Carbon Capture and Storage – Not Attractive But Probably Necessary

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China's dual carbon strategy - to peak its emissions by 2030 and to become carbon neutral by 2060 – commits the country to examining all potential pathways to reduce carbon dioxide levels in the atmosphere.

Such an examination should thus definitely include Carbon Capture and Storage (CCS), even though this technology currently is not viewed very favorably in many countries both from a regulatory and a social point of view. As we will outline below, we believe that using CCS is both economically sensible and necessary to achieve strict decarbonization goals.

Carbon neutrality – as targeted for China for 2060 – means that the net carbon dioxide emissions of a country are zero. To achieve this target, a large number of current carbon dioxide sources have to be eliminated and the remaining ones have to be compensated for by taking carbon dioxide out of the atmosphere.

Some of current carbon dioxide emissions are relatively easy to stop as there are other technologies that can be utilized as substitutes. A prime example for such "low hanging fruit" is the generation of power from the burning of fossil fuels – which can be replaced by, e.g., nuclear power, solar power or wind power.

Others are much harder to substitute, particularly those in which fossil carbon (e.g., in oil and downstream petrochemicals) is not just burned to carbon dioxide but rather turned into organic chemicals used for the production of, e.g., plastics, pesticides, paints and pharmaceuticals (to only give a few examples starting with the letter p). While the carbon for these applications can in principle come from renewable sources or from carbon dioxide captured directly from the atmosphere, the cost of such alternative processes far exceeds current levels.

Obviously, the more difficult the decarbonization task becomes, the more sensible it is to use an alternative approach. Instead of completely replacing fossil sources, in such cases the compensation of the carbon dioxide emitted is more economical. This is where we believe CCS technology has its rightful place.

Let us look at this in some more detail. If one looks at the current uses and applications of fossil hydrocarbons, they can be classified from "easy" to "difficult" to decarbonize. Power generation or power & steam generation is rather simple. With direct heat and hydrogen, it becomes more difficult. Things get difficult when it comes to fuels, especially for fast, heavy transport tasks over long distances. And when it comes to energy-intensive basic chemicals and specialty chemicals derived from them, things get really difficult, as shown in Fig. 1. Basically, the degree of difficulty of decarbonization can be determined primarily by three points: thermodynamic efficiency, number and type (steam-driven, chemical or biological reaction) of the conversion steps, and investment & operating costs (capital and operational expenses).

Specifically, when moving from “electrons” to “molecules” the electrical & thermal energy efficiency declines and primary energy needs rise exponentially, as shown in Fig. 2.

For example, while the thermal efficiency for power generation is still the same for fossil and renewable energies, it is only 2/3 for steam and just over 40% for transport tasks. The energy efficiency is also getting worse. In the case of H2 synthesis, 2.8x as much energy is required from renewable energies, with ammonia 3.7x and with synthetic fuels 4.2x as much energy compared to production from oil or gas.

The last example is a good illustration of the decarbonization problem. Sustainable aviation fuels can be made from water. The hydrogen is obtained by electrolysis of water and the carbon is separated from the CO2 in the air. This is obviously an expensive way to produce the kerosene of the future, both with regard to materials and energy. But without the use of alternative pathways to achieve net zero emissions, it may become necessary to use such inefficient pathways.

It may be argued that one can use recycled materials, renewable raw materials or organic waste as a source of carbon and thus do without the CCS process (Fig. 3). Indeed, both green feedstock and/or CCS application are valid decarbonization options.

