

# The Role of Biomass in Norway's Energy Mix

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**Centre for Development and the Environment**

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UiO 

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# 1. Introduction

## A greener future

Countries the world over have acknowledged the threat that climate change poses to them as well as the global environment. In an effort to limit global warming, many countries have made pledges to reduce their greenhouse gas (GHG) emissions through signing The Paris Agreement (United Nations Framework on Climate Change, 2015). Norway was an early adopter of The Paris Agreement and in 2016, it became the first developed country to ratify the agreement ("Norway to ratify Paris Agreement", 21st June, 2016). As of July, 2019, there are 195 countries which have signed the Paris Agreement in an effort to reduce GHG emissions ("Paris Agreement", 18th July, 2019).

## Why investigate Norway's bioeconomy and the role of bioenergy in Norway?

Norway will need to employ many economic, technological, political, and social strategies in order to achieve their emissions reductions goals. Among these strategies is an increase in bioenergy production. To this end, Norway set a goal in 2008 to nearly double their bioenergy production levels by reaching 100PJ of bioenergy production by 2020 (Scarlat, Dallemand, Skjelhaugen, Asplund, Nesheim, 2011). Norway is not alone in their goals to intensify bioenergy production. Gardiner & Moore (2014) believe that global demand for wood will increase between 1.3% and 1.8% every year until 2030 due to growing biomass harvesting.

In conjunction with greater pressures on forestry, technological innovation based on extracting oils, cellulose, and carbohydrates from wood, algae, grasses, and human waste are accelerating every year. Countries, companies, and universities are investing significant money and expertise into creating novel bio-based chemicals, building materials, fuels, and processing techniques (Keisjers, Yilmaz, van Dam, 2011; Gardiner & Moore, 2014; Philip, 2017). Europe alone has invested roughly 4 billion euros into developing its bioeconomy (Hackett, 2019). This includes direct investment into infrastructure as well as investment into large research and development (R&D) projects aimed at nurturing future technologies and techniques (EuroBioRef, 2014).

The bioeconomy has the potential to not only lead to technological and economic change, but also social change as individuals and communities are realizing more choice and ownership over the energy they consume and greater expectations about the carbon footprints of the companies they buy goods from. This shift towards a more heavily bio-based society and bio-based economy may, if well managed, lead to greater energy democracy and energy justice as more citizens demand decentralized and clean energy options (Creutzig, Hadahl, Rydge, & Szulecki, 2014; Szulecka, 2019). Furthermore, bioeconomy-based projects have the ability to create specialized jobs in rural economies which can lead to rejuvenation and growth in local

economies (EuroBioRef, 2014). EuroBioRef predicts that the EU initiatives within EuroBioRef will lead to the creation of a significant number of jobs; many of which will be in rural areas.

For all its promise, the bioeconomy is not without risks. An intensification in agricultural, aquacultural, and forestry practices has led to concerns about: the global bioeconomy's sustainability, soil degradation and fertilizer use, the ethical use of arable land, national security, and energy transition goals (Sheppard, Gillespie, Hirsch, & Begley, 2011; Sovacool, 2017; Stupak et al., 2007; Szulecka, 2019; Trømborg et al., 2011).

Furthermore, Norway in particular is a unique case study to examine the bioeconomy through. It is relatively decarbonized due to its readily available and cheap electricity generated from hydroelectric dams. Norway also has very little farmland, and nearly no cultivation of energy crops (Scarlat et al., 2011; Trømborg, Havskjold, Lislebø, & Rørstad, 2011). Additionally, it is densely forested with forests making up nearly 40% of Norway's area (Scarlat et al., 2011).

But before taking a deeper dive into this world of cellulose, microalgae, petajoules, and spruce trees, it might be helpful to define some terms which will be used throughout this paper.

### **Biomass, bioenergy, bioeverything?**

Before embarking on an exploration into the role of bioenergy and the bioeconomy in Norway, we'll start with a definition of foundational terms and concepts used throughout this paper. *Bioenergy* is energy produced from *biomass*, often through a *biorefinery*. This biomass can also be used for a number of applications outside of energy production. The constellation of uses for harvested biomass is known as the *bioeconomy* (the economy of biomass-based products).

Biomass means different things to different disciplines. To an ecologist, biomass is the mass of all living biological things in a given area (IUPAC, 1997). This includes all the plants, animals, fungi, microorganisms, etc. in a given space. However, for the purposes of this paper, we'll refer to biomass using the definition that an economist or energy analyst may use. For the energy analyst, biomass is a biological resource used for energy, fuel, heat production, or industrial processes such as material or chemical manufacturing (Ur-Rehman, Mushtaq, Zahoor, Jamil, Murtaza, 2015). These biological resources are broad, including plant resources (such as trees and agricultural or aquacultural crops); animal byproducts and human waste; and even municipal waste found in landfills.

Bioenergy is the energy output which comes from a biomass resource. This energy can come in many forms and be used in many applications. Biomass can be burned directly to create electricity and heat (such as in a combined heat and power plant). It can also be converted into *biogas* which can be used in a number of heating, electricity, and transportation applications. Additionally, biomass can be turned into a liquid fuel (referred to as *biofuel* throughout this paper) which has applications in transportation. Biofuel can replace gasoline or diesel fuel completely; or be used as an additive in gasoline or diesel fuels. Oftentimes, before biomass

can become bioenergy, there is an extensive pretreatment and conversion phase which makes the cellulose, carbohydrates, or sugars within the biomass more readily available. This pretreatment and conversion often happens at a biorefinery.

A biorefinery is the space where biomass resources are processed into marketable goods or energy sources ("Factsheets Biorefineries," 2013). This includes all refineries where biomass is turned into bioenergy, food, materials, or chemicals. In other words, the biorefinery is where biomass is turned into the end product which is consumed. Due to its important role in transforming biomass, Philip (2018) has stated that "biorefineries are the physical embodiment of the bioeconomy" (p. 14).

As stated above, the bioeconomy is the constellation of all the economic uses of biomass resources. According to McCormick & Kautto (2013) "a bioeconomy can be defined as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources" (p. 1). The larger bioeconomy surrounding these biomass resources is important to keep in mind when discussing bioenergy because it illustrates that many -if not all- of the biomass resources discussed in this paper have additional applications beyond being converted into energy. For example, a single tree may be utilized to create timber, paper and pulp, and energy. This means that a single tree is valuable to stakeholders across the construction, paper, and energy industries. This cascading feature of biomass resources makes them especially important in the wider economy due to their ability to contribute to multiple markets.

Energy and power (rate of energy transfer) are reported in this paper. In this paper, they are expressed using joules, or watt-hours. 1 watt-hour is equal to approximately 3600 joules ("Unit Juggler", n.d.). Often, these units are too small to appropriately express the amount of energy produced or consumed by a nation, therefore, they are often expressed in multiples of these units. For Example:

A petajoule (PJ) is equal to  $1e15$  joules  
An exajoule (EJ) is equal to  $1e18$  joules  
A gigawatt-hour is equal to  $1e9$  watt-hours  
A terawatt-hour is equal to  $1e12$  watt-hours

### **Purpose of this paper:**

This paper explores the biomass resources which Norway uses for bioenergy and what some of their alternative uses are. This is not intended to be an exhaustive inventory of Norway's bioeconomy, but rather an exploration into what Norway is doing with the bioenergy resources it has and what it may do in the future.

Additionally, the role of biomass and the bioeconomy in Norway will specifically be looked at through INCLUDE's objectives: Reduction of Emissions, Energy Security, Utilization of Resources, Innovation, Inclusiveness/Democracy.

**Structure of this paper:**

Section 2 of this paper proceeds with a brief introduction of some of the major bioenergy resources used today as well as some strengths and weaknesses they carry in respect to cost, sustainability, and emissions. In section 3, some of the major bioenergy products that biomass is refined into will be discussed as well the alternative uses for these resources in the wider bioeconomy. In section 4, Norway's access to and use of these biomass resources are discussed as well as Norway's overall energy mix. Section 5 examines the bioeconomy in Norway through INCLUDE's framework as a preliminary mapping of how biomass interacts with INCLUDE's objectives. Section 6 discusses what the future may hold for Norway's bioeconomy, how to may be promoted, and popular criticisms of the global bioeconomy.

## **2. Where Does Biomass Come From?**

Biomass comes in many shapes and sizes. This section will outline some of the major types of biomass used for energy, discuss what they're commonly used for, and briefly explore some of criticisms and promises surrounding these biomass resources. Due to this paper's focus on bioenergy, some crops which are otherwise important for the bioeconomy are beyond the scope of this paper.

### **Woody Biomass**

Woody biomass is biomass from trees. Woody biomass can come either from farmed tree plantations which are grown to be cut down, or by cutting down a portion of naturally occurring forests which are managed to varying degrees.

Tree biomass comes in several varieties and the size and species of tree will determine what it is used for after being harvested. Due to the demand for construction materials, of the mass of a large tree will be used for timber instead of energy (Oregon State University College of Agricultural Sciences [OSU], 2015a). Processing lumber creates wood chips and sawdust which can be used in a number of ways. These residual products often go to producing paper and pulp, wood composites, and landscaping material. The residual products which aren't sold are often used to provide heat for the lumber mill's processing or for heating nearby homes and industry (OSU, 2015a).

Tree plantations often contain small, fast growing trees such as willow and poplar (OSU, 2015a). These trees are typically harvested before they grow big enough to be used for lumber and are instead used in wood composites, energy production, or chemical production.

### **Agricultural Crops**

"Energy crops" are agricultural crops harvested specifically for their energy yield. These crops tend to be quick growing and relatively easy to convert into energy (OSU, 2015a).

