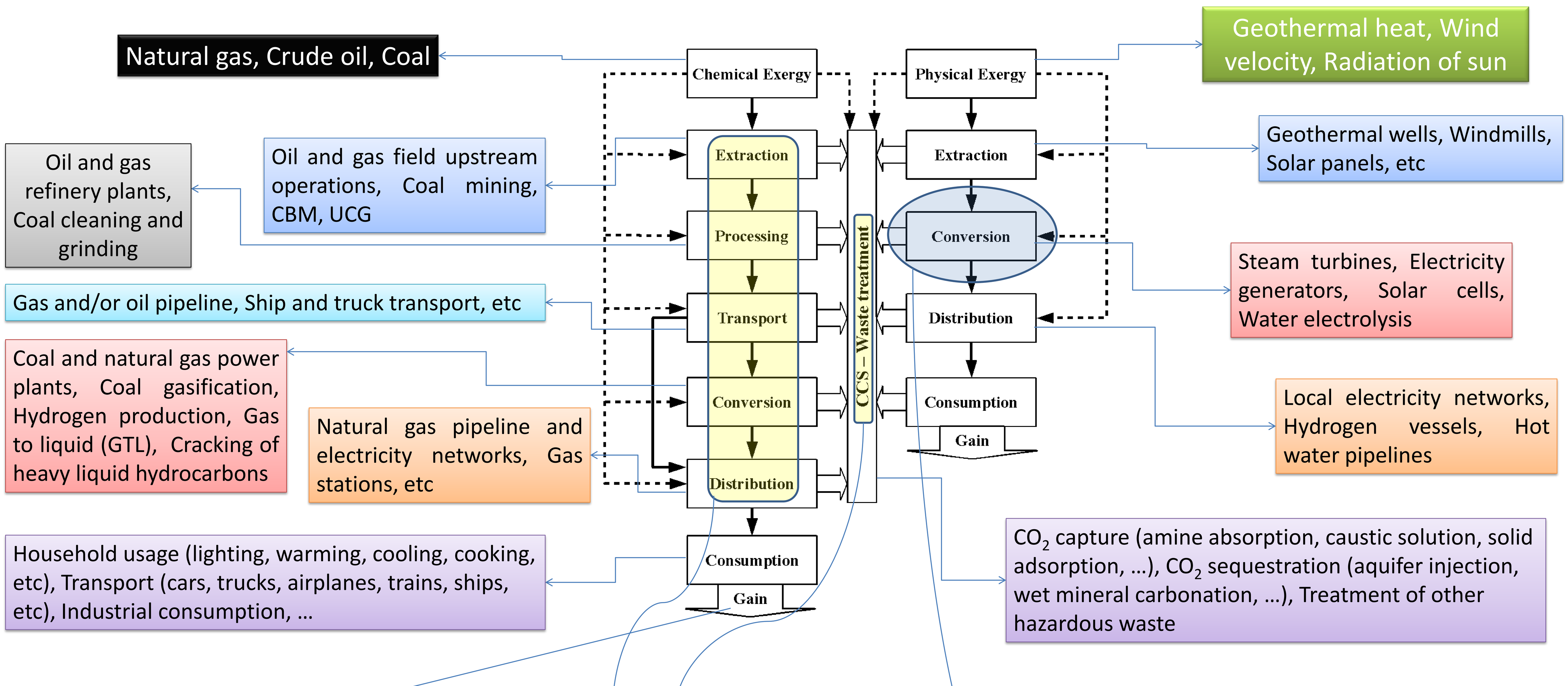
To recover the energy sources available in nature, a processing scheme must be followed that needs energy and material resources. On the other hand, for every energy resource a certain fraction is needed for its recovery. In this contribution, the exergy concept is used to take into account the useful energy that is consumed in each unit of an energy recovery process. The calculation starts by assuming isentropic unit operations and physical/chemical phase equilibrium. Put into the first and second law of thermodynamics one finds the maximum (theoretical) exergetic recovery. Then, using the practical data available in the open scientific and industrial literature, the ideal or theoretical energy consumption can be updated to practical recovery values. Finally, the useful energy required in the treatment of hazardous waste/byproducts produced during the fuel processing and consumption is added to the practical energy consumption, to find the sustainable recovery factor. The theoretical, practical, and sustainable recovery for chemical, i.e., natural gas, crude oil, and coal and physical, i.e., wind and geothermal resources, were calculated and compared to reliable data sources from the industry.

