Energy uses of biomass

Elements of a thermodynamic and systemic analysis

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The climate and geopolitical context are forcing our societies to look at how best to use new energy resources without contributing to the greenhouse effect. However, "greenhouse neutral" does not mean carbon-free. Assessing carbon neutrality must therefore be carried out across the entire processing chain, and the laws of thermodynamics apply at every stage.

In today's energy mix, fossil carbon dominates. And even in a future system, carbon will remain essential for materials, chemicals and energy, just as it is for food. We shall see that it is not so much a question of "decarbonising" the system as of "defossilising" it. Since carbon is a critical resource, we need to encourage the best uses of it and maximise its conversion efficiency.

Energy mix, renewable resources, biomass

In Europe, annual final energy consumption is around 1,640 Mtoe/year, or 19.073 TWh/year[a] (2018 data). Fossil fuels account for 74% of the total, with nuclear power generation and the use of renewable resources-contributing equally to 13% of consumption each, or 216 Mtoe/year (2 512 TWh/year). Biomass uses account for 65% of renewable uses, mainly for electricity/heat cogeneration and agrofuels.

In France, final energy consumption in 2019 was 152 Mtoe. Due to the use of renewable energies and nuclear power, around 50% of European electricity is decarbonised. French electricity is approximately 97% decarbonised in terms of direct emissions.

In France, as in Europe, 90% of carbon-based fossil fuels (coal, gas and oil) are used for heating and transport. **Efforts to reduce fossil fuel consumption should therefore focus** on **these two areas.** Heating needs can be reduced by insulating buildings, and low-temperature needs can be met by solar thermal or thermal machines. On the other hand, although light vehicles (for short and medium distances) and land-based public transport can be electrified, mobility should continue to depend on fuels in sectors where substitution remains difficult (air transport, long-distance land transport excluding rail, maritime transport).

Here we look at how biogenic carbone contributes to the current energy system as the leading renewable energy, and also how it could contribute in the future, particularly in relation to electrical energy. A reminder of thermodynamics (Box 1, p. 52) will help to position the respective contributions of the different resources and vectors.

Biomass and energy: general physics and thermodynamics

Biomass ? A définition

The term "biomass" refers to all living matter or matter derived from living organisms, both plant and animal, present on Earth. In the context of energy, Directives 2003/30/EC, 009/28/EC and 2018/2001 of the European Parliament and of the European Council together under the term biomass "the biodegradable fraction of products, waste and residues of biological origin originating from agriculture, including

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SICET, a biomass power plant in Ospitale di Cadore, in the Veneto mountains in Italy. The plant generates electricity using the steam released by the combustion of plant matter, which drives a turbine connected to an alternator.

plant and animal substances, forestry, related industries, including fisheries and aquaculture, as well as the biodegradable fraction of waste, in particular industrial and municipal waste of biological origin".

Plant biomass is made up of organic matter, water and minerals. It grows in a wide variety of environments and has a wide range of humidity levels, varying from 20% to 95% of the total mass for terrestrial biomass, and up to 99% for aquatic biomass (the typical humidity of a tree in a temperate zone is around 50%) . Production is seasonal in temperate zones, and collection, storage and transport costs are high compared with fossil carbon resources.

The organic part can be summed up as an average molecule with the gross formula $C_6H_9O_4$, containing by mass: 50% carbon, 6% hydrogen and 44% oxygen. The molar ratio of hydrogen to carbon is H/C = 1.5, compared with 2 for most hydrocarbons and 4 for methane. Biomass is therefore a hydrogen-poor resource, making it a poor candidate for the production of gaseous hydrogen.

The high oxygen content of biomass reduces its mass energy density, as oxygen does not contribute to the energy content, unlike carbon and hydrogen. Its moderate calorific value, at 18 to 20 MJ/kg (5 to 5.5 kWh/kg), is 2 to 2.5 times lower than that of liquid, oxygen-free hydrocarbons, at 40 to 45 MJ/kg (11 to 12.5 kWh/kg).

Given the transformations required to produce energy, biomasses are frequently classified according to their moisture content.

1- "**Wet**" biomass contain more than 50% moisture (up to 90% in some cases). These include sugar biomasses, which are the least moist, and other moist, almost liquid biomasses such as animal waste, black liquor from paper mills, and agri-food waste such as fruit peels. Algae and microalgae, whose water content generally exceeds 99.9%, are also included in this category.
2- So-called "**dry**" or "lignocellulosic" biomass are solids containing a maximum of around 50% moisture. They include wood, straw, herbaceous species and energy crops.

Moisture has a direct impact on the way biomass is processed and on the associated products. For example, wet biomass are transformed using low-temperature processes (below 100°C at atmospheric pressure), to avoid using up the energy required to dry the product. They are sometimes in competition for energy or food production. Sugar beet and sugar cane, which essentially produce sugar, are used for food purposes or to produce ethanol by fermentation. An oil plant is used to produce oil, which can then be used for food or fuel. Lignocellulosic biomass, which is relatively dry, can be used in high-temperature processes. It is less subject to competition constraints.

