Which biomass resources should be used to obtain a sustainable energy system?

Biomass is the leading renewable energy in the world today. Moreover, the introduction of biomass into energy systems presents certain advantages as far as reducing greenhouse gas emissions is concerned. However, its mobilization still presents many challenges relative to the competition between uses and the management of local natural resources (e.g. water, soil and biodiversity). Therefore, the technologies involved should be structured so that this resource can be developed to be truly sustainable.

Whereas the 20th century saw oil grow to be the principal source of energy, the 21st century is expected to bring a new energy mix including a large proportion of renewable energies, with bioenergies occupying a place of choice.

The term "bioenergies" applies to all energies produced from biomass, composed of all living organisms (micro-organisms, plants and animals) found on land or in the sea.

Ever since mankind first discovered fire, biomass has been used as a source of energy. Firewood and organic waste still figure prominently as heat sources in certain less developed countries (Table 1).

Only in the last few decades have more modern, efficient biomass conversion technologies been developed. Recurrent episodes of spiking oil prices and a desire to reduce dependence on fossil fuels gave rise to the first innovations in the 20th century, such as vehicles fueled by wood gas during World War II or those running on vegetable oil, first used as a motor fuel by Rudolf Diesel in the late 19th century.

The movement has picked up momentum now that oil has entered its final decades of supremacy, with oil prices periodically reaching record highs, and now that climate change has become a global environmental concern.

Key strong points

Biomass is the world's leading renewable energy, ranking ahead of hydroelectric, solar and wind power. Biomass, especially plant-based biomass, offers an immutable

Table 1

Commercial uses of wood and breakdown of conventional energy uses in 2007

	Roundwood Harv. 2007 (Mm^3)	Incl. sawn wood (Mm^3)	Incl. wood for paper (Mm^3)	Incl. wood for board (Mm^3)	Incl. wood for fuel (Mm^3)	Fuelwood
World	3.591	1.007	354	266	1.886	53%
Incl. Europe	729	330	102	84	153	21%
Incl. North America	640	386	149	56	54	8%
Incl. South America	366	82	36	15	194	53%
Incl. Asia	1.027	150	55	105	787	77%
Incl. Africa	672	25	6	3	603	90%

Source: FAOSTAT

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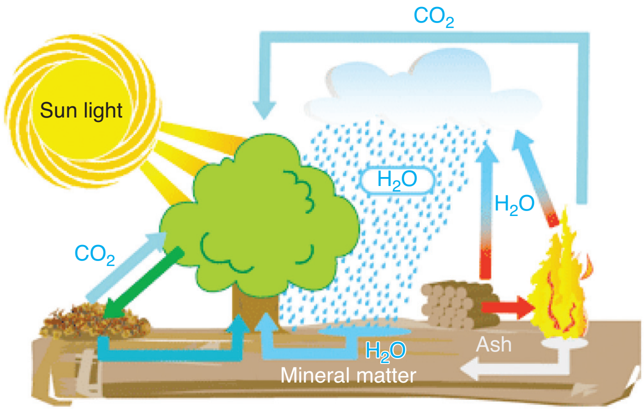
advantage: plants use photosynthesis to grow. It uses solar energy to break down moisture in its cells and CO_2 from the atmosphere to transform them into plant matter, mostly carbon hydrates and including cellulose.

Thanks to this process, the CO_2 emitted to the atmosphere during the conversion of plant matter to energy can be considered neutral from the carbon footprint standpoint.

During the combustion of a gasoline-bioethanol blend in an engine, only the fossil CO_2 (and other gases implicated in global warming, such as CH_4 and N_2O) is counted as contributing to the greenhouse effect along the entire chain, e.g. during the stages of production and gasoline combustion and the cultivation of the plants used (e.g. production of fertilizer and use of farm equipment). Using a biofuel obtained from biomass derived 100% from a plant requiring few agricultural inputs can very significantly reduce one's contribution to the greenhouse effect.



A broad array of resources and energy extraction technologies

Energy can be extracted from different biomass resources that break down into four main families.