Energy crops include many species of tall grasses, grains, seeds, and beans. Popular tall grasses used for energy include sugarcane, miscanthus, switchgrass, and napier grass. Popular grains include maize, wheat, rice, and barley. (OSU, 2015a, ). Rapeseed, castor, canola, and palm are popular seeds and beans used in energy and fuel production (Chen, Weselake, & Singer, 2018)

Energy crops tend to be chosen for their high sugar or carbohydrate content. Grasses are often used to create a solid bioenergy source such as pellets. Grains, seeds, and beans are more commonly used in biofuel production.

### **Agriculture**

Agricultural residues include unused parts of crops such as the stems, husks, and prunings coming from an already harvested plant (OSU, 2015a). Agricultural residues from crops are commonly harvested for their lignocellulosic fibers and are often used to produce ethanol.

## **Aquaculture**

The main source of aquatic biomass globally is algae. Broadly speaking, algae can be divided into two categories: micro and macro. There are several species of microalgae harvested for their biomass including spirulina and chlorella (OSU, 2015b). Macroalgae includes kelps and other seaweeds.

Microalgae are considered a rather attractive bioenergy source due to their high oil content, low lignin, and high yield per km<sup>2</sup> (Chen et al., 2018; Hannon, Gimple, Tran, Rasala, Mayfield, 2010; Sheppard, Gillespie, Hirsch, Begley, 2011). Due to their composition, microalgae are typically used to produce biofuel. Globally, macroalgae is most commonly used in food; although the chemical, pharmaceutical, and fuel markets also utilize macroalgae (Stévant, Rebours, Chapman, 2017).

Floating plants are another source of aquatic biomass. Floating plants are typically seasonal, invasive, and fast growing (OSU, 2015b). Their qualities mean that harvesting them may be an attractive option for local governments who can both clean their waterways and produce some energy.

## **Anthropogenic Waste**

Anthropogenic sources of biomass include human sewage and waste which otherwise would be found in a landfill. Landfill waste can be burned in industrial incinerators in order to produce energy. This waste is often a combination of organic and inorganic matter such as food, plastics, construction materials (including concrete), and industrial chemicals and metals (Statistics Norway [SSB], 2018).

Human waste in sewage systems is known as *sludge*. In large metropolitan areas, sludge is often concentrated and cheap to harvest. In areas where processing is cheap enough, sludge is a useful source of biogas (OSU, 2015b).

Landfills include many high-calorie items, making them a valuable source of bioenergy when incinerators can handle the variability of the landfill items (OSU, 2015b). Different materials necessitate different incineration temperatures and also produce different gaseous byproducts; all of which is important to keep in mind when burning waste for energy.

## **Animal Byproducts**

Animal byproducts include animal remains after slaughter and processing as well as manure produced by livestock throughout their lifetime. Manure is commonly used to create biogas and soil fertilizer (Chen et al., 2018). Animal byproducts from harvesting can be used for heat production on mid- to large scale power plants.

### **Benefits and drawbacks:**

Bioenergy and biofuel use is an attractive alternative to fossil fuels for a number of reasons ranging from emissions reductions to rejuvenating rural economies (EuroBioRef, 2014). Agricultural residues are especially enticing from a utilization of resources perspective as it consists of parts of the plant which otherwise would not be used (discussed more in section 5). Creating energy or materials from agricultural residue is often praised as being one of the more sustainable agricultural practices (Energy Transmissions Commission [ETC], 2019a).

Although bioenergy has many benefits, some authors are skeptical to its sustainability. Intensive biomass harvesting has raised questions about ethical uses of arable land and concerns about soil degradation, water use, fertilizer use, and damage to local ecosystems (Diltz, Luckarift, Johnson, 2011; Humpenöder et al., 2014; Stévant et al., 2017).

Energy crops are especially controversial as they are grown on arable land which could otherwise be used to grow food crops instead. For example, in The United States of America, there are 320,000 km<sup>2</sup> of land exclusively dedicated to maize cultivation (Farm Energy, 2019). Nearly 30% of the maize grown in the US is used for ethanol production with very little of the maize being consumed as food for humans (Foley, 2013). Heavy subsidies for non-food crops, extensive land use, and the fertilizer, pesticide, and water which these crops receive has led to criticism of US agricultural practices surrounding energy crops (Carter & Miller, 2012; Foley, 2013).

Seaweed and forestry have received less criticism than energy crops because forests can grow in marginal land not fit for agriculture (Scarlat et al., 2014), and seaweed is grown offshore. Additionally, since seaweed grows in saltwater, it does not put pressure on water supplies (Stévant et al., 2017). Intensive forestry, however has faced criticism for its potential to affect biodiversity (Gardiner & Moore, 2014), while seaweed harvesting's effect on local environments has also led some authors to be skeptical of its sustainability claims (Stévant et al., 2017).

### 3. Uses for Biomass

Biomass has many uses once it's been harvested. This section will highlight five major categories of energy utilization from biomass sources as well as provide an overview of some of the potential uses beyond energy in the wider bioeconomy.

#### **Biomass Conversions**

Before being used as an energy or heat source, biomass often must undergo pretreatment in order to make the cellulose, carbohydrates, sugar, or building-block chemicals more accessible. These conversions can be divided into 4 main categories: mechanical, thermal, chemical, and biological.

Mechanical conversions include things such as crushing, cutting, grinding, and pressing in order to refine the biomass. Pellets burned for their heat are made primarily through mechanical conversion. Thermal conversions include combustion (to create heat), pyrolysis (to create bio-oil and bio-charcoal), and gasification (to create gas). Chemical and biological conversions are used in order to create gasses, oils, liquid fuels (such as ethanol or biodiesel), and isolate chemicals for industry or consumption (OSU, 2015c-e, Zafar, 2019).

After the appropriate conversions are done, the biomass can then be transformed into heat, electrical power, liquid fuels, gas, and many other commercial and industrial products.

#### **Biomass for Energy**

##### **Heat production**

Biomass can be used for heating, as has been done for millennia. Biomass burning is used as a heat source from the household to the city scale. Heating at a city or district level is known as *district heating* because it is usually done at a centralized heating plant in order to supply heating services to many people. District heating is typically done in relatively densely populated areas.

##### **Electrical Power**

Thermal power plants turn heat energy into electrical power. This is commonly done by burning a fuel source in order to heat water until the water becomes steam. This steam is then used to turn turbines which produce electricity (Kitto & Stultz, 2005)

##### **Combined heat and power plants**

Combined heat and power (CHP) generates electricity and power from a single source. This is most commonly done through burning an energy source, which creates steam that spins a

turbine to generate electricity. The residual heat generated in this process is then delivered to consumers (“Combined heat and power basics”, n.d.). The benefits of using a CHP plant instead of generating electricity and heat separately include potential emissions reductions and efficiency benefits. CHP plants are on average 65%-75% efficient; while generating heat and electricity separately is on average 50% efficient (Jones, Lea-Langton, Ma, Pourkashanian, Williams, 2014).

## Liquid fuels

Liquid fuels can be extracted from biomass through a number of biochemical and thermochemical processes including fermentation and pyrolysis. A very common biofuel is ethanol- a combustible alcohol. Ethanol is often used as a gasoline additive. When blended in with fossil-fuel-based gasoline, ethanol can lead to reductions in GHG emissions (Chen et al. 2018). Gasoline blended with ethanol can often be used in gasoline burning vehicles without any modifications to engines, making it an appealing transitional fuel source.

Biofuels such as biodiesel and bio-jet fuel are seen as an especially useful fuel source in difficult-to-decarbonize transport such as long distance trucking, aviation, and shipping (ETC, 2019a; NVE, 2018).

Biodiesel has already seen substantial growth in Europe over the last 20 years as can be seen in figure 1:

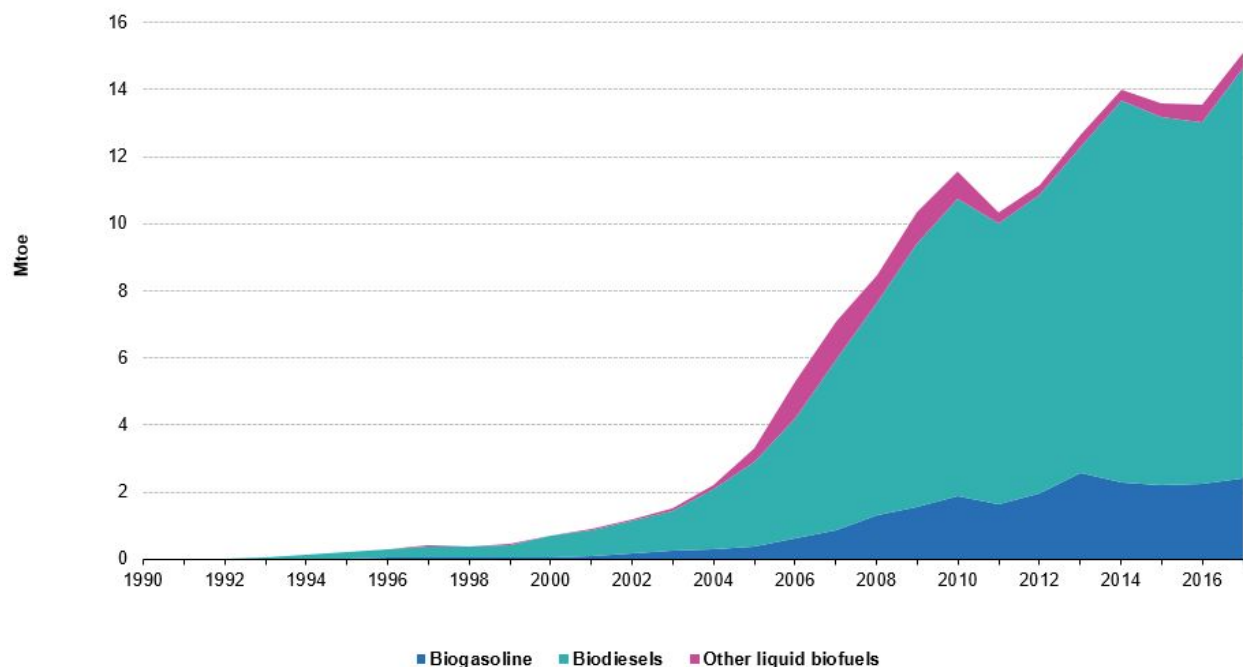


Figure 1. The change in biofuel consumption in Europe over time. *Note.* Reprinted from EuroStat: [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Figure\\_6-Primary\\_production\\_of\\_liquid\\_biofuels\\_EU-28\\_1990-2017.png](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Figure_6-Primary_production_of_liquid_biofuels_EU-28_1990-2017.png)

Biodiesel is an especially useful fuel source for the trucking industry which is currently reliant on petroleum-based diesel. Biodiesel production will likely continue to grow in order to reduce carbon emissions in this sector (NVE, 2018; ETC, 2019c).

