Biomass in transition; a role for biomass in replacing fossil fuels and feedstock in the future?

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May 2019

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1. Introduction

Modern bioenergy (excluding the traditional use of biomass) was responsible for half of all renewable energy consumed in 2017 [1]. It provided four times the contribution of solar photovoltaic (PV) and wind combined. However, the use of biomass for energy purposes is under pressure.

Where the price of PV- and wind energy has decreased dramatically, the price of bioenergy roughly remained at the same level. Besides, there is a growing debate on the sustainability of biomass as a source of energy and feedstock. The use of biomass is often associated with deforestation, loss of biodiversity, pollution caused by large scale agriculture and the displacement of food crops by energy crops. This raises the question whether biomass should still play a role in the energy transition and if so, what that role could be.

2. Aims of this essay

This essay will discuss the possible role for biomass in a transition towards a fossil-free economy in the future.

It describes the nature and characteristics of biomass and summarises the technologies for the conversion of biomass into fuels, chemicals, heat and electricity. A comparison will be made between price trends for bioenergy and alternatives such as solar and wind energy. Attention will be paid to the public debate on the sustainability and the perceived disadvantages of the use of biomass.

In the second part of this essay, the need for biomass as a transition feedstock will be investigated. Besides, a number of fossil feedstock applications will be selected that will be not be easy to electrify in the near future. For these applications, the use of biomass will be compared to alternatives. Attention will be paid to the technical possibilities, time to market and economic viability. This will lead to a conclusion which biomass options will be necessary and viable in the future and what should be done in terms of policy measures and technology development to encourage and implement these options.

3. Conceptual framework.

In this essay, the following questions will be addressed:

- What is biomass and what is its role in the current role of biomass in the energy system?
- What are the price trends for biomass compared to alternatives?
- What is the public perception on the use of biomass?
- What are the opportunities and threats for the use of biomass in a future energy system?
- What could be the role of biomass as a feedstock for chemical industries?
- What could be the role of biomass for aviation and maritime shipping?
- What policy measures are needed to stimulate the use of biomass for the selected options?

4. An introduction to biomass and bioenergy

According to the European Energy Directive, biomass is defined as follows [2]:

'biomass' means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste;'

In practice, this implies that biomass is all material originating from plants and animals, that can be used to produce energy, fuels, chemicals and materials such as plastics, in order to replace fossil fuels.

Biomass mainly consists of molecules (carbohydrates) which are originally produced by plants from carbon dioxide (CO_2) and water. Biomass can be a renewable source of energy when the harvested plants or trees are replaced by new ones. When the biomass or bio-based products are burnt, the hydrocarbons are converted into CO_2 and water. The newly planted crops will take up the same amount of CO_2 and thus, the carbon cycle is closed and there is no net CO_2-emission. For this reason, energy from biomass (bio energy) is often considered to be climate neutral by legislative bodies.

The International Energy Agency (IEA) distinguishes traditional bioenergy from modern bioenergy. Traditional bioenergy is the small scale use of biomass for cooking and heating in developing countries. Biomass like wood, charcoal and animal dung is used in open fires or simple inefficient stoves, causing deforestation, pollution and health problems. The energy efficiency generally amounts 5 to 15% [1]. Modern bioenergy includes the use of biomass on an industrial scale, with a high energy efficiency and sufficient flue gas cleaning. The use of the word 'biomass' or 'bioenergy' in this document always refers to the modern use of biomass on an industrial scale.

Today, biomass is mainly used for two energy applications:

- The generation of heat and power;
- The production of biofuels, mainly bioethanol and biodiesel.

Heat and power can be generated by burning dry biomass such as wood pellets in a boiler or by co-firing it in a coal fired power plant. Wet biomass, like manure, organic waste or sludge, can be converted into biogas in ananaerobic digester. The gas produced can be used for heating or power generation in a CHP. Bioethanol is generally produced by fermentation from cane- or beet sugar or sugars made from corn- or wheat starch. Biodiesel is in most cases produced from either vegetable oil or used cooking oil (UCO) in a catalytic process. The conversion processes mentioned are all proven technologies.

Figure 1 and 2 illustrate that bioenergy production has grown strongly since the late 1990's. This was stimulated by government policies, focussing on a more sustainable energy production and less dependency on fossil fuels. These policies include subsidies, feed-in tariffs and obligations to blend biofuels with fossil fuels up to a certain percentage (blending obligation). Figure 3 shows the importance of bioenergy in the production of renewable energy today. Biomass is the major renewable energy source.

