Focus on the state of CO2 industrial usage in 2021.

Fieldlab CEBI - Individual CE project block 2

Abstract

This study presents the various aspects of the CO_2 usage market. Indeed, climate pressure has made CO_2 one of the key resources of the 21st century. Governments have committed themselves to reduce CO_2 in the atmosphere, which has led to its taxation and therefore increased its value. In addition to aiming to reduce emissions, new technologies have made it possible to capture and store CO_2. This access to very large quantities of CO_2 has questioned the current model of industrial use of this resource, which has for a long time been considered as waste. But things are developing slowly and the market for the industrial use of CO_2 will remain marginal if the infrastructures and institutional framework are not put into place. It is therefore time for governments to assess the potential of these technologies in order to take advantage of what could become one of the main solutions in the fight against global warming.

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Date: 19/01/2021

Word count: 6938

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Introduction

In 2019, humans released a staggering 43 billion tonnes of CO_2 into the atmosphere (World Bank, 2020). A quantity never reached before but that we must drastically reduce if we want to limit the rise of the Earth's temperature to 1.5 ° C by the end of the century, as the countries have committed to during United Nations Climate Change Conference 21 (COP21).

While the main solution remains and will remain the reduction at the source of greenhouse gas emissions, other avenues are now being explored to "clean" the atmosphere of its excess CO_2. Capturing, re-use and landfill storage is one... but another solution seriously explored by researchers is much more daring, since it is nothing less than viewing atmospheric CO_2 as a new resource. In short: use it as a raw material and not as a waste.

In this review we will first look at the link between climate change and CO_2 emission, since slowing down global warming is the final objective of many public policies and research projects. Indeed, as we will see, the effects of global warming on the environment and consequently on the economy and human life on Earth more in general are tremendous. We will then have a closer look at how the European Union tries to reach its emission reduction targets via its carbon market system EU ETS.

In Part 2 we will explore the current industrial use of CO_2 and current technological progress in making the lifecycle of CO_2 re-use more cost-efficient. By looking at the different phases of the recycling lifecycle of CO_2 we will identify key issues that still need to be solved.

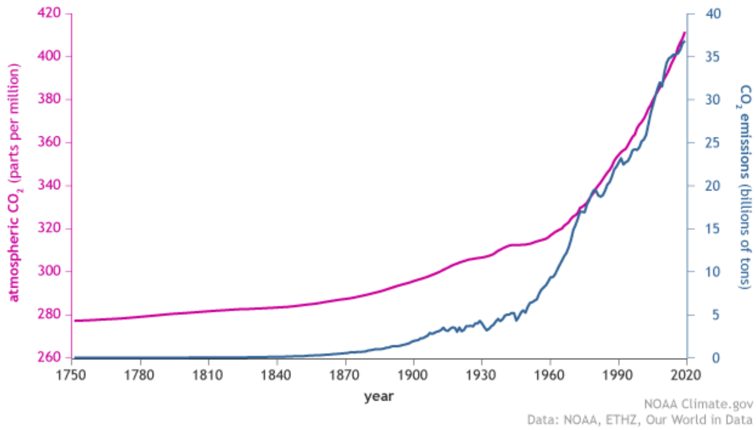
Part 3 focuses on promising technologies for using CO_2 as a raw material in industrial products and processes. Nevertheless, as we will see, there are still important challenges to be dealt with in order to reduce the quantity of CO_2 humans release into the atmosphere.

Part I – Economic & environmental Impacts of CO_2

A - Link between climate change CO_2 emissions.

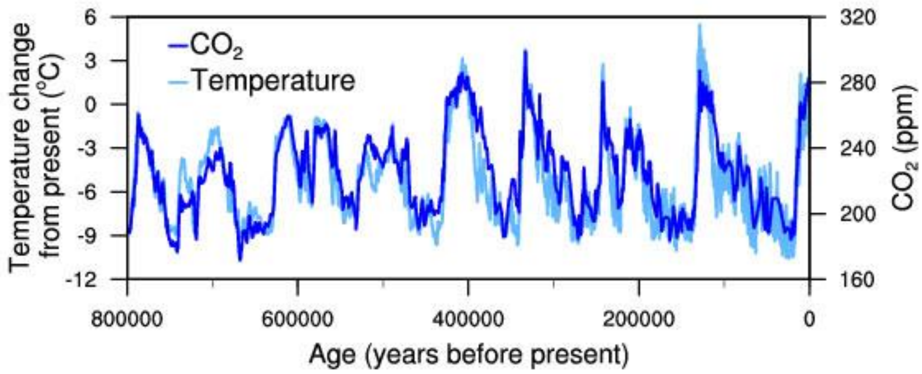
In order to assess the potential benefits of using CO_2 as resource it is important to understand the magnitude of the negative impacts it has on our society. First of all, it is common knowledge that CO_2 is the main cause of climate change, due to the greenhouse effect it produces. Although other gases have a greater greenhouse effect than CO_2, it is mainly the quantity of CO_2 in the atmosphere that makes it the main contributor to global warming. Moreover, it is also common knowledge that there is a link between CO_2 emitted by human activities and the CO_2 levels in the atmosphere as shown in figure 1.