Bio-jet fuel is likely to see growth in the coming decades due to the difficulty of electrifying aviation (ETC, 2019b). Avinor, Norway's largest airport operator has already begun experimenting with biofuel in their planes and expects a much higher share of biofuel in aviation in the near future (Avinor, n.d.). Avinor expects much of the Norwegian production of aviation biofuel to come from woody biomass. Microalgae is also a promising candidate for fuel production due to algae's high percentage of oil and quick growth rate (Hannon et al., 2010).

Another bio-based fuel source is vegetable based cooking oil. Vegetable oil use has been experimented with since some of the earliest diesel engines. Research and interest in vegetable oils has historically hinged upon the price of oil- with higher oil prices has been associated with greater interest in vegetable oil (Chen et al., 2018). Today, vegetable oil is used in many forms of transport including busses, cars, and planes. A notable case study (found in Appendix A) is Maersk shipping company experimenting with using a cooking oil blend to power one of their freight ships.

Biofuels are separated into four "generations". First generation biofuels are made from food crops grown on arable land. Second generation biofuels do not need to use arable land and include woody biomass, agricultural residues, and animal byproducts. Third generation biofuels are biofuels which do not require freshwater or farmland in order to be produced such as algae. Fourth generation biofuels are biofuels that don't require destruction of biomass in order to produce fuel.

## **Biogas**

Biogas is typically harvested through an anaerobic digester. Anaerobic digesters promote the production of biogas by having microorganisms decompose biomass in the absence of oxygen (Chen et al., 2018). Biogas harvested from anaerobic digesters can displace natural gas in heating and electricity production, making it a valuable resource (Burgmeister, 2008). After anaerobic digestion is completed, the solid parts of the biomass can be used to fertilize soil. Popular sources of biogas include animal manure, food waste, and sludge.

## **Scales of operation**

Many of these energy outputs require extensive and expensive conversion and processing. The infrastructure needed to create them means that generating electricity through thermal power plants or producing biofuels are typically produced at medium- to large- scales by utilities companies or large entities. Using bioenergy as a heat source, on the other hand, can be done on small scales. Burning firewood or pellets for heat or for cooking is commonly done at the household level throughout the world.

### **Other uses for biomass: The wider bioeconomy**

Many of these biomass sources have multiple uses outside of energy. For some of these sources, energy production may be significantly less economically valuable than the alternative uses. For example, woody biomass is more valuable as a construction material or paper product than as a fuel source and the pharmaceutical and cosmetic chemicals extracted from seaweed are more valuable than the energy output generated from seaweed (Scarlat et al., 2011; Stévant et al., 2017). Appendix B provides an overview of some of the popular uses for these biomass resources. It's also important to note that any single resource can have multiple uses meaning that the product options are not necessarily an either/or decision.

## **4. How does Norway use its biomass resources?**

Norway is a unique case study in regards to its natural endowments and its grid infrastructure. This section provides an overview of how Norway uses its biomass resources and how it meets its energy demands.

### **Woody biomass**

The most abundant biomass resource in Norway is woody biomass from naturally occurring forests. Forested areas make up roughly 37% of Norway's land area and cover 120,000 km<sup>2</sup> (Scarlat et al., 2011). Roughly 1% of Norway's biomass resources come from tree plantations, the rest of their woody biomass comes from managed natural forests. Norway's most abundant tree species is spruce which accounts for 60-70% of Norway's woody biomass (Erik Hohle, personal communication, 14th July, 2019).

Approximately 50% of a healthy tree will become lumber products, 30% will be used for paper and pulp, and the remaining 20% will be used for energy production (Erik Hohle, personal communication, 14th July, 2019). In energy production, Norway's woody biomass is primarily used in generating heat with the largest contributors to heating being firewood, forestry residues, and wood chips. Firewood has a large market in Norway as the largest contributor to household heating (Scarlat et al., 2011).

### **Energy Crops & Agricultural Residue**

Norway has little-to-no cultivation of energy crops as of 2011 (Scarlat et al., 2011). According to Scarlat et al., this is partially due to Norwegian agricultural policy which doesn't promote the cultivation of energy crops. It is likely also due to the fact that Norway has little arable land. As of 2017, roughly 3% of Norway's area was arable land (Burton, 2017).

Agriculture does contribute to some of the energy production in Norway with agricultural residues being used for biogas and cellulosic extraction.

### **Aquaculture**

Algae cultivation is still a young industry in Norway (discussed in greater detail in section 6). Seaweed is the main source of algae in Norway and it is mainly used in cosmetics, pharmaceuticals, and food production (Stévant et al., 2017).

### **Anthropogenic Waste**

In 2018, waste incineration was the single largest source of heat used for district heating in Norway. As can be seen in figure 2, waste incineration accounts for roughly 3000 GWh of

district heating. Wood waste is the second most utilized resource, producing roughly 1500 GWh of energy.

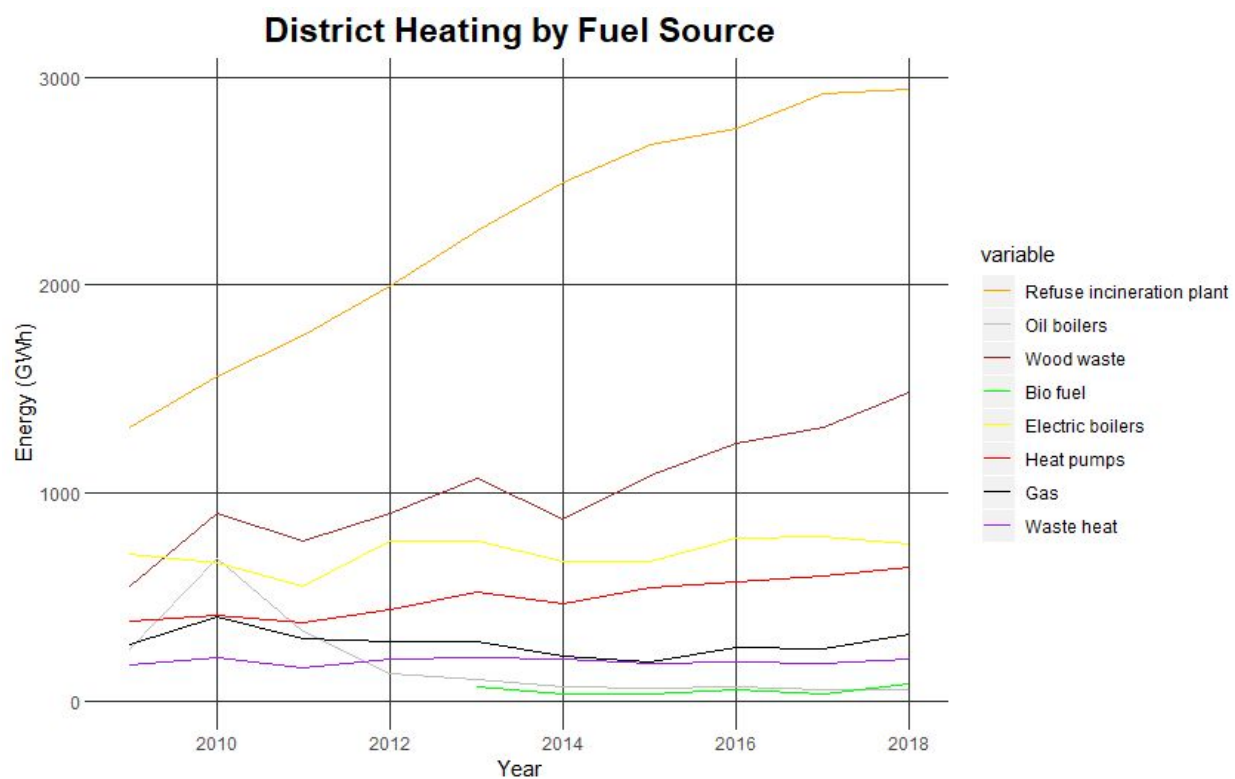


Figure 2. Norway's district heating by fuel source. *Note.* This graph was created from data accessed from SSB at <https://www.ssb.no/en/statbank/table/04727/>

Not only is energy from waste a prevalent energy source for district heating, it is also one of the most common methods of waste processing in Norway. As can be seen in figure 3, nearly 40% of non-hazardous waste is incinerated in Norway.