Method	η_i	Ex_1 (preparation)	Ex_2 (abatement)	ψ
Theoretical	1	Ex_1^t (Minimum)	0	$\frac{Ex_{res} - Ex_1^t}{Ex_{res}}$
Practical	practical values	$Ex_1^p = \frac{Ex_1^t}{\eta_1}$	0	$\frac{Ex_{res} - Ex_1^p}{Ex_{res}}$
Sustainable	practical values	$Ex_1^s = \frac{Ex_1^t}{\eta_1}$	$Ex_2^s = \frac{Ex_2^t}{\eta_2}$	$\frac{Ex_{res} - Ex_1^s - Ex_2^s}{Ex_{res}}$

Exergy Consumption (% of 20 years of Natural Gas production)

		Theoretical	Practical	Sustainable
Well	drilling	4.10E-04	8.20E-04	1.04E-03
	Steel	1.39E-03	1.00E-02	1.27E-02
	Cement	1.10E-04	2.89E-04	3.65E-04
Transport	Compressor	0.90	2.26	2.85
	Steel	9.19E-02	0.66	0.84
Refinery	Compression	3.04E-02	0.08	0.10
	Heating	0.38	1.50	1.90
Total (exclude CCS)		**1.40**	**4.51**	**5.70**
CCS	Total	-	26.44	33.43
Total (include CCS)		***1.40***	***30.95***	***39.13***

Flow Diagram



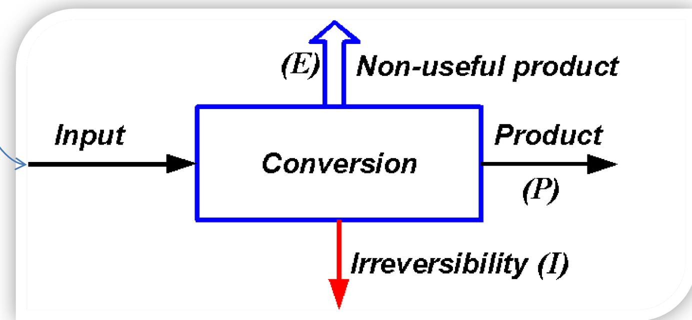
Effective Recovery Factor: $\psi = \frac{Ex_{gain}}{Ex_{res}}$

