Assessment Of Pre-Combustion Decarbonisation Schemes For Polygeneration From Fossil Fuels.

Jens Hetland
SINTEF Energy Research,
Kolbjorn Hejesvei 1A, N-7465 Trondheim, Norway

This article relates to emerging poly-generation schemes that employ pre-combustion decarbonisation of fossil fuels with options for geological storage of the CO_2. Inevitably, such schemes are highly complex, and may require new approaches and knowledge on interactions between key components in large plants, as even new technologies and features are expected to occur in due course as polygeneration mature. Reference is made to the European DYNAMIS project and the Sino-European project COACH[1] - both conducted under the auspices of the European Commission.

1. Introduction

Although community policy and national energy strategies much relate to a subset of major concerns such as the issues of (1) security of energy supply, (2) climate change, (3) local pollution, (4) general business development and (5) harmonisation, the relative importance of these issues is likely to depend on the stage of development and the availability of indigenous fuel reserves. Recent prognoses show that the global electricity demand will grow by a factor 3 to 7 within the 21st century. Nevertheless, no sustainable primary energy has so far been identified that is capable of supplying electric power in very large quantities at a reasonable cost. This implies that fossil fuels (most likely) will pre-dominate over the renewable energy sources in the foreseeable future, despite of the CO_2, which inherently is regarded a major drawback of fossil fuels. Therefore (and most likely), a substantial transition towards the more sustainable advanced clean fossil fuel technologies, in which capture and storage of the CO_2 (generically known as CCS) will (expectedly) take place in the coming years. And, far more than hitherto, new energy supply schemes must compromise primary energy demand against environmental concerns and geopolitical issues – post Kyoto.

The isolation of CO_2 is inherently linked with additional energy input and cost. As (so far) advanced CCS technologies are associated with a fuel penalty between 15-30% just for the capture and pre-treatment of the CO_2, it is likely to assume that CCS can only be justified in a commercial setting if the gap between cost and market price is being closed or compensated for. Therefore there is a quest for enabling efficient and less expensive CCS technologies, whereof pre-combustion decarbonisation is a strong candidate – especially in plants using coal or lignite as feedstock.

[1] Towards Hydrogen and Electricity Production with Carbon Dioxide Capture and Storage, EC/FP6 Contract #019672 DYNAMIS, under co-ordination of SINTEF Energy Research, Norway.
Cooperation Action within CCS China-EU, EC/FP6 Contract #038966 COACH, under co-ordination of Institut Français du Petrole (IFP), France.

2. Justification of gasification technology

In this article gasification means a thermo-chemical conversion (including reforming) of carbonaceous materials - such as fossil fuels - into a synthesis gas (syngas). Seemingly there is a growing interest for the emerging gasification processes that combine a gas turbine with a steam bottom cycle (IGCC). The rationale is that these processes:

1. offer options for polygeneration, notably for deriving synthetic fuels from coal,
2. fit into visions for future hydrogen markets that are being envisaged,
3. feature capture of carbon dioxide as an integral quality
4. do not add an exceedingly high additional cost for a full CCS scheme.

A variety of products can be produced via gasification including electricity, ammonia, and hydrogen, as summarised in Table 1. As seen from the table the world's inventory of modern large-scale gasification units in operation amounts to 160 (2004).

Table 1: World inventory of modern gasification plants by primary products produced through fossil fuel gasification; Operating and planned plants (PowerClean, 2004, [1])

Product	***Pimary product***	
	Operating plant	***Planned plant***
Electricity	35	25
Hydrogen	11	1
Ammonia	34	3
Syngas	14	1
Methanol	12	1
Oxy-chemicals	22	0
Carbon Dioxide	7	0
Others (FT liquids, fuel gas)	25	4
Total	**160**	**35**

In order to develop viable CCS schemes via pre-combustion decarbonisation three main directions should be pursued, however, with a firm emphasis placed on cost, fuel availability, and primary energy demand (i.e. efficiency). These main directions are:

1. Assessment of capture technology options versus fuel (as indicated under "capture" in Figure 1) thus facilitating appropriate polygeneration schemes, refinement of products and export systems.
2. CO_2 handling system, including pre-conditioning, pressurisation, transport and injection.
3. Identification of geological storage capabilities including large-scale use of CO_2 for enhanced recovery of oil, natural gas and coal-bed methane (EOR/EGR/ECMB).