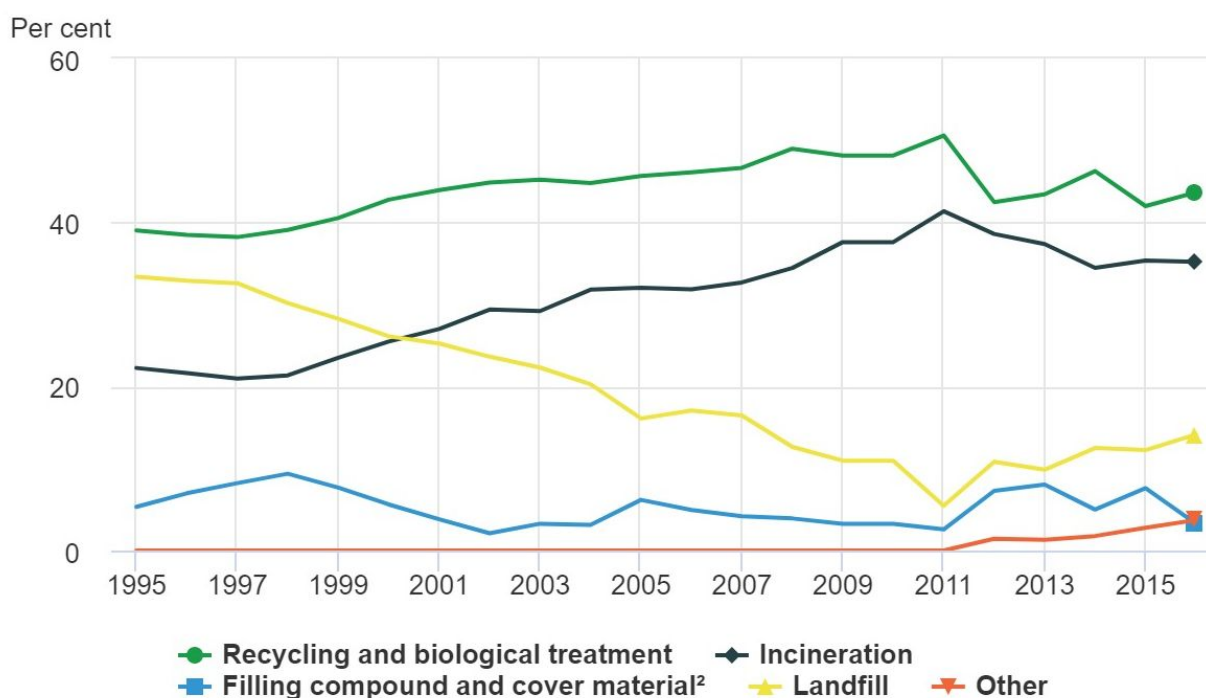


Figure 3. Non-hazardous waste in Norway, by method of treatment. *Note.* Reprinted from SSB. Graph found at:

<https://www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/less-recycling-more-waste-to-land-fill>

Norway's incinerated waste includes a variety of organic and inorganic matter and when waste incineration occurs, it's often a mix of several materials. Figure 4 shows the composition of waste in Norway.

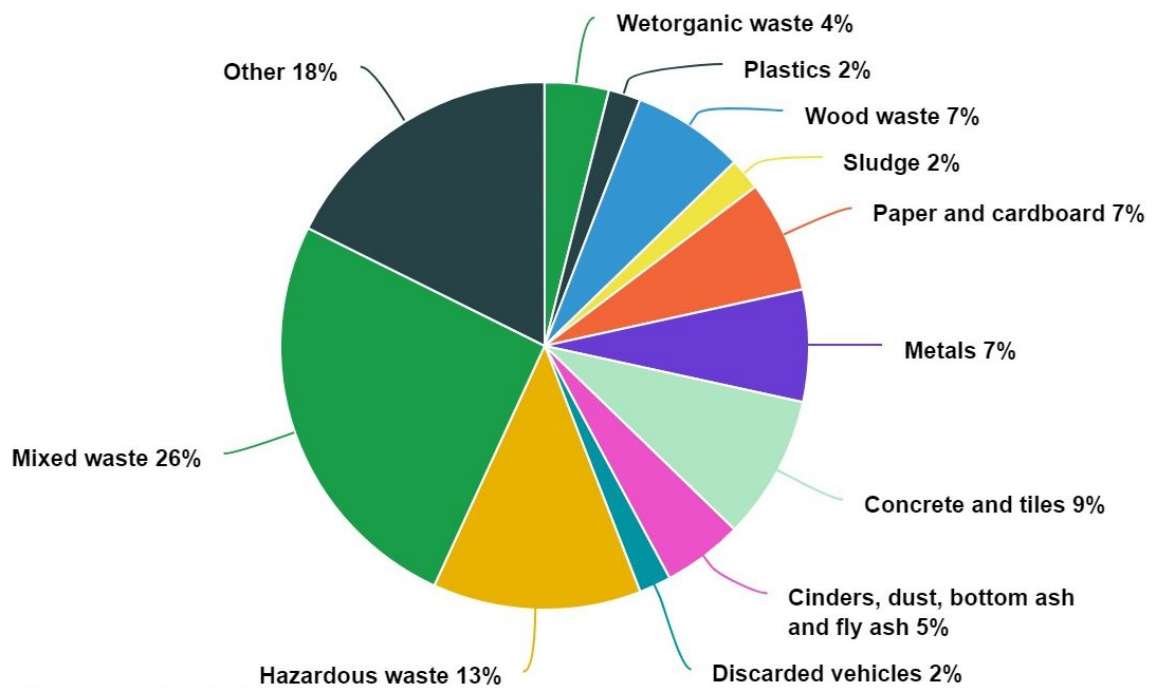


Figure 4. Norway's waste by type in 2016. *Note.* Reprinted from SSB. Graph found at: <https://www.ssb.no/en/natur-og-miljo/artikler-og-publikasjoner/less-recycling-more-waste-to-land-fill>

**Animal byproducts:**

The creation of biogas and heat are popular uses of animal byproducts in Norway.

Animal byproducts are utilized at a large scale in the Brevik cement factory and the Skogn biogas plant. At the Brevik NorCem cement factory, 23% of the energy consumption comes from biomass, which includes woodchips, paper, textiles, and animal meal ("Carbon," n.d.). At the Skogn biogas plant (Biokraft Skogn), biogas is created using animal byproducts from farmed fish and forestry residues ("Biokraft Skogn | Biokraft," n.d.).

Manure is also utilized in the Norwegian bioeconomy by turning it into biogas. Creating biogas from manure is important from a GHG emissions perspective because the biogas can displace fossil-fuel based gas and prevent the manure from producing GHG emissions as it decomposes. Creating biogas from manure is one of the strategies the Norwegian government has outlined for reducing emissions from agriculture (Norwegian Ministry of Agriculture and Food, 2009).

### **Energy Potential from Norwegian bioenergy**

Norway harvests approximately 44% of its woody biomass potential every year (Scarlat et al., 2011). Scarlat et al. estimate that Norway could sustainably harvest between 86 and 108 PJ of forest biomass per year. This would comprise the majority of Norway's sustainable biomass potential which Scarlat et al. estimate is between 117 and 140 PJ per year.

Although Norway has substantial amounts of additional forestry potential, Norway's challenging topology makes accessing additional forest area challenging, meaning that additional forest biomass may be more expensive and resource intensive to actually harvest (Scarlat et al., 2011).

### **Putting Norway's bioenergy into perspective**

As discussed in the introduction, in 2008, Norway set a goal to reach 100PJ of bioenergy by 2020 (Trømborg et al., 2011). Figure 5 has been created to illustrate Norway's energy mix over the last 28 years. The graph has been extended to 2020 in order to show how steep the growth in bioenergy would need to be in order for Norway to meet their goals from 2008.