$Ex_{gain} = Ex_{res} - (Ex_1 + Ex_2)$

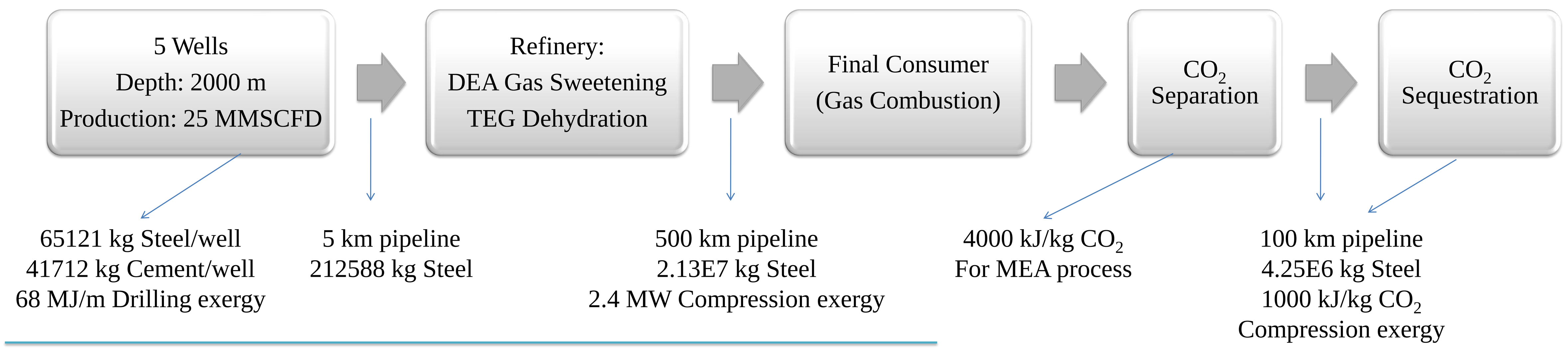
Resource Chemical/Physical Exergy

Efficiency Factor [1]: $\eta = \frac{P}{E + P + I}$

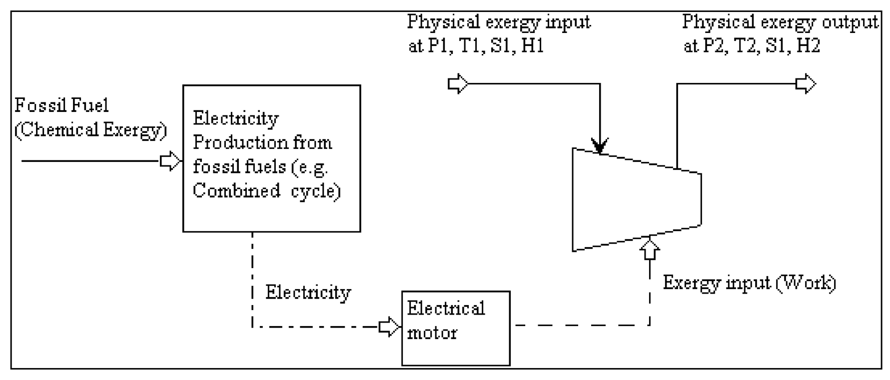
This efficiency factor can be calculated and applied to the other process steps (See the simple example below)