Transport and storage of energy resources and carriers: the advantages of biomass and the influence of mass and volume calorific values

The vast majority of renewable energy sources are flow energies, meaning that they cannot be stored naturally on a long-term basis. They are generally used to produce heat and electricity, which are also difficult to store. These uses also require the development of advanced and often costly means of storing and regulating systems.

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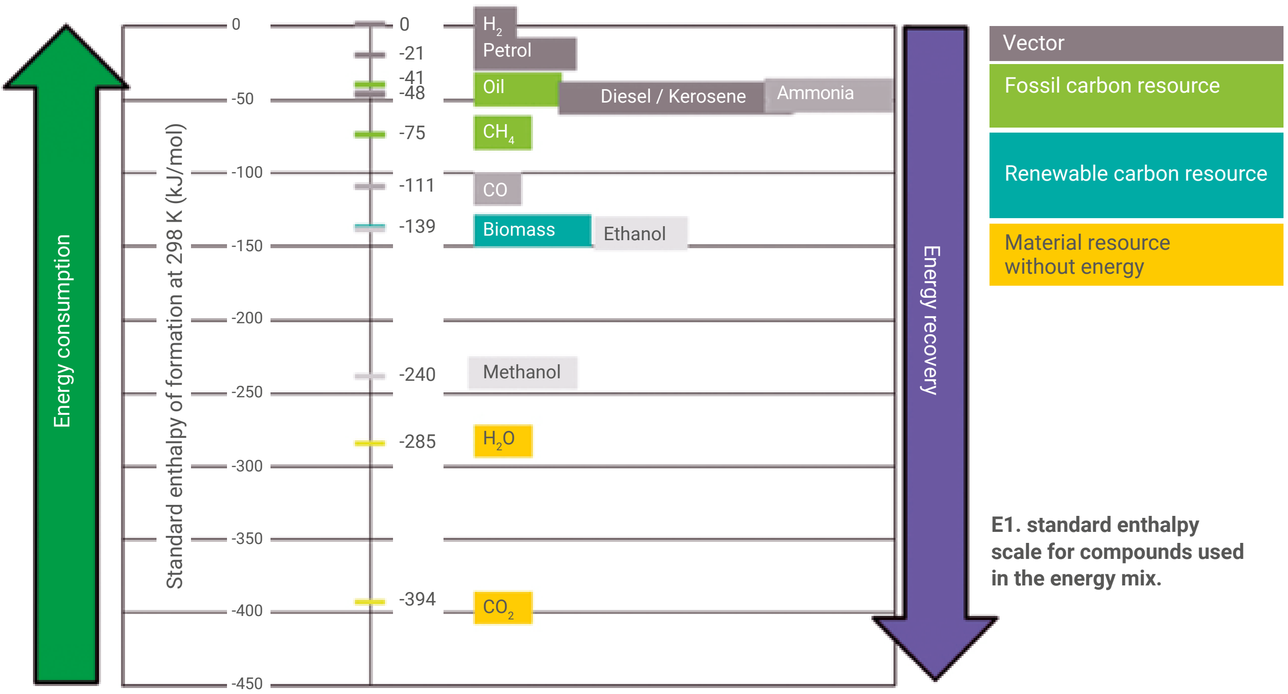
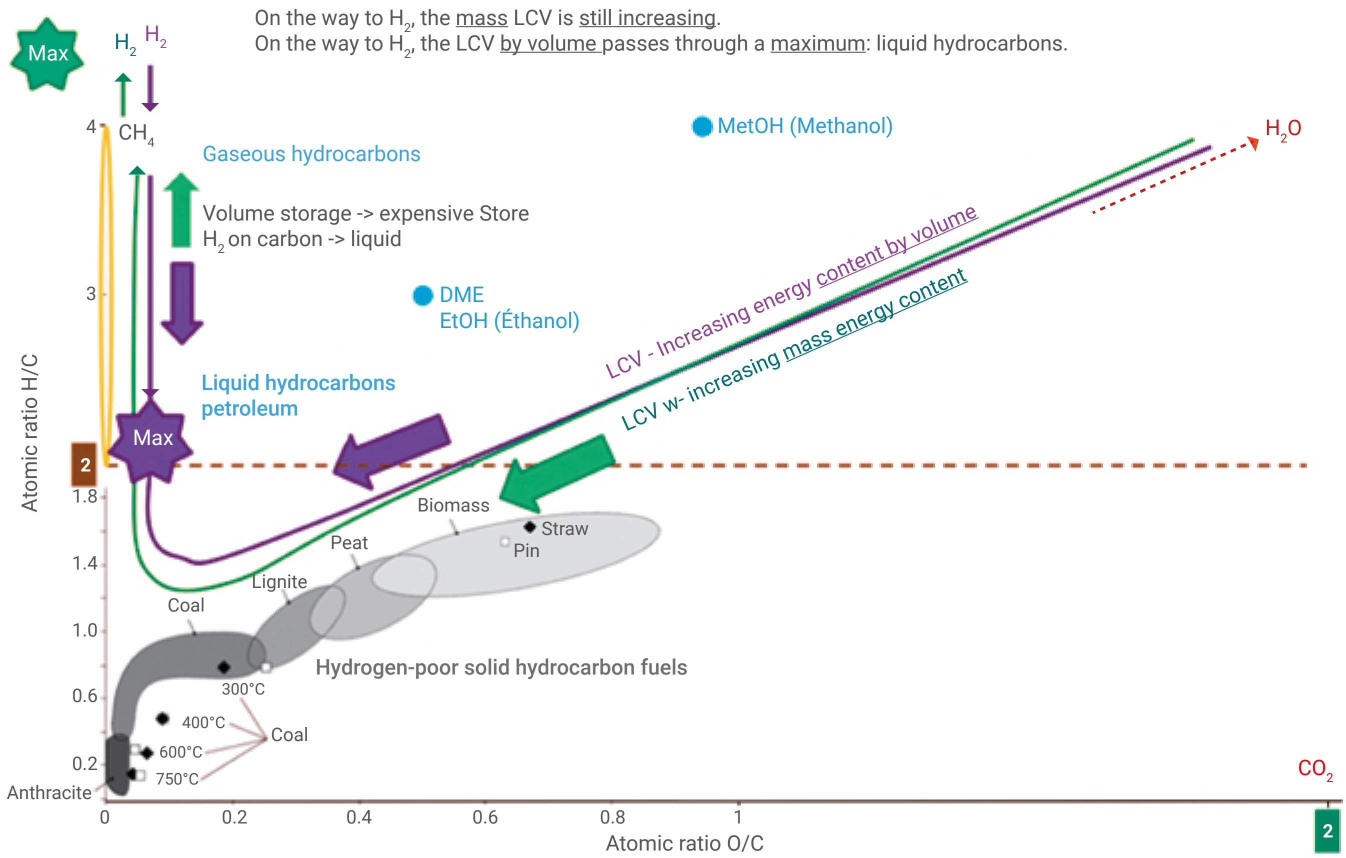
THERMODYNAMICS, CALORIFIC VALUE, STANDARD ENTHALPY OF FORMATION AND CARBON-RELATED ENERGY TRANSFORMATIONS