Dedicated food crops

Agricultural crops were originally used to develop first-generation biofuels (e.g. VOME[1] and ethanol) in Europe (Figure 1). In parallel to the search for cleaner motor fuels to replace fossil fuels, the growers of most of these crops were seeking new outlets, because the food markets were offering poor returns. Rapeseed oil, sugar beet and some cereals took up a positioning on these new energy segments. Grain processing yielded co-products like dried grain residues (cereals) as well as oilseed press cake (oilseed-bearing crops), which is valued in the animal feed business, particularly in many countries like France that run a feed deficit and import American soybean cake. Incentive policies and measures targeting producers and distributors were implemented, enabling further development of ethanol and biodiesel technologies. This model was also adopted in the United States, where ethanol is produced from corn and biodiesel from soybeans. In Asia a biodiesel market from palm oil has developed in response to growing demand for biodiesel in Europe. In this way, it capitalized on a resource in full boom, an expansion initially driven by the food sector (Table 2). However, these technologies have come up against serious controversy and seeing certain limits to their continued growth with curbed resource availability, the emergence of competition between uses, the impact on commodities markets and the increasing pressure to reduce fossil GHG emissions.

Table 2

Crops mobilized for energy purposes versus total production in 2007

	Total harvest 2007 (Mt)	% dedicated to bioenergies 2007
Wheat	606	0.3%
Incl. EU	*120*	*1%*
Corn	792	13%
Incl. USA	*331*	*20%*
Rape-Sunflower	77	17%
Incl. EU	*23*	*51%*
Soybean	221	1%
Incl. South America	*114*	*2%*
Palm oil	193	0.2%
Incl. Asia	*165*	*0.3%*
Sugar beet	247	4%
Incl. EU	*115*	*8%*
Sugar cane	1.591	15%
Incl. South America	*641*	*37%*

Source: FAOSTAT, FAPRI

Ethanol production from sugar cane – broadly developed in Brazil, which pioneered and long remained the world leader in ethanol production – remains one of the most efficient technologies in terms of energy and environmental performance, provided that the sugar cane is cultivated on land that was originally farmland.

New oilseed resources under development

Two technologies for producing diesel replacement fuels are potentially on the market: one relies on vegetable oil methyl esters (VOME) and the other on hydrotreated vegetable oils (HVO). The latter has an extra advantage:

(1) VOME: Vegetable Oil Methyl Ester

it can be blended with kerosene to make aviation fuels. Certain oilseed-bearing plant species, previously little used, are now under study with a view to limiting the constraints associated with the competition between uses. Most of these species, which include the jatropha, camelina and cynara, grow well in weather conditions ranging from the Mediterranean climate to semi-arid. Large-scale programs for the cultivation of these crops, especially jatropha, are underway, mostly in Asia and Central Africa. Flight tests on jet biofuels containing some jatropha oil and/or hydroprocessed camelina have recently been carried out by various airlines.

One of the aviation biofuels tested is a blend containing a new algal oil extracted from cultured microalgae. This is a new technology, still in the exploratory stages, for producing oil from biomass from aquatic and not terrestrial species. The microalgae are selected to reproduce very quickly, then produce and store lipids in their single cell under controlled growing conditions. Depending on the species, microalgae can be grown in an open pond or a closed tank, in fresh or saline water; they require sunlight, carbon dioxide and a few vital nutrients such as nitrogen and phosphorus in order to grow, like higher-order plants, by means of photosynthesis. Systems of this type could produce 30-80 tons of dry matter per hectare a year for an oil output of 8-35 t/ha/yr, a yield 25 times greater than obtained for rapeseed. However, there is no feedback yet from operations at industrial scale and the stages of cultivation, harvesting and oil extraction still pose substantial technical and economic challenges that must be overcome before the production of algal oil for biofuels can be commercially viable.

By-products and organic waste from agricultural, forestry, industrial and urban activities

Large quantities of non-recycled by-products and organic waste can potentially be used in a waste-to-energy system. A large percentage of waste incinerators in France today recover energy in the form of heat nevertheless, the percentage of biomass in incinerator feedstock remains variable and small. Some urban authorities, industries and farmers have opted to use methanization to recover energy from the fermentable fraction of their organic waste. Green waste, livestock farming effluents, dairy residues and other types of agribusiness waste can be used to produce biogas for the generation of heat, electricity and motor fuels for fleets of dedicated vehicles.