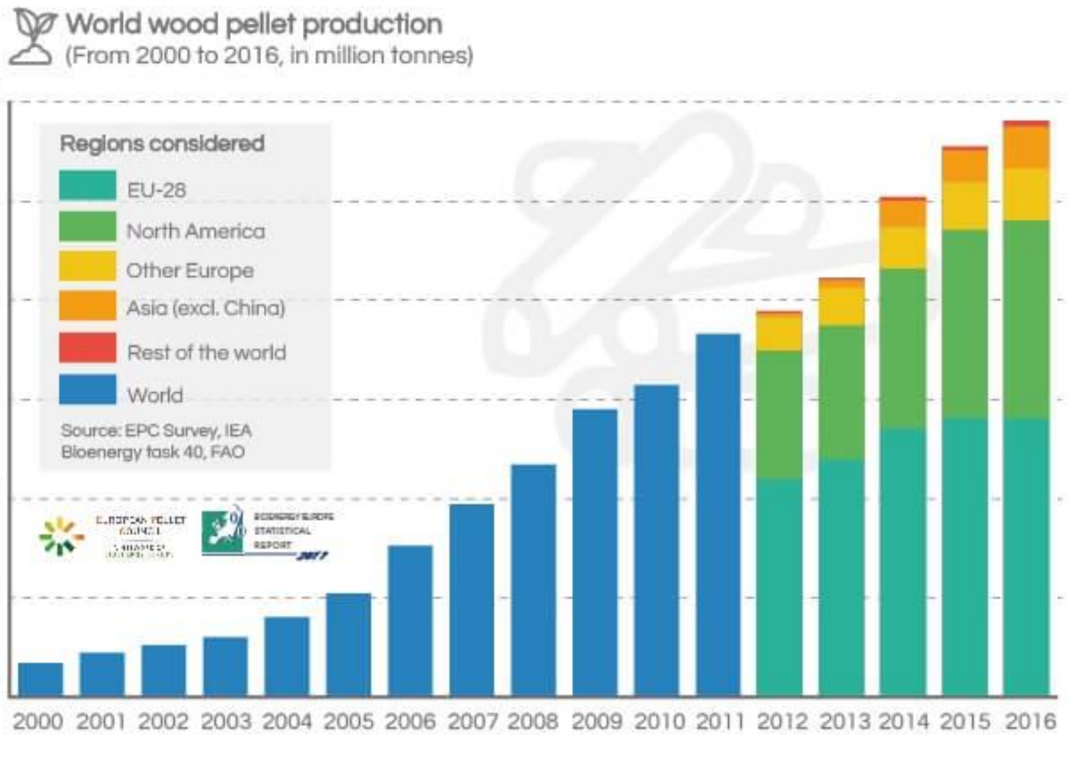

Figure 1: world wood pellet production [3]

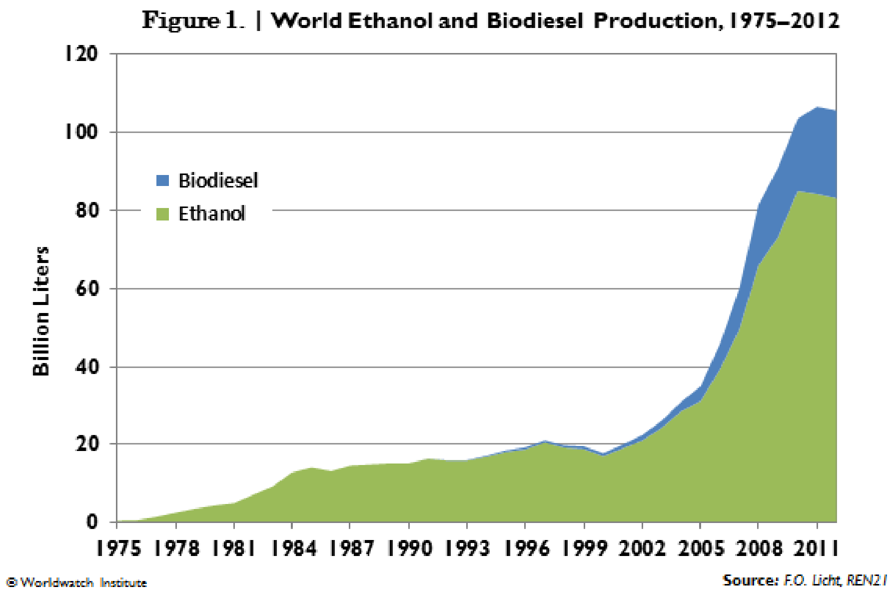

Figure 2: world ethanol and biodiesel production [4]

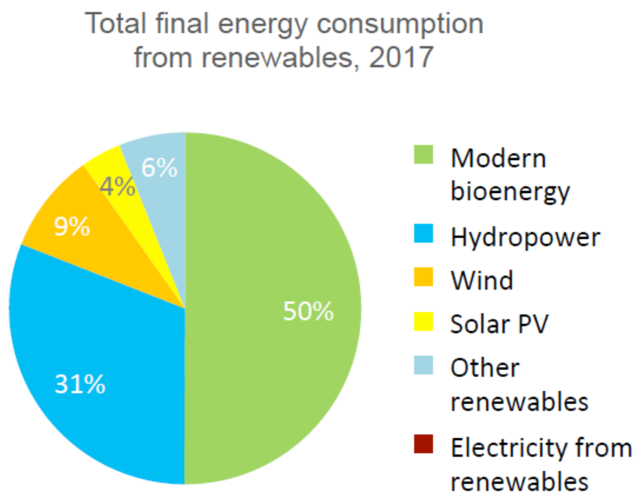

Figure 3: Renewable energy consumption 2017 [5]

5. Price trends for bioenergy

To discuss the future role of biomass in the global energy system, it is important to take a closer look at its main competitors. Figure 4 shows the growth of renewable energy for three applications: electricity, heat and transport.

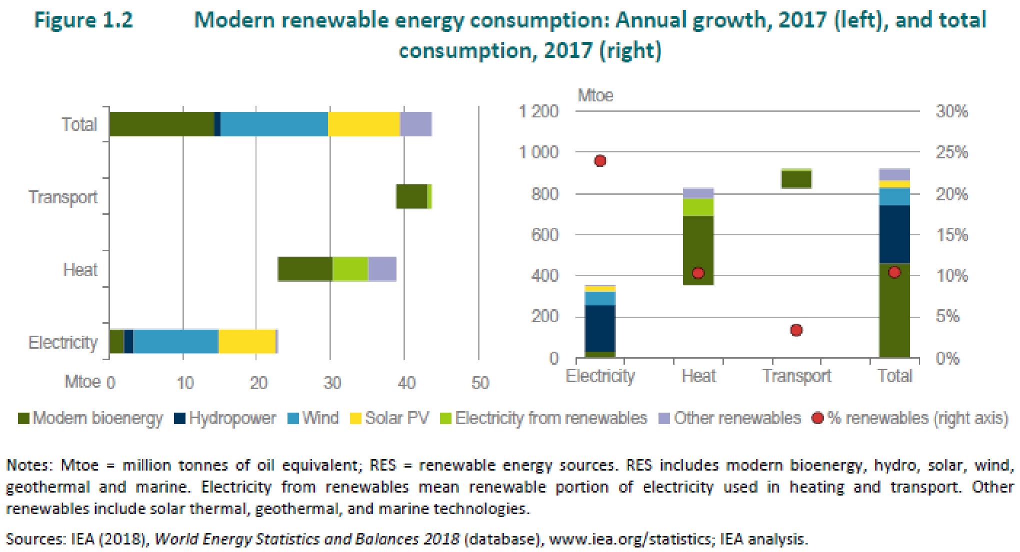

Figure 4: growth of modern renewable energy consumption in 2017 [1].