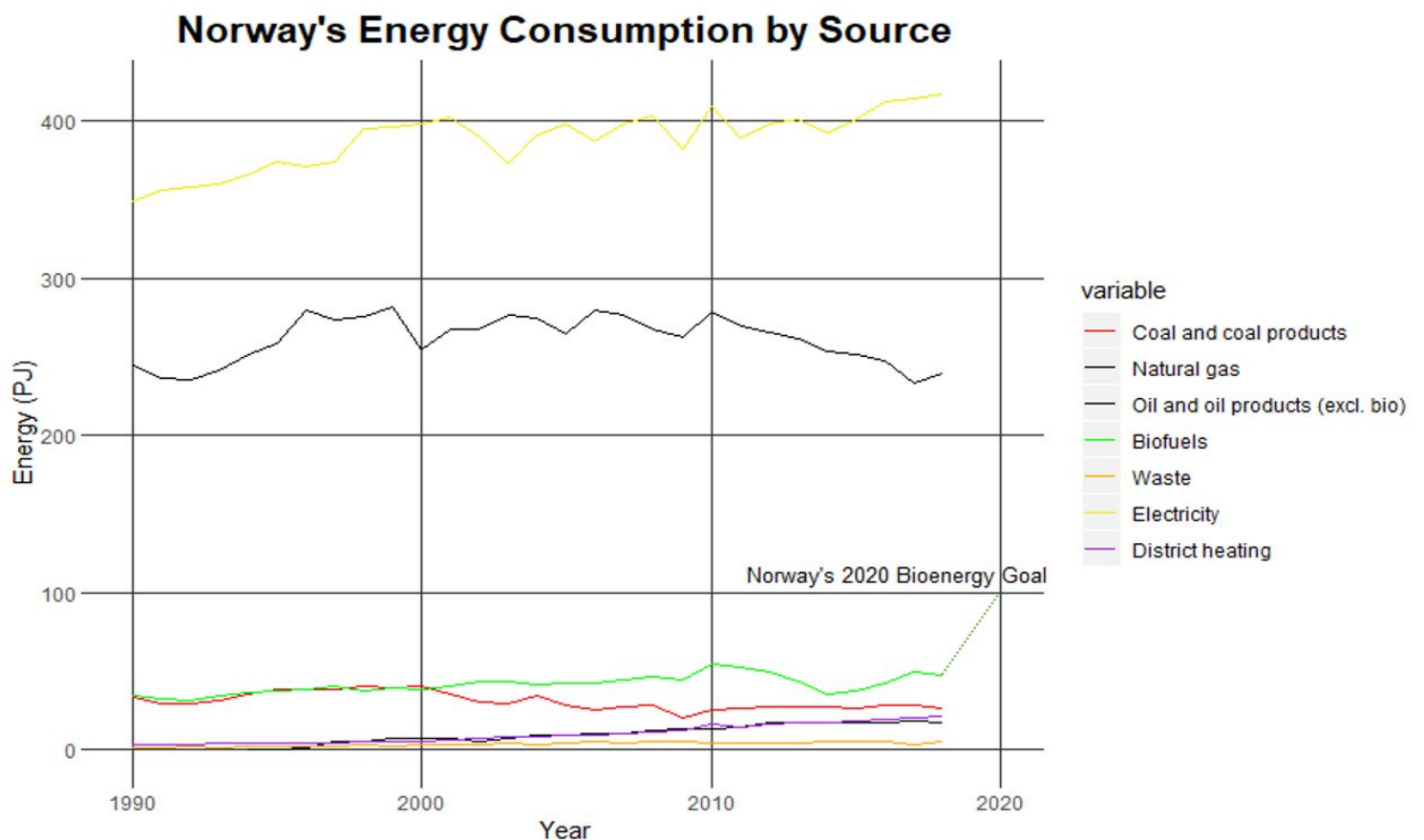


Figure 5. The energy mix of Norway from 1990 to 2018. Biofuels in this dataset refers to all sources of bioenergy consumed in Norway. The dashed green line leading from 2018's biofuels consumption to 2020 illustrates the growth which would be needed in order for Norway to reach its goal. *Note.* This graph was created using data made available by SSB at: <https://www.ssb.no/en/statbank/table/11562/>

Norway's most prominent energy source is electricity generated from hydroelectric dams. Norway's hydro production accounts for the majority of its electricity consumption and allows cheap, sustainable electricity for much of the country.

The prevalence of oil and oil products in the energy consumption mix is in large part due to the transportation sector. Of the roughly 240 PJ of oil consumed in Norway in 2018, 170 PJ was consumed by the transportation sector. This is important to note because in 2012, transportation accounted for nearly 40% of Norway's GHG emissions within the energy sector (United Nations Climate Change Secretariat, n.d.). A decarbonization of the transportation sector would mean a reduction of much of Norway's GHG emissions.

Norway has made efforts to decarbonize the transportation sector which are likely to continue into the future. As of 2018, roughly 20% of Norway's transportation sector was powered by

renewable fuels. As can be seen in figure 6, much of the overall renewable energy in the transportation sector was generated through biofuels.

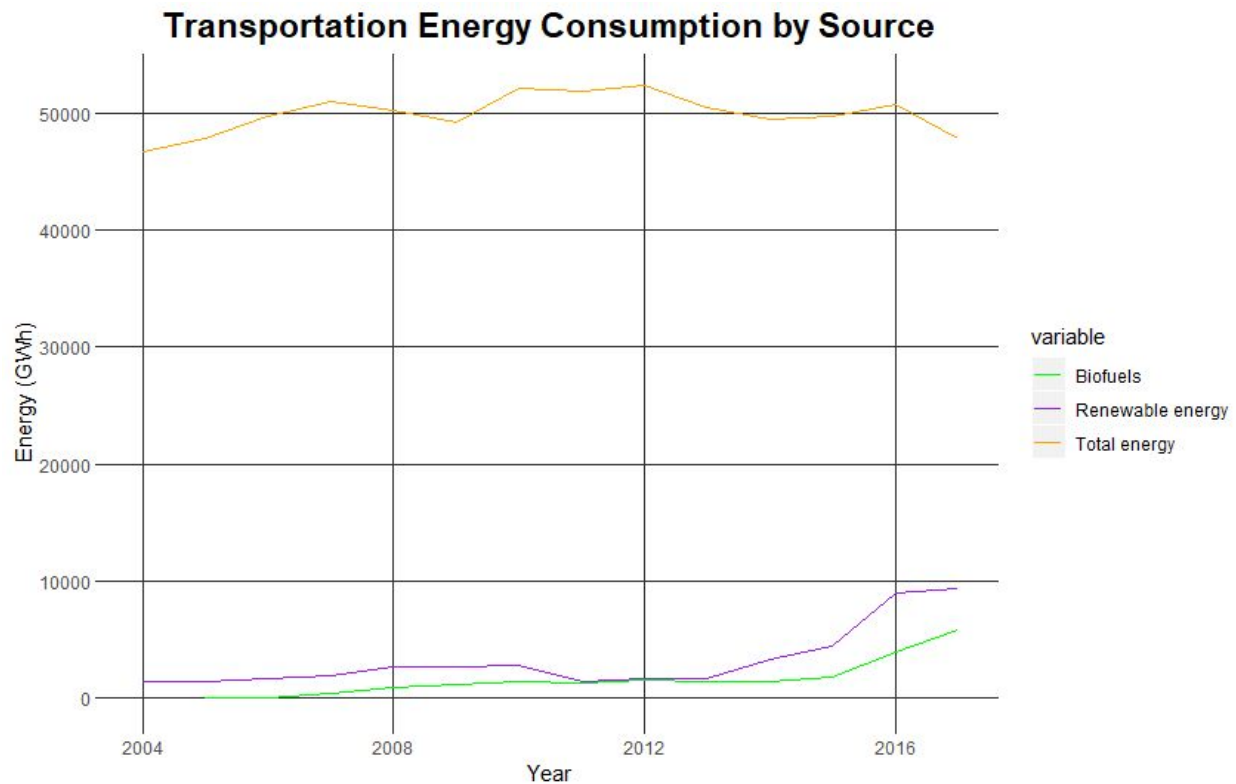


Figure 6. Transportation energy consumption in Norway. Biofuels are separated from renewables in this illustration to show the contribution that they make to renewable energy in the transportation sector. The majority of the remaining renewable energy in the transportation sector is comprised of electric vehicles. *Note.* Graph created using data made available by SSB at: <https://www.ssb.no/en/statbank/table/11564/>

## **5. INCLUDE's Criteria**

### **INCLUDE Framework**

In order to understand and address social changes brought about through energy transition, the INCLUsive Decarbonization and Energy transition (INCLUDE) center was created at the University of Oslo. INCLUDE is comprised of stakeholders and partners from a number of organizations including: CICERO, FNI, UiT, OsloMet, TØI, and Durham University. INCLUDE is interested in solutions anchored in knowledge about social structures due to the potential these types of knowledge have to lead to a quicker transition to a low carbon society.

INCLUDE's framework is included in this paper to provide an overview of how Norway's bioeconomy pertains to socially inclusive decarbonization. This paper attempts to identify how the bioeconomy relates to these objectives in order to provide a starting point for more thorough research to be done in the future.

### **Objective 1: Reduction of Emissions**

A growth in the bioeconomy has the possibility of reducing GHG emissions through displacing fossil-fuel based products in the energy, materials, transportation fuels, and chemical sectors.

#### **Power Sector**

In order to determine the emissions of different energy sources, lifecycle assessments are commonly employed. The strength of using a lifecycle assessment instead of just quantifying the emissions produced by an energy source each year is that it offers a more complete picture of how much of a burden different sources put on the environment over the duration of their life times (Amponsah, Troldborg, Kington, Aalders, Hough, 2014). Amponsah et al. carried out a meta-analysis of lifecycle assessments measuring a variety of energy sources in order to compare the amount of CO<sub>2</sub>-equivalent emissions they emit per kilowatt-hour of energy produced over their lifetime. This includes emissions stemming from: plant and equipment production; acquisition, processing, and transportation; operation (the actual production of energy); and storage/disposal.

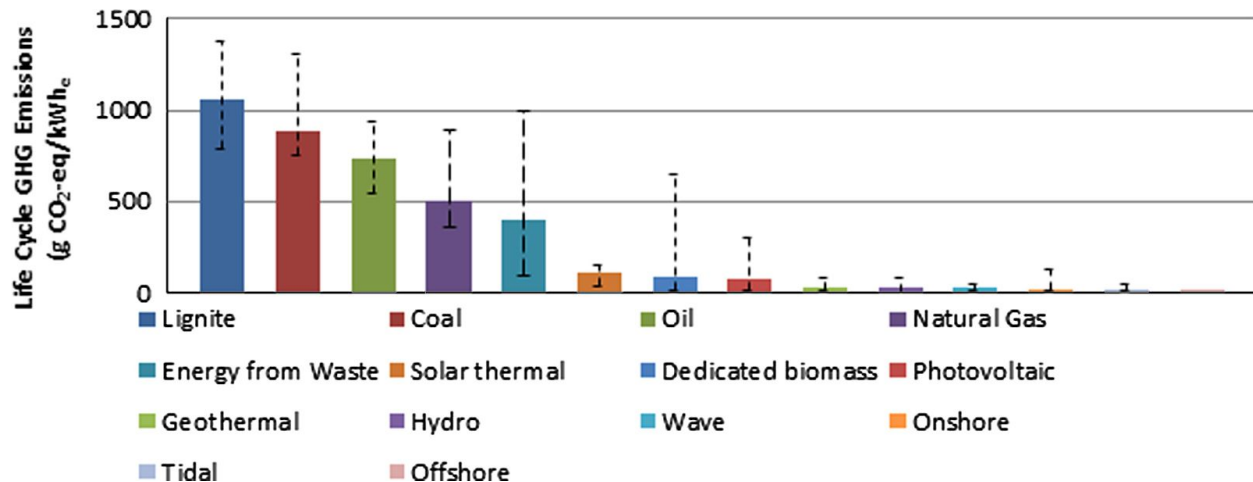


Figure 7. The amount of CO<sub>2</sub> equivalent emissions emitted per kilowatt-hour of energy produced for a number of popular energy sources. *Note.* Reprinted from “Greenhouse gas emissions from renewable resources: a review of lifecycle considerations”, by Amponsah, N., Troldborg, M., Kington, B., Alders, I., Hough, R., 2014, *Renewable and Sustainable Journal Reviews*, 39, p. 471

In addition to producing CO<sub>2</sub>, burning mass for energy also creates other harmful air pollutants such as methane and sulphur dioxide. (Jones, et al., 2014). In order to standardize GHG emissions measurements, CO<sub>2</sub> equivalent is used instead of reporting many different types of pollutants.