Indeed, model calculations (Fig. 4) show

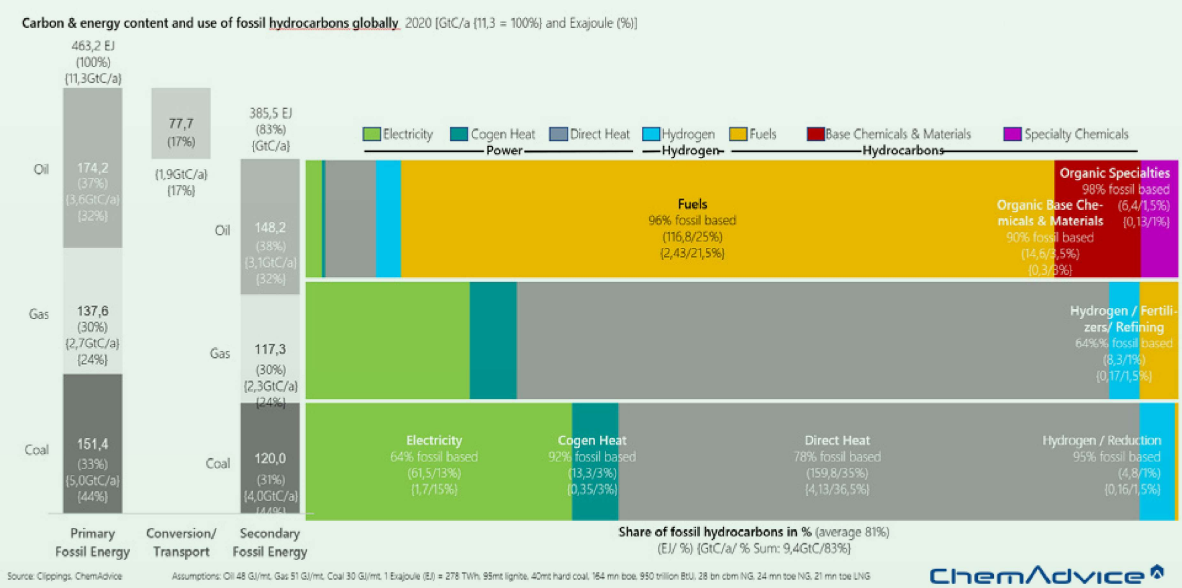

Fig. 1: From left to right - declining thermodynamic efficiency [EJ/a], increasing number and type of energy conversion steps, higher operating & especially capital expenses

Application	Thermal efficiency [%] Fossil hydrocarbons	Renewable power	
Electricity	35%	35%	90-100%
Heat / Steam	85%	55%	60-70%
Transportation	35%	15%	40-45%

Application	Primary energy needs [%] Fossil hydrocarbons	Renewable power	
Hydrogen	100%	279%	X 2,8
Ammonia	100%	367%	X 3,7
Synthetic Fuels	100%	415%	X 4,2

Source: Clippings, ChemAdvice

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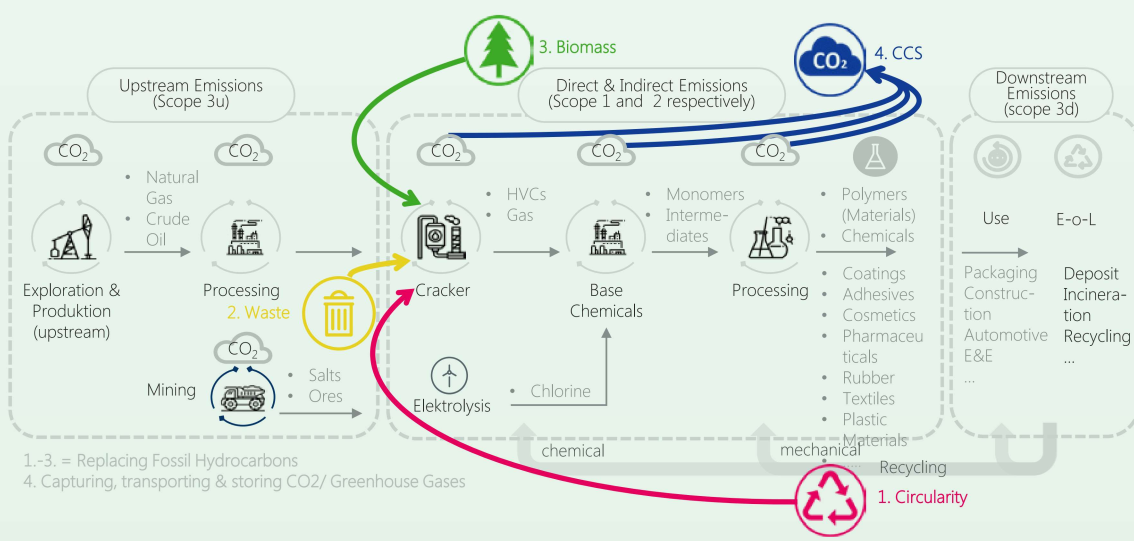
Fig. 2: Thermal & energy efficiency of using fossil hydrocarbons or renewable energy

that reuse and mechanical or monomer recycling in particular can achieve significant emission reductions with comparatively moderate cost increases that are of the same order of magnitude as the CCS process (-60% emissions, +25% costs). All other methods have lower emission reductions and higher costs. With the recycling process, however, it should be noted that the return of recycled material is limited and can sometimes take a very long time in long-term applications (e.g. construction). The capacities are therefore far from sufficient to meet the goals and future growth cannot be mapped in this way either.