The net or low calorific value (LCV) of a fuel is equal to the quantity of heat released by the complete combustion of one unit mass of this fuel in air at a pressure of mass of this fuel in air at a pressure of 1.01325×10^5 Pa and at a constant temperature of 0°C [i], with the water formed during combustion remaining in a gaseous state.
Since biomass is a family of fuels with varying compositions and energy contents, it is often time-consuming and tedious to measure the LCV in each individual case. This is why an average value for the LCV of the organic part of a biomass, close to 18 MJ/kg, is generally considered.
The calorific value of a chemical compound is directly related to its standard enthalpy of formation, which is the enthalpy involved in the formation of one mole of this compound from simple, pure bodies taken in the standard state and stable at the temperature T in question.
As we have said, biomass is a mixture of polymers, volatile organics and minerals. However, by considering an average crude formula $C_xH_yO_z$, it is possible to define a standard enthalpy of formation for biomass and calculate it from its LCV.
Figure E1 shows the scale of standard enthalpies of formation of carbon compounds, ammonia, hydrogen and water, expressed in kJ/mol for compounds reduced to one carbon atom, in their crude formula (for biomass, for example, $CH_{1.5}O_{0.66}$). Releasing or consuming energy during a transformation involving these compounds amounts to going up or down this ladder. Producing an energy carrier that is concentrated in energy means moving up the ladder. Combustion involves moving down the ladder, transforming potential energy (calorific value) into another form (thermal, mechanical, electrical, etc.). Combustion produces waste in oxidised form: CO_2 and H_2O, which cannot provide usable energy.
To produce hydrogen, for example, the lower the standard enthalpy of formation, the greater the energy required for production. Conversely, the higher the compound to be burnt (zero maximum for hydrogen), the more exothermic the combustion. Natural fossil fuels, as well as carriers such as petrol and paraffin, are positioned at the top of the scale, as they are naturally concentrated in energy. Biomass, which is less dense in energy because it is partially oxidised, is the lowest carbon resource on the scale, but it is also **the only renewable carbon resource containing energy** (CO_2 is a recyclable carbon source with no energy content). The fossilisation of biomass into oil, gas and coal has had the effect of transforming less dense resources into denser ones, essentially through the loss of oxygen.
The scale in figure E1 shows the order of magnitude of the amount of energy required to produce a dense energy carrier from a resource that is not very dense, or even lacking in energy. For example, producing paraffin from biomass is three to five times more energy-intensive than producing it from oil or CH_4. Similarly, producing a hydrocarbon from biomass requires less energy than from H_2O and CO_2, which are the totally oxidised "energy waste" from biomass. energy waste" from the combustion reaction and contain no energy.