For electricity, it is clear that the major growth comes from wind and solar energy. For heat and transport, bioenergy still accounts for the major growth. However, for heat, the use of renewable electricity is increasing, at a faster rate than total heat consumption growth. This includes the electrification of industry and the use of heat pumps in buildings. In the Netherlands, a country where almost every household is connected to a natural gas grid, the government has ambitious plans to replace all gas boilers in the built environment by electric heat pumps. Also for transport, the use of electricity is a main competitor, considering the growth of the electric car production. In Norway, almost 60% of the cars sold are electric now. These developments fit into a trend towards electrification of the energy system.

Considering power generation, a revolution has taken place in the past 7 years, see figure 5.

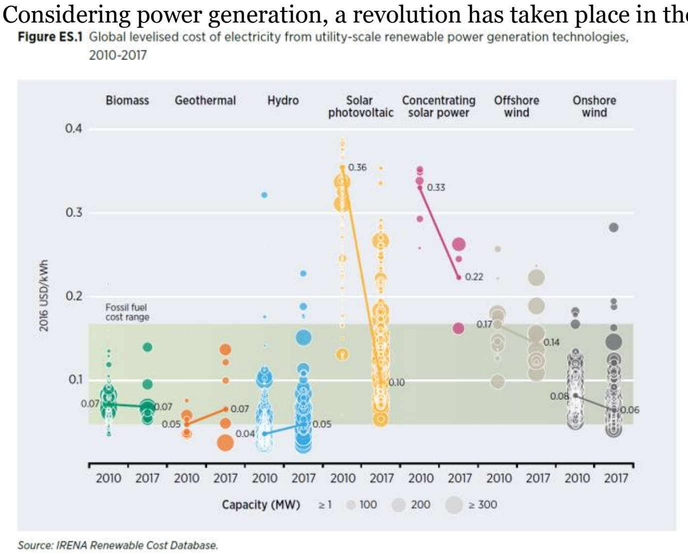

Figure 5: price trends in power generation for different renewable technologies [6].

Where the price of PV- and wind energy has decreased dramatically, the price of bioenergy roughly remained at the same level. It should be noted, though, that there are main differences between individual projects, depending on local circumstances and regulations. For example, solar panels will be more profitable in countries closer to the equator. In the Netherlands, offshore wind does not need a feed-in tariff anymore because the government pays for the necessary infrastructure. Nevertheless, the graph shows a clear trend. The prices for solar photovoltaic energy and for onshore wind have been decreasing dramatically and are now on the same level or lower than the price of biomass. According to the figure, they are even in the fossil range but in many countries a feed in tariff is still needed to compensate for the additional costs of renewable energy. It is not so easy to make a general comparison between fossil and renewable prices. Again, differences depend on local circumstances. For the Netherlands, the author found out that renewable energy is still 2-3 times as expensive as fossil energy [2016].

To keep up with solar and wind energy, ways have to be found to decrease the price for bio-energy. However, two factors complicate the development of bioenergy projects and its price reduction:

- The price of solar and wind power is rather predictable over lifetime. It is mainly determined by the depreciation of the equipment. Maintenance costs can be easily predicted. The necessary wind and solar power are free of charge and can be easily predicted as well, based on historical data. Feed-in tariffs are often fixed for the lifetime of the installation. The price of bioenergy is mainly determined by the price of the biomass, which may fluctuate during lifetime of the equipment because it heavily depends on market circumstances. This makes the profitability of the business case quite unpredictable, putting off investors.
- The price of PV solar panels decreased rapidly because of the increase in the scale of manufacturing in China. Wind energy prices fell because wind turbines got bigger, lowering the investments per Megawatt power installed. For biomass, a comparable increase in scale is not applicable anymore. Equipment like boilers and gasifiers were developed for coal and oil as a feedstock, they have been in existence for over 100 years and are already optimised and upscaled. The same accounts for fermentation processes, which mainly originate from the food industry.

The favourable price developments for solar and wind power leads to a growing interest in the electrification of the energy system. On the other hand, a lot of research and development has been put into cost price reduction of bioenergy. Technologies will be discussed in more detail in chapter 7, in this chapter we will focus on possibilities to decrease the price in more general terms.

As feedstock prices are the dominant factor in biomass technology, cost price reduction could be reached by changing from energy crops to cheaper feedstocks like agricultural and municipal waste. This, however, is complicated by the following factors:

- Waste streams are inhomogeneous by nature; their composition varies. This makes it more complex to process these streams, compared to ‘clean’ feedstock of a constant quality like fossil, oil, wood or sugars. Therefore, in most cases pre-treatment processes are needed, such as washing, sorting and heating.
- The varying feedstock composition may result in a variable quality of the end-product, which in that case demands an extra refinery step.
- Fermentation processes like bioethanol production need single sugars like glucose and fructose as a feedstock. Agricultural waste streams, like straw and stover, are made of cellulose fibres embedded in a matrix of and hemicellulose and lignin. Therefore, it is often called ‘lignocellose’. The extraction of these fibres and the conversion into glucose demands a number of extra process steps.
- Dry waste streams often contain more ash and salts compared to for example clean wood. When burning these waste streams, ash and salt leads to more corrosion and production of slag, resulting in more costs to clean the equipment and eventually replace parts. Salts can be partially washed out, resulting in wet biomass which first has to be dried again before it can be incinerated.

In practice, this implies that the use of cheaper biomass comes with extra equipment for pre-treatment and refining. This results in higher operational and investment costs and consequently not always in lower production costs. Besides, the price of waste streams may increase when the demand for this feedstock rises. For example, this was observed in the Dutch anaerobic digester industry. In the early 2000’s, many Dutch cattle farmers invested in anaerobic digesters because of an attractive feed in tariff. These digesters were running on a mixture of 50% manure and 50% waste streams from food industry. This resulted in rising prices for these waste streams, making the digester hardly profitable anymore.

These findings are confirmed by IEA Bioenergy, that also predicts that a dramatic drop in the price of bioenergy cannot be foreseen in the near future [7].

6. Social acceptance of biomass

As for all new technologies, social acceptance is key for the deployment and implementation of biomass as a renewable feedstock. Scientific research shows that the public acceptance of bioenergy systems is much lower compared to other types of renewable energy such as wind and solar energy. The acceptance of bioenergy appears to be higher in countries with high levels of biomass, such as Sweden and Austria, which traditionally have an extensive paper and logging industry. In countries with little biomass resources, like the Netherlands, the acceptance is lower. [8].

