BIOENERGY, GEOLOGICAL CARBON STORAGE AND WATER RESOURCES

CHALLENGES, IMPACTS AND GOOD PRACTICES

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Editorial note

Why this report?

The Paris Agreement affirmed the goal of limiting global temperature increase to 2°C, with efforts to limit the increase to 1.5°C. This target will be difficult to reach; it requires countries to make their national greenhouse gas (GHG) reduction programs more ambitious. Besides mitigation measures, one way to reach this target is to intensify what is called negative emissions[1] . Negative emissions could play an important part in achieving carbon neutrality by 2050, a goal set by several Parties including EU member states.

The IPCC's special report on the impacts of warming of 1.5°C, published in October 2018, identified new measures to meet this target, such as BECCS (Bioenergy with Carbon Capture and Storage), which appears in most carbon dioxide removal scenarios. The advantage of BECCS is that it both produces biomass and bioenergy and captures the CO_2 thus generated in deep geological storage sites.

We believe it is important to examine not only the carbon impact but also the potential effects of this industry on water resources because it poses high risks in terms of water consumption and surface or groundwater contamination. Apart from the problem of water resources, there is a risk of competition with other major sectors for the use of resources, like agricultural production for food, and there are potential consequences for biodiversity.

This study aims to provide an overview of the technical, economic, social and environmental viability of BECCS, and to identify potential impacts on water resources.

A few BECCS facilities are currently in operation in the world. Many French operators, some of which are presented in this document, are active in the three subdomains of this industry.

All solutions must be taken into consideration in order to address the urgency of the fight against climate change and make up for the lost time. The BECCS industry is just one possible negative emission industry among others and could potentially capture much larger quantities of carbon dioxide. But the first step is to measure the industry's potential and impacts, particularly on water resources. Consequences often extend beyond the aspect of carbon and we don't always know how to measure them accurately.

The French Water Partnership (FWP) seeks to open all the spheres of action that will limit the effects of climate change on water resources, so as to not worsen existing water disorders. However, it highlights the need to give priority to measures that will reduce GHG emissions and help relevant sectors adapt. Many solutions already described in several FWP reports can be implemented by stakeholders in the water sector.

1.Negative emissions are activities that remove carbon dioxide from the air to reduce atmospheric levels. This can be done by increasing the capacity of natural carbon sinks or through engineering technologies.

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Towards carbon neutrality

(Foreword)

In line with the Paris Agreement signed in 2016 and its central goal of limiting global warming to 1.5°C, 195 countries have agreed on the objective of keeping global temperature rise "well below 2°C" above pre-industrial levels, and to pursue efforts to limit the temperature increase even further to 1.5°C by massively decreasing their emissions of CO_2 and other greenhouse gases (GHGs). France has set a carbon-neutral target for 2050 with a roadmap defined in its "National Low Carbon Strategy", ↗ (SNBC) which guides its climate change mitigation policy. This target is in line with the EU's Green Deal goal of reducing net greenhouse gas emissions "by at least 55%" below 1990 levels by 2030.

There is a general consensus around the use of negative emission technologies, as the massive reduction of CO_2 emissions alone is no longer enough. The goal of negative emission technologies is to remove part of the atmospheric carbon dioxide over the long term. Among the available technologies mentioned by the Intergovernmental Panel on Climate Change ↗ (IPCC SR1.5)are afforestation and reforestation, land restoration and soil carbon sequestration, BECCS, direct air carbon capture and storage (DACCS), enhanced weathering of rocks and ocean alkalinization. These technologies are at different development stages and may generate considerable costs. Yet their use on a large scale is still subject to controversy. Except for some Nature-based Solutions (NbS) none is currently ready to be deployed at the scale and speed necessary to meet the target of a temperature increase of 1.5 to 2°C.

The objective of negative emission technologies is to enable the long-term **removal of some CO_2 from the atmosphere.**

While measures related to carbon neutrality focus on curbing carbon dioxide emissions and capturing carbon, **a global approach must take into account other impacts and environmental challenges such as biodiversity, soil quality, resource depletion, etc.**

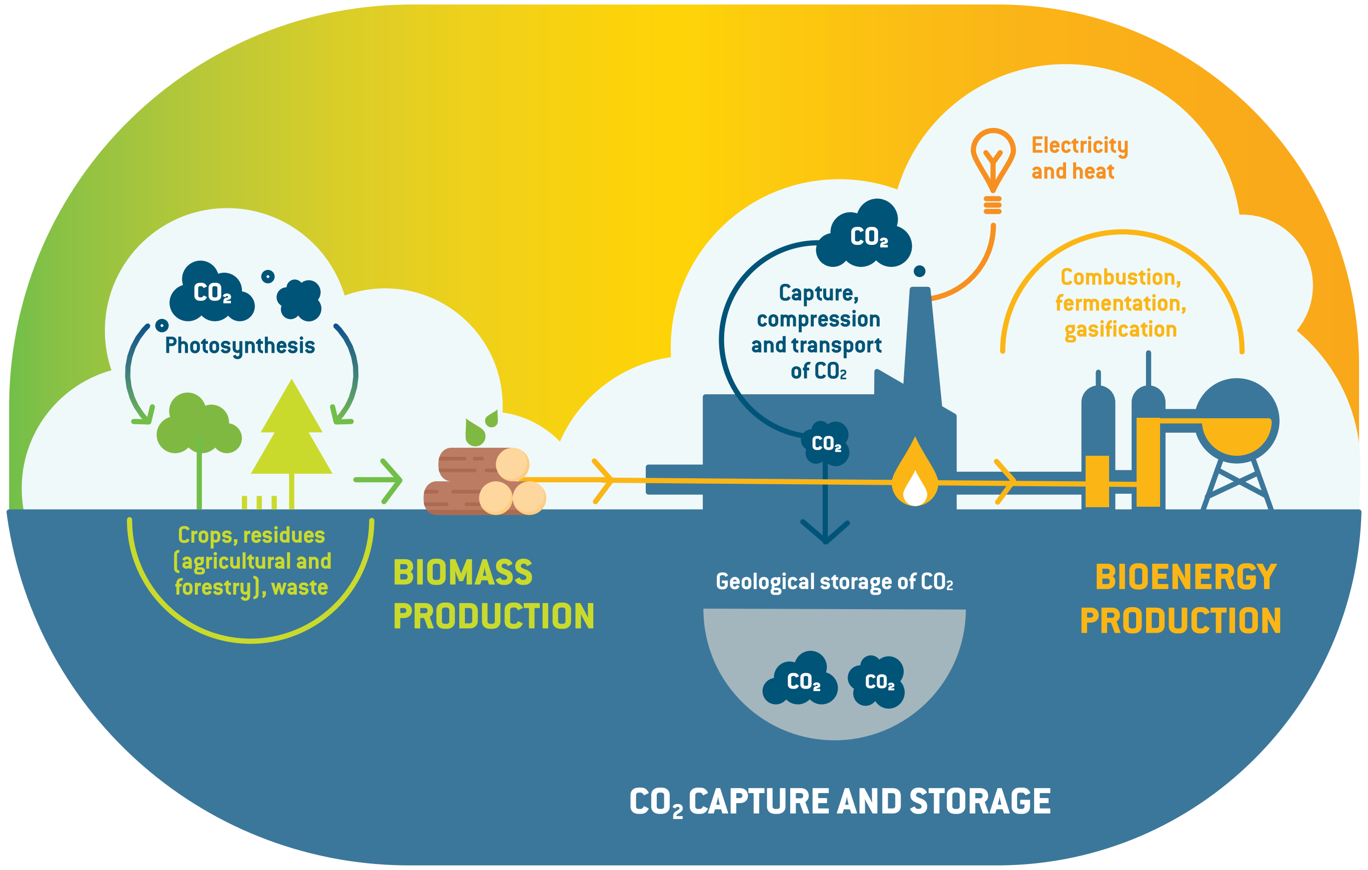
When implemented through suitable practices, carbon sequestration in ecosystems may generate co-benefits: restoring ecosystems, protecting forests, improving soil quality and biodiversity, etc. Adequate practices may also increase the water retention capacity of soils, improve the water cycle, etc. thus positively impacting water resources. Conversely, the development of certain practices or technologies will compete for land use with other purposes such as food security, biodiversity or ecosystem services provided by nature. Most potential negative emission measures, when set up on a large scale, could have major consequences on land, nutrients or water.