[i] D. Laguerre, "Mesure du pouvoir calorifique des gaz", *Techniques de l'Ingénieur*, r2980, p. 17, Éditions T.I., Paris (2005). doi: 10.51257/a-v2-r2980



E1. standard enthalpy scale for compounds used in the energy mix.



1. Van Krevelen diagram of hydrocarbon solids, liquids and gases, and mass and volume LCV.
Abscissa: molar ratio O/C, ordinate: molar ratio H/C of the organic compound. The evolution of the LCV as a function of the H/C and O/C ratios is shown in green for the mass LCV, and in violet for the volume LCV.

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Thanks to its state as a material and its chemical composition, biomass is the only renewable source of carbon and **the only renewable energy resource in stock.** In addition to its applications in food and materials, its energy applications are varied, from heat carriers to fuels, which are technically easy and inexpensive to store. This makes it possible to absorb transient regimes by simply adjusting reservoir levels, which is not very technological or costly, and is a major advantage over flow energy.

Carbon's ability to bind to four atoms, and in particular to hydrogen, means that organic molecules with a high energy content can be formed. This energy density is sought in terms of both mass and volume. **Fuels have different energy densities, particularly by volume,** depending on whether they are solid, liquid or gaseous. This has a technical and economic impact on the transport and storage chain.

The Van Krevelen diagram shown in Figure 1 positions all the organic molecules and compounds in a space bounded on the abscissa by the maximum value 2 of the O/C ratio, and on the ordinate by the maximum value 4 of the H/C ratio. It also has the advantage of being able to contain solid, liquid and gaseous organic compounds under normal conditions. On this diagram, the solid compounds, from biomass and its coals to anthracite, are shown in grey, allowingthe evolution of their O/C and H/C ratios to be visualised.

Biomass is rich in oxygen and hydrogen. These two atoms are lost when biomass is fossilised to produce coal. The low proportion of oxygen in coals explains why their LCV by mass is higher than that of biomass. The low proportion of hydrogen has a negative impact on the LCV. In the liquid category, compounds containing oxygen, such as alcohols and ethers, are penalised energetically because of their high oxygen content. Finally, liquid or gaseous hydrocarbons are the most energy-dense organic compounds, since they contain no oxygen. The H/C ratio of liquid alkanes tends towards 2 as the chains lengthen (H/C of pentane: 2.4), while that of gases varies between 2.5 and 4. Their LCV by mass increases with the value of the H/C ratio. Hydrogen, which contains no carbon, has the highest mass LCV. Finally, carbon dioxide and water contain no energy. **In terms of mass, it is therefore preferable to use carriers with the highest H/C ratio.**

Unlike the mass LCV, which increases steadily towards hydrogen, the **volume LCV reaches a maximum**