Wüstenhagen et al. [9] have proposed a three-dimensional approach to social acceptance:

1) Community: perception by local stakeholders and residents close to a newly planned installation;
2) Market: acceptance by market players such as suppliers, equipment manufacturers and consumers.
3) Socio-political: acceptance by political stakeholders and the broad public;

All these aspects regarding bioenergy will be discussed below:

Community

In this respect, the position of biomass does not differ very much from other renewable options like wind mills, fields with solar panels and a well for geothermal energy. They all come with their own specific risks and disadvantages perceived. For biomass, the main objections of residents are in general:

- Increase of traffic due to transport of biomass and end-products, in most cases by truck;
- Emissions of odour, waste gasses, particulate matter;
- The installation does not fit within the landscape;

In most cases, these problems can be mitigated by technical measures, construction of an extra road and/or building the equipment on an industrial estate. Initiatives that inform residents and local government in an early stage and in a transparent way appear to have a higher success rate.

Market

The market for biomass is almost entirely determined by government support like blending obligations, subsidies and feed-in tariffs. The EU has set a blending obligation of 10% in 2020 for road transport fuels. At the moment, both biofuels and bioenergy are more expensive then the fossil equivalents and this gap should be compensated one way or the other. It has become a well established market that largely depends on government support. Therefore, social-political acceptance is key.

Socio-political

There is an ongoing public debate on the sustainability of biomass. A number of NGO's and 'green' political parties are sceptical about certain bioenergy applications, especially co-firing of wood(pellets) and biofuels from food crops. Besides, there is fierce debate between scientists. Scientific opinions differ fundamentally. Some scientists state that it is better to fire coal than to fire biomass, others state that we can produce enough biomass to supply the world with food and energy in a sustainable way'. This discussion gains lot of media attention and consequently has great influence on politics and public opinion. The main objections can be summarised as follows:

- The use of biomass such as corn leads to an increase in food prices (food versus fuel debate);
- Entire forests are harvested to make wood pellets for incineration in power plants. This is a low value application of wood. It's much better to use it for construction purposes or furniture, where the harvested carbon is captured for decades;
- The growing demand for biomass leads to deforestation, in 2 ways: forests are destroyed for harvesting biomass and for making room for energy crop production;
- When agricultural land is diverted from food and feed production to biofuel production, food and feed demand still needs to be satisfied. This may lead to the extension of agriculture into areas such as forests, wetlands and peatlands. This is called Indirect Land Use Change (ILUC);
- Biomass cultivation and harvesting leads to a loss of biodiversity. Replanting trees leads to monoculture with less diversity of animals and plants;

- When harvesting and burning biomass, the carbon dioxide emissions initially increase. The uptake of the CO2-emissions by new crops takes time, especially when trees are concerned, where the uptake of same amounts of CO2 takes years. This is called carbon debt;
- Manure for anaerobic digestion often comes from large scale farms, perceived by some NGO's as animal-unfriendly and polluting;
- For cellulosic ethanol production, but also for other fermentation processes, often genetically engineered (GE) organisms are used. When released in nature, these organisms are a danger to health and the environment;
- Biomass often comes from overseas countries. The transport of it emits a lot of CO_2.

Biomass industry and some scientists, on the other hand, argue that:

- There is no scientific proof of a relation between food prices and the use of biomass. Increasing food prices are caused by speculation;
- Wood pellets are made out of forest residues or sawdust, which have no high-end application;
- For wood pellets, also trees are used that are infected by diseases and insects. This wood does not have a high-end application either;
- Many woods were planted for paper production. As the demand for paper has dropped dramatically, energy production is a good alternative use.
- Biomass production stimulates the local economy of rural areas;
- Health organisations discourage the use of cane- and beet sugar in food. Consequently, the demand for sugars from food industry will decrease. The use of cane and beet sugar for the production of biofuels will help farmers to maintain their income. Besides, sugar beets have a major role in crop rotation in Europe, keeping the soil fertile;
- In many places of the world, the yield of agricultural land can be improved by using better agricultural methods. In some cases, the yield can become 2-4 times higher [10]. This improves the local economy as well;
- ILUC-risks exist for all biomass application but there are ways to reduce these risks. Policies should be based on evidence-based sustainability assessments;
- GE organisms are well contained in laboratories and factories and are not able to survive in nature;
- The CO_2-emission from transport per kg of biomass is negligible compared to the CO_2-reduction it brings, about 3% of the carbon content of the biomass.

It will not be possible to draw a single conclusion from this debate. On the one hand, there is no doubt that certain forms of bioenergy are not sustainable. For example, replacing a tropical rainforest by a palm oil plantation will result in a dramatic loss of biodiversity and therefore cannot be called sustainable in any way. These kind of examples lead to a lot of reputational damage and emotions.

On the other hand, there are a lot of biomass sources that are undisputed, like organic waste that cannot be used as a cattle feed. When left on the fields or landfill, the biomass will degrade, leading to methane and CO_2-emissions. Converting this waste into biogas, to replace natural gas, is sustainable and leads to CO_2-reduction, that's beyond doubt.

In fact, a detailed sustainability assessment should be made for every single combination of feedstock and biomass application to determine whether it contributes to the mitigation of climate change. This will be time consuming, as supply chains and production processes are complex and not always transparent. Besides, the outcome largely depends on the assumptions made at the start of the process, assumptions that can lead to new discussions.

One of the effects of this debate is the development of sustainability criteria for biomass. Recently, several European countries developed their own criteria and the new EU Renewable Energy Directive (RED II) sets European-wide sustainability criteria for solid biomass and biofuels.

The development of these criteria is a huge step forward. Nevertheless, this will not entirely stop the debate. The future has to show whether these criteria will change the public attitude. Some NGO's already stated that these criteria are not stringent enough. Objections against the use of biomass come with emotions, generalisations and frames. These have influence on politicians and policy makers and on the decisions they make. They will feel the urgency of a quick energy transition, where biomass can fast and easily replace fossil fuels at rather low costs. On the other hand they are aware that they should not lose public support, as this will slow down the energy transition.

Additionally, opinions are not only based on facts and emotions. They are also based values. Should an unexplored field near a rural village be used for solar panels to provide the inhabitants with sustainable electricity? Should we plant trees on it to store carbon? Or should we improve the land for agriculture so that we improve the local income and economy? What has the highest priority? Someone's opinion on this will also be based on personal values and interests. There will be no objectively 'best' solution that is entirely based on facts and figures.