3. Polygeneration technologies

Polygeneration technologies at hand are prone to employ gasification and reforming in an initial stage as shown in Figure 1, thus operating under reducing atmosphere. In this manner a syngas will be formed that is rich in carbon monoxide (usually comprising a blend of CO, CO_2, H_2 and H_2O). The syngas is first diverted to a water-gas-shift reactor prior to a gas separation unit. At this stage the intermediate yield will basically consist of a hydrogen-rich fuel gas and CO_2. At this stage the CO_2 stream has already been isolated and made available by the concept. Hence, the logical step further is the preparation of the CO_2 for transport to the storage site, and for the final injection into a permanent geological storage. This requires some purification, compression and pre-conditioning of the CO_2 to obtain a dense phase.

There is a growing interest in advanced clean coal technologies that include CCS, as they justify a continued use of coal to co-produce electricity and synthetic fuels in a fairly efficient way. In this context polygeneration contributes to lessen the import dependency of oil – especially in countries with growing economies like China and India.

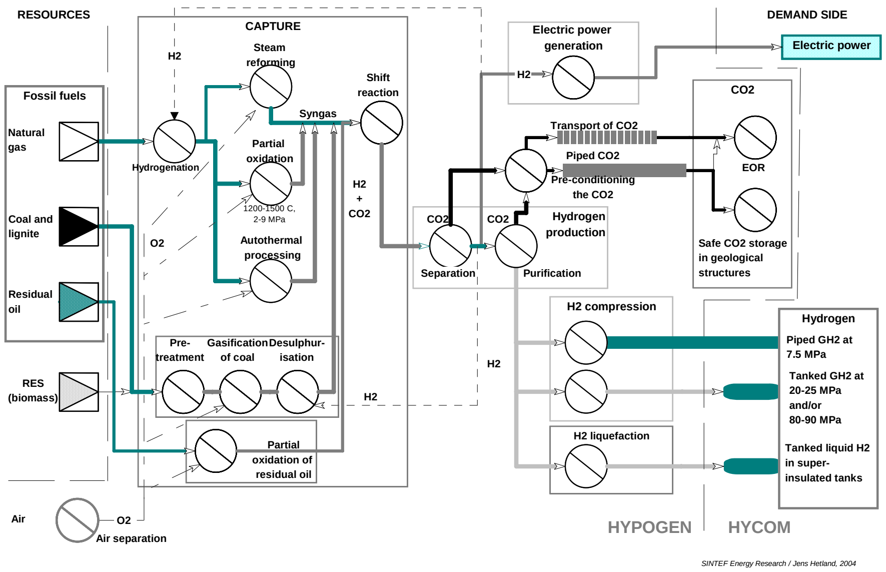

Figure 1: Generalised polygeneration schemes with CCS. The chart was developed by SINTEF Energy Research for the DYNAMIS project aimed to prelude the HYPOGEN demonstration and HYCOM by 2012-2015 under the European Quick-start initiative.

About 20% of the gasification projects throughout the world that use coal and lignites as the feedstock produce electric power in integrated gasification combined cycle plants (IGCC), the remaining 80% produce various chemicals (refer Table 1). Among the commercial gasifiers, basically three concepts prevail: a) Entrained flow, b) fluidised bed, and c) moving bed gasifiers. According to PowerClean (2004, [1]) entrained flow gasifiers[2] made by Shell and Texaco are used in nearly 75% of the 160 projects referred to in Table 1. Of the rest, Lurgi moving bed gasification technology is also used to a significant extent. For "planned" gasification projects, it is understood that approximately 75% of these will use either the Texaco or Shell designs.

A generalised scheme for polygeneration via coal gasification is shown in Figure 2. Although any coals (and biomass) can be gasified, preference is usually given to low ash-content coals mostly for economic reasons. Furthermore, natural gas and naphtha

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[2] Entrained flow gasifiers usually operate at high temperature of 1200–1600°C and pressure in the range of 2–8 MPa. Most large plants operate, however, at around 2.5 MPa.

are widely used to produce chemicals and fuels, primarily carbon monoxide, hydrogen, methanol and oxy-chemicals. (PowerClean, 2004, [1])

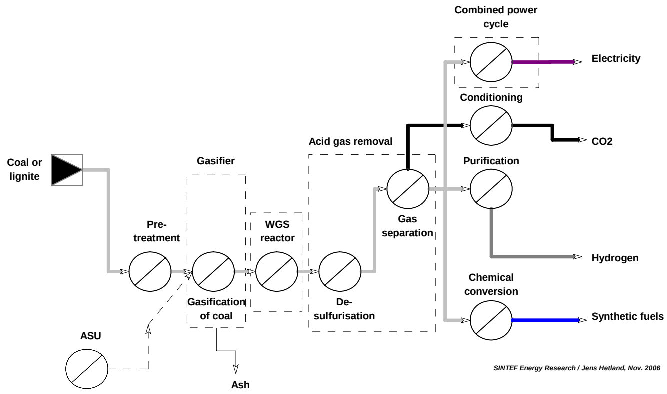

Figure 2: Polygeneration from coal broken down in unit operations.