Figure 1 : CO2 in the atmosphere & annual emissions (1750 - 2019)



It was also demonstrated that there is a causal link between CO2 levels in the atmosphere and the rise in temperature as it can be seen I figure 2.

Figure 2 : Temperature Change and Carbon Dioxide Change



Source : NOAA, Temperature change (light blue) and carbon dioxide change (dark blue) measured from EPICA

B - Environmental consequences

This report will not analyse the environmental consequences of CO2 in depth, but only briefly describe their nature. According to the European Commission, climate change affects all regions of the world. The polar ice caps are melting, and sea levels are rising. In some regions, extreme weather and precipitation events are becoming more frequent, while others are facing increasingly extreme heat waves and droughts. These effects are expected to intensify over the coming decades as temperatures gradually rise.

C - Economic consequences

Beyond the uncertainties about the causes, global warming is now a certainty. The rise in average atmospheric and ocean temperatures leaves no ambiguity as to the extent of the changes to be expected in the hydrological and climatic cycle. In addition to modifying the climate, climate change will have an impact on biodiversity and ecosystems and consequently on human beings and their activities: changes in agricultural yields, an increase in the number of climate refugees, natural disasters, economic adaptation etc.
All sectors are economically impacted by the effects of climate change. Indeed, through a domino effect, even industries such as banking or insurance will suffer from it as explained by Henri de Castries CEO of the multinational insurance firm Axa :

"*Climate change is a crucial issue. A two-degree increase in the average global temperature may still be insurable, but what is certain is that a four-degree rise is not*."

Beyond the macroeconomic consequences, it is important to also consider the microeconomic impacts of CO2. Indeed, after the ratification of the Kyoto protocol in 1997, the European Union was expected to implement various instruments in order to reach its emission reduction targets. Between 1997 and 2002 the European commission presented several ideas and options to design the new European climate policy.

Finally, it was only in 2003 that all the member countries agreed on a Carbon market system. In its current phase, the EU ETS is a market for trading CO2 emission quotas. These quotas are allocated for free by each State or directly auctioned on the market. Companies can then sell or buy allowances, creating an equilibrium price for carbon .The EU ETS is based on a 'cap and trade' system. A "cap" is set on the total amount of certain greenhouse gases that are allowed to be emitted by installations being part of the ETS system. The "cap" is then lowered over time so that total emissions are obliged to decrease.

Companies receive and/or can buy emission allowances, which they can trade with one another. They can also buy limited amounts of international credits from emission-saving projects around the world. Each year, companies have to surrender enough allowances to cover all their emissions, otherwise heavy fines (taxes) are imposed. If a company reduces its emissions, it can keep the spare allowances to cover its future needs or sell them to another company. The limited number of allowances available ensures that they have a market value. Cap-and-trade systems are seen as versatile because external developments causing a reduction in production may lower the need for emission allowances due to a reduction in emissions by the industry. The objective is to incite companies to cut emissions in order to avoid heavy fines, without, however, weakening the own economy too much due to carbon leakage.

Until now, the European Union has always refused to set a price floor or ceiling. The quota exchange market is managed by the EEX group ("environmental markets" branch), which offers a cash market and derivatives markets (futures and options markets). The traded unit is one lot of 1,000 Carbon Emission Allowances (EUA) . Each EUA being an entitlement to emit one tonne of carbon dioxide equivalent gas. The mechanism is thus rather simple to understand since by reducing the number of allowances the EU is able to influence the overall levels of emissions. Indeed, the reduction of "free allowances" should technically increase the carbon price and thus incite companies to reduce their levels of emission. In addition, the funds raised by the EU during the auction of CO2 allowances should be one of the main contributions to the financing of the EU climate policy. The EU ETS is a major tool of the European Union in its efforts to meet emissions reduction targets now and in the future. The trading approach helps to combat climate change in a cost-effective and economically efficient manner. As the first and largest emission trading system for reducing GHG emissions, “the EU ETS covers more than 11,000 power stations and industrial plants in 31 countries, and flights between airports of participating countries.” (EU climate action, European commission, 2020). This represent approximatively 45% of the 4 500 million tonnes of CO_2 emitted in the EU in 2019.