This report focuses on bioenergy with carbon capture and storage (BECCS) as a negative emission technology. Other technologies exist, but the present publication does not propose to offer a comprehensive overview of negative emissions.

2 Bioenergy with carbon capture and storage (BECCS)

1. INTRODUCTION

BECCS, Bioenergy with Carbon Capture and Storage, involves the utilization of biomass as an energy source and the capture and geological storage of CO_2 produced (CCS, Carbon Capture and Storage). **Five BECCS facilities are currently in operation worldwide capturing 1.5 $MtCO_2$/year.** [DNV2019]



Biomass may be solid (pellet, biocoal, etc.), liquid (ethanol, palm oil, etc.) or gaseous (biomethane, etc.). It is used as fuel either directly or after biological transformation (mainly by fermentation) or gasification (which produces flammable gases (syngas) through thermal processes). The fuel is burnt in biomass thermal power plants to produce energy (as electricity) and heat (in the case of cogeneration).

55% of renewable energy in France is bioenergy. [MTE]

The International Energy Agency (IEA) estimates in its report that global demand for bioenergy reached nearly 65 EJ in 2020. 90% of this demand was for solid biomass. **However, around 40% of this biomass was used for traditional cooking methods, which are non-sustainable, inefficient, and generate air pollution which is linked to 2.5 million premature deaths annually.** [IEA]

BECCS system of negative emissions

Biomass is produced by photosynthesis, drawing down carbon dioxide from the atmosphere. The production of bioenergy from sustainable biomass is deemed carbon neutral since the CO_2 emitted during combustion was previously captured from the atmosphere during the photosynthesis stage.

When coupled with a carbon capture and storage (CCS) system, the bioenergy production process can be carbon negative. The carbon dioxide generated by biomass combustion is not released into the atmosphere, it is captured and stored in a lasting manner in deep geological formations. However, only sustainable sources of biomass should be considered for these systems; the end result would be far less beneficial if non-renewable biomass (e.g. deforestation) or, more broadly, any process that results in a significant change in land use (e.g. replacement of food crops, which would be produced elsewhere) were used.

Where does biomass come from?

ENERGY CROPS

Perennial herbaceous crops:
silvergrass, switchgrass, etc.

France allows energy crops to be planted only as intermediate crops (cultures intermédiaires à vocation énergétiques, CIVE). To ensure energy crops do not become the main activity of a given plot of land, regulations determine how much may be grown in proportion to the initial food crop.

FOOD CROPS

Conventional annual crops:

- oil crops (palm, rapeseed, sunflower, etc.),
- sugar/starch crops (sugarcane, sugar beets, corn, cereals, etc.).

FOREST MANAGEMENT

- **Short rotation forestry (SRF):** alder, cedar, beech, birch, eucalyptus, paper mulberry, sycamore etc.
- **Short rotation coppice (SRC):** willow, poplar, etc.

The most widely consumed biomass in the world is wood-energy.

OTHER RESIDUES AND WASTE

- **Primary forest residues:** wood shavings from branches, treetops or poor-quality sticks, etc.;
- **Secondary forest residues:** by-products from sawmills: sawdust, bark, etc.;
- **Tertiary forest residues:** wood from municipal management, wood waste;

Agricultural residues, green waste, household biowaste, waste from restaurants, the retail sector, the food and fishing industries, sewage sludge, landfill gas.

MARINE BIOMASS

Algae, microalgae, phytoplankton and macroalgae

Marine biomass is increasingly being studied and production prospects are promising. In terms of space, water resources and nutrients, BECCS based on marine biomass could be a better long-term option than wood or crop biomass. Indeed, productivity is higher, freshwater is not an issue and nutrient needs are lower with an efficient recycling system. Yet marine biomass has received little attention so far because its irregular composition, inadequate for conventional combustion, limits its expansion. Large-scale development is still a distant perspective and many more years of research will be needed before its deployment is reliable, viable and cost-effective.

BECCS is only relevant if sustainable biomass is used. In the European Union, the use and trade of biomass are regulated by two directives – LULUCF[2] and REDII[3] – which ensure that it is sustainably sourced, irrespective of its geographical origin. The latter directive was transposed into French law with ↗ ruling n° 2021-235, dated 3 March 2021. Sustainability criteria apply throughout the entire supply chain, all the way to the consumption stage, i.e. from extraction or cultivation of feedstock to transformation, transport, distribution and use. Every operator in the supply chain should be able to prove they fulfill the environmental criteria.

Biomass is currently used in many ways: as food, fuel, fertilizer, fibers, furniture, timber, heat, electricity, green chemistry, biosourced products, biomaterials, etc. The multiplicity of uses may cause usage conflicts, as well as conflicts regarding the necessary production space, with an increasing risk of pressure on resources over the coming years.

How does the CO_2 capture and geological storage (CCS) system work?

The three stages in the CCS process are as follow:

1. **CO_2 is captured** at the level of the bioenergy production system. It is isolated from other items it could be combined with such as steam, particles, gaseous sulfur or nitrogen, etc. Three different methods, each at a different maturity stage, can be employed for capture: pre-combustion, post-combustion and oxy-combustion.
2. **After compression CO_2 may be transported** (1) through pipes which requires a CO_2-specific network to be built (there already are many gas pipelines in North America); (2) by boat: currently not used much, but transport conditions are similar to that of liquified petroleum gas (LPG); (3) by train or truck: these are not cost-effective, except perhaps locally.
3. **Geological storage of CO_2 :** may be done in depleted oil or gas fields or in deep saline aquifers. Storage may be onshore (on land) or offshore (at sea). **The worldwide geological storage potential is estimated between 8,000 and 10,000 billion tons, of which 300 to 500 billion tons in Europe, mainly in Norway and the United Kingdom.**

The process may be combined with industrial activities that necessarily emit carbon dioxide because of the nature of their raw materials or production processes and for which emissions cannot be reduced through traditional decarbonization measures. It is the case of oil refineries, cement plants, steel and petrochemical plants, etc. which account for a quarter of global industrial carbon emissions.

Some twenty projects are currently underway across the world, mainly linked to oil production. The volume of carbon stored so far, just under 40 million tons per year, remains trivial compared to global emission levels. As a comparison, greenhouse gas emissions on French soil reached 441 $MtCO_2eq$/year in 2020 and global carbon dioxide emissions caused by industrial activities and the burning of fossil fuels (not counting deforestation) reached 37 billion tons in 2019. **CCS plants currently capture only one thousandth of global CO_2 emissions,** whereas the IEA forecasts that 1.6Gt/year will be stored by 2030 and 7.6Gt/year in 2050. ↗ [IEA]

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[2] *Regulation on Land Use, Land Use Change and Forestry*

[3] *Renewable Energy Directive II (2018)*

France has developed one pilot project and none so far at industrial scale. In its note on CCS published in June 2020 ↗ [ADEME], **the ADEME (the French ecological transition agency) identified three exploitable carbon storage areas, located near Dunkirk, Le Havre and Lacq,** based on technical, geological, economic, legal and social constraints.