4. The carbon dioxide stream

The compression of the CO_2 could be made as illustrated in Figure 2 in order to achieve a liquid phase above the critical point (Hetland et al., 2007, [2]): In order to liquefy a gas stream of CO_2 from ambient conditions the gas must first be compressed to a pressure well above its triple point (0.518 MPa) until the gas stream can be condensed (or densified) via cooling. Just cooling the gaseous CO_2 at atmospheric pressure would make it pass directly from gaseous phase into solid state via sublimation (i.e. from state A to B in Figure 3). Therefore, in order to bring the CO_2 to a storage site ready for injection into a geological formation, a rather high pressure is required to keep the dense phase of the CO_2 in order to prevent the CO_2 from leaking (at this state CO_2 is heavier than water). Hence, the CO_2 gas stream is compressed from state A via C to F.

Options exist for atmospheric tank transport, which requires cryogenic densification from A via C to D, and then pumping to state E, as the CO_2 at point D appears in liquid phase. The pressure will then basically be kept at this level until the CO_2 is injected to the sink. Optionally it could be used for enhanced oil and gas recovery.

Presumptions have been made that basically three (or four) compression stages with inter-cooling are required (assuming a mechanical efficiency of 92%). Three stages require a pressure ratio of roughly 5 that represents a compressor outlet temperature of about 145^{o}C – or a temperature increase of 125^{o}C over each compressor. Hence, the exergy demand of a three stage compressor train with seawater-based intercoolers amounts to 90 kWh per tonne CO_2. In Figure 3 this loop corresponds to the trajectory from point A through C and from C directly towards F. In order to obviate plugging anywhere in the system special precautions must be made in order to prevent the formation of dry ice.

In the event, however, that seawater cooling is not at hand, some 100 kWh exergy would be required for the inter-cooling in order to reach an injection pressure at the order of 10-20 MPa. And likewise, if the captured CO_2 is to be tanked for shipments at meso-pressure around 1 MPa, it should be condensed at cryogenic level close at -50^{o}C. This would require some 115 kWh per tonne CO_2 exergy (Hetland et al. 2007, [2]).

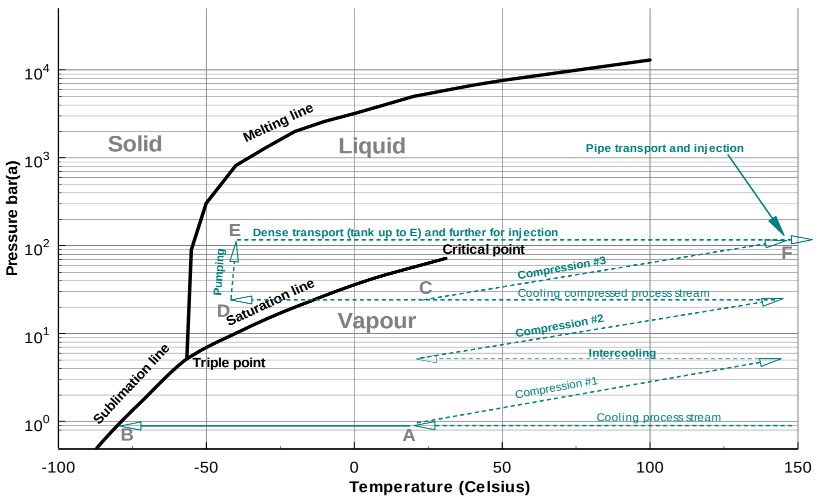

Figure 3: Phase diagram of carbon dioxide (CO_2) (Hetland et al, 2007, [2])