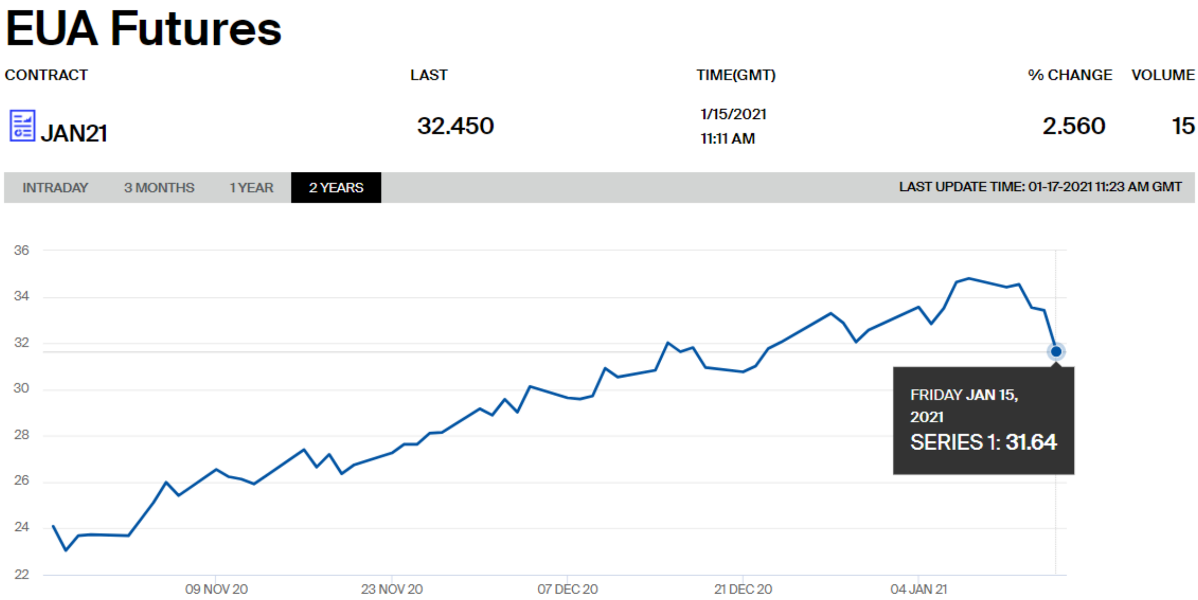
The EU ETS aims to be a long-term policy and is thus planned long in advance. During its elaboration, the EU decided to split its program in four different phases between 2005 and 2030. These different steps have as objective to help the EU adapting its policies to the existing economic situation allowing it better to protect its own industries. In other words, the EU is thus able to readjust its targets for each phase. The implementation of the system has been divided into distinct trading time periods, known as phases:

Figure 3 - Different phases of the EU ETS

Source: European Union, ETS Handbook, 2015

The year 2021 is therefore a crucial moment of the ETS agenda since it marks the transition from the third to the fourth phase of the programme. This detailed explanation of the EU ETS gives an idea of the pressure that is being put on companies to change their production methods. Indeed, other similar programmes are being set up all over the world, from California to Japan.

Figure 4 - EUA prices from October 2020 to January 2021 in €/TCO2



Source : ICE (Intercontinental exchange)

To summarise the different ETS programmes, it is important to insist on the major economic stakes that this represents for the economy. With an EU ETS at €31.64 per tonne of CO2, the (monetary) value of European emissions (4,500 million tonnes of CO2 in 2019) would be more than €140 billion each year. Consequently, companies based in the EU that emit CO2 are exposed to this growing financial burden. The search for solutions to reduce CO2 emissions is therefore becoming a major economic challenge for the coming decades. Companies will want to lighten this burden whereas local and national government as well as the EU bodies, while striving for lower CO2 emissions, will want to keep their economy healthy and competitive.

Part II – Use of CO_2 nowadays

A - Current industrial use of CO_2

Contrary to what one might think, CO_2 is already used by many industries to produce certain products or to influence certain processes. For example, CO_2 is used to make urea, a widely used fertiliser that is also used as a precursor for many plastics. It is also used by the food industry to enhance the yields of biological processes or in soft drinks. As explained by professor Bourgeois (Interview 2.) at a supercritical state, CO_2 becomes a “non-toxic natural solvent”. CO_2 also allows to produce a substance, which is used in aspirin and some anti-acne products. As a last example, CO_2 allows to produce polycarbonates, the polymers found in CDs, DVDs and spectacle lenses. In 2019, the consumption of these last industries only corresponds to about 150 million tonnes of CO_2 (IEA, 2020).