2. ISSUES

Major challenges are associated with BECCS as a technology to reach carbon neutrality, especially since it fits into a complex network involving agriculture and food, energy and climate.

BECCS features increasingly often in energy transition scenarios drafted to meet the 1.5°C goal. **It appears in three of the IPCC's four scenarios** ↗ [IPCC],though it is not touted as the only solution. More recently, the IEA's 2021 report ↗ [IEA], forecast that BECCS will help store 1.3Gt of CO_2 per year in 2050.

The scenario that calls for resorting massively to bioenergy is very ambitious, as are many other scenarios. It is deemed unrealistic, mainly because of the necessary surface of arable land and the lack of information regarding the sustainability of the biomass used. The French think tank IDDRI (*Institut du Développement Durable et des Relations Internationales*) argues that cross-analyzing the IPCC's 1.5°C and "Climate Change and Land" reports brings to light a risk in land use if BECCS is deployed as in scenarios P3[4] and P4[4], and even in scenario P2 in the case of ill-adapted land management. ↗ [IDDRI] **The report produced jointly by the IPCC and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) puts forward the lack of positive relation between BECCS and biodiversity as well as dangers caused by large-scale deployment.** ↗ [IPCC/IPBES]

France's national low-carbon strategy (SNBC) plans that 15 $MtCO_2$/ year will be captured via CCS by 2050, including 5 $MtCO_2$/year originating from industrial sources and 10 $MtCO_2$/ year from biomass for energy (BECCS). ↗ [SNBC]

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[4] Scenario P2 emphasizes a convergence between sustainability and economy, with limited social acceptability of BECCS. Scenario P3 is an intermediate one, in which social development follows usual patterns, as does technological development. Emissions are decreased mainly by changing the way energy and products are obtained, and to a lesser extent, by decreasing demand. Scenario P4 allows for high-intensity resources and energy, and an intensive use of BECCS helps curb emissions.

Major role in decreasing emissions

Eliminating CO_2 may be a necessary factor to meet the goal of 1.5°C, **yet it is important to emphasize that it cannot replace a rapid, strong decrease in emissions of carbon dioxide and other greenhouse gases. Reducing emissions must go hand-in-hand with reducing energy demand.**

It is necessary to consider setting up a form of governance that will ensure that the potential existence of negative emission technologies does not hinder efforts to reduce carbon dioxide emissions at all levels, from the local to the global level.

Failing this, in a scenario in which carbon emission reduction is reached belatedly, BECCS and other negative emission solutions would have to be deployed on a large scale to maintain global warming within the 1.5° or 2°C limit. The IDDRI warns that such a deployment would perhaps help reduce atmospheric CO_2 levels, but would have disastrous consequences for ecosystems, biodiversity, resources and Sustainable Development Goals: it would threaten food security and access to drinking water and increase risks of conflicts and health problems, etc. ↗ [IDDRI]

3. OTHER METHODS

Other technologies are similar to BECCS: BECCU (bioenergy with CO_2 (re)use), direct air capture, biochar.

Use or reuse of CO_2

Instead of being stored, carbon may be used or reused (BECCU). This can be done in various domains such as methanation, which produces methane by combining CO_2 and H_2, in manufacturing, construction, and in the chemical and food industries to cite but a few. It is important to remember that the principle of negative emissions depends on the long-term sequestration of carbon dioxide. **Therefore, reusing captured CO_2 only counts as a negative emission if that same CO_2 is not released into the atmosphere again when the good or service it helped create is consumed.** Let us note that in certain cases, using captured carbon dioxide helps decrease the exploitation of fossil carbo n. The water footprint of BECCU is similar to BECCS's, which is mainly due to biomass production, but it must also take into account the water consumed during the CO_2 reuse processes.

Direct air carbon capture

Another negative emission process is the direct removal of CO_2 in the atmosphere with geological storage known as DACCS (*Direct Air Carbon Capture and Storage*). The idea is to filter air from the atmosphere, capture molecules of carbon dioxide and then store them long term in-depth.

This technology, which is often compared to BECCS, requires fewer resources. Setting up DACCS takes up less land and uses fewer water and nutrient resources, so its impact on ecosystems and biodiversity is supposed to be lesser. However, the water it does use is drawn from surface resources and groundwater available for human use and could therefore conflict with urban, industrial and farming usages. A report published in 2020 ↗ [WF]] establishes that the water footprint of DACCS is 4.01 m^3/ton of captured CO_2. As of yet, this technology is not very developed and its financial and energetic cost is high. France's SNBC mentions it, but only as an alternative because it is still in the early stages of research and development. The IEA views DACCS as a major innovation opportunity.

The idea is to **filter air from the atmosphere, capture molecules of CO_2** and then store them long term at depth.

BIOCHAR →

Like BECCS, biochar uses the ability of biomass to capture atmospheric carbon dioxide. Biochar (short for biocharcoal) is a solid mass produced by pyrolysis – heating in the absence of oxygen – of biomass, generally crop residues. The by-products of the pyrolysis of biomass are gases (methane and hydrogen) and a liquid that may be used as biofuel. Biochar takes the form of light, porous, black particles, mainly made of carbon. When carbon content is lower than 70% these particles are called "biocoal" or "black pellets" and serve as solid biofuel to produce bioenergy. Biochar is used both to enrich soils and to sequester carbon. It stimulates soil metabolism and the immune defense system of plants to better fight back insects and diseases. In addition, it improves water retention and so is suited to arid soils. According to Pro Natura ↗ [ProNatura]sustainable biochar systems "are carbon negative by transforming the carbon in biomass into stable structures which remain sequestered in soils for hundreds and even thousands of years". The IPCC also mentions biochar as a way to achieve negative emissions that could reach 1 to 2 billion tons of CO_2 per year if deployed on a large scale. ↗ [IPCC]

When carbon content is lower than 70% these particles are called biocoal or black pellets

3 Limits and risks of BECCS

1. ECONOMIC VIABILITY

BECCS is not yet ready for large-scale deployment. The slow development of CCS hinders that of BECCS. Taken separately, the different phases of the BECCS process have reached technological maturity, as have the different stages of CCS. What slows the deployment of the full process is the lack of economic opportunity.

At the moment, CCS is mainly developed in **EOR (Enhanced Oil Recovery) projects**

Although CCS has been attracting political interest since 2005, it is developing slowly, particularly compared to forecasts for 2020. At the moment, CCS is mainly developed in EOR (Enhanced Oil Recovery) projects, as the additional extraction of oil covers the costs of CCS, making the process profitable.

Capture costs represent the bulk of CCS costs. These are reduced when concentrations of CO_2 in the flue gases are high. **The CCS cost unit, around 100 to 150€/t of captured CO_2, is higher than the regulated cost of emitting a ton of carbon.** However, there have been shifts in carbon markets since 2020, and the price of carbon exceeded 40€/t in the first months of 2021. There seems to be a strong consensus among market analysts, who have revised their forecasts upwards for 2021-2030 and estimate that prices will reach 70€ to105 €/tCO_2 in 2030. ↗ [ECOACT]

The cost (LCOE) of bioenergy may vary between 70€/MWh and 125€/MWh depending on the characteristics of the biomass used (type, origin, etc.) and the size of the plants.

2. SOCIAL VIABILITY

In addition to weak economic opportunities, BECCS has so far suffered from low social acceptance. Onshore storage, currently forbidden in Germany, is hotly debated. **France's ADEME points out that many geological storage projects have faced strong opposition from local populations,** which at the European level has brought a substantial number of onshore CCS projects to a halt. Social acceptability is less of an issue for offshore storage, but offshore CCS projects are more complex and involve increased transport and storage costs. ↗ [ADEME]

Deploying BECCS on a large scale could also impact food security in terms of availability, access, use and stability. Bioenergy may indeed affect the availability and the production capacity of land or other resources. It could also result in an increase in food prices, which would hit the poorest people the most, as they devote a substantial share of their income to food.