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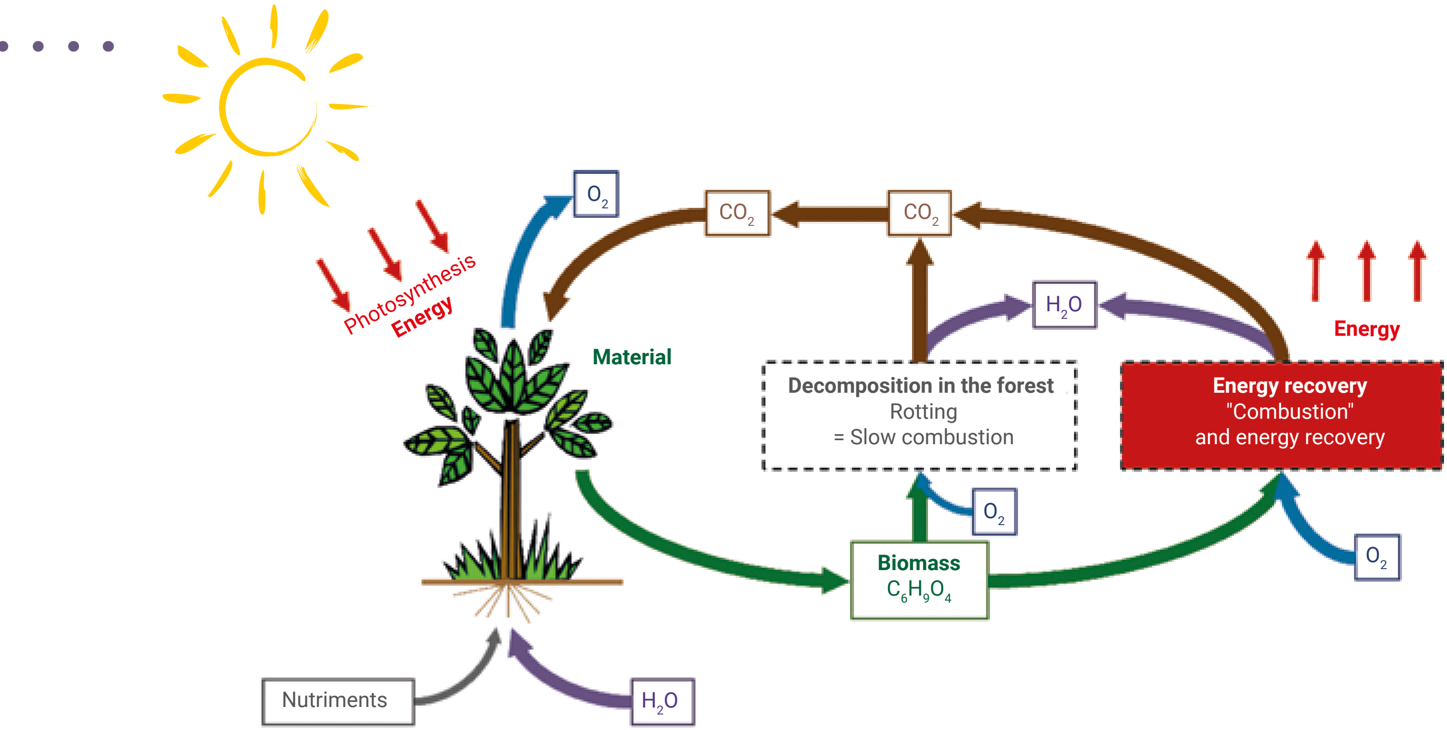

2. Biomass carbon cycle, excluding food and construction.

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for liquid hydrocarbons, at around H/C = 2. Unlike gases, liquids and solids require few technological resources and little energy for transport and storage. Liquids, in particular, have a physical advantage over solids and gases in terms of storage, pumping, injection and operation under pressure. This means significant energy savings throughout the chain, and *ultimately* economic gains.

Closing the carbon cycle: is the use of biomass neutral for the greenhouse effect?

Human activities release into the atmosphere, in the space of a few decades, the carbon accumulated over millions of years in fossil 'resources'. The accumulation of CO_2 in the atmosphere is around 94 million tonnes/day, or an average of 4.5 tonnes per capita of the planet per year, which is also the French average, while the European average is around 6.5.

The question of the neutrality of biomass uses with regard to the greenhouse effect is often raised, without being really clear-cut. From the point of view of uses, it is simply a question of theoretically establishing an input/output balance with a zero accumulation term. In practice, achieving this balance is tricky because it is complex and concerns all ecosystems: soils, above-ground biomass (forests, crops) and aquatic environments. Its analysis is based on the study of the physico-chemical mechanisms of plant growth, soil life and aquatic environments. Studies into direct or indirect land-use change and its impact on carbon stocks include these issues [1]. These aspects are regulated at European level by the Renewable Energy Directive - Recast to 2030 (RED II). It is also important not to harm ecosystems, which include all living species, both plant and animal.

In terms of the CO_2 balance, if we limit ourselves to using only the biomass that has grown during the year, the flows balance out and a steady state is established (fig. 2). The stock of carbon and energy in the form of biomass then remains more or less constant. Ecosystems are therefore both **carbon stocks and environments that help to regulate carbon flows**.

As Figure 3 shows, a young, maintained forest grows faster than an old, unmaintained forest, which reaches equilibrium: as many trees die as are born. This is the case of primary forests, which constitute a large carbon stock but accumulate almost no carbon and which, in the event of deforestation, become CO_2 emitters. The more a forest is maintained or harvested, the more carbon it stores each year, by removing the dead wood and leaving room for young trees to grow. A maintained forest[b] continues to grow and supplies a greater quantity of biomass each year than it produces during its stagnation phase. This increase, in both flow and stock, is linked to the carbon absorption balance from the atmosphere.

This biomass can be left in the forest, where it will eventually rot and be transformed back into CO_2 and H_2O, or it can be extracted and used for human activities (construction, chemicals, energy). But the practices associated with the use of biomass must not remove the carbon contained in these above-ground and underground reservoirs, at the risk of exacerbating the greenhouse effect.

If people are few in number, they will only remove a tiny portion of a forest's biomass, with no impact on its balance. If the harvesting becomes massive, there is a risk of imbalance. on a large scale, we need to invent a management method that respects the balance of the forests to avoid environmental nonsense in terms of CO_2 and for other reasons (biodiversity, soil balance, etc.). In 2015, France adopted a National Biomass Mobilisation Strategy as part of the Energy Transition Law for Green Growth [2].