By adding up all the different ways CO_2 is used the annual consumption worldwide is estimated at least 10 MtCO_2 per year according to the International Energy Agency in 2019. This number gives a good idea of the near-term market potential for the major key categories of CO_2-derived products and services. This would also mean that CO_2 usage represents about one quarter of worldwide CO_2 emissions (43 MtCO_2/yr in 2019).

The goal would be not to use "atmospheric" CO_2 for servicing this need but to capture and re-use waste CO_2. However, nowadays, the great majority of the CO_2 used by industries is specifically produced for industrial use. Professor Marc Robert (interview 1) explains that the cost of “capture” and “transport” makes it less profitable to use captured CO_2 than “produced on purpose” CO_2. There is thus a lack of logistic capacities in the CO_2 market that, for the moment, prevents the economic development of trading of atmospheric waste CO_2.

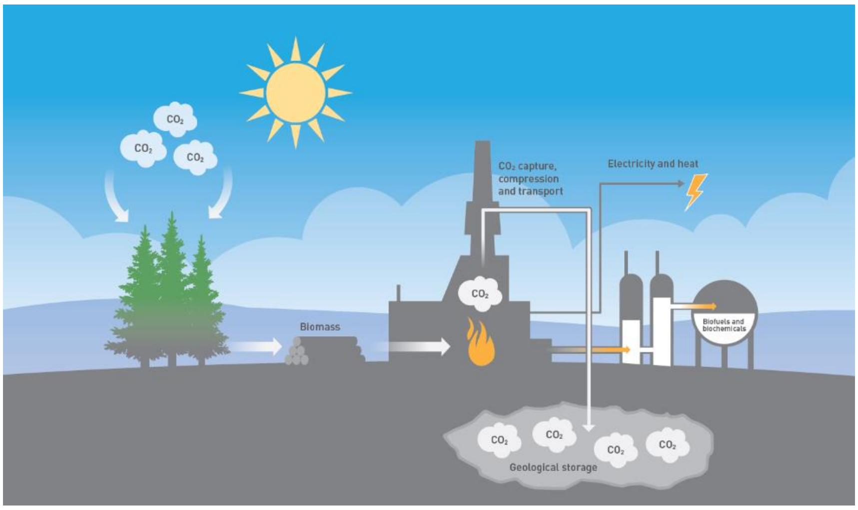
B - The CO_2 lifecycle

Nevertheless, important technological progress has been made in making the lifecycle of CO_2 re-use more cost-efficient. First of all, **CO_2 capture technologies** are getting increasingly performing with a “80% to 90%” capture rate, says Professor Marc Robert (Interview 1.). Although this means that 10% to 20% of the gas captured is not CO_2, this capture rate makes it already possible to equip factories and power plants with it. For example, Klaus Lakner, a researcher at the University of Arizona is developing systems for capturing CO_2 in the ambient air in the form of “CO_2 trees". However, this device is for individual use and can thus not be deployed on a large scale before two or three decades. More feasible at the short term seems to be systems that allow for capturing CO_2 at the exit of factory chimneys where it is most concentrated. Indeed, very efficient factory exits capture processes already exist. By dissolving the CO_2 in acidic PH baths, placed just at the level of these chimneys, factories and power stations could already capture CO_2 before it goes into the atmosphere as waste.

The second technology needed is the **capacity to store CO_2**. The most promising option is to store the CO_2 is the Carbon Control and Sequestration method (CCS). In a CCS the CO_2 is injected into deep rock formations in supercritical form via wells in permeable rocks located beneath formations considered to be sufficiently hermetic. (The supercritical phase of mater is when a material (such as

CO_2) is put under a pressure and at a temperature that exceeds its “critical” point (loss of mater equilibrium). To simplify, under this form, CO_2 is in-between the liquid and gas phases.) The notion of permeability is key when talking about carbon CCS. Nowadays, depending on the permeability of the rocks and the quality of the captured CO_2, 1 to 10 percent of the CO_2 will escape in the 30 years following its sequestration (A. Vinca, 2018). But with smaller amounts the US government has recently reached a 0,1 percent leakage for 30 years (A. Vinca, 2018). The main problem here is thus that there is no long-term data on the permeability of CSS. But the technology is already available. The goal would be to store most of the CO_2 for the long term (thousands of years) and the rest would be redistributed for industrial purposes.