In the meantime, some European countries have already announced a decrease in support for biomass projects. The Dutch government, for example, announced that no subsidies will be paid for co-firing of biomass after 2023 and Germany has decreased its support for anaerobic digestion. These are clear signs that governments have become more reluctant in supporting biomass projects.

7. Technology development

Chapter 5 shows that the bioenergy industry is still very much depending on government incentives such as subsidies and blending obligations for transport fuels. Besides, the price of bioenergy is mainly determined by the price of the biomass used. Chapter 6 showed that there is a growing debate on the sustainability of biomass as a source of energy and feedstock. These factors have led to the following trend in the use of biomass and biomass-related research and development:

- A lot of effort has been put into the search for cheaper biomass. By replacing virgin feedstock such as wood, vegetable oil and sugars by waste streams, bioenergy could be made cheaper;
- A shift from virgin feedstocks such as wood and vegetable oil towards the use of waste streams as a feedstock, the so called second generation feedstock;
- A shift from the use of biomass as a source of heat and power into the use of biomass as a feedstock for more high end applications such as fuels, chemicals, plastics and other materials;
- The refining of biomass into different fractions with a different value and field of application, the so called biorefinery. This can improve the business case, as biomass often contains small amounts of specific compounds with a high market value;
- Extraction of the minerals present in the biomass, such as phosphate and ammonium, which can be used as a fertiliser. By doing so, not only the carbon cycle but also the mineral cycle can be closed;

This has resulted in technology developments, such as:

- The production of ethanol and other chemicals from agricultural residues, like straw and corn stover. Enzymes and acids are used to break down the fibres into individual sugars. Modified yeasts are used to convert the mixture of sugars into ethanol. Also other technologies are under investigation to convert these kinds of sugar mixes into fuels, chemicals and monomers for bioplastic production. These include fermentation processes and catalytic processes;
- Pyrolysis: by heating dry biomass in the absence of oxygen, a liquid is produced that can be used in a boiler or as a feedstock for transport fuels after treatment (hydrogenation);
- Biomass gasification: at high temperature, the biomass reacts with controlled amounts of oxygen or steam into a mixture of carbon-monoxide and hydrogen. This gas mixture, often called syngas, can be used as a feedstock for the production of methane or liquid fuels. It can also be used in a boiler or CHP.

It should be noted that the development of these kinds of new technologies takes 10 to 20 years. Some waste stream, like used cooking oil, are easy to process but most of these waste streams are not. For all of the technologies mentioned, several pilot plants and semi-commercial demonstration plants have been constructed in the past ten years. Not all of these plants are fully operational, often caused by technological setbacks [11].

Investors and politicians can be put off by these kinds of projects, that cannot meet the high expectations within 4 to 5 years. This is critical, as this is the span of time that a democratic government is in office and a venture capitalist would like to step out and cash. It should be noted, though, that successful technologies faced similar problems in the past. This should not give reason to stop research and development in this field. The first solar panels were constructed in the 1960's. The first modern wind turbines in the 1970's. It took decades before these technologies matured and reached a competitive cost price level.

8. A future for biomass? Biomass as a feedstock in an electrification scenario

The previous chapters show that wind and solar energy have a number of advantages over biomass. The public acceptance is higher and the price development is more advantageous. The markets for electric cars and heat pumps is growing. Both applications can be powered in a sustainable way by wind and solar energy.

New bio-based technologies like cellulosic ethanol, biomass gasification and pyrolysis have not yet made the expected breakthrough yet. The general public and policy makers might jump to the conclusion that other sources like biomass will not be necessary anymore in a future sustainable energy system. It may seem that the energy transition will be complete when every house has solar panels on the roof, is heated by an electric heat pump and has an electric car on the driveway. Unfortunately, the solution will not be that simple.

In the first place, electricity accounts for 19% of total final consumption of energy today. In many countries, electricity grids are not ready for decentralised power generation and an increasing power supply and off-take. For instance, in the Netherlands, some large scale solar energy projects are on hold because the local grid capacity is too low. Large investments in infrastructure will be necessary and the realisation of that will take years.

In the second place, the replacement of fossil-fuelled cars and heating equipment will take a lot of time. For example, the average life expectation of a new car is 19 years now. Up to 2018, 4 million electric vehicles were sold globally [12] while about 1 billion cars were operational in the World [13]. This illustrates the challenge of the electric car revolution. Diesel and gasoline cars will be in use for at least 20 years. For that period, governments will impose blending obligations to reach their environmental targets. Consequently, there will be a market for bio-ethanol and biodiesel for the years to come.

In the third place, for countries with an existing natural gas based infrastructure, biogas can be an excellent source of sustainable energy. Heating pumps need low temperature heating systems as there efficiency decreases rapidly with higher temperatures. Industrial processes often need high temperatures and for historical buildings the installation of low temperature heating systems combined with the necessary insulation and heat pump is often very difficult.

The role of biomass in power generation may become smaller, in favour of sun and wind power but as the major part of electricity is still produced in coal and gas fired power plants, we have a long way to go. Besides, wind and solar power have an intermitting character and large scale electricity storage is still in an embryonic stage and expensive. Even for power generation, biomass may be needed as a transition fuel.

Besides, there are a number of applications that cannot easily be electrified. These applications provide opportunities for biomass, as there are few alternative renewable options. In this respect, it is important to consider the main cause of the current climate change: the abundant use of fossil feedstocks like coal, oil and gas.

Fossil feedstock have become so popular because they mainly consist of hydrocarbons: molecules made of carbon and hydrogen atoms. Hydrocarbons have two beneficial properties:

- When burnt, hydrocarbons produce a lot of energy in proportion to their weight: they have a high energy density;
- Hydrocarbons are an ideal feedstock for producing materials such as plastics and for chemicals that make life easier, such as cleansing products, detergents, paints, coatings, lubricants et cetera.

Often, the use of fossil fuels as a feedstock for materials and chemicals is not considered as energy use, but they still contribute to climate change. At the end of their life time cycle, plastics and chemicals are in many cases incinerated, causing CO_2-emissions. In fact, the mitigation of climate change demands a carbon transition instead of an energy transition.