Other by-products containing less moisture (e.g. sawmill waste, forestry residues and surplus straw) can be conditioned to fuel boilers ranging from domestic to collective/industrial size. In 2006, 7.4 and 2 million tons oil equivalent (Mtoe), respectively, of heat were generated ex-biomass in these sectors in France, mostly from wood. To meet the 2020 targets set by France's Grenelle Environment Forum, the production of heat from biomass for collective and industrial heating purposes will have to increase by a factor of 4. In addition, output at cogeneration plants using biomass will have to grow substantially to reach nearly 4 Mtoe of heat and electricity by 2020. National and local measuring systems already exist or are in the works (e.g. calls for bids by the French energy regulation commission; the Fonds Chaleur renewable heat fund run by the French Agency for the Environment and Energy Management (ADEME); the revision of electricity purchase rates, etc.).

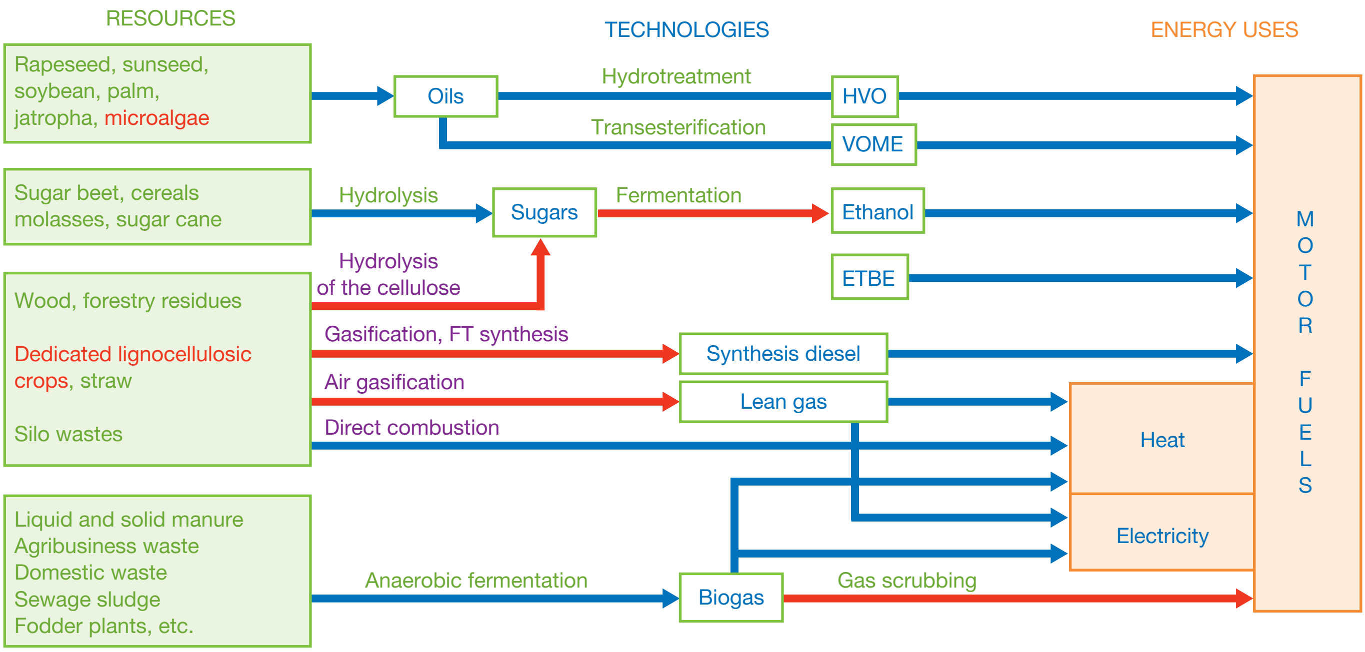
If available by the target date, agricultural and forestry by-products may also contribute to the production of second-generation biofuels. Currently the object of R&D at pilot scale, these new solutions are able to produce ethanol from cellulose, which makes up the cell walls of biomass, or synthesis diesel by gasifying the entire biomass (Figure 1). At present, these processes obtain comparable energy efficiencies. Given the ambitious targets set by the European Commission and at national level pertaining to the mobilization of biomass to produce heat, electricity and biofuels, dedicated energy resources will have to be made available to facilitate the supply of future installations.