Source: Cefic, VCI, ACC, DGMK, ChemAdvice * Not CCU, except for some selected applications (ammonia, syngas/methanol, CO/CO_2-applications); HVC = High Value Chemicals (primarily cracker derivatives and methanol)

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Fig. 3: Polymer Value Chain with focus on non-fossil carbon sources

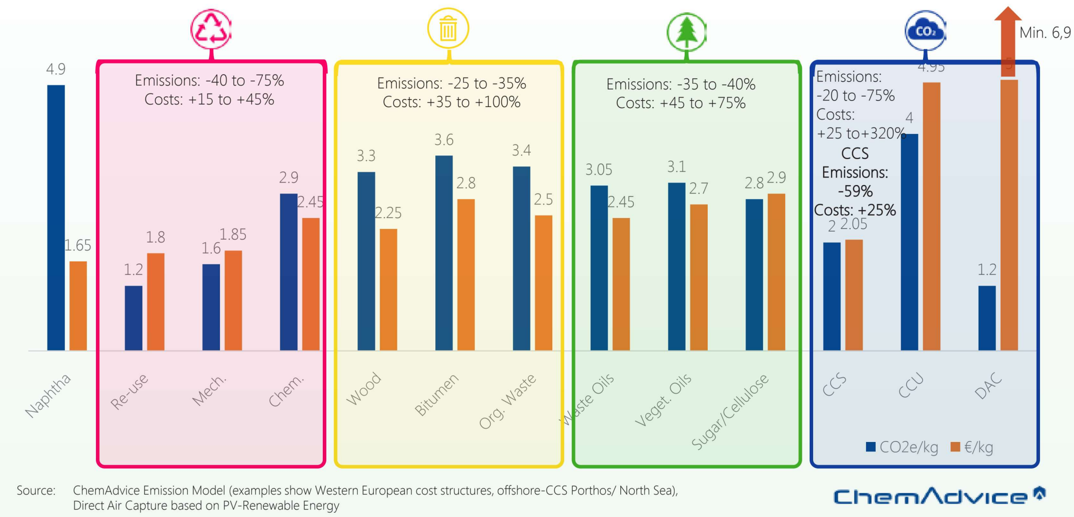

Fig. 4: Model calculation – economic & ecologic impact of alternative decarbonization options

A life cycle comparison across all sectors shows that, for technical reasons, emissions cannot be reduced by more than 80% at most, both with defossilization and with CCS (Fig. 5). At the same time, the additional energy required for defossilization is 3.5 times higher than when using CCS technology. This much higher energy requirement means that the ecological balance of defossilization is only comparable and not better than the CCS application. At the same time, where CCS is feasible, it is usually much more economical to use CCS and no other decarbonization technology.