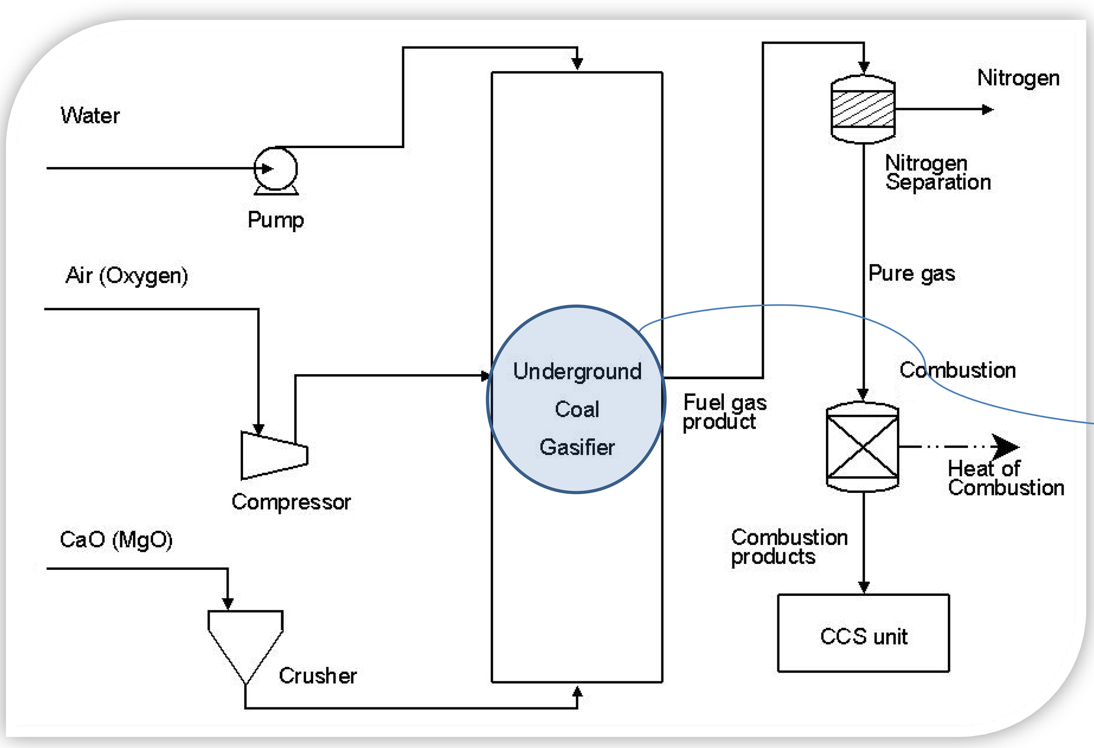
Case Study 1: Natural Gas Production



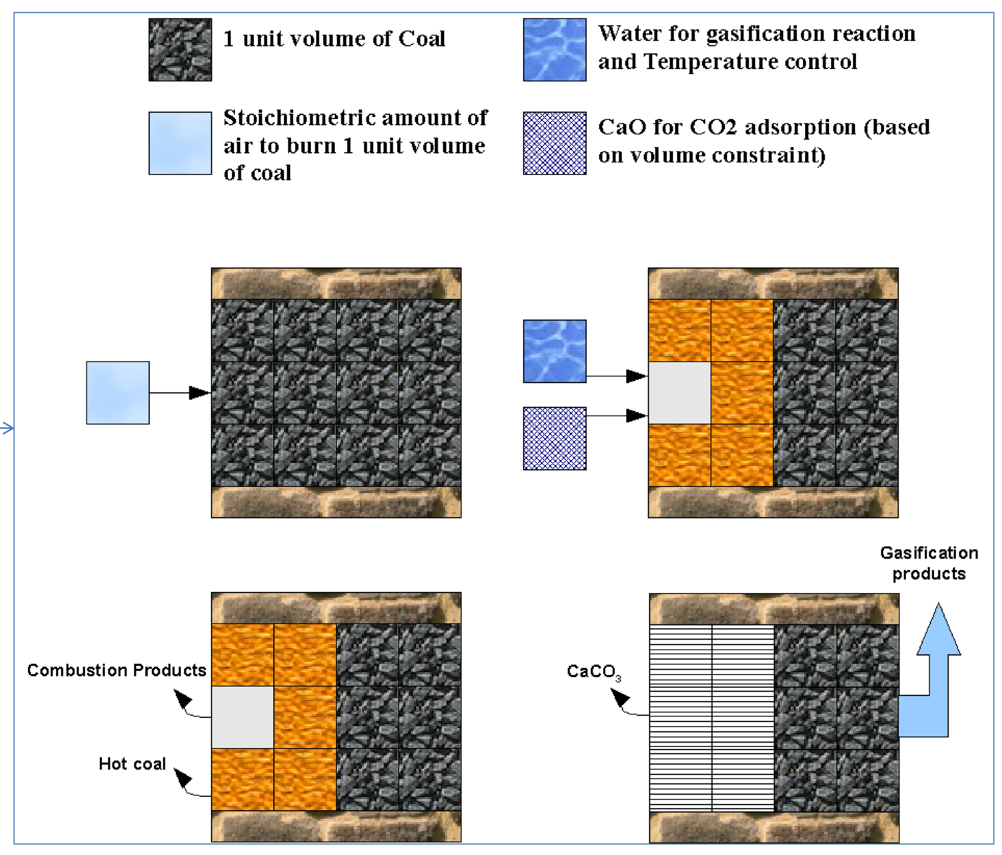
Simple Example:
Theoretical Compression Exergy = $H_2 - H_1$
Practical Compression Exergy = $(H - H_1)/\eta_{Compressor}\, \eta_{Driver}\, \eta_{Power\ Plant}$
Zero Emission Compression Exergy = Practical Compression Exergy × $(1 + \varepsilon_{PP}\, Ex_{CCS})$
ε_{PP}: CO_2 emission per unit electricity generated in the power plant
Ex_{CCS}: Exergy consumed per unit CO_2 captured and sequestered