Figure 5 – CCS functioning

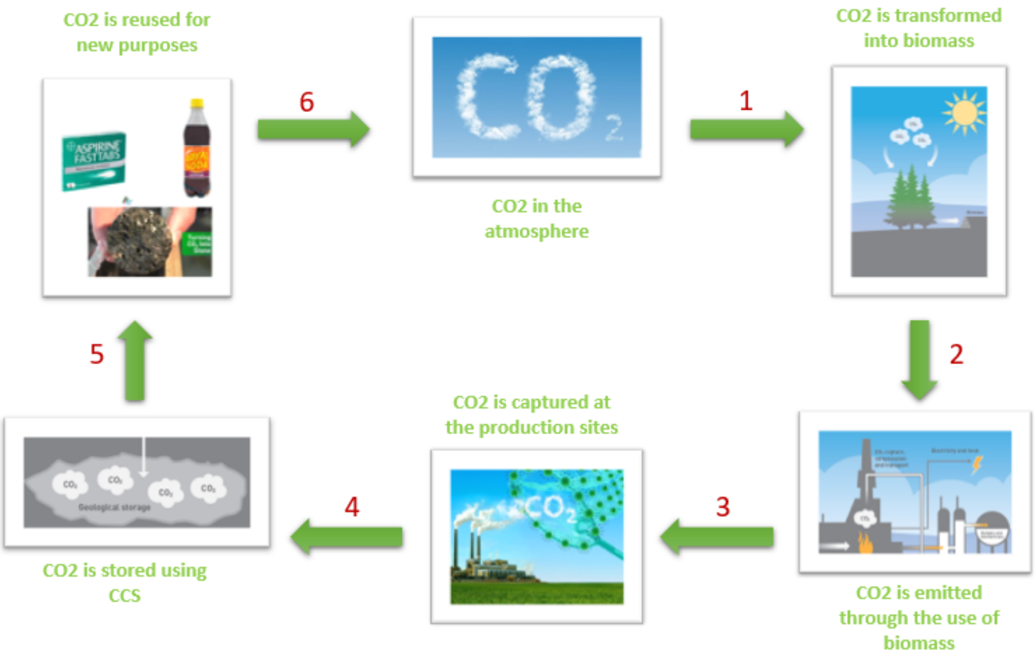


Source : C. Benjaminsen, Norwegian University of Science and Technology (NTNU), 2011

The third stage is **to transport CO_2** from the point-of-capture to sites where it will be stored more long-term and from these points where it will be stored for (much) later use to the places where it will be used at the lower cost than is currently possible. To realize this, the construction of a pipeline seems to be the best option (J. Serpa, 2011). This technology is also available, but very costly on a national or continental scale. In addition, the cost of the pipeline also depends on the quality (concentration) of the CO_2 transported. In order to transport the CO_2 from the point it will be stored to the places it will be reused, the best option seems to be the use of small pipelines to serve large industrial areas and the use of trucks swill be necessary for factories that will be far from any pipeline. It is therefore important to concentrate these plants and factories in the same location.

The last phase of CO_2 lifecycle is its **"re-use"**. In fact, industry already uses CO_2. Indeed, it is mostly extracted from the subsoil, where it is found in the form of deposits, or is the produced as by-product of industrial processes. In this case the key characteristics are the "time of capture", the "quality" of CO_2 required, the cost of this operation and the quantity of CO_2 that it permits to re-use. As professor M. Robert (interview 1) explains, the "time of capture" refers to the time that CO_2 will be stored in its new application. For example, CO_2 used for sparkling beverage won't be stored as long than CO_2 used to create rocks.

Figure 6 – CO2 lifecycle



Source : Elaboration on data, 2021

CO2 lifecycle flows :

- **1 :** The CO_2 is naturally captured by trees and seaweed.
- **2 :** Biomass is consumed by human activity.
- **3 :** The CO_2 produced is send to capture technologies present on site.
- **4 :** The captured CO_2 is sent to storage site (CCS) with pipelines.
- **5 :** Part of the CO_2 stored is redistributed to productions sites to be reused.
- **6 :** The CO_2 is emitted with the consumption of goods produced with CO_2.

Part III – The future of CO2 industrial usage

A – Promising technologies using CO2

New ways of using CO2 in the production of fuels, chemicals and building materials are attracting worldwide interest. This interest is reflected in growing support from governments, industry and investors, with global private financing for CO2 start-ups reaching nearly $1 billion over the past decade (IEA, 2020).

One of the most promising options is to produce fuels with CO2. Indeed, once captured, there is no lack of transformation possibilities: the carbon atoms present in CO2 are in fact found in many carbon molecules highly valued by manufacturers. From CO2, one can produce carbon monoxide (CO), a basic product that the chemical industry uses to make more complex molecules (M. Robert, Interview 1). Enriched with hydrogen, CO makes it possible, for example, to obtain formic acid, a liquid compound at ambient temperature and pressure. Formic acid allows for operating the fuel cells of future cars with lower risks than "pure hydrogen" which is highly flammable (C. van der Giesen, 2014). More complex to synthesize than formic acid, methanol is another promising outlet for CO2: this alcohol is used as a solvent in paints, varnishes, and inks but also as fuel, in particular for rockets.