On the other hand, bioenergy may also have a positive effect on food production by boosting the growth of the agricultural sector, creating new employment and income opportunities, supporting rural development and poverty reduction. Producing energy biomass could also improve soil quality and thus benefit food crops.

A number of factors will determine the nature and scale of potential impacts, including choices that will be made regarding the type of feedstocks, the type of bioenergy, production management and its general appropriateness to the social, economic and environmental context: food prices, energy security, food security, deforestation, land use, impact on climate change, etc.

3. ENVIRONMENTAL VIABILITY

The debate around the development of BECCS also raises environmental issues, depending on the scale of deployment. Producing biomass for BECCS causes direct or indirect changes in land use: existing farmland may be turned over to energy crops, with the result that food crops need to be moved elsewhere with negative consequences for natural areas, or natural areas may directly be converted to farmland. It is still difficult to integrate these changes and their consequences in assessment methods such as life-cycle analyses (LCA) given how complex it is to measure them. **In 2020, 330 million hectares of land across the world – the equivalent of the area of India – were used for bioenergy, according to the IEA. Its scenario envisions that this figure will reach 410 million hectares in 2050.** ↗ [IEA] The figure is estimated at 500 million hectares in other scenarios, if emissions caused by fossil fuels are not reduced and BECCS is used to limit warming to 1.5°C or 2°C. Let us not forget that in addition to this land area allocated to bioenergy, we will need agricultural land to produce increasing amounts of food for a growing global population.

Changes in land use modify or wipe out rich ecosystems (forests, wetlands, grasslands, etc.), therefore impacting biodiversity there. The World Wide Fund's "Living Planet Report 2020" ↗ [WWF] states that the most important direct driver of biodiversity loss is the destruction of natural habitats. According to this report, agricultural activities are responsible for 80% of global deforestation and 70% of terrestrial biodiversity loss. At present information regarding the impact of large-scale deployment of BECCS on biodiversity is very insufficient. The IDDRI has sketched out two scenarios for BECCS deployment on two different scales and points out that large-scale deployment would severely affect biodiversity. ↗ [IDDRI] Besides the impact on changes in land use, it seems the bulk of crops could be located in tropical areas (which enjoy favorable growing conditions) or in biodiversity hotspots. The IPBES has also warned of potential competition in land uses between bioenergy and protected areas. Negative biodiversity implications would be worse if deploying monocultures rather than diversified, complexified crops, and if invasive species are introduced. This is valid for farmland but also for forested habitats, though the case of BECCS from residues may be more nuanced. Human pressures on ecosystems not only deteriorate nature, but they also threaten human health and food security, which are dependent on large numbers of wild species (more and more overexploited) and cultivated species (less and less diverse). The potential economic impact is high; the WWF estimates it could exceed 479 billion dollars per year.

Farming is already responsible for 80% of global deforestation and 70% of terrestrial biodiversity loss.

Removing forest residues as part of sustainable forest management helps forest growth. However, forest and crop residues also improve soil quality as they enrich soils and preserve nutrient content. Harvesting residues could therefore adversely affect soil properties, nutrient availability and existing biodiversity. Up to 90% of living organisms in terrestrial ecosystems, including certain pollinators, spend part of their life cycle in soil habitats. Without soil biodiversity, terrestrial ecosystems risk collapsing.

The IPCC-IPBES report says that when planted at smaller scales, woody or perennial grass bioenergy crops in principle can support the restoration of severely degraded areas. Biodiversity can benefit from perennial bioenergy crops in agricultural landscapes previously dominated by monocultural crops. ↗ [IPCC/IPBES]

The impact of BECCS will depend on the conditions of its development. Depending on the choices that will be made, the effects may be diametrically opposite: biodiversity support, protection of carbon stocks, ecosystems and resources, or quite the opposite, biodiversity loss, positive carbon balance and resource depletion. **There is no universal answer to these questions.**

In addition to these effects, let us not forget about the pollution and end-of-life management of the elements and chemicals involved in the various processes, for example, the amines[5] used for CO_2 capture, which generate dangerous waste ↗ [ADEME]

Is the emission balance truly negative?

Measuring the total balance of BECCS carbon dioxide emissions is difficult because it depends on each plant. **BECCS also involves various sectors, which raises the twin issues of managing and calculating emissions from one sector to another, to avoid "carbon leakage".** Furthermore, the reasoning that posits that the amount of carbon dioxide emitted while transforming biomass into energy is equivalent to the amount drawn from the atmosphere during photosynthesis may be valid, strictly speaking. But the emission balance for BECCS must also take into account the CO_2 emissions resulting from direct and indirect changes in land use, as well as the emissions linked to agricultural processes, in particular N_2O emissions related to the increased use of nitrogen fertilizers, which goes against the principle of GHG emission reductions. The emissions caused by biomass transport at the CCS stage also need to be factored in: transport, energy used to capture CO_2 and modify its state, injection into deep rock formations, losses during the process.

Wood biomass is a particular focal point for controversies about emissions. It is often criticized for its weak energy efficiency, lower than coal's, and which involves emitting between 3% and 50% more greenhouse gases than coal per unit of electricity produced. Moreover, when trees, and not just residues, are burned, the CO_2 emitted will take years to be captured again by newly planted trees. Additionally, young forests do not have the same absorption capacity as established ecosystems, and this capacity to absorb CO_2 also depends on such factors as temperature, rainfall, density, soil, slope gradient, altitude, etc. Finally, wood combustion emits pollutants that are detrimental to human health and climate.

As the online magazine Reporterre points out, these activities need to be regulated tightly so as to avoid industrial dishonesty – a company could very well release the CO_2 at sea instead of completing the full process, and do so with impunity in the absence of smells or other traces visible to the naked eye. ↗ [REPO]

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5. Organic solvents used to capture carbon dioxide from gases after combustion.

BECCS & SUSTAINABLE DEVELOPMENT GOALS (SDGS)

BECCS is narrowly linked to certain SDGs, for which the positive or negative impacts depend on how the technology is deployed.

SDG — POTENTIAL IMPACTS

2 ZERO HUNGER

Zero hunger

+
- Preserved ecosystems.
- Improved soil quality, agricultural productivity, nutrient content[6].

−
- Competition with food production.
- Problems in equality of access to land.
- Intensive farming which goes against ecosystem preservation and adaptation to climate change and extreme events.

3 GOOD HEALTH AND WELL-BEING

Health

+
- Reduced air pollution as a result of gas capture – if fossil fuels are replaced.

−
- Impact on water, soil and biodiversity which may cause diseases.

6 CLEAN WATER AND SANITATION

Clean water and sanitation

+
- Preserved, better-managed ecosystems linked to water (forests).
- Improved quality of certain soil characteristics: water retention, infiltration, etc.[6]

−
- Pressure on water ressource, water stress.
- Water pollution caused by fertilizers or pesticides.
- Degraded ecosystems linked to water (forests, wetlands).

7 AFFORDABLE AND CLEAN ENERGY

Affordable and clean energy

+
- Increased share of renewables in the global energy mix.
- Sustainable, controllable, safe bioenergy in developing countries.

−
- Potentially higher cost of energy resulting from the use of biomass[7] rather than fossil fuel, and from the costly installation of CCS.

12 RESPONSIBLE CONSUMPTION AND PRODUCTION

Responsible consumption and production

+
- Agricultural, industrial and urban waste converted to energy.

−
- Increased consumption of resources (intensive agriculture).