Replacing carbon by electrons (electricity) has some major disadvantages:

- Storage (in batteries) is still expensive and comes with energy losses;
- The energy density of a battery is 85-140 times lower than the energy density of fuels, which is in fact one of the reasons that electric cars are much heavier and have a lower range;
- Electricity is not a feedstock for chemicals and plastics, a source of carbon is needed.

These disadvantages make it very difficult to electrify applications where either weight is leading or large amounts of energy are needed: aircraft, shipping and long haul truck traffic. Using batteries is not an option for these applications at present. For now, electric flying and shipping is limited to small vehicles that are able to transport a couple of persons for a very limited period of time. For these applications fuels will be needed for years. Besides, we will have to find a renewable source of carbon for chemicals and plastics.

Biomass could be a solution for these options. It consists of carbon hydrates and consequently is a renewable source of carbon and a source of fuels with a high energy density. In general, the energy density is lower than fossil fuels because biomass contains more chemical bonded oxygen. However, this can be overcome by hydrogenation, a reaction with hydrogen, which can be generated in a sustainable way by the electrolysis of water. The final product of hydrogenation have properties comparable to those of hydrocarbons from fossil feedstock.

This leads to the conclusion that the future use of biomass will be most promising in industries that cannot be easily electrified. The next chapter will focus on these industries: aviation, shipping and the chemical industry.

9. Biomass for aviation, shipping and chemical industry

In this chapter the use of biomass as a feedstock for marine and aviation biofuels and chemicals and materials like plastics will be discussed. Figure 6 shows that 31% of the world oil consumption is related to these industries. Figure 7 shows that oil consumption accounts for 32% of the energy consumption. Consequently, 10% of the total energy production world-wide is related to these applications. In practice, it may be more because natural gas is also used as a feedstock for materials and chemicals.

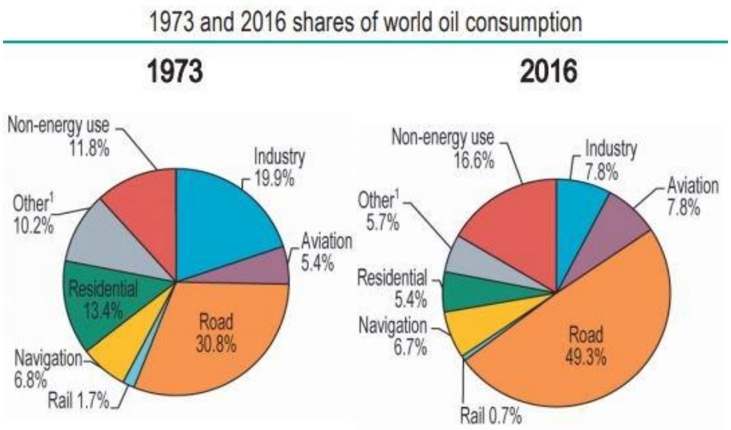

Figure 6: shares of world oil consumption. Non-energy use refers to the use of oil as a feedstock for chemicals, plastics and other materials. [14]

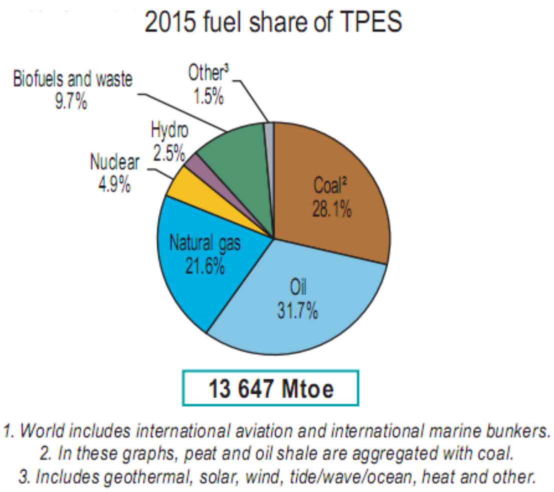

Figure 7: World fuel shares [14]

Market and market development

The airline industry is growing fast, especially in countries like India, Indonesia and China. Aircraft manufacturer Airbus expects that traffic will double in the next fifteen years, about 7% a year, IRENA expects a growth of 3% per year [15]. Yet, there is a growing public awareness of the environmental impact of air traffic. In 2018, the word 'Flygskam' (fly shaming) popped up on the Internet from Sweden and led to fierce debates. It makes the public more aware of the impact of travelling by plane and alternative options. NGO's in Europe call on to improve and extend the European high-speed railway network in order to become more competitive compared to flying on shorter distances.

The world seaborn trade by container ships is also growing at about 4-5% a year [16]. The climate impact of shipping is comparable to flying but it lacks public awareness because it is mainly focused on carrying goods as opposed to passengers. Nevertheless, there is much attention for its environmental impact, since the oil used for shipping is often of very poor quality with a high sulphur content, causing a lot of pollution. The same applies to fossil based materials like plastics, which are perceived more as an environmental problem than a climate problem. The market growth for plastic packaging is about 7% per year [17]. These figures show that these three sectors have a major share in fossil feedstock consumption and that the fossil feedstock consumption will grow in the years to come. Consequently, the impact on climate change will be significant.

Available bio-based technologies

Biofuels for aviation and shipping are on the market, but the volumes are very limited at the moment. For aviation, a number of biofuels are certified but there is only one type of fuel that is available on the market, called HEFA. It is allowed to blend this biofuel with kerosene up to a maximum of 50%. HEFA (Hydroprocessed Esters and Fatty Acids) can be made from vegetable oil, used cooking oil or animal fat. These feedstocks are treated with hydrogen in order to lower the oxygen content. The HVO global HVO production exceeds 4,3 billion litres per year. The 2012 global jet fuel consumption amounted to 310 billion litres [15]. As HEFA is also used as a replacement for diesel, it is not possible to make a reliable estimation for the use as aviation fuel, but it is still very low. Many airliners worldwide made test flights and some of them use it on a more regular basis, but it is clear that an enormous upscale in HEFA-production is needed and alternative technologies have to be explored and developed.