New dedicated lignocellulosic energy crops

In response to increasing demand and in an effort to determine how large quantities of biomass might be supplied to motor fuel production units, a number of species have been selected for their high biomass productivity and relatively low input requirements. These species may be annual cultures already used in existing culture systems, such as whole-plant triticale, which is a hardy hybrid of wheat and rye with high-growing, stiff stems, or a variety of corn or fiber sorghum offering high biomass productivity, cultivated specifically. Experimental fields planted with other, less-well-known perennial crops are under study to identify suitable technical routes, determine how to integrate them into agricultural systems and evaluate their impacts on the environment and existing ecosystems. Among these crops are miscanthus, switchgrass and giant reed, which present two particularities. First of all, their yields range from 12 to 25 tons of dry matter per hectare, depending on the growing conditions. Secondly, the same plant can be harvested annually for a period of at least ten years. A system like this requires minimal maintenance (weed control and the addition of nutrients to the soil, if needed).

Which biomass resources should be used to obtain a sustainable energy system?

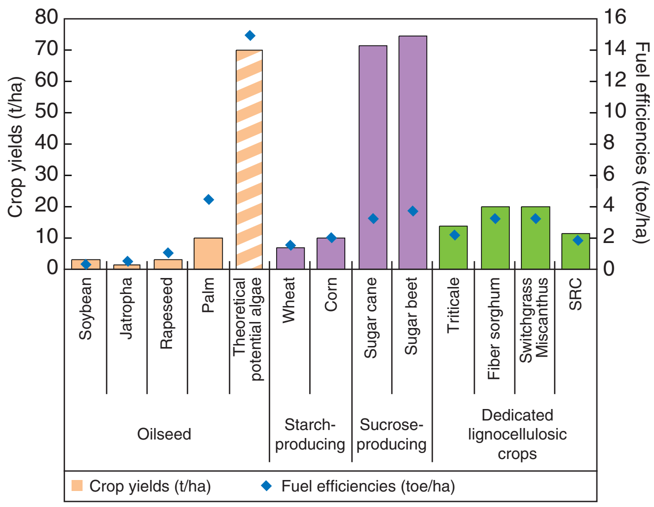
Fig. 1 - Technologies for recovering energy from biomass



Source: IFP

Among the perennial species, growing trees in short rotation coppices (SRC) is also under experimentation. For the most part, broadleaves species, such as the poplar, willow and eucalyptus, are preferred; more recently, the black locust has also come under study. These trees spread by throwing out shoots and can offer high productivity (Figure 2), harvested at intervals of seven years or, for the shortest rotations, only three years.

Fig. 2 - Agricultural yields and conversion efficiencies for various biomass resources



Source: IFP

Although it seems that the energy extracted from by-products and waste can supply energy technologies in the short run, various other types of biomass are under study to ensure the long-term viability of existing bioenergy solutions and develop new and potentially more sustainable pathways. While this type of biomass represents potentially large feedstock reserves, its mobilization is subject to many limits and represents many challenges.

Potentially large reserves but mobilization accompanied by various challenges

The stock of terrestrial biomass is estimated at about 2,000 billion tons (Gt). If the goal is to put biomass for energy to a "sustainable" use, then this stock should not be exploited. The annual flow of biomass output should be used instead. According to José Goldenberg (2000), 13 of the 220 Gt/yr of biomass produced worldwide could serve to produce energy (Table 3). Today, 27% of this potential is consumed, including 22% for wood energy. The bulk of the remaining flow of biomass potentially available for energy is composed of products from under-exploited forests, agricultural surpluses and by-products, and residues from the woodworking industry. Moreover, although most of the industrialized countries can only develop their agricultural land areas to a limited extent, some regions still have significant potential in terms of arable land. The differences in the soil climate conditions

Table 3

Potential quantities of lignocellulosic biomass that could be mobilized for energy and % of consumption of replacement motor fuels

	Total biomass potentially available for energy (Gt DM)	Medium-term potentiel, by-products* (Gt DM)	Medium-term potentiel, dedicated crops** (Gt DM)	% of motor fuels demand by 2030 (depending on region)
World	13	2.3 – 2.8	1.4 – 1.70	19 to 23
including Europe and North America		0.3 – 0.6	0.5 – 0.75	10 to 15
including rest of world		2.0 – 2.2	0.9 – 0.95	3 to 100

*Agricultural and forestry by-products. **Depending on scenarios for planting on potentially available land