15 LIFE ON LAND

Life on land

+
- Good agricultural practices, intermediate cultures: improved soil quality and improved storage of organic carbon in soil surface.[6]

−
- Change in land use: impact on ecosystems, risk of deforestation, biodiversity loss. Impact on freshwater ecosystems in case of major water abstraction/consumption and polluted water discharge.

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6. Potentially valid if deployed sustainably and on a small scale.
7. The cost depends on the type of biomass used, but is generally higher than that of fossil fuel. Of course this can be debated on a case-by-case basis, especially when using local residues as solid biomass.

Additional SDGs

mentioned on the diagram in a secondary list

8 DECENT WORK AND ECONOMIC GROWTH

Decent work and economic growth

+ • Job creation, boost to rural areas.

− • Risk of increased child labor in developing countries.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE

Industry, innovation and infrastructure

+ • Democratized use of CCS, which may be applied to other industries (cement, steel, etc.).

11 SUSTAINABLE CITIES AND COMMUNITIES

Sustainable cities and communities

+ • Sustainable disposal of urban waste.

− • Increased vulnerability of cities in the face of extreme climate events linked to water (droughts, floods, etc.) due to the loss of major ecosystems (forests, wetlands).

13 CLIMATE ACTION

Climate

+ • Creation of a system to decrease atmospheric CO_2 concentration.

− • Loss of resilience and adaptation capacity in the face of climate events due to the loss of major ecosystems (forests, wetlands).
• Change in priorities: efforts to decrease emissions vs. negative emission solutions.

14 LIFE BELOW WATER

Life below water

− • River and ocean pollution resulting from the use of fertilizers, pesticides or chemical products (or release of CO_2 in case of an accident), eutrophication.

4 Impacts on water resources

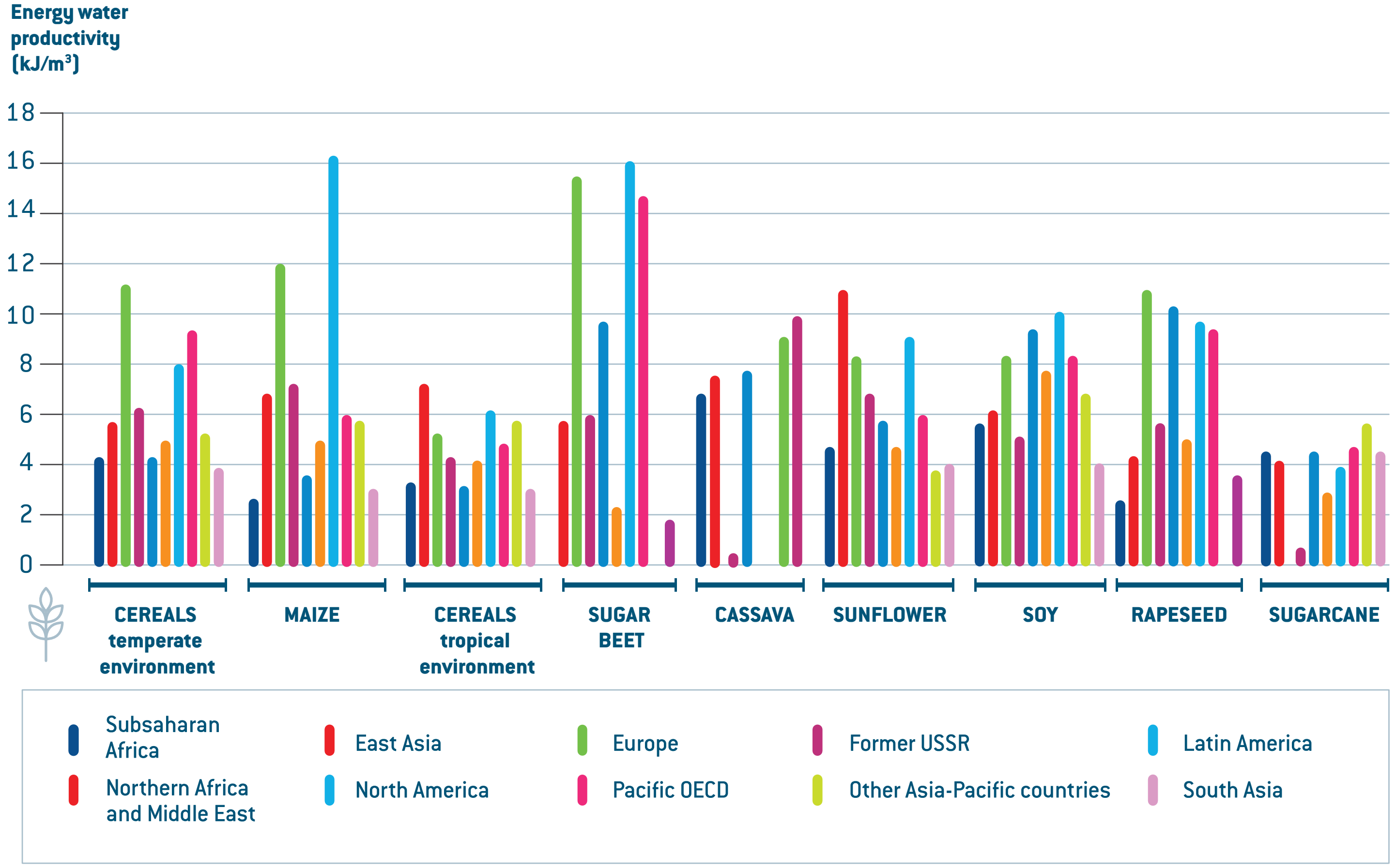
1. BIOMASS PRODUCTION

The impact of biomass on water resources mainly concerns biomass from agriculture and forest cover. Converting waste or using marine biomass has little impact on freshwater.

From a global perspective, agriculture is the planet's largest water consumer, accounting for 70% of water use

Agriculture already occupies a third of the planet's land surface. The bulk of agricultural production relies on rainfall alone (rain-fed agriculture). Rainfall is insufficient in some parts of the world, and at certain times during the year it is supplemented with irrigation systems, which draw the necessary water resources from the environment. This impacts the environment in many ways, and water resources are often overexploited. Developing countries rely heavily on irrigation, and irrigated areas there could reach 242 million hectares by 2030. From a global perspective, agriculture is the planet's largest water consumer, accounting for 70% of total water use. Moreover, this is net consumption: the water is evapotranspired, not returned to the environment after use. Consumption is distributed unevenly depending on regions and seasons. Periods of high irrigation needs also tend to be periods when water resources are least available, meaning farmers resort massively to underground water. Additionally, climate change generally decreases the amount of available water, as evapotranspiration increases and rainfall intensifies. **An important point to bear in mind is that water is a local resource, meaning that an assessment on a global scale is not very relevant.** Resource assessment must therefore be done on a case-by-case basis, as the consequences of extracting a liter of water vary from one area of the world to another.

The water footprint of different cultures depends on the varieties being cultivated. To give an order of magnitude, the water footprint of crops ranges between 165m^3/MWh and 1425 m^3/MWh: 200m^3/MWh for sugarcane and sugar beet; 250m^3/MWh for maize; 700m^3/MWh for soybean and 1300m^3/MWh for rapeseed. ↗ [HOEK] It is difficult to study the water footprint of these crops, since it also depends on the location, agricultural system and climate conditions. Taking into account irrigation requirements, water consumption may vary depending on the crop, but also for a same crop, depending on geographical location (see chart below). Finally, the amount of energy produced depends on the crop, and varies depending on its composition.



Biofuel produced per unit of water consumed for a selection of crops. Average water requirements for bioenergy at national level, regardless of country size. The figures are average values for a simulation covering the period 1998 to 2003.