Ships are more flexible in fuel compared to aircraft. In almost all cases, large diesel engines are used for propulsion. Consequently, both traditional biodiesel and HVO can be used. HVO is a hydrotreated vegetable oil, comparable to HEFA. Also liquid (bio)gas and hydrotreated pyrolysis oil could be sustainable fuels of the future. The sector consumes more than 330 Megatons of fuel a year, where the estimated supply of renewable diesel is 10-20 Megatons [18]. No reliable figures could be found on the actual use. Several companies, research institutes and fleet owners are testing and using renewable diesel for shipping, of which the US navy is one of the major players.

Comparing the aviation and shipping industry, there is at least one major difference. Aircraft need high quality fuels with narrow specifications. Air liners are used to pay relatively high prices for fuel. Ships can run on relatively low quality fuels, a mix of hydrocarbons that have little or no alternative applications. Consequently, the price gap between regular fuels and biofuels will be larger.

In the chemical industry, a range of products is already made from bio-based feedstock like oil, fats and tallow. These products include cosmetics, detergents and feedstock for paints. Bioplastics are another range of well-established bio-based products, although the market has been stable for many years at only 0,5% of the entire plastics market due to the higher price levels. Another chemical where a lot of research has been carried out is methanol, which can be produced from e.g. glycerin (waste from biodiesel production). A couple of demonstration plants were built but none of these are commercially operational now. Companies like Sabic blends HVO with fossil naphta for the production of ethylene.

In the last couple of years, a lot of research projects have been started on new bio-based platform molecules, specialty chemicals and performance materials. Crucial for the chemical industry is that the feedstock is (almost) free of oxygen and that they are a liquid at room temperature so that they can be used in existing oil-based infrastructure and mixed with liquid fossil feedstock (co-processing). This implies that HVO/HEFA, biodiesel and ethanol are very interesting feedstocks for the chemical industry as well. In fact, road transport, aviation, shipping and chemical industries are competitors in terms of feedstock. Therefore, more research on new processes based on alternative feedstock would be favourable.

10. Sustainable alternatives for biomass in shipping, aviation and chemical industry

Although electrification of these industries is not easy, there are some alternative technologies that will be discussed in short below.

Carbon Capture and Use (CCU)

As carbon is the main problem in climate change, the recycling of carbon by using CO_2 as a feedstock for new fuels and chemicals seems attractive. This process is called CCU, the resulting fuels are often called synthetic fuels. In fact, CCU imitates nature as plants also produce hydrocarbons from CO_2. Although there are a lot of possible pathways, in general a CCU-process consists of the following steps:

- Capturing CO_2 from either air or from flue gasses;
- Production of hydrogen from either natural gas, biomethane or by water electrolyses;
- A reaction of CO_2 and hydrogen into a carbohydrate, which can be the final product or a feedstock for other chemical reactions.

Any CCU-process consumes a lot of energy. Either heat or electricity is needed to convert CO2 into a fuel or chemical. This is determined by nature, as CO_2 is at the lowest energy level in terms of thermodynamics. It makes a CCU-process rather inefficient. Figure 8 illustrates this, comparing an electric car, a hydrogen-powered car and a car running on synthetic fuels made from CO_2 and electricity. The fuel efficiency, 44%, will not differ from fuels produced for airliners or ships, or feedstock for chemistry, as the basic production processes are very similar. Besides, a switch from oil to CO_2-based fuels will come with a giant increase in power demand, which is not yet available from renewable sources. Most CCU-processes are still in a very early stage of research and development (TRL1-3) although some steps have been demonstrated on a larger scale, like air capturing. The use of CO_2 as a feedstock will be most profitable on locations where flue gasses with a high CO_2-concentration are available. These locations are scarce. There are currently only a few installations for carbon capture form flue gasses due to the relatively high investment and operational costs. Although CCU may be attractive in the future, large-scale implementation within the next ten years does not yet seem feasible.

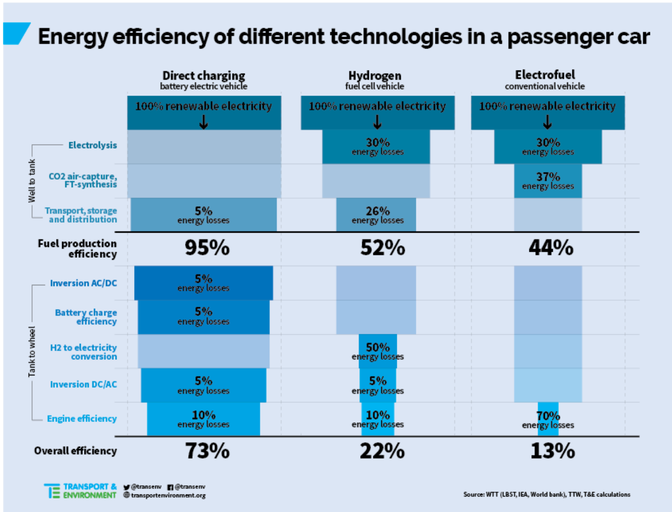

figure 8: energy efficiency of different technologies in a passenger car [19]

Electric flying and shipping

As stated, the energy density of a modern Lithium ion battery is 85 to 140 times lower than the density of a liquid fuel. A modern Lithium Ion battery has an energy density of 85-135Wh/kg or 0,3 to 0,5 MJ/kg [20]. It is expected that the energy capacity will double to 250 Wh/kg or 0,9MJ/kg in 2030. Diesel has a density of 43 MJ/kg. Even though electric motors are 2-3 times as efficient as a diesel motor and weight reductions can be reached by using new materials, there is still a long way to go. Storage of electricity in hydrogen performs better, according to DOE.

Currently, an energy density amounts to 1400 Wh/kg or 5MJ/kg. It illustrates that the use of liquid (bio)fuels will be favourable in the years to come.

Nuclear power

As nuclear fuel has a large energy density, it could be an option for shipping. Nuclear propelled ships and submarines are common in military. However, only 3 nuclear powered merchant ships have been built, of which only one is still in operation, a Russian ice breaker. The operational costs turned out to be too high. Besides, it demands specialised crew on board. There is a renewed interest in civil nuclear shipping, but there are no concrete plans to build a new ship and there are many safety and environmental issues. For aircraft, nuclear power is no option: the consequences of an accident are too big.