Source: various sources

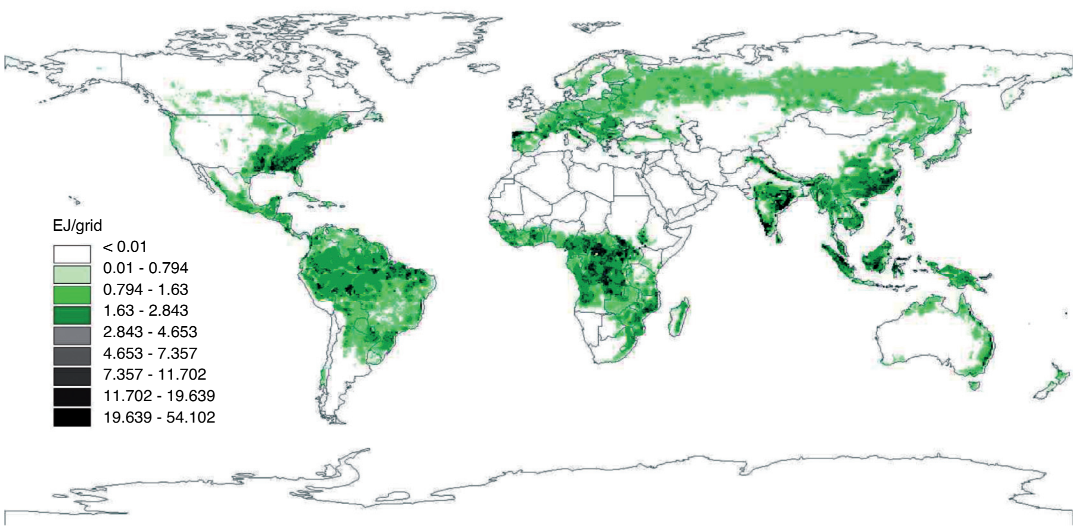
to be found in different parts of the world imply inequalities in terms of access to the resource (Figure 3).

In Asia today, there is little land potentially available for planting new energy crops in the short term. On the other hand, its potential reserves of forestry and agricultural by-products are significant. More than 40 Mtoe could be mobilized in the short term, especially in China and India (USAID, 2009). In Africa and South America, the forest is able to supply large volumes of resources: 250 to 600 Mtoe, respectively (Berndes, 2003). Some countries in Africa (e.g. Republic of Congo and Mozambique) enjoy conditions that are favorable for bringing under-exploited land into rainfed culture. Finally, some CIS countries, such as Russia, Ukraine or Belarus, present a high potential in terms of unexploited resources and, thanks to improved productivity, could set aside large areas of arable land particularly well-suited to dedicated energy crops.

In some geographic regions, such as the European Union and North America, the theoretical availability of wood resources and agricultural residues is high, but their mobilization remains subject to constraints that will have to be overcome to enable a broader development of supply in the short term. By-product resources are often geographically dispersed or, in the case of forestry resources, physically hard to reach due to topographical constraints (steep slopes) or a lack of infrastructure (e.g. paths, roads, trails, storage sites and harvesting equipment). According to Cemagref, a French agricultural and environmental engineering institute, natural constraints on access to resources in France reduce its wood energy potential by 11%, which corresponds to a medium-term potential of about 8 million tons of dry matter (Mt DM). Energy may only be generated from cereal straw stocks not used by livestock farming activities or in plains areas dedicated to cereal production. This brings the cereal straw resources available for energy in France down from 22 Mt DM of straw produced/year to 4 Mt DM.

The forestry industry in France and other European countries also features a large proportion of forestry

Fig. 3 - Aggregate production of biomass for bioenergies between 2000 and 2011, in EJ/grid.



Source: IIASA, 2006

land that is privately owned. As a result, a systematic approach to forestry resource management is not possible; owners must give their consent to supply. Similarly, farm and forestry businesses must agree to have their land planted with perennial cultures, i.e. exclusively occupied by energy crops for more than ten years. In France, this type of culture, experimental for the most part, occupies a few thousand hectares. Despite the difficulty of evaluating the impact of this constraint on resource availability, an evaluation is necessary to provide a basis for possible incentive measures.

A certain amount of land pressure may develop if the demand for energy crops increases sharply. However, since perennial crops are less demanding in terms of soil quality, so-called "marginal" land can be used at the outset (e.g. set-aside land, disused industrial land and other types of land that cannot be used to grow food crops).