Renewable energies, biomass resources and complementarities

Current uses in France

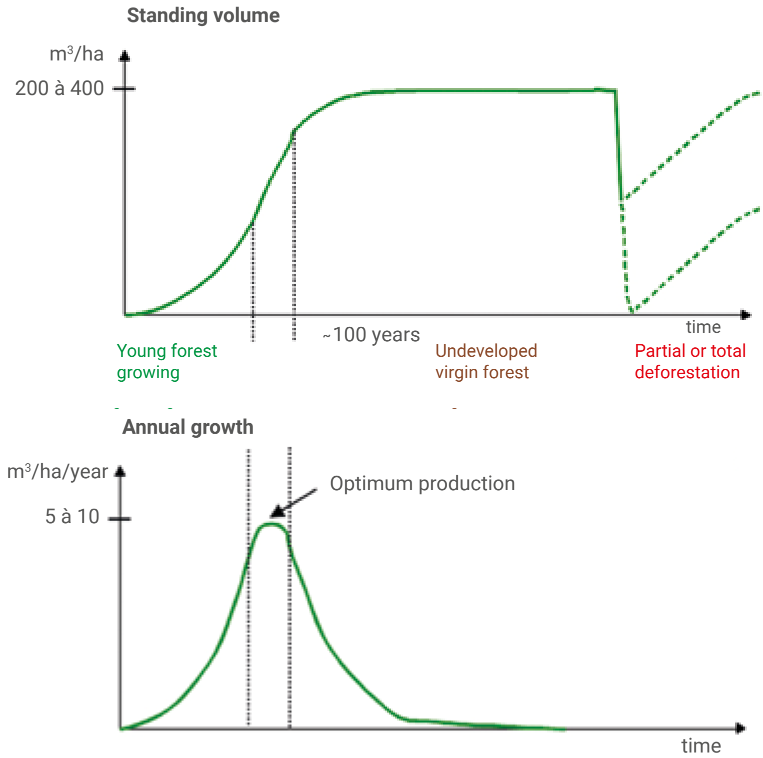
In 2019, final consumption of renewable energy was 26.5 Mtoe/year, i.e. 308 TWh/year[c] and 17% of final consumption. Biomass is the main renewable resource, accounting for 54% (wood for energy 39%, biofuels 12%, biogas 2%). Wood for energy is mainly used for heating, 2/3 of which is used for household wood and 5% for electricity production (see image p. 51). Biogas is used equally for electricity and heat.

The other renewable resources are mainly used to produce electricity (hydro 20%, wind 10%, solar photovoltaic 4%). Non-biomass heat production comes from heat pumps and geothermal energy (10%).

Total consumption of liquid biofuels is 3.2 Mtoe/year, stable over recent years. In terms of LCV, it represents 9% of transport consumption, in line with the EU's 2020 target of 10%. Ethanol, which can be incorporated into petrol, is produced in France mainly from sugar beet; its consumption is 0.7 Mtoe/year [3]. FAME and HVO[d] are the two main biofuels incorporated into road diesel. They are produced from biomass containing fatty acids, such as oilseed crops (rapeseed, palm, soya, etc.), waste oils and animal fats. Their consumption is around 2.5 Mtoe/year.

The biomass resource base cannot meet all our heat, electricity and fuel needs, because it is limited. We therefore need to look at how best to use these resources.

Physical and systemic analysis shows that burning biomass on a massive scale to produce heat is not an optimal solution (it is preferable to insulate buildings), and that it should be reserved for marginal cases of cogeneration of electricity and heat where there is no alternative (isolated mountain sites, for example). buildings). There are other technological solutions for producing heat and electricity, and combustion does not allow carbon to be recovered for use as a material or energy carrier. As far as mobility is concerned, it is possible to cover certain distances with electrification solutions (batteries for medium-sized journeys in light vehicles, hydrogen). The use of liquid fuels such as paraffin remains unavoidable in the case of long-haul, wide-body aviation, due to their energy density by volume, that no other energy carrier can match (particularly hydrogen and batteries). Liquid fuels also remain highly advantageous for long-haul land and sea transport.



3. evolution and different stages in the life of an unexploited forest.

Can we access an additional offer?

To answer this question, we need to take stock of potential biomass resources for energy purposes. This is a tedious and uncertain exercise. The assessments that have been made are scattered and methodologically difficult to implement. There is a growing number of studies which, depending on the assumptions made, still produce widely differing estimates, as shown by the work of Imperial College London and Concawe, Kearney, WWF and Solagro, to name but the most recent.

This assessment will evolve in the future, thanks in particular to the work carried out in France by the Alliance nationale de coordination de la recherche pour l'énergie (ANCRE) and the Programme pluriannuelle de l'énergie, and in Europe by the Joint Research Centre (JRC).