Recycling

Regarding renewable for feedstock for chemistry, recycling of materials is very promising, especially for plastics. By recycling of plastics instead of incineration, CO_2-emissions are reduced at the incinerator and in plastic production, as the production of new plastics requires a lot of energy and related CO2-emissions. Plastics can be mechanically and chemically recycled. Mechanic recycling involves shredding and re-melting of plastic waste. As plastic waste is often a mix of different polymers, sorting is needed. Chemical recycling is needed for plastics that cannot be separated, for example because a packaging consist of layers of different kind of plastics and coatings. Also for more high-end applications, chemical recycling is necessary. Chemical recycling involves the 'chemical cutting up' of polymers into separate monomers, which can be used as feedstock for new plastics. Chemical recycling is in most more energy intensive then mechanical recycling as it takes place at elevated temperatures.

It should be noted though, that recycled plastic cannot completely fulfil the demand for feedstock. Not all types of plastics can be recycled and collection systems for old plastics will not be able to return everything to the factory. Besides, the plastic industry is still growing and virgin feedstocks will be needed to ensure a good product quality. Plastics cannot be mechanically recycled endlessly, as the quality deteriorates with every cycle. In this respect, both bio-based and recycled feedstocks will be necessary to make the chemical industry more sustainable.

11. Policy measures

Biomass will only have a future with the right policy measures. This starts with the setup of sustainability criteria for all kinds of biomass in different applications. Without these criteria, the debate on sustainability will continue with great intensity. Subsequently, the use of biomass for energy and chemicals will lose all public support. These criteria should guarantee that the demand for alternative feedstock will not lead to loss of biodiversity, deforestation, increasing poverty in developing countries and indirect land use change. This will not be easy, as it demands a case by case evaluation. Besides, the production and trade of biomass is an international business with often long supply chains and many different companies involved. One of the main challenges will the monitoring, especially in countries where companies and governments are not very transparent and in countries were corruption is still daily practice. It is clear though, that rapid changes are needed to mitigate global warming and to meet the goals of the Paris agreement. Ambitious goals for the replacement of fossil fuels on short notice can only be met with a contribution of bioenergy. However, biomass will always have to be additional to other sustainable sources like solar, wind, hydro and geothermal energy.

In setting priorities, governments should focus on the optimal use of interior waste streams in the first place, as these sources are nearly undisputed. Besides, priority should be given to applications that are not easy to electrify. As the need for biofuels will grow, support for the development of second generation (lignocellulosic) fuels should continue. The development of these kinds of technologies comes with setbacks and failures. It takes more than one term in office. For solar and wind energy, it took 40 years to become a mature industry.

For most applications, feed in tariffs, tax schemes and/or blending obligations will be necessary for the years to come, as fossil alternatives are often cheaper. Especially the use in shipping, aviation and chemical industry need attention in this respect.

The current market for biofuels for shipping and aviation is still very much depending on premiums: customers who are willing to pay extra for sustainable products and services. The international character of these industries makes it difficult to develop an effective government support scheme. In general, international shipping and aviation and feedstock for chemical industry are not included in national targets for CO_2-reduction. In fact, these emissions ‘belong to no one’, or everyone if you like. A blending obligation, like for cars, would help but may also damage local economy because fuel prices may rise and airliners and ship-owners could decide to change destinations. On a European level, however, such a blending obligation might be feasible. On a national level, a tax on airline tickets may work, provided that these revenues are used for the introduction of biofuels in aviation.

For bio-based materials and chemicals, taxation might stimulate the market introduction as well. A tax on packaging, with a lower tax for bio-based materials, would be beneficial and create a level playing field. As these taxes are charged for every packaging, independent of the county of origin, local industries will not be outcompeted.

12. Conclusions

In this essay, the role for biomass in a future sustainable energy system was explored. An analysis was made on available technologies, markets and public perception. It resulted in an evaluation of the position of biomass in the energy system that can be summarised as follows:

Strengths - Renewable source of energy and carbon - High energy density - Proven technologies available - Waste streams, that have no high-end application at the moment, can be used as a feedstock for biofuels and biomaterials - Well established market and supply chains for biofuels and wood pellets	**Weaknesses** - Sustainability depends on source and local circumstances and regulations - Poor public image compared to sun and wind energy - Often not competitive with fossil feedstock without incentives (the same counts for sun- wind- and geothermal energy at the moment). - No major price decrease to be expected in the near future. - Production price largely depends on price of feedstock. This makes a business case less predictable and may put off investors.
Opportunities - Immediate action necessary to mitigate climate change, all options are needed - Diesel and gasoline powered cars will be in use for a long time, same accounts for natural gas fires boilers. Biogas and biofuels will be necessary as a transition fuel. - No sustainable alternatives for biomass available for air traffic, shipping and chemical feedstock - Sustainability criteria established in some parts of the world	**Threats** - Declining public and political support in some countries - Lack of awareness that break through developments in bioenergy take time - One sided focus on climate change as an energy problem instead of a carbon problem - One sided focus on electrification and energy storage as the only solution for mitigation - International shipping and aviation not included in national and European targets for CO_2-reduction

In spite of the lower public acceptance and the growth of sustainable electricity production from sun and wind, biomass will be necessary to enhance the sustainability of the World energy system. The demand for biomass will grow, considering the short time frame needed to mitigate climate change. It will be needed for road transport as a transition fuel as the implementation of electric vehicles will take time. For heating, also the use of biomass and biogas will be needed for the years to come. Besides, biofuels will be needed for shipping and aviation as there will be no sustainable alternative available within the next decades.

Biomass will also play a role as a sustainable feedstock in chemistry, next to recycled plastics and chemicals. All these options need the same kind of feedstock: hydrocarbons with a low oxygen content like HVO/HEFA. Consequently, the supply of sustainable biomass and the development of technologies for biofuels from non-oily biomass are challenging. Additionally, sustainable hydrogen must become available at a large scale, as it is necessary to produce biofuels with a low oxygen content.

Government policies will have to focus on setting up and monitoring sustainability criteria in the first place. Besides, the use of interior waste streams and the development of technology converting these waste streams should be promoted. Support for the use of biomass will still needed as the cost price for biofuels is often higher than the cost price of fossil fuels. Because aviation, shipping and chemistry are trans-national industries, it is difficult to take measures on a national level while not outcompeting domestic companies. Taxation on consumer products and services and blending obligations on a transnational level like the EU appear to be most effective because a level playing field will be maintained.

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