The confidence intervals are noted by the black lines in the bars. The size of a confidence interval can be affected by the variability between samples as well as the total number of samples used (Dienes, 2008). As can be seen in the above figure, the confidence interval for the CO<sub>2</sub> emissions produced from Energy from Waste and Dedicated biomass is quite large. Amponsah et al. (2014) note that this is due to the different kinds of LCA analyses done on energy, different modeling techniques, and also due to the different types of wastes which are used and which biomass resources are utilized.

Although energy from waste is shown by Amponsah et al. (2014) to be one of the highest emissions-producing renewable resources, capturing energy from waste can be seen to be an appropriate use of waste because producing energy from biomass can “alleviate some of the environmental pressures associated with landfill, such as methane emissions from anaerobic decomposition of biomass in landfill” (Amponsah et al., 2014, p. 468). This utilization of biowaste may lead to lower greenhouse gas emissions in the long-run than leaving the biomass in landfills to decompose and produce greenhouse gasses.

The degree to which burning biomass for energy will lead to a reduction of greenhouse gasses is dependent upon the crop and the amount of resources which go into cultivating, fertilizing, and harvesting it (Jones et al., 2014). For example, the amount of water or fertilizer needed, the transportation needed, and the processing requirements all affect the total amount of greenhouse gasses which are produced through using a bioenergy resource.

Additionally, the amount of greenhouse gas emission reductions which bioenergy brings to an energy system also depends upon the energy source which bioenergy displaces. Racoceanu (2018) has demonstrated that by substituting a portion of coal for biofuel in a cofiring plant, greenhouse gas emissions can be found.

Following the LCA emissions calculations found in figure 7, if bioenergy (from either waste or dedicated biomass) displaces coal, lignite, oil, or natural gas, a reduction in emissions can be expected. However, if waste burning displaces hydropower, a reduction in emissions is not expected. Therefore, whether bioenergy leads to reductions in GHG emissions is context dependent. A country like Norway which utilizes large scale hydro, would not see reductions in the electricity sector by displacing hydro with biomass.

However, in countries such as Germany and Poland, where coal is the dominant energy source ("Overview of electricity production and use in Europe," 2019), replacing coal with biomass may yield large decreases in GHG emissions. This is an especially attractive option if power plants in these countries already have the ability to co-fire biomass and coal together and do not require new infrastructure in order to decrease their carbon emissions.

### **Building materials:**

There are substantial emissions reductions which can be had in the materials sector by increasing tree use. According to the Energy Transmissions Commission, substituting timber for cement can account for up to an 85% reduction in emissions from construction (ETC 2019b). A relevant example of substituting lumber for cement is the Wood Hotel in Brumunddal, Norway. The wood hotel is advertised as being the world's tallest timber building (Frish, n.d.) and is constructed primarily from wood.

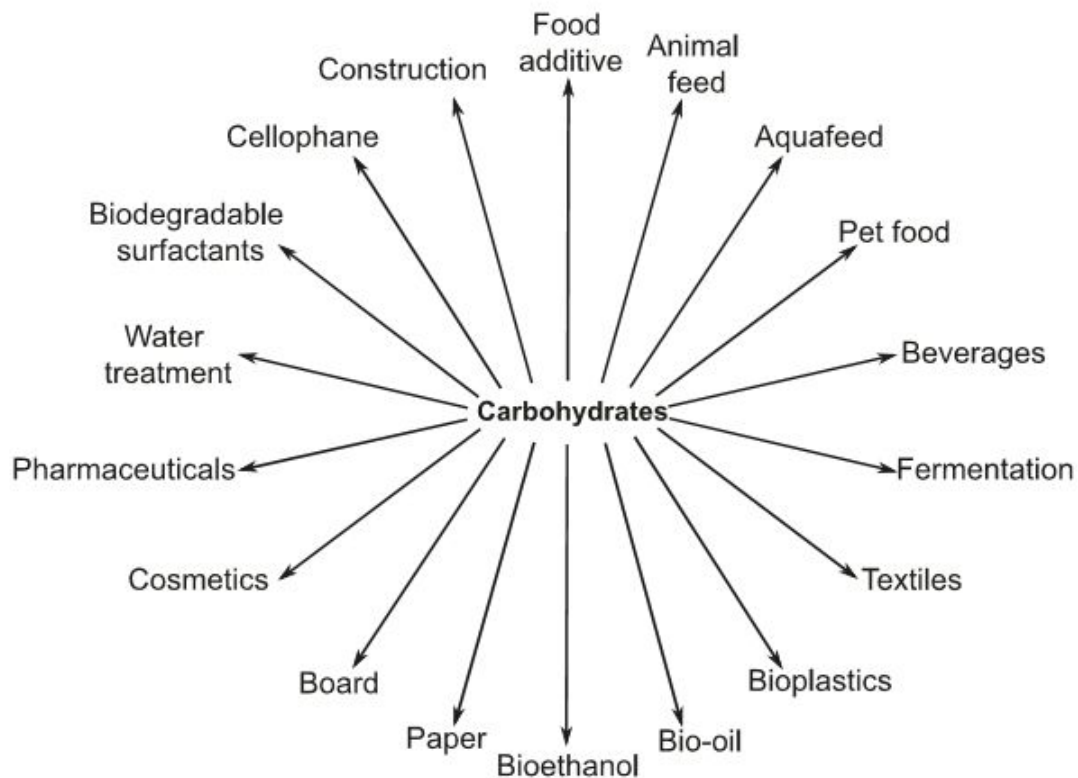


Figure 8. Material possibilities from biomass carbohydrates. *Note.* Reprinted from “*Plant Bioproducts*”, Chen, G.; Weselake, R.; Singer, S., 2018, p.110, New York, NY, copyright 2018 Springer Science+Business Media LLC, 2018.

Biomaterials are not only capable of displacing cement, as seen in figure 8, they have the ability to displace many other materials outside of construction as well.

The biomaterials which can displace non-biodegradable and non-recyclable materials are especially interesting. Among those, bioplastic use is a fast developing field. Bioplastics are currently used in a number of markets such as packaging, textiles, transportation, and consumer goods (“Bioplastics Market Data”, n.d.). According to Bioplastics Market Data, packaging is the largest bioplastics market with roughly 65% of the market share in 2018.

### **Biofuels:**

Some industries are particularly difficult to decarbonize due to logistic and technological challenges in electrifying them. It is in these industries that biofuel can make a significant difference.

In Norway in 2014, a total of 68 TWh of energy was used for transport. Of this 68 TWh, approximately 91% of the energy was generated using fossil fuels and 9% was generated through renewables (NVE, 2018). In 2017, nearly 48 TWh of energy was consumed for transport with roughly 80% coming from fossil fuels and nearly 20% coming from renewables (SSB, 2019). As can be seen in figure 6 in section 4, much of this renewable energy came from biofuels.

Biofuels will likely continue to be an important fuel source in Norwegian transportation alongside electricity. NVE (2018) projections indicate that although electric vehicles can displace much of the fossil fuel based transportation, some sectors such as long distance trucking, shipping, and aviation will primarily be displaced by biofuels and hydrogen. According to NVE (2018), future biofuel production will primarily come from forestry.

## **Chemicals**

The chemicals industry is the third largest GHG emissions producer globally (Philip, 2017). This means that a greater focus on chemical extraction from biomass may lead to significant global GHG emission reductions.

Substituting petrochemical for biochemicals can lead to emissions reductions through cleaner processing and cleaner resource extraction. (Chen et al., 2018). Furthermore, biomass has the potential to produce a multitude of chemicals for plastics, gasses, solvents, and many other alternatives.