To establish the values below, the following constraints have been considered:

- **no competition with the food industry:** the biomasses in question are not in competition with those of the agri-food industry in terms of land use or end use;
- **no competition with currently exploited biomass:** as this work is not forward-looking, there is no need to discuss possible changes of direction;
- **leave the stock untouched:** use only the annual growth, increase sustainability and reduce the impact on the greenhouse effect.

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The estimate shows an **additional potential of 200 to 300 Mtoe/year in Europe**, compared with 140 Mtoe/year today, with agricultural and forestry resources each contributing around half. For France, the additional potential would be **10 to 30 Mtoe/year**, compared with 14 Mtoe today. The difference between the minimum and maximum figures is based on assumptions about the contribution of forests and the potential reserves of energy crops.

Waste (excluding forests) accounts for only around 10% of biomass. This estimate reinforces an analysis [4] according to which "a country or a region cannot base its economy and its energy policy on waste, because its share is too low in terms of energy and materials. "

With these additional sources, biomass could replace 20% of total final energy consumption, compared with 8.5% today, 30% of fossil carbon-based energy, and 70% of the energy consumed in the transport sector. The situation is therefore mixed: biomass is the resource with the highest current use and potential, and the only renewable carbon-based energy resource. However, it does not have the potential to replace 100% of fossil fuels, or even motor fuels. So we have come to the following conclusion: "Essential but insufficient".

The production of electricity and low-temperature residential heat is currently the largest use of biomass. This production can be based on other substitute sources, such as wind or solar power. To take account of the future scarcity of biomass, its use in the production of electricity and heat should be reduced and reserved for applications for which the use of carbon is not substitutable, such as chemicals or fuels, particularly transport fuels.

The uses of carbon in relation to electricity. Biomass or CO_2 as renewable or recycled carbon sources, combined with hydrogen

The scarcity of carbon from renewable biomass is driving the need to maximise its conversion into a high energy density and higher added value carrier. Recycling CO_2 is also a solution for sustaining the need for non-fossil carbon. Biomass has an **H/C** ratio of **1.5**, whereas **high energy density liquids (diesel, paraffin) have an H/C of 2 and methane an H/C of 4**.

In the case of biomass uses, achieving H/C = 2 necessarily implies a loss in carbon efficiency, unless hydrogen is injected. The use of CO_2, on the other hand, requires the injection of 100% of the hydrogen required.

The combination of biomass and electricity has been studied at the CEA since 2005 [5]. For its part, the electricity transmission system operator RTE is integrating the interactions between electricity and other vectors, including the use of biomass. Multi-criteria analyses have shown that, during the production of synthetic fuels (diesel, kerosene, methane, methanol), the use of biomass in the production of electricity is a significant factor injecting hydrogen can double the biomass-to-fuel carbon yield [6]. For a 200 MW_{LCV} fuel production unit, standard technology produces around 0.5 MWh_{Carb}/MWh_{Bio} at an estimated cost of €1.0 to €1.4/l. For technologies using electrolytic hydrogene injection, conversion increases to 0.8 MWh_{Carb}/MWh_{Bio} with production costs of around €1.8/l. The electricity storage capacity in this case is 0.5 MWh_{elec}/MWh_{Carb}, which corresponds to a net electricity requirement of around 0.4 $MWh_{elec}/MWh_{LCV\text{-}Bio}$. **There is therefore a strong case for injecting hydrogen to maximise carbon efficiency.**

For example, a study carried out in 2019 showed that European biomass could potentially cover the needs of air, sea and part of land transport, provided that the majority of land transport is electrified (50 to 70% of kilometres) and by maximising the conversion of renewable carbon into high LCV fuels [7].

Of course, CO_2 can also be used as a raw material. for the same quantity of fuel product, the energy to be injected in the form of hydrogen is twice that of the most energy-intensive biomass case. In fact, the electrical energy required to produce hydrogen to massively recycle CO_2 into liquid fuels is of the order of 1.4 $MWh_{elec}/MWh_{LCV\text{-}Fuel}$.

To establish orders of magnitude, we can project that converting the quantity of concentrated CO_2 from industrial emissions theoretically recoverable in one year (140 Mt CO_2 in 2020 and 25 Mt CO_2 by 2050[e]) would require hydrogen flows of 19 Mt/year and 3.4 Mt/year respectively. As a reminder, the hydrogen production projections made by RTE for 2035 are 0.63 Mt/year, which lower by a factor of 5 to 30. Hydrocarbon production would be equivalent to total fuel consumption in 2019, starting at 140 $MtCO_2$/year, or to aviation fuel consumption starting at 25 $MtCO_2$/year.