A priori, the cultivation of microalgae to produce oil, biomass, cellulose or hydrogen would be free from most of these constraints: algae are cultured in photobioreactors that do not have to be located on agricultural or forestry land. On one hand, algae can reach potentially higher levels of productivity than terrestrial plants. On the other, these industrial installations require dedicated land areas that cover several hundred hectares and must be close to sources of light, heat, water and/or CO_2 (Figure 4).

These possible solutions are still very much at the exploratory stage. The technologies involved are currently suitable for adding further value to high-value products and do not transpose directly to energy production in terms of energy balances and economic profitability.

Among the alternative resources, biomass can be expected to make a substantial contribution in the area of energy

Fig. 4 - Examples of open and closed microalgal culture reactors

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production. However, the environmental sustainability of this technology depends on following a number of rules in producing and extracting energy from this resource.

Eco-friendly resources, heavily dependent on good practices

These technologies are intended to reduce greenhouse gas (GHG) emissions while respecting natural resources. Yet it must be ascertained that their implementation does not induce adverse impacts on the climate or on the environment at large. The environmental benefits of first-generation biofuels have been questioned. At European level, eligibility conditions have been introduced for bioenergies based on their GHG balance as well as their other environmental, social and economic impacts. Article 17 of Directive 2009/28/EC of the European Parliament and of the Council sets forth the sustainability criteria applicable to biofuels and bioliquids. In particular, it sets minimum levels for the reduction of GHG emissions to be imposed on the fossil technologies. It also lists the types of land where biomass cannot be produced (e.g. areas of high biodiversity value, high-carbon-stock land, peatland and so forth). Certain specifics of these criteria have yet to be determined, especially concerning how local resources and imported products are to be tracked and accounted for. A few impact-minimizing precautions of a general nature may already be mentioned, knowing that most of these precautions are under study to determine their advisability.

The impacts assigned to recovered agricultural and forestry by-products or waste (e.g. straw, forestry residues) are low, because they are mostly induced by the product that is being commercially exploited (e.g. grain, timber and industry wood). Straw and forestry residues also play an important role in maintaining the organic matter content in the soil, especially in areas in which the land has been depleted by overintensive farming systems. The extent to which this type of resource can be mobilized depends on the conditions and requirements of the local environment.

The same practices are used to grow food crops and conventional crops for first-generation biofuels. Improving productivity is a priority in both of these activities, but since appearance and comestibility are not required of harvested energy crops, it is not always necessary to apply crop protection products. The level of the environmental impacts associated with the cultivation of energy crops (or any other type of dedicated culture) will mostly depend on the type of soil involved and the level of impact generated by the activity being replaced. For instance, planting a crop requiring heavy inputs on soil originally occupied by a young growing forest or a meadow with vegetation cover all year round, will yield a negative GHG balance.

Dedicated perennial lignocellulosic cultures are more economical than annual cultures which, in rotation, require several operations a year (e.g. soil preparation, sowing, weed control, fertilization, application of crop protection products and harvesting). Crops like miscanthus, switchgrass or SRC, which have a life span of more ten years, only require a few planting operations in Year one and Year two. These crops develop extensive root systems, which can potentially help prevent nitrates from leaching into the groundwater and streams. On the other hand, some of them are likely to consume large quantities of water. It may be that growing certain crops should be banned in zones subject to recurrent water deficits.

Finally, while microalgae does not have to cultured on agricultural or forestry land areas, the associated water demand and pressure on local resources remain to be established. *A priori*, it would seem that the risk of direct pollution to the three environmental compartments (water, air and soil) is lower than for terrestrial biomass. On the other hand, biodiversity would be exposed to the risks of the dissemination of species and possible contaminants.

Biomass is positioned as a serious alternative energy resource with substantial potential. The conditions of its development should be controlled to maximize the benefit of its sustainable characteristics.

The efforts being made in this respect can be measured in the number of current R&D projects undertaken to develop new technology pathways and also in the implementation of multi-criteria methodologies to assess environmental, social and economic impacts. It is also visible in various directives and incentive measures – such as the REN Directive and Energy/Climate Package (EU) as well as the Grenelle environmental targets, the *Grand Emprunt* national loan plan and the competitiveness clusters (France) – that allow one to imagine that several of these technologies will take off within time frames compatible with the targets set.

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