While the needs of the chemical industry are a source of inspiration for scientists, it is not the only one. Indeed, many scientists are trying to simply copy natural processes such as for example making rocks from CO2 (F. Bourgeois, interview 2). Indeed, nature uses CO2 in two distinct ways. First, it uses CO2 to make rocks in the form of carbonates. For example, this so-called carbonation process is carried out over periods of several thousand years in the heart of the oceans. The advantage of turning CO2 into rock is that it is extremely stable in its solid form (E. Nduagu, 2013). Second, nature uses CO2 to make biomass through photosynthesis. In this last case, plants use the atmospheric CO2 and water to produce sugars and oxygen.

B – Challenges of CO2 usage

One of the main issues over which scientists have no control is the price per tonne of carbon. Nowadays, carbon costs about 32 Euros per tonne in the EU (IEA, 2020), which corresponds more or less to the price of its extraction from the subsoil. According to Françoise Guyot (F. Guyot, 2018), in order for the capture and re-use of CO2 to become economically interesting, it is necessary for the price of carbon to be at around 80 Euros per tonne.

Moreover, in order to decide on priorities in terms of public policies and investment, a better understanding and improved methodology for quantifying the life cycle climate benefits of CO2 applications is needed. Indeed, the CO2 used is not the same as the CO2 avoided. The use of CO2 may as such reduce the CO2 in the atmosphere, but it does not necessarily reduce CO2 emissions. The quantification in terms of climate benefits is thus complex.

Also, the different options for reducing emissions and recycling waste CO2 may each have their own costs in CO2 production or may have other polluting consequences. For example, transporting captured CO_2 by tanker truck or the use of electrical batteries may cause pollution of its own. Such consequences increase even further the complexity of priority setting.

Finally, the prospects of CO_2 use will largely be determined by political support. Many CO_2-using technologies will only be competitive compared to conventional processes if their potential is recognised in the framework of climate policies or if incentives for CO_2 using products are available. To do so, it is important to establish performance-based standards for products such as building materials, fuels and chemicals to facilitate the adoption of CO_2-derived alternatives

Until then, the market for the use of CO_2 is expected to remain relatively small in the short term when compared to total CO_2 output (IEA, 2020), but opportunities could be developing rapidly, particularly those related to construction materials and energy production (Interview 2.).

Conclusion

As demonstrated throughout this article, the industrial use of CO_2 is a complex issue. First of all, the phenomenon of global warming is leading to increasing public pressure to introduce environmental policies which will further the reduction of CO_2 emissions. At the same time, climate change is increasing interest in research into a large number of new technologies allowing to reduce the quantity of CO_2 in the atmosphere, whether by capturing waste CO_2, absorbing CO_2 from the atmosphere or increasing demand for CO_2 as a raw material.

In addition, the economic stakes that CO_2 increasingly represent thanks to carbon market systems has convinced many companies and universities to invest in such new technologies. As seen from the EU ETS example, the introduction of a carbon market system by public authorities can strongly influence the costs of emitting CO_2, which will help to make the capturing of waste CO_2 more economically interesting. Moreover, as has been seen in this article, many technologies needed for the large-scale use of CO_2 already exists but are not yet exploited.

It seems clear that political action will be necessary in different areas and at different stages in order to really develop the markets for both, the recycling of waste carbon and the use of CO_2 as raw resource in the creation of industrial products. Indeed, as far as the use of recycled CO_2 is concerned, major infrastructure projects such as the creation of pipelines are needed for its successful implementation. Concerning the use of CO_2 as raw material, governments will have to create performance-based standards for products using CO_2 in order to facilitate the adoption of CO_2-derived alternatives.

Finally, “CO_2 used is not the same as the CO_2 avoided”, it is therefore first and foremost necessary to evaluate the real benefits that the industrial (re-)use of CO_2 would bring to the environment, since, in the end, the reduction of the greenhouse effect should remain the priority.

Appendixes

Appendix 2 – Experts' interviews and feedback

Interview 1 : Marc Robert (translated from French)

Marc Robert is in charge of the Reactivity and Electron Transfer Catalysis Team (REACTE) at the Molecular Electrochemistry Laboratory (University of Paris and CNRS). He is known as one of the leading experts on the industrial use of CO2 in Europe.

Hello Professor Robert.

Hello

Thank you for giving us some of your time. I know you have a busy schedule.

Yes indeed, but no worries, it is one of my duties. (laugh)

Where is the research on CO2 industrial uses standing nowadays?