Evaluation of water use for bioenergy at different scales. S. Yeh *et al.* 2011

Agricultural practices have consequences on water quality beyond water consumption and the impact on the water cycle. **Pollution is caused mainly by the excess fertilizers, including nitrogen, and pesticides (herbicides, insecticides, fungicides, etc.) employed for intensive agriculture. Pollution also results from agricultural and irrigation methods and from accidental contamination when handling chemicals.** If fertilizer use were stepped up to increase biomass yields, this would affect the quality of both surface water and groundwater. Fertilizer use also impacts soil quality, which in turn may worsen groundwater pollution. Likewise, phosphate, though used in lesser amounts than nitrogen, may degrade water quality mainly by eutrophicating surface water and groundwater.

Pesticides also significantly degrade the quality of water and associated aquatic ecosystems. Certain crop protection products (such as atrazine) and their metabolites are highly persistent and levels in soils, aquatic ecosystems and water resources still locally exceed legal limits although they have been banned for several decades. Chlordecone, long used in banana plantations in Martinique and Guadeloupe, has contaminated not only the land environment but also the marine environment downstream; it affects fish populations by exposing them to contaminated water along the entire food chain.

Forest covers, similarly to other vegetal covers, may limit erosion caused by intense rains. Generally speaking, forestry doesn't require much fertilizer or crop protection products, and human intervention (planting or cutting down trees, thinning out) is less frequent, so the impact of forest management on water quality is limited. Nonetheless, forests need water to develop, as do all plants and therefore rain-fed crops (forests are rarely irrigated). Their requirements in terms of rainwater are usually higher than those of other types of vegetal covers, even agricultural ones. Planting or replanting a forest on a territory may significantly impact the water cycle, for example, slowing the replenishing of water tables or decreasing the flow of rivers during low-flow season. These effects, through feedback loops, may in turn have effects on water quality (polluting discharges in rivers might be less diluted for example). It is therefore necessary to assess the impacts on water quantity and quality on a case-by-case basis, depending on the tree species and the sensitivity of catchment areas. In Australia for instance, forestry is taxed according to a "user-pays" principle, similar to the taxation system applied in France in the water sector and collected by water agencies. Furthermore, certain types of forest stands, especially in arid or semi-arid environments, have deep root systems able to extract water from the first few meters of soil, which are not completely saturated with water, and from aquifers up to several tens of meters deep. This concealed water extraction disrupts the water cycle: the low-water flow may diminish and less water may be available for other uses or ecosystems. The "water" impact of forestry must be assessed from this perspective as well. Evapotranspiration from plants translates into atmospheric humidity and ultimately rainfall. However, it has been demonstrated that the effects of increased rainfall are significant only on a continental scale (for example deforestation in the Amazon inducing reduced precipitations on the Andes' eastern side), and therefore do not locally benefit reforested areas smaller than the continental scale.

Planting or replanting a forest on a territory may significantly impact the water cycle, for example **slowing the replenishing of water tables or decreasing the flow of rivers during low-flow season.**

Wetlands are areas permanently or temporarily saturated with and/or covered with freshwater, saltwater or brackish water. These areas play an ecological role (self-purification of water, biodiversity reservoir, CO_2 sink) and some of them, or parts of them, absorb or store water during extreme weather events like floods or tsunamis, and help mitigate flooding impacts. They may also serve as reservoirs during low-water season (when the flow of waterways is lowest) or during droughts. **Therefore wetlands are highly valuable when facing climate change and extreme weather events caused by it.**

These areas are already under severe threat from current human activities. As wetlands were initially deemed of no use in France, pressure from human activity caused their surface to drop by 50% over the past century. They are also under threat in Brazil's Pantanal region, the world's largest continental wetland. The combination of drought induced by climate change and fires started for land-clearing has caused colossal fires which have destroyed huge portions of this biodiversity hotspot.

European forests may be expanding, but it is not the case in the rest of the world, where many areas are heavily deforested. In addition, soils are degraded as a result of changes in land use or agricultural practices. A degraded soil is more at risk of erosion and run-off, which in turn limits water infiltration. When the underground part of the water cycle is thus disrupted, there may be significant consequences in terms of availability and quality of surface water and groundwater resources as well as for human or ecosystem use of water.

The large-scale development of BECCS could increase pressure on these territories and thus further disrupt the water cycle. Modeling these impacts should help assess how acceptable this additional pressure is, while also integrating the effects of climate change, since BECCS needs to be considered from the long-term perspective of the entire 21st century.

2. BIOENERGY PRODUCTION

Just like any central power plant, a bioenergy plant uses cooling water as a heat sink of the thermodynamic cycle, to close the heat-transfer circuit. To function in open circuit, water is usually taken from a nearby source (lake, river, aquifer or ocean), injected into the circuit, and then discharged at the end of the circuit after partial evaporation. In the case of a closed circuit, less water is extracted since it circulates in a loop. It is important to distinguish water extraction – when water is taken from a source and can be returned afterwards – and water consumption – a certain amount evaporates during the cooling process or leaks out and cannot be recovered. The amount of water extracted and consumed depends on the plant's operation, its activity peaks, its thermal efficiency, the water source, etc. In France, 51% of freshwater drawn in 2013 was used for cooling. ↗ [STATMTE]. In areas where water resources are limited, water withdrawals can quickly turn into a sizable problem and compete with other uses. **Furthermore, withdrawals tend to increase during hot years, which are becoming increasingly frequent as a result of climate change.**

In France, 51% of freshwater drawn in 2013 was used for cooling.

Bioenergy production may also impact water quality. **France has defined rules to regulate the temperature of water discharged after withdrawal withdrawal** taking into account biodiversity, especially fish species, in the discharge zone so as to avoid altering the ecosystem substantially. **In a similar perspective, there are regulations regarding chemical treatments** of industrial water meant to protect the circuits and general operation of the plant (additives, biocides, corrosion inhibitors, etc.). **However, not all parts of the world have implemented such rules.**

Biomass production (fertilizers) and transport may be significant factors of bioenergy's acidification potential[8] , but emissions caused by combustion are the main culprit, responsible for 60 to 74% of it. Eutrophication[9] is mainly the result of biomass transport, production and combustion and the disposal of ashes. ↗ [EDFACVBIO]

Last but not least, the amount of water consumed depends on the way biomass is converted to energy. Cogeneration systems significantly decrease water consumption per unit of energy produced. Similarly, for most crops, the water footprint of electricity production is often almost half that of biofuel. The difference is explained by the proportion of the crop used: total biomass may be used to produce electricity, compared to only a fraction of it to produce biofuel (biodiesel or bioethanol for example). ↗ [HOEK]

The water footprint of bioenergy production must also be put into a local perspective: Were other energy operations active on this territory previously? Does the bioenergy system replace them? Is the water footprint higher or lower in the current situation?

3. CO_2 CAPTURE AND GEOLOGICAL STORAGE (CCS)

Few studies have documented the impact of CCS deployment on water resources so far. However, a 2020 study ↗ [WF] warns that a large-scale deployment of CCS according to the objectives of 1.5°C scenarios may double the water footprint of human activities. The finding is qualified depending on the technologies used, especially at the CO_2 capture stage, for which oxyfuel combustion seems to have the lowest water footprint. Depending on which technique is used to capture CO_2, the water footprint of CCS varies between 0.74 and 575 m^3 H20/ton of captured CO_2. A mature technology, post-combustion capture is deployed in CCS projects worldwide; it uses up vast amounts of water to wash the amines. The global water footprint of human activities does not currently exceed the planet's boundaries. But pressure on water resources must be examined through the prism of local conditions. At the local level, 50% of the consumption of water sourced from surface and aquifer resources and 18% of the consumption sourced from rainwater or soil moisture exceed the maximum levels for sustainable operations. Implementing CCS technologies would increase the consumption of surface and aquifer water estimated at 1700 km^3/year by 84 (±56) km^3/year. ↗ [WF]. Before setting up a CCS project, a study of locally available water resources must be carried out.