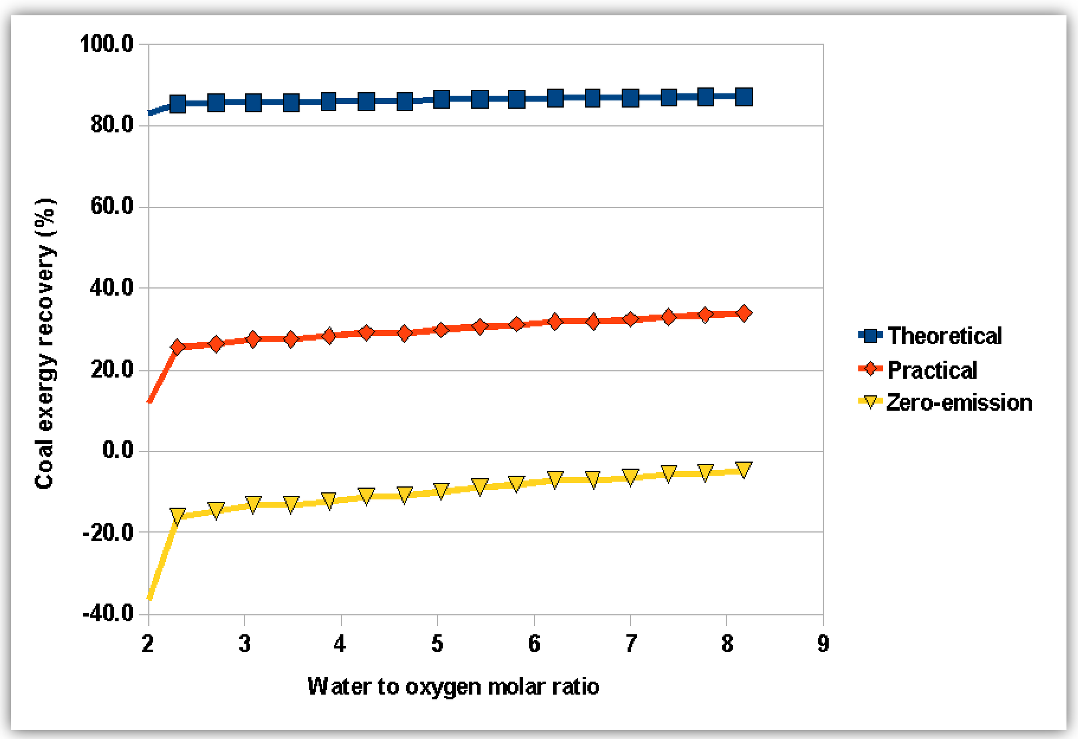


Case Study 2: Underground Coal Gasification

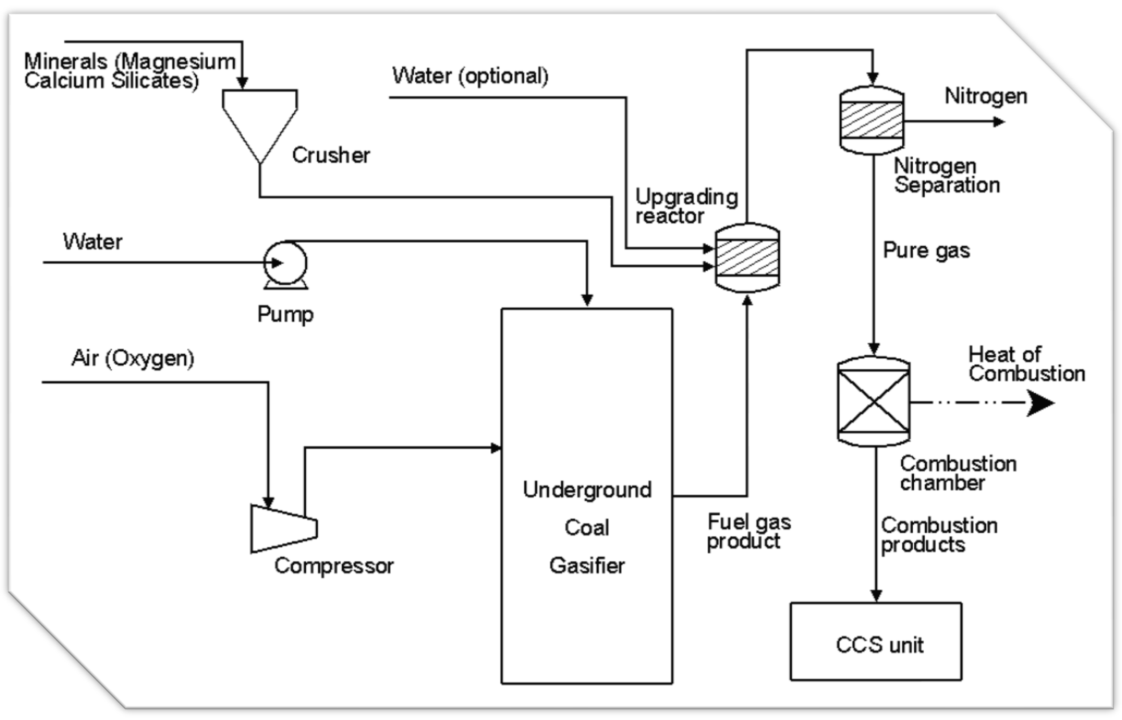


Process Flow Diagram (PFD) of Underground Coal Gasification: Scenario 1- Synthetic CaO injection



