Example: Corn-based Ethanol Supply Chain

This table shows how one might depict the supply chain of corn-based ethanol. Some possible inputs and outputs are listed above and below each step, respectively.

CO_2, H_2O, sunlight energy, fertilizers, pesticides, gas for machinery, people to perform work ↓	Fuel energy for vehicles transporting corn, people to perform work ↓	Fuel energy for machinery, electrical energy for facilities, water, people to run the machines ↓	Fuel energy for vehicles transporting the fuel, truck drivers ↓	Fuel energy for vehicles driving to gas stations, fuel and electricity to operate gas stations, drivers ↓	O_2, fuel energy, drivers ↓
Corn is grown and harvested →	**Corn is taken from farm to refinery** →	**Machines and chemicals change corn into fuel** →	**Fuel is taken to retail locations** →	**Customers buy fuel** →	**Fuel is burned in cars, trucks, or planes** →
↓ O_2 from living corn, CO_2, chemicals from fertilizers and pesticides, heat, CO_2	↓ CO_2, emissions from vehicles burning fuel, heat	↓ **Co-products (like feed for livestock)**, CO_2, emissions from machinery burning fuel or using electricity, heat	↓ CO_2, emissions from vehicles burning fuel, heat	↓ CO_2, emissions from vehicles burning fuel, heat	↓ CO_2, emissions from vehicles burning fuel, heat

Breaking News!

As Ethanol Takes Its First Steps, Congress Proposes a Giant Leap[3]

(*New York Times* 2007)

Bioenergy: Fuelling the food crisis?[4]

(*BBC News* 2008)

Is Ethanol a Solution, or a Problem?[5]

(*New York Times* 2011)

Corn Prices Rise Worldwide Due to U.S. Ethanol Policy, FAO Says[6]

(*Bloomberg* 2012)

Oil, biofuel companies evolve into uneasy 'frenemies'[7]

(*Chicago Tribune* 2012)

Feedstock Fact Sheet: Algae[8]

Algae are organisms that live in water and range in size from single-celled to complex multicellular forms like kelp. Algae can survive in a wide variety of habitats and have been found in salt water, freshwater, deserts, hot springs, and ice.[9] Microalgae, or single-celled algae, are the form of most interest to people in the biofuels industry. Over the years, researchers have found that about 10-50% of algae is oil that can be extracted and used to produce biofuels.

Feedstock

Algae need