A mature technology, **post-combustion capture is deployed in CCS projects worldwide; it uses up vast amounts of water to wash the amines.**

When CCS projects are implemented, there is also a risk of contamination of surface reservoirs and aquifers, mainly when drilling to store CO_2. However, good practices can eliminate this risk almost entirely.

Several LCAs give a more nuanced picture of the benefits of CCS in terms of CO_2 emissions when other factors are weighed in. A 2011 study estimates that emissions of the methane (NH_3) and solvents (particularly products that decompose amines and are sometimes toxic) used by the CCS industry could increase water eutrophication potential by 35%, acidification potential by 43%, terrestrial ecotoxicity by 143% and surface water ecotoxicity by 167%. France's INERIS stresses the need to ponder these figures to take into account technical progress and improvements in capture processes. Amines are more and more often replaced by cleaner technologies. ↗ [INERIS]

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[8] Acidification potential measures the loss of nutrients, which are replaced by acids because of sulphur dioxide (SO_2), carbon monoxide (NO), nitrogen dioxide (NOx) or ammonia (NH_3) pollution.

[9] Eutrophication is the result of excess amounts of nutrients. This causes phytoplankton and other aquatic plants to multiply excessively; the bacteria that decompose this organic matter proliferate as well, depleting the oxygen levels in water.

BECCS with deep carbon storage may contribute to carbon neutrality but must be analyzed on a case-by-case basis, depending on the context, as it may negatively impact surface water and groundwater, and locally put these resources under additional stress. It seems therefore difficult to contemplate deploying BECCS on a large scale, particularly since climate change will potentially intensify certain impacts, especially on the water cycle. Deploying it in a sustainable way, on a small scale, integrating the availability of local resources, as mentioned by the IPCC and IPBES regarding biodiversity, appears to be a more sustainable option and a preferable one from the perspective of water resources. However, such a scenario will have to go hand-in-hand with both a major reduction of GHG emissions and adaptation measures.

5

French expertise, examples of solutions

There are currently no industrial-scale BECCS projects on French soil. Nonetheless, French operators are active in bioenergy and carbon capture and storage. A number of such projects as well as some BECCS plants or pilot projects exist at the European and global levels.

FRENCH OPERATORS

BIOMASS PROJECT,
FOREST
RESIDUES

French Guiana

The French Development Agency funded Voltalia's wood-fired plant of Cacao in French Guiana. The demand for energy is increasing and is forecast to continue to do so in the coming years as the local population grows and household equipment levels rise. To reach a target of 100% renewables in its energy mix by 2030, as per the energy transition law, **Guiana is counting on its forest estate open to exploitation, including land cleared for agriculture, leaving its primary forest intact. In this way, the territory will develop stable bioenergy projects to complement intermittent solar and wind power.**

The plant, with a capacity of 5.1 MW, started operating in December 2020. It is located near a major forest and is to be supplied with wood from logging industries and nearby sawmills, since this waste is currently not exploited. The forestry operations are supervised by the National Forestry Office (ONF). The output will be injected into the public grid and sold at a price below the cost of existing diesel-powered thermal plants in Guiana. The power plant will have storage capacity, with batteries with a capacity of 550kWh/250kWh, so as to be able to quickly modulate output and help stabilize the non-interconnected network of French Guiana.

BIOVEA PROJECT, PALM RESIDUES

Ivory Coast

Since 2019 EDF, Meridiam and BIOKALA (a subsidiary of SIFCA) have been developing the Biovéa project, a 46 MW biomass plant that runs on agricultural waste. The plan is designed to meet the annual electricity needs of 1.7 million people. **The goal of the project is to develop both Ivory Coast's renewable energy sector and a circular economy based on agricultural residues (palm, cotton, cacao).** It is meant to support the Ivorian agribusiness and improve conditions for the country's rural population by creating more than 1,000 jobs or full-time equivalents and boosting the income of thousands of small farmers by up to 15%.

The biomass used here mainly comprises the stalks of the leaves left over after the palm trees are pruned to allow harvesting. Locally produced palm oil is the primary cooking oil used in Ivory Coast; local production is not sufficient for export. **The 25-year supply plan guarantees that the feedstock will be sourced from within a 60 km-radius around the plant, from existing, long-established plantations (established since 1963). This project therefore does not cause deforestation, nor does it require new oil palms to be planted. On the contrary, the plan is to improve yields so as to decrease planted areas by 9,000 ha over 25 years.** The project can count on a surplus of biomass, as it requires an estimated 480,000 tons per year compared to a potential local supply of 680,000 tons. About 25% of the supply of biomass is provided by two plantations managed by PALMCI, a subsidiary of the SIFCA group, and the remaining 75% by numerous village plantations.

BIOSTAR PROJECT, AGRICULTURAL RESIDUES

Western Africa

The Biostar project aims to improve Western Africa's energy supply and to support the independence of SMEs in the food sector by converting their residues into heat, electricity or kinetic energy and developing the bioenergy sector. Five sectors were identified for this project: cashew, rice, mango, peanut and shea. These sectors were chosen because of their economic weight in the countries concerned, the massive involvement of women and existing national strategies for their sustainable development. In all the above sectors, there is a demand in energy to transform the agricultural product into food (shelling, drying, extraction, steaming) and the residues are currently not used, or very little. Pilot experiments have been started in agro-industrial factories in Burkina Faso and Senegal.

The goal is to address the irregular quantity and quality of energy supply in rural areas, which hinders the development of SMEs and forces them to set up near cities. This is problematic because it means raw materials need to be transported from production areas to transformation units, resulting in additional costs and post-harvest losses. Energy inefficiency in food processing affects the quality of end products and may cause significant losses. This situation also contributes to densifying urban areas, draining activity away from rural areas which become purely agricultural. Some natural residues from transformation factories, like cashew shells, mango stones, rice balls, liquid effluents, etc., are detrimental to human health and the environment, yet are potentially useful for energy production.

The project is led by national research and training institutes in Western Africa and Europe including the French agricultural research and international cooperation organization (Cirad) and the French non-profit Nitidae. It is co-financed by the European Union and the French Development Agency.

LACQ PROJECT, CCS

France

Lacq is a pilot project of carbon capture and storage in a former gas field. The project was carried out by Total from 2010 to 2013; during this period **more than 50,000 tons of CO_2** were injected underground. The project was built into the steam production generated for the Lacq industrial complex by a 30-MWt gas oxy-combustion furnace.

The four furnaces supplying steam generate flue gases containing CO_2. The fifth furnace was modified to capture CO_2 through oxy-combustion. The carbon dioxide was purified and dehydrated, then compressed at 27 bars (concentration was 90 to 93%) and dried. After that, it was transported 27 km through existing pipes all the way to the injection site. These pipes had previously been used to transport the natural gas extracted from the Rousse field to the Lacq factory. The gas field, now depleted, was exploited for 36 years, from 1972 to 2008. The carbon dioxide, again compressed at 40 bars, was injected into the reservoir at a depth of 4,500m. This reservoir is optimal for the safe, long-term storage of CO_2, as it is protected by a 2,000-meter layer of clay and marl which formed more than 35 million years ago.

This project offered the opportunity to validate a method to select and qualify potential CO_2 storage sites and to test various monitoring tools. A monitoring process was set up to check the quality of surface water and groundwater, the ecosystems (plants and animals) as well as the gases from the soil. No particular or abnormal deviations were reported.