Of what I understood many research projects existed dealing with this subject during the eighties especially in the US and Japan, but most of them were stopped in the beginning of the nineties. Indeed, with the stabilization of oil prices there seemed no need any more for governments to finance it. We had to wait until 2005 (approximatively) before new researches were started on the subject. This "second wave" was motivated by the climate emergency. Since then, a growing number of scientist and engineers have started to work on it.

What is the potential of CO2 usage to counterbalance CO2 emissions?

It is a very broad question. First of all, we only use a very small amount of the CO2 we produce. I don't know the precise numbers, but we produced more than 40 billion tonnes of CO2 in 2019 while less than 200 million tonnes were used for industrial purpose so less than 0,5%. Moreover, CO2 usage does not mean that it will necessarily be stored or transformed. Indeed, CO2 used for soft drinks is directly released in the atmosphere during its consumption. So, not all CO2 usage are equally efficient in terms of CO2 capture. There is thus a notion of "time of capture".

I read that a great part of the CO2 used nowadays for industrial purposes was extracted from natural sources or produced directly for its use. What can you tell me about it?

Yes, your absolutely right and I understand that this can seems strange. But there are two main reasons for this. As always, the main reason is the price. It cost way more money to capture and transport CO2 than producing it or extracting it from a natural source nearby. The other reason is that there are different "types" of CO2 depending of its form and concentration. This is even more true for the food industry. But I hope this will change in the upcoming years since the "CO2 capture" technologies are becoming more and more efficient. The recent models can capture 80 to 90% of the C02 that goes through it. In my opinion it is the transport of CO2 that represent the main problem now. Both financially and logistically. I would like to point out that the extraction of CO2 directly from the atmosphere is currently difficult since the CO2 is not sufficiently concentrated in the atmosphere.

But If you are interested in this, I advise you to look at Klaus Lackner's work on the "CO_2 tree" that is already very successful and promising.

I understand you were developing a battery made with CO_2 could you tell us about it ?

In 2012, with my team, I presented an iron-based catalyst capable of electrochemically reducing carbon dioxide to carbon monoxide. In 2017, the team developed a new process that converts carbon dioxide into methane under the action of sunlight. The goal is to produce either fuel from methane or a battery system recharged with carbon monoxide from oxygen.

How do you convert carbon dioxide to carbon monoxide?

This is electrolysis: an electric current allows us to carry out the chemical reaction. We have two electrodes, one of which is made of carbon paper. On it is a catalyst, cobalt phthalocyanine. Indeed, carbon dioxide (CO_2) cannot be converted alone into carbon monoxide (CO): to do this, a carbon-oxygen bond, which is very solid, must be broken. It is the catalyst that makes the reaction possible by providing the necessary energy. When the current passes between the two electrodes, thanks to the catalyst, the CO_2 is reduced to CO on one electrode; on the other, water (H_2O) is transformed into oxygen (O_2). The process is therefore quite simple: it requires only water and current. We are not the first to use this technique. What is innovative is that we achieve an efficiency and performance that was impossible until now, with cheap materials and in mild conditions, at ambient temperature and pressure. Furthermore, our cell is based on very simple technology and design.

Does this make CO_2 recovery possible on a large scale?

Our electrolysis cell is small in size: the carbon paper electrode has a surface area of 1 cm^2. In one day, it produces about 1 liter of CO. Let's imagine that we expand to 1m^2: we would then produce 10,000 liters per day! This high output is due to the fact that we manage to use almost 100% of the electricity we inject. Indeed, it takes 2 electrons to reduce 1 molecule of CO_2 into CO. With our new process, when two electrons pass through, we do have 1 molecule of CO that is formed: all the electrons are used. In 2012, we had already succeeded in recovering carbon dioxide, but large-scale use was out of the question: the efficiency of our electrolyzer was close to 90%, and the currents we were passing through the electrodes were low - but the higher the currents, the more CO_2 is transformed. Our current catalyst is much more efficient, the currents are 100 times greater than in 2012. By optimizing the power consumption, we can produce in larger quantities, thus making industrial use possible.

You also avoid the use of expensive noble metals?

Usually, in chemistry, noble metals are used because they have interesting catalytic properties. But they are not economically viable: we are not going to build electrodes of several square meters in gold! In 2012, we are using an iron-based catalyst: it is a more abundant metal and therefore cheaper than noble metals. This time, we decided to use a cobalt-based molecular catalyst which, like iron, is abundant and whose catalytic properties are already known. Our innovation is to have succeeded in shaping it molecularly on carbon paper while maintaining its catalytic efficiency. That is to say, we synthesize a molecule, and mix it with a carbon-based ink, before depositing a drop of this solution on the carbon paper. The ink then evaporates, and the molecules are dispersed in the pores of the paper. Noble metals such as gold and silver are used in the form of solid nanomaterials, a more expensive technique. Thanks to our innovation, we are making it possible to recycle CO_2 at a lower cost and with a simple device using renewable energy.