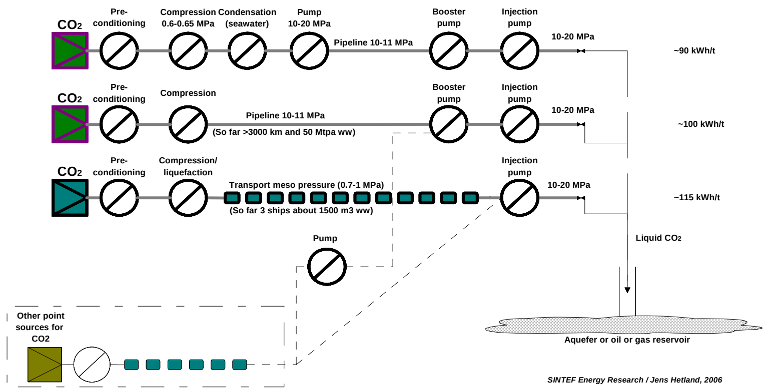

Figure 4: Pre-treatment and transport arrangements with typical exergy demand (indicated to the right) for CO_2 to be stored at some distance from the point source.

5. Potential for retrofitting with CCS (post combustion)

Owing to the high fuel penalty combined with the rather low efficiency of older power plants, the option for retrofitting post-combustion capture techniques is deemed less encouraging. The reason is that the amount of energy (and exergy) required for the flue gas cleaning process relates to the amount of CO_2 – and not to the power output.

Figure 5 shows that the relative losses increase substantially as the efficiency of the power cycle decreases, and vice-versa. The implication is that it is rather detrimental to retrofit plants that per se are not sufficiently efficient at the outset. In order to make a reasonable fit, it is necessary to start with a highly efficient power cycle, and to make a high degree of process integration in order to limit the fuel penalty as much as practical.

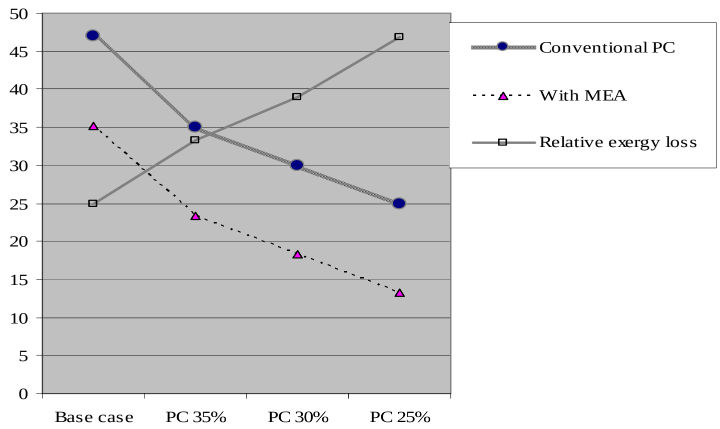

Figure 5: Comparing efficiency (%) and loss (%) of pulverized coal plants and their potential for retrofitting with post-combustion capture using MEA. Plants hereunder are chosen to produce exactly the same amount of flue gas that is subjected to cleaning[3].

6. Conclusion

Much owing to the issues of *security of energy supply* and *climate change*, energy is a matter of growing concern. Large efforts are made in industry and research to address these issues. CCS is seen as an important step that appears high on the international research agenda. As the isolation of CO_2 is an integral feature of pre-combustion capture schemes, these processes are deemed to constitute a viable option – especially in markets that - additional to electricity - require fuels that are derived from coal (IGCC).
Hence, since complexity prevails in these systems a plausible question is how these schemes may be constituted and integrated in a most favourable manner? This question could probably be best answered by international actions on techniques and approaches including methodology for how CCS systems may respond to a subset of criteria made up by primary energy demand, cost, environmental impacts, and societal issues.

REFERENCES:

1 PowerClean RD&D Thematic Network: "Fossil Fuel Power Generation; State-of-the-Art". PowerClean Thematic Network report prepared by, 30th July 2004. Appears on http://www.olade.org.ec/documentos/eficienciaenergetica/state_art_ CFT.pdf (last visited 4 April 2007)

2 Hetland, J.; Li, C.; Pollard, D.; Xu, S.: "*How polygeneration schemes may develop under an advanced clean fossil fuel strategy under A Joint Sino-European initiative*" Paper to be presented at the 3rd International Green Energy Conference, Västeraas, Sweden, June 18-20, 2007

[3] The assumptions are: 1) a conventional PC power plant with 43% efficiency and 500 MW electric power output forms the base case. b) A similar plant is integrated with an amine (MEA) absorption/desorption unit so that the resulting efficiency drops by 8 percentage points. This implies that an electric power output of only 407 MW_e would result from the power plant. Hence, 125 MW_e exergy would be sacrificed in this fuel gas cleaning process. This assumption is a rather coarse approximation, as a significant portion of the energy required is steam extracted from the steam cycle.