Evaluations based on an electricity-consumption of 45 MWh/t H_2 and on an energy efficiency of 100% of H_2/CO_2 conversion to products (favourable theoretical case), result in an electricity requirement of between 1100 TWh/year in 2020 and 200 TWh/year in 2050. Based on electricity production of 335 TWh/year in 2020, the electricity requirement in 2020 and 2050 would be equivalent to multiplying the nuclear fleet by 3.4 and 1.5 respectively. If we refer to renewable electricity production in 2019[f], this would mean multiplying wind power production by a factor of 35 to 5 or photovoltaic production by a factor of 100 to 15, just to convert CO_2 and produce hydrocarbons.

The analysis of potential deposits and energy balances shows the need to **combine biomass and CO_2 as raw materials**, in order to replace fossil carbon with renewable or recycled carbon in the long term. This also shows that this substitution will have an impact on the **massive production of electricity** .

Conclusion

This summary demonstrates the **strong impact of thermodynamic constraints** on our energy systems. **These constraints are physical rather than technological in nature,** and there is no single ideal solution to carbon defossilisation. In a system that takes account of physical and thermodynamic constraints, solutions will probably emerge that combine

sobriety (reduced consumption) and **energy efficiency** (reduced consumption for the same service rendered).

By its very nature, biomass is the only renewable stock energy containing carbon. Although its LCV is lower than that of fossil fuels, it contributes to the energy mix, and could see its share increase significantly if its exploitation is organised sensibly.

Carbon resources and energy vectors are often the most advantageous, given their density, energy content and properties adapted to existing infrastructures (transport and storage). Faced with a limited supply of renewable energy/carbon, it is necessary to promote the best practices and the best uses of biomass, giving priority to those where substitution by other renewable or decarbonised sources is not possible. This means promoting transformation processes that maximise the conversion of carbon into a concentrated carbon carrier. In other words, we need to avoid burning the biomass and ultimately generate heat and CO_2, when alternative production methods exist.

As nature has not done any better than hydrocarbons in terms of energy density (excluding nuclear), carbon is a good way of storing hydrogen. This leads us to consider decarbonised electrolytic hydrogen and carbon sources as intermediates towards carbon-based chemical products and fuel carriers. Throughout the chain (extraction, transformation, storage and transport), liquid carriers are highly advantageous from a physical point of view, but also from a technological (engines) or infrastructures (storage and transport) point of view.

Second-generation biofuels have the greatest potential, particularly for aviation and potentially for maritime and land-based applications. They have advantages in terms of CO_2 emissions and the reduction of local emissions. For reasons of carbon resources, the use of recycled carbon from CO_2 should be considered, with the constraints associated with its capture in large quantities and the massive production of electricity. ▮

“We need to avoid burning the biomass and ultimately generate heat and CO_2”

(a) The International Energy Agency standard defines the energy content of toe - tonne of oil equivalent - as: 1 toe = 41.868 GJ, 1 Mtoe = 11.630 TWh. A 900 MW power station produces 0.7 Mtoe/year.

(b) The notion of good maintenance is rather dangerous. We are talking here about good maintenance in the sense of respecting a balance, diversity and an ecosystem, not in the sense of intensive industrial exploitation that does not respect the environment.

(c) Figures for 2020 and 2021 are affected by the health crisis.

(d) Fatty acid methyl esters (FAME) are derived from vegetable oils (VOME). Hydrogenated vegetable oils (HVO) are similar to synthetic diesel. The original resource is the same, but FAMEs are produced by esterification, whereas HVOs are produced by hydrogenation.

(e) According to the projections of the National Low-Carbon Strategy revised in July 2022 (https://cutt.ly/snbc).

(f) Wind power generation: 32.3 TWh/year in 2019, i.e. 2.8 Mtoe/year. Photovoltaic electricity production: 11.4 TWh/year in 2019, i.e. 1 Mtoe/year.

1• https://cutt.ly/europa-commission-presscorner

2• https://fr.wikipedia.org/wiki/Stratégie_nationale_de_mobilisation_de_la_biomasse

3• https://cutt.ly/ifp-biocarburants-2020

4• Déclaration de Kjel Anderson (Svebio – Bioressources Suède), lors du workshop "Where will we get our biojet ?" de la conférence Biomasse EUBCE de Lisbonne en 2019.

5• J. M. Seiler *et al.*, "Sc-BtL routes for massive biofuel production", presenté au 8th World Congress of Chemical Engineering: Incorporating the 59th Canadian Chemical Engineering Conference and the 24th Interamerican Congress of Chemical Engineering (2009).

6• E. Peduzzi *et al.*, "Thermo-economic analysis and multi-objective optimisation of lignocellulosic biomass conversion to Fischer–Tropsch fuels", *Sustain. Energy Fuels*, **2** (2018) 1069–1084. doi: 10.1039/C7SE00468K.

7• G. Boissonnet, "Coupling electricity and biomass to biofuels increases performances in mobility. An overview in Europe (1BP.1)", 27th *European Biomass Conference & Exhibition EUBCE*, Lisbonne (mai 2019).