Waste heat reuse for enhanced CO₂ liquefaction and reduced transport costs

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Abstract

This work aims at assessing the relevance of novel CO₂ liquefaction technologies operating with waste heat and the logistics for transporting this liquid from and to several sites. Based on previous work carried out in about “CO₂ Value Chains” program of Climate KIC (Knowledge Innovation Community) information gathered about Greenhouses in the Netherlands, Sweden and France showed market opportunities if CO₂ collected presents a low price.

This work focuses mainly on the use of CO₂ in small to medium size user, for instance greenhouses, but not exclusively. CO₂ is condensed in order to reduce the volume to be transported. Distances between the CO₂ sources and users in two spots in Europe are limited to less than 100km. As it is known, purity of CO₂ directly impacts the needs on energy to compress and liquefy it. Considering that the triple point of CO₂ is at 5.12 bar and -56°C, and that CO₂ is frequently available at atmospheric pressure in biogas purge streams and fermentation units, impurities may represent an important energy consumption point during the compression of gases that enable to lead the partial pressure of carbon dioxide above the triple point. Compressing the impurities does not represent any possibility to add them much value, hence compression energy is lost. Liquefaction needs cooling devices, frequently these are compression chillers that enable to reach cooling at -55°C. A novel technology developed in our research centre uses waste heat to generate cooling utilities at the same temperature of -55°C. The target is to render more competitive the transport of liquid CO₂ by replacing the compression chillers by the novel technologies.

Advanced absorption refrigeration machines can contribute on the recovery of waste heat currently rejected into the atmosphere and reuse it at cold utilities in industry. The novel machine designed in our research centre shall be built and tested in 2018 and enables cold utilities, from -20°C till -60°C to be generated by using waste heat below 100°C. The objective is to benefit from waste heat to liquefy CO₂ and foster energy and material clusters.

A comparable and mature reference technology is the compression of CO₂ and the use of compression chillers to generate the cold utilities needed to liquefy the gas. In general, liquefaction of gases is carried out by compression and cooling, which means that operating costs are mainly lead by the consumption of electricity. The higher the pressure of CO₂ condensation, the higher the consumption of compression would be. However, energy consumption for cooling may be reduced as the COP of chillers increases when getting closer to ambient temperatures. There is a trade-off effect between compression and cooling energy consumption. Pressure has been considered up to 25 bar. Higher levels of pressure will face restrictive regulations on transport by road.

Energy consumption converted into economic values is presented in Figure 1. Results are presented for the compression, the cooling and the total energy consumption, assessed at three different electricity prices. It can be observed a general trend for compression that increases and cooling that decreases when pressure levels increase. The trade-off is observed at pressures above 13 bar, at which the energy consumption remains almost constant independently of the pressure of
the CO₂. At low pressure, the cooling expenses have a relatively higher impact, which leads to higher energy consumption. This is related to the low temperatures required to liquefy CO₂. Besides the general trends, it can be observed that liquefaction energy costs using conventional compression-cooling ranges from around 4 to 12 €/ton CO₂ depending on the electricity prices considered.

![Figure 1](image1.png)

Figure 1. Expenses per ton of CO₂ for Energy consumption considering electricity prices at 40, 80 and 120 €/MWh.

Calculations have been made for novel Absorption machines for a CO₂ providing cooling and condensation power. Machine performance varies strongly depending on fluid used as working pair and temperature in evaporator selected. In order to calculate the electric energy consumption in pumps, an average coefficient of performance (COP) is considered at 5 times the one of conventional compression heat pumps. This value has been observed as an average in calculations performed (confidential). In Figure 2 are presented the curves for electricity consumption for CO₂ liquefaction as a function of pressure of CO₂ supplied. It can be observed the impact of the novel machine on expenses at low pressure of CO₂ and mainly at high prices of electricity. Below 40€/MWh of electricity price, there is not a major difference on the costs of CO₂ liquefaction for both technologies.

![Figure 2](image2.png)

Figure 2. Comparison of expenses per ton of CO₂ for Energy consumption considering electricity prices at 40, 80 and 120 €/MWh, for compression and absorption technologies.
The main advantage is that novel absorption technologies reduce the consumption of primary energy and reuse the waste heat. Hence, indirect reduction of CO$_2$ emissions can be achieved. This indirect reduction of emissions has an important leverage on potential subsidies and finance streams. For instance, use of waste heat from industry will open the possibility to Energy Efficiency Certificates, reduction on emissions of CO$_2$ liquefaction and collection, doubling the possibility of impact on CO$_2$ credits and transfer of quotas. The latter represents a competitive advantage, as conventional compression chillers consume electricity and are unable to recover waste heat to generate low temperature utilities. For the distances and volumes in stake at the Rotterdam and Götaland sites, considered in this study, the cost of delivered CO$_2$ will mainly range between 11 to 25€/t. Niche markets are potentially available for this novel CO$_2$ energy-material optimization pathway.