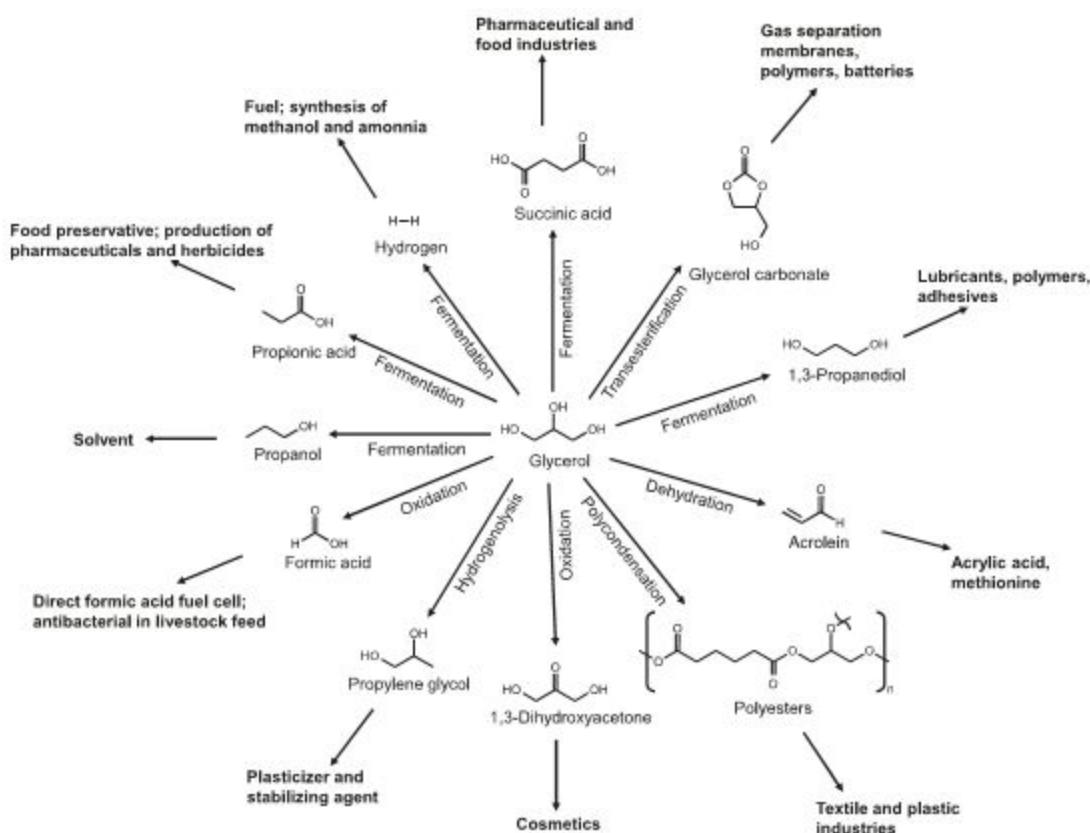


Figure 9. Chemical possibilities from glycerol extracted from biomass. *Note.* Reprinted from “*Plant Bioproducts*”, Chen, G.; Weselake, R.; Singer, S., 2018, p.182, New York, NY, copyright 2018 Springer Science+Business Media LLC, 2018.

As figure 9 illustrates, the potential for chemical extraction from biomass is substantial. Aquaculture may be especially relevant for chemical extraction due to microalgae’s unique composition (Hannon et al., 2010). Chemical extraction has already shown to have potential in Norway’s aquaculture through the production of chemicals for the cosmetics and pharmaceutical industries (Stévant et al., 2017).

The greatest decreases in GHG emissions coming from biomass within Norway would likely come from replacing fossil fuels with biofuels, replacing cement with biomass, and procuring chemicals from biomass instead of petroleum (ETC 2019a, ETC 2019b).

## Objective 2:Energy Security

Energy security is a concept which has a variety of definitions and foci (Ang, Choong, Ng, 2014). Ang et al. (2014) conducted a literature review which yielded 83 unique definitions of energy security. From these definitions, Ang et al. identified seven main parameters which many

authors used in their definitions of energy security: energy availability, infrastructure, energy prices, societal effects, environment, governance, and energy efficiency.

Biosecurity is a subsection of energy security which has been defined as being chiefly concerned with “protecting the integrity of each nation’s biological resources (agricultural production, biodiversity, and ecosystem services)” (Sheppard et al., 2011, p.7). A growth in the bioeconomy may have undesirable biosecurity risks if not planned appropriately. This includes crops introduced into new ecosystems becoming invasive and spreading in detrimental ways, new toxins and allergens from novel crops, and new pest management techniques needed for novel crops (Sheppard et al., 2011).

Some of the concerns about energy security and biosecurity aren’t especially pressing in the Norwegian context. If much of the expansion of Norway’s bioenergy will come from more intensive forestry, issues surrounding new invasive species is not currently a problem. Additionally, Norway currently doesn’t use genetically modified trees (Erik Hohle, personal communication, 14th July), so a concern of genetically modified trees dominating an ecosystem also isn’t relevant. Since Norway doesn’t cultivate a significant amount of energy crops (Scarlat et al., 2011), issues related to ethical use of arable land are not as relevant in Norway. Norway is also a net exporter of primary energy (oil) and produces much more oil than they consume, meaning that energy availability is not an especially worrisome issue for Norway.

Issues surrounding energy security and biosecurity are likely to be especially pressing for a country with extensive agriculture which imports much of their energy supply from neighboring countries. In a scenario such as this, concerns about energy security are likely powerful drivers towards a greater adoption of biomass.

### **Objective 3: Enhanced utilization of natural resources**

One of the benefits of using bio-based products is that they are often used for more than one thing. In Forestry, agriculture, and animal slaughter, waste products from the primary product can be utilized for energy or materials production.

Promoting Norway’s bioeconomy can lead to greater utilization of natural resources through using waste products (such as in the Skogn biogas and Brevik cement factories) and also through using raw natural resources for novel purposes as is the case for the still nascent seaweed industry in Norway.

### **Objective 4: Innovation and value creation**

The bioeconomy is a field which has no dearth of innovation potential. As can be seen in figures 8 and 9 above, biomass can be converted into a number of chemical and material products which can create a much greater diversity of products than petrochemical production with less processing required (Chen et al., 2018). The potential to displace petrochemicals and materials

is immediately apparent; but biomass is also likely to produce a number of novel products which aren't currently produced.

Aquaculture will likely see much innovation in Norway in coming years. Since aquaculture is quite new in Norway, there will likely be growth in utilization and cultivation techniques as well as an expansion in the importance of algae in Norway's bioeconomy.

Value creation in Norway's bioeconomy is likely to come from secondary processing. This will be determined -at least in part- by the number and the types of biorefineries which Norway builds. As presented in section 4, Norway has already begun seeing a number of new biorefineries specialized in creating biofuel. It is possible that Norway will explore biorefinery options related chemical extraction and biomaterials creation in order to capitalize on their aquaculture potential.

### **Objective 5:Energy Democracy, Energy Justice, and Inclusiveness**

An important consideration in the INCLUDE framework is the potential effects which the energy transition has on issues related to social justice, democracy, and inclusiveness.

Energy democracy entails giving energy consumers a greater degree of choice over the energy they use. Energy democracy has been described as an "ideal political goal, in which citizens are the recipients, stakeholders (as consumers, producers), and accountholders of the entire energy sector policy" (Szulecki, 2017, p. 35). According to Szelucki, energy democracy can lead to more legitimate and higher quality decisions which have a higher probability of serving more people's interests than when simply giving all energy-related questions to the "technoscientific power sector" which is more focused on economic frameworks.

In a similar vein to energy democracy, energy justice entails that societal actors are represented and are allowed access to cleaner energy production and quality-of-life improvements which may come from an energy transition. According to Creutzig et al. (2014), efforts to mitigate climate change have foundations in energy justice and is most powerful when a synthesis of local, national, and global goals are met.

The bioeconomy has the potential to promote energy democracy and justice as well as support rural communities by creating additional income through new industry. The policy foci of energy security, continuous reductions in GHG emissions, and rural development are the forces behind the EU's biofuels industry development (Chen et al., 2018). According to EuroBioRef (2014), bioeconomy-based projects have the ability to create specialized jobs in rural economies which will lead to business -based on and located- in local economies. EuroBioRef predicts that the EU initiatives within EuroBioRef will lead to the creation of 200,000 jobs.

Europe's bioeconomy development is designed in part to enrich rural economies. Whether the bioeconomy leads to greater energy democracy or justice is dependent upon how much choice

and representation these communities have in bioeconomic decision making. Presumably, a greater selection of bioplastics, biomaterials, and bioenergy will allow consumers who prefer plastic-free alternatives to have greater choice over what they consume.

## **6. The Future of Bioenergy in Norway (Hurdles & Promising Developments)**

### **The forest, the air, and the sea**

Important biomass endeavors in Norway's future will likely include utilizing forest biomass for fuel creation and increasing the capacity of algae harvesting (Avinor, n.d., Stévant et al., 2017).

The construction of 2nd generation biofuel plants is already underway in Norway. In Tofte, Statkraft & Södra Cell have designed a medium-scale commercial facility which is slated to begin producing biofuel by 2025 (Chudy, 2019). Additionally, Biozin Holding As has plans to build a 2nd generation biofuel plant in Åmil, on the site of a large sawmill. Biozin plans on building four more biofuel plants in Norway, most likely nearby other sawmills or forestry processing facilities ("Sustainable biofuel from Norwegian forests," 2019). Both the Biozin and the Statkraft & Södra Cell plants plan on using forestry residues as their primary source for production.

Avinor echoes the importance of Norwegian forests for biofuel production and believes that large-scale use of biofuel in Norway's aviation industry can occur in the near future (as early as 2020-2025) (Avinor, n.d.). Avinor also believes that this fuel production will come primarily from Norwegian forestry.

With large R&D projects such as the EurBioRef (2014), and Europe's initiatives to accelerate its bioeconomy growth, it's probable that Norway's woody biomass be used for a variety of fuels and secondary products.

In addition to an increase in the products coming from forestry, algae will likely become an increasingly important resource with a multitude of products created from it. Seaweed cultivation is still quite new in Norway- with permits for commercial cultivation of seaweeds granted for the first time in 2014. Between 2014 and 2016, the cultivation area of Seaweed tripled in Norway (Stévant et al., 2017). Algae will likely grow be utilized for chemical extraction, animal and human consumption, biomaterials use, and fuels. Microalgae is likely to become an important source of biofuel if processing costs continue to fall.

### **Strategies for Promoting bioenergy and the bioeconomy**

Policy can incentivize a greater biomass utilization through promoting research into new technologies and promoting the use of existing technologies.

Governmental funding of technologies which are far from commercialization and have applications in many sectors can be important for kickstarting future products (Harvey, Orvis, &

Rissman, 2018). A salient example of this is the European Union's European Multilevel Integrated Biorefinery design for sustainable biomass processing (EuroBioRef). EuroBioRef was a four year R&D program which allowed for large-scale research and testing of a number of biorefinery processes including bio-jet fuel production and novel biochemical extraction techniques. EuroBioRef included bioeconomy stakeholders throughout Europe- including Norwegian stakeholders such as SINTEF and Borregaard.