Only CDR + CCS in combination

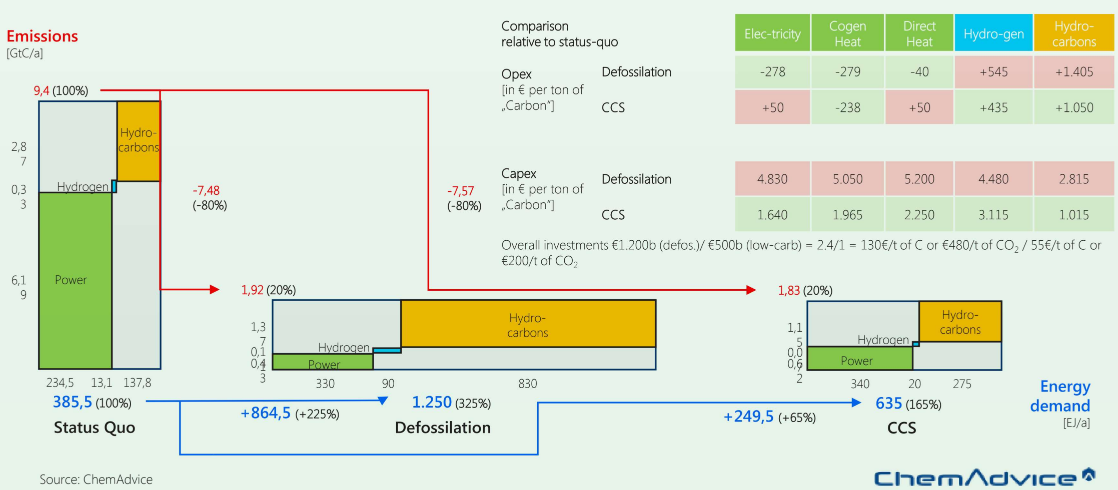

Fig. 5: Comparison life cycle ecologics & economics defossilation and low-carbon fossil abatement technologies (status quo 2020, target 2050)

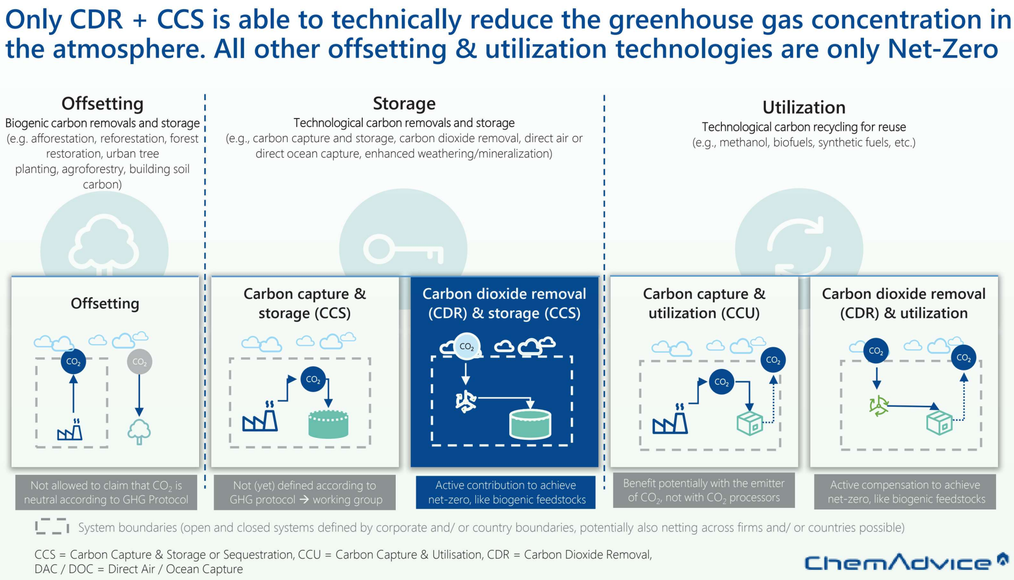

Fig. 6: Comparison of carbon dioxide offsetting and utilization technologies

is currently able to realize "negative emissions", i.e. to actively reduce the CO2 concentration in the atmosphere (Fig. 6). CCS costs currently average €90/mt CO2. DAC costs are still prohibitive, but it is expected that by 2050 DAC costs could reach the same order of magnitude as CCS costs. Then a DACCS procedure for €200-250/mt CO2 is realistic, which also seems economically feasible.

Reducing carbon dioxide emissions is a particular challenge for the chemical industry. While carbon dioxide emissions from the production of chemicals are to rise until 2030-35, so far only about a 35% CO2 reduction has been identified towards Net Zero. So, while there are many approaches to remove carbon dioxide ranging from planting forests, fertilizing the oceans, accelerating weathering to converting nutrient to permanent humus, to carbon sequestration in farmland, these approaches have very different levels of technological maturity. Realistically, they will only be ready for use in 10-20 years at the earliest. The chemical industry may require shorter-term solutions. We think that in order to achieve the reduction target, the storage of CO2 cannot be avoided, at least in the decades of transition. The CO2 will probably first come from the burning of biogas/biomass (BECCS) and later perhaps also from the separation of carbon dioxide from the air (DACCS).

In conclusion, we believe that CCS can make a vital contribution to helping the chemical and other industries their emission targets, particularly in the short term. And while the technology is indeed not particularly liked and sometimes heavily criticized, an academic perspective such as that of Professor Stuart Haszeldine of Edinburgh University is substantially more positive: “Carbon capture and storage is going to be the only effective way we have in the short term to prevent our steel industry, cement manufacture and many other processes from continuing to pour emissions into the atmosphere”. ■