MÉTHA TREIL PROJECT, CCU

France

Métha Treil is a methanation project located on a 540-hectare farm in the French department of Loire Atlantique. The facility consists of two digesters, a post-digester and a set-up to capture CO_2. The digesters are mainly fed agricultural inputs originating from solid and liquid manure and silage (70%), intermediate energy crops planted between two main crops (10%) and waste vegetables ("ugly" tomatoes or potatoes). A partnership was created during the covid crisis to use unsold produce as well. The produce is fermented to create gas, made up of methane (60%) and CO_2 (40%), plus a digestate which is then used as high-quality fertilizer, thus returning minerals to the soil. **In this way 2 million m^3 of biogas and 15,000 m^3 of raw digestate are produced each year.** The biomethane is directly injected into the nearest GRDF (French gas network management company) network; it currently makes up 8% of the gas consumption of the town of Machecoul-Saint-Même.

A carbon dioxide capture process was set up to avoid releasing part of the CO_2 in the atmosphere as is the case in traditional methanation systems. Once captured and separated from the methane, the carbon dioxide is compressed, dried, cooled off and liquefied. **It is then transported by truck to partner vegetable producers who use it as an input to boost the growth of their plants, tomatoes in particular. This "feeds" 15 hectares of greenhouses.** For vegetable producers to be able to use the CO_2, it must be 99% pure. In this case, it is 100% pure and is in the process of being approved for the food industry.

EUROPEAN AND GLOBAL PROJECTS

DRAX PROJECT, FROM CHARCOAL TO BIOMASS

United Kingdom

DRAX, located in Yorkshire, is the United Kingdom's largest coal-fired power plant. Once the country's most polluting factory, it now boasts the most ambitious CO_2 emission reduction plan. The power plant started shifting from coal to biomass a decade ago; the plan is to forego coal altogether by the end of 2021. This conversion is part of the United Kingdom's plan to definitely stop producing electricity from coal.

In 2020, four of six units at DRAX burned wood pellets; 80% of the 7.5 million tons of wood burned each year are imported from North America. The transportation represents only a minimal part of the project's carbon footprint. The power plant consumes mainly residues such as branches or tree crowns, which are not used by other industries. While 20% of the feedstock is still provided by trees felled to supply the power plant, DRAX assures it is done as part of forest management, to clear forests of their weakest elements. The two remaining units are due to be replaced by 3.6 GW combined cycle gas turbines and batteries with a storage capacity of 200 MW. A carbon-capture system was also set up to curb the plant's carbon emissions. During COP25 the group stated that its goal was to achieve negative emissions by 2030.

Yet this shift from charcoal to wood biomass is polemical on several counts: deforestation issues, carbon neutrality, impact on North-American forests, the energy required to produce the wood pellets, etc.

Aside from the controversy on the carbon neutrality of the project and the sustainable sourcing of the biomass, DRAX's conversion project has highlighted how difficult it is to supply such large plants with biomass, hence the need to resort to imports for most of the wood biomass used there. **Even though the shift was gradual, the DRAX power plant required 13 million tons of wood in 2018 alone, an amount equivalent to 120% of the United Kingdom's total wood production.**

After its conversion to biomass, the DRAX site began carbon capture in 2019 as part of a BECCS pilot project. The goal is to transport the CO_2 by pipelines to store it in the North Sea.

ARCHER DANIELS MIDLAND (ADM) DECATUR, BECCS

Illinois, United States

The economic activity of the city of Decatur, Illinois, is based on corn production. The two main agribusinesses there are Tate & Lyle and Archer Daniels Midland (ADM), which produce corn syrup, sweeteners and biofuel among others. Between 2011 and 2014, ADM took part in a pilot carbon capture and storage project. Over that period, 1,000 tons of carbon emitted during the corn fermentation process were captured every day, transported by pipeline, and injected into the sandstone under Mount Simon which proved to be a suitable storage zone for this pilot project. The CO_2 is stored in the porous rock formation, beneath a cap formed by three impermeable layers, which prevents CO_2 leakage. **Following the success of the pilot project, the site was once again chosen in 2016 to set up an industrial-scale BECCS project.** The capture process is relatively simple as the fermentation of corn produces CO_2-rich gas. Back in 2014, the IPCC had identified this BECCS project as the most relevant at the time. But according to the most recent assessments, the project captures less CO_2 than initially planned. No leakage or negative impacts have been reported so far. This facility is one of the world's largest BECCS projects.

NORTHERN LIGHTS PROJECT, CCS

Norway

Northern Lights is a carbon capture and storage (CCS) project in the North Sea for the European industry. It is led by the Norwegian government and carried out in partnership with Equinor, Shell and TotalEnergies. **The goal is for industrial activities generating CO_2 near the coastline to be able to exploit the storage zone.** It is up to each company to capture and liquefy CO_2. Northern Lights will then collect the liquefied CO_2 and carry it by boat from an appropriate port such as Zeebrugge or Dunkirk. The fact that the carbon dioxide is collected by boat at intermediate pick-up points makes the collection more flexible and helps extend the transport and storage network. The CO_2 will be stored temporarily at the Naturgassparken terminal, in Øygarden in western Norway. Afterwards, it will be pumped into a 110-km pipeline and transported to the storage area, which is located approximately 2,600m under the Norwegian seabed. Equinor is an expert operator in the field of CCS and has observed no CO_2 leakage in the past 24 years. Operations are due to begin in 2024. **Northern Lights will handle and store up to 1.5 Mt of CO_2 per year, and the plan is to increase its capacity to 5 Mt.** Among the industrial actors that have already shown interest for the project are Air Liquide and ArcelorMittal. An expected 400,000 tons of CO_2 per year will come from the Norcem cement plant, which is owned by Germany's HeidelbergCement. The cement plant will be equipped with capture systems as part of the broader Langskip (Longship, the Viking boat) project, of which Northern Lights is just one aspect. Part of the CO_2 will also come from an industrial plant in Oslo.

CARBFIX PROJECT, STORAGE IN MINERAL FORM AND DACCS

Iceland

Initiated in Iceland in 2007, Carbfix is a carbon sequestration project that uses reaction with basaltic rock formations. Carbonated water is injected at high pressure into deep basaltic layers through injection wells. There, the gas reacts with the calcium and magnesium present in the rock (forced reaction of calcium and magnesium). The carbonates thus obtained remain stable for hundreds of years and can therefore be considered permanently stable. The pilot phase of the project showed that 95% of the CO_2 injected was mineralized within two years. The process requires vast amounts of water. But the water is pumped from and released into the same aquifer, meaning that the process is circular to a certain extent. A demonstration project based on the same principle but using seawater is planned for 2022.

Since 2017, Carbfix has been working together with Climeworks, a Swiss company specialized in the direct air capture (DAC) of CO_2 in the atmosphere. Climeworks is developing a DAC pilot project next to Carbfix's mineralization site, at the Hellisheidi geothermal plant. **The plan supplies the renewable energy necessary to run the DAC operation as well as Carbfix, the carbon storage solution. Following the success of the pilot project, Climeworks and Carbfix have decidedto develop a wider project, which was due to begin in 2021, and which could capture up to 4,000 tons of CO_2 per year.**

The French Water Partnership (FWP) is the only platform for all French water stakeholders, public and private, operating at the international level. For almost 15 years, the FWP has been advocating for water to become a top priority in sustainable development policies. The FWP also facilitates exchanges of know-how between France and other countries. Together, the members of the FWP (states and public bodies, local authorities, NGOs, companies, research and training institutes and qualified experts) develop common messages and communicate them in European and international bodies and networks such as the United Nations, the European Union, and at events such as the Conventions on Climate Change and high-level political forums on Sustainable development goals.

Find out about the FWP's activities and read its publications on its website:

www.partenariat-francais-eau.fr/en/