What source of energy do you use ?

Yes, our electrolyser is powered by photovoltaic panels. This is why we talk about "solar fuel": it is produced thanks to solar energy. We capture the light energy and store it as carbon monoxide using carbon dioxide. This monoxide is then used to make fuels, such as methanol (CH_3OH) or methane (CH_4), which is none other than natural gas: it is already used to heat houses or run buses. More generally, CO is a basic building block in the chemical industry. From this simple molecule, we can manufacture polymers, plastics, etc. **The aim is to transform the vision of CO_2: from a waste product, it becomes a renewable raw material, and its consumption and production become circular.**

However, is this a miracle solution to limit greenhouse gas emissions?

We would like the system to be expanded and installed on large industrial sites: it would capture the CO_2 emitted by factories, while storing a large amount of solar energy and producing carbon monoxide. But let's be realistic: every year, 36 million tons of CO_2 are emitted by the system. For any additional information I'll send you the link of a video I made on the subject for the university of Paris.

That would be perfect! Thank you for your time professor.

It was a pleasure, good luck for your paper.

Interview 2 : Florent Bourgeois (translated from French)

Florent Bourgeois is an expert of CO_2 utilisation by mineral carbonation; Minerals and (physico-chemical) waste processing. He works for the prestigious French CNRS (Scientific Research National Center) at the Chemical Engineering Laboratory of Toulouse.

Hello Professor Bourgeois.

Hello.

Thank you for giving us some of your time. I will try to be precise in my questions. What can you tell us about the current state of the industrial use of CO_2?

In fact, CO_2 is interesting in more than one way for industrialists, because in the supercritical state, it becomes a natural solvent, certainly very specific, since it is a non-polar solvent, but whose properties allow it, at a relatively low temperature and pressure (from 31°C and 74 bars) to become an alternative to chemical and toxic solvents. A very wide field of application. In fact, this technology is today increasingly used by industry for technological applications. And the field of these applications is very wide.

Do you think that research on industrial applications of CO_2 is sufficient?

I know from experience that it has greatly intensified in recent years. Indeed, this is an area that has been rather neglected for a few years. But there has been a real change in mentality and now a large number of young scientists are attracted to the subject and ask to work on it. So, I think we can expect many discoveries and innovations in the coming years.

Do you have a few examples of how it is being used nowadays?

As far as solid extraction is concerned, supercritical CO_2 is mainly used by the food industry. The best-known example in this field is the extraction of caffeine from coffee, but it is also used to extract flavours such as pink berry, ginger, vanilla or hops. The health sector also uses this process to extract the active ingredients from plants.

While the needs of the chemical industry are a source of inspiration for scientists, it is not the only one. Nature did not wait for us to use CO_2 from the atmosphere, it uses it in two distinct ways: to make biomass, via photosynthesis - in this case, plants use CO_2 from the atmosphere and water to produce sugars and oxygen -, and to make rock in the form of carbonates. An example of this so-called carbonation process carried out over periods of several thousand years in the heart of the oceans: the chalk cliffs of Etretat or Dover, entirely made up of calcium carbonates ($CaCO_3$)!

I read that you are currently working on CO_2 “rocks”, what is the interest of this technology ?

The interest in transforming CO_2 into rock is that it is extremely stable in its solid form. There is no risk of finding it in the atmosphere. The interest of transforming CO_2 into rock is that it is extremely stable in its solid form. In nature, rocks are leached (leached) by rainwater and release calcium (Ca), but also iron (Fe) or magnesium (Mg) - minerals that end up in the oceans and groundwater. There they precipitate with the CO_2 dissolved in water (as the CO_3^{--}ion) to give calcium carbonate or calcite ($CaCO_3$), iron carbonate or siderite ($FeCO_3$), or magnesite ($MgCO_3$), as tiny solid residues. The idea is to reproduce, but above all to accelerate these natural geological processes by heating the mixture. With our technique, we manage to produce "pebbles" of about ten microns. But to do this, we have to bring the solution to 180°C and apply a pressure of a few bars, levels which still require too much energy input and which we are working to lower.

What are the other advantages of this technology?

Storing CO_2 in solid form is not the only goal. Carbonates are materials that are used in the manufacture of cement, in particular. The ones we make artificially could also be used as building materials.

I think we've come full circle. Thank you very much for your time, Professor Bourgeois.

No worries do not hesitate to ask me if you need any information.

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