A growth in the bioeconomy doesn't only rely on the development of new technologies, however. Carbon pricing is one of the most powerful policy tools for inducing change and can lead to some of the greatest reductions in global GHG emissions without relying on future technologies (Harvey et al., 2018). Governments can also set performance standards which limit the amount of emissions power plants are able to emit. Setting a sufficiently high carbon price could push coal-burning power plants to begin co-firing with biomass and increase biomass usage rapidly.

### **Issues surrounding bioeconomy intensification**

Due to the rising importance of bioenergy products, there is likely to be a greater demand globally on biomass from forestry and agriculture (Gardiner & Moore, 2014). This may lead to incentivizing unsustainable forestry and agricultural practices for short term profit if there isn't enough oversight. In Norway, there will likely be a greater demand on forest resources in order to provide construction material, heating, and fuel.

Furthermore, in order for the bioeconomy's goals to be realized, the definition of *sustainability* may need to be expanded. Szulecka (2019) envisions sustainability as a spectrum wherein full sustainability entails a holistic perspective which includes taking into account the impact which the bioeconomy has on people who make a living from harvesting and processing biomass resources. This means that a low emissions emitting biomass source couldn't be considered sustainable if the impact which it has on people isn't taken into consideration.

If an overarching goal of the bioeconomy is to reduce total GHG emissions over a 50 year period, producing power from biomass may not be the most effective way to achieve this. Beginning to co-fire biomass with coal may create short-term emissions reductions compared to power plants which use only coal, but if co-firing biomass with coal slows down the adoption of lower carbon options such as offshore wind or hydropower, it's possible that this could lead to greater GHG emissions in the long run. Biomass is a readily available transitional energy source as society transitions away from fossil fuels, but if the use of bioenergy slows the adoption of lower-carbon alternatives, it may not effectively mitigate climate change.

Biomass is not an unlimited resource and there are limits on how much can be sustainably harvested before diminishing global capacity. Due to the limitations of the global biomass supply, it may be important to focus biomass efforts and use them to pursue industries which are the hardest to decarbonize. The Energy Transitions Commission (ETC) has identified

aviation as one of the most important industries to use biomass in due to its foreseeable reliance on a liquid fuel source (ETC, 2019b).

ETC states that the global supply of sustainable biomass is between 70-100 exajoules (1 exajoule is equal to 1000 petajoules). It is also estimated by the ETC that the 2050 demand for aviation fuel will require up to 45EJ of biomass. Due to this, the ETC recommends that aviation receive priority for biomass production. Maintaining an overview of how much biomass supply is available is paramount in making sure that its production goes to the areas that most need it.

## **Discussion**

This paper has attempted to outline what biomass is and how Norway uses the biomass resources that it has. This paper has also examined biomass use through INCLUDE's framework and extrapolated what the medium-term future of biomass in Norway may be based on current trends.

This paper has examined the supply side of biomass and the bioeconomy, but a look into the behavior of the demand side is potentially just as important. In order to reduce GHG emissions, reducing the demand for transportation fuels through collective transportation and improved bicycling routes may be as important as increasing the supply of low-carbon transportation fuels. Reducing the energy demands for heating or cooling buildings could come from higher energy efficiency standards and greater climate-specific design choices for buildings instead of burning more wood chips. Reducing agricultural emissions through creating biogas is powerful, but perhaps reducing agricultural emissions through raising less cattle is even more important. These topics are beyond the scope of the current paper, but are nonetheless important to ponder when considering what a low-carbon future may look like.

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## 8. Appendices

### Appendix A.

#### Maersk Case Study

A promising case study from a shipping company which gives optimism for highly polluting companies which need to change in the near future:

Shipping vessels around the world currently use “bunker fuel”, a marine heavy fuel which is considered an especially highly polluting fuel source due to its high levels of sulfur oxide emissions (Pearce, F., 21st November, 2009; IMO, 2016). Sulfur oxide has been shown to harm a large range of natural systems including agriculture, forests and aquaculture as well as to contribute to ocean acidification and acid rain (IMO, 2016).

In 2009, a representative of the world’s largest shipping company, Maersk (MoverDB.com, n.d.) had said that the cost of switching to a cleaner fuel was prohibitively expensive and a reason why Maersk and other shipping companies continued to use bunker fuel (Pearce, F., 21st November, 2009).

9 years following these statements, Maersk has made a pledge to become carbon neutral by 2050 (Jacobson, S., 5th, December, 2018). The pledge to become carbon neutral may entail using a variety of fuel sources, and biofuels are likely to be one of them.

Maersk has embarked upon a pilot project for shipping with H&M wherein they will begin using cooking oil blended with fuel oil to power one of their ships (Hand & Hand, n.d.). Although blending biofuel with fossil fuel is not carbon neutral, it is less polluting than using only fossil fuel, and blending cooking oil with fossil fuel can be an effective transition towards a less carbon-intensive future. It’s also a technology which can be used right now in many vehicles without significant engine modifications, potentially cutting down the adoption times of emissions reducing fuel sources.

Maersk operates out of Denmark and has more than 500 ships in its fleet (“Maersk Line – International Shipping Services & Reviews,” n.d.). This news may provide some hope for companies in 2019 which say the cost of switching over to more sustainable alternatives isn’t feasible.

**Major products produced from various biomass sources**

| Source                       | Energy Uses                    | Construction/Building Material | Other carbohydrate Material  | Food, Chemical, etc.                                                                  |
|------------------------------|--------------------------------|--------------------------------|------------------------------|---------------------------------------------------------------------------------------|
| <b>Woody Biomass</b>         | bioethanol, biodiesel, heat    | lumber                         | paper, bioplastic            |                                                                                       |
| <b>Energy Crops</b>          |                                |                                |                              |                                                                                       |
| Grass                        | heat                           |                                | bioplastic, paper, adhesives |                                                                                       |
| Grains                       | bioethanol, biodiesel, bio-oil |                                | bioplastic                   | building-block chemicals, animal & human consumption, alcohol distillation            |
| Seeds/Beans                  | bioethanol, biodiesel          |                                | starches, bioplastic         | building-block chemicals, animal & human consumption                                  |
| <b>Agricultural Residue</b>  |                                |                                |                              |                                                                                       |
| Crop Residue                 | ethanol                        |                                | bioplastic                   |                                                                                       |
| <b>Algae</b>                 |                                |                                |                              |                                                                                       |
| Micro                        | biodiesel, bio-oil             |                                |                              | building-block chemicals                                                              |
| Macro                        |                                |                                |                              | animal & human consumption, building block chemicals - esp. pharmaceutical & cosmetic |
| <b>Anthropogenic</b>         |                                |                                |                              |                                                                                       |
| Landfill Waste               | heat                           |                                |                              |                                                                                       |
| Sludge                       | biogas                         |                                | soil fertilizer              |                                                                                       |
| <b>Animal Waste Products</b> |                                |                                |                              |                                                                                       |
| Byproducts from slaughter    | heat                           |                                |                              |                                                                                       |
| Manure                       | biogas                         |                                | soil Fertilizer              |                                                                                       |

## **Appendix C. Research, organizations, and companies involving the bioeconomy**

### **Academic Papers**

Scarlat, N., Dallemand, J.-F., Skjelhaugen, O. J., Asplund, D., & Nesheim, L. (2011). An overview of the biomass resource potential of Norway for bioenergy use. *Renewable and Sustainable Energy Reviews*, 15(7), 3388–3398.

<https://doi.org/10.1016/j.rser.2011.04.028>

Scarlat et al. have quantified Norway's biomass potential in systematic and comprehensive report.

Stévant, P., Rebours, C., & Chapman, A. (2017). Seaweed aquaculture in Norway: recent industrial developments and future perspectives. *Aquaculture International*, 25(4), 1373–1390. <https://doi.org/10.1007/s10499-017-0120-7>

Stévant et al. have provided an account of current Norwegian seaweed aquaculture as well as mapping out some barriers to further development.

### **Organizations and Universities**

The energy farm in Brandbu, Norway educates the public on bioenergy use and advises on projects across Norway.

<http://www.energigarden.no/>

Oregon State University's Agricultural Sciences Department have put out a number of lectures surrounding bioenergy sources, processing, and use. They are a helpful introduction into the world of biomass.

<https://agsci.oregonstate.edu/bioenergy-education/lecture-1-early-bioenergy-history>

The Nordaqua Center of Excellence project run by SINTEF is aimed at developing products from algae. Nordaqua includes stakeholders in Norway, Sweden, and Finland.

<https://www.sintef.no/prosjekter/nordaqua/>

Norwegian seaweed farms is an association of seaweed cultivators in Norway. It includes companies

<https://www.norwegianseaweedfarms.com/farmers>

The Energy Transitions Commission's Mission Possible reports are a helpful source to learn more about how to decarbonize difficult-to-decarbonize sectors of the economy.

<http://energy-transitions.org/mission-possible>

PROMAC conducted research on energy efficient value chain for macroalgae. PROMAC was funded through the Research Council of Norway.

<http://promac.no/about-the-project/>

## **Companies and Products**

Trefokus (Tree Focus in english) is a Norwegian company dedicated to disseminating knowledge about timber use, especially in construction. Trefokus is dedicated to increasing the use of wood as a construction material.

<http://www.trefokus.no/om-oss>

The wood hotel opened its doors in May 2019 in Brumunddal, Norway. The wood hotel is advertised as being the world's tallest timber building.

<https://www.frich.no/no/overnatting/brumunddal>

The Biofore concept car made from a collaboration of university and industry participants in Finland is a wood-based car made with wood composites, cellulose biocomposites, and runs on wood-based biodiesel.

<https://www.upm.com/bioforeconceptcar/>