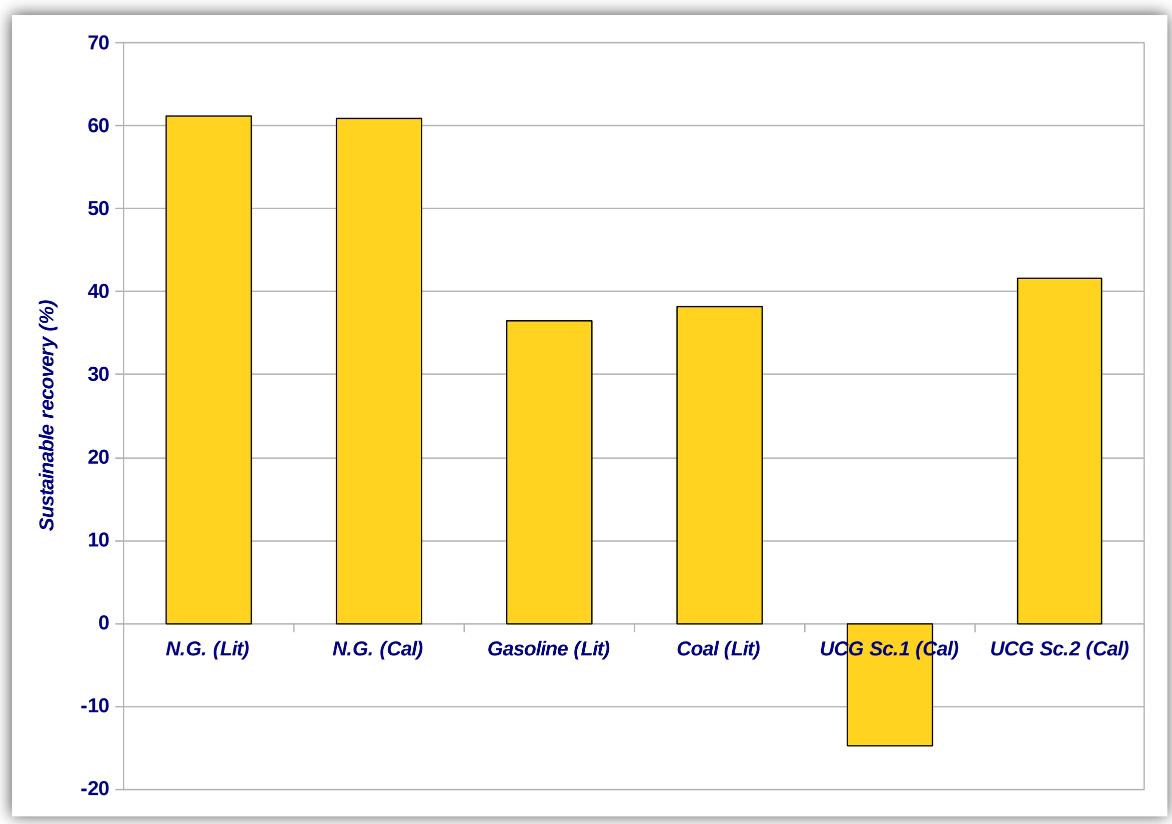


Theoretical, Practical and zero-emission recovery of coal as a function of injected water to oxygen ratio



Process Flow Diagram (PFD) of Underground Coal Gasification: Scenario 2- Ex-situ upgrading with natural magnesium calcium silicates

Conclusion



Zero-emission exergetic recovery of natural gas (N.G.), gasoline (from crude oil), coal, UCG (scenario 1 and 2). The calculated value (Cal) is in agreement with the literature data (Lit) [2] for natural gas recovery. Negative value for the UCG process (sc.1) means that this process can not provide the required exergy for capture and sequestration of its own CO_2 emission based on current state of technology.

References

[1] Dewulf J, et. al., "Illustrations towards quantifying the sustainability of technology", The Royal Society of Chemistry, 2000

[2] Delucchi M., "lifecycle emissions from transportation fuels, motor vehicles, Transportation modes, electricity use, heating and cooking fuels, and materials", Institute of Transportation Studies, University of California, 2003

Annual Research Meeting,
Department of Geotechnology
January 2010, Delft, the Netherlands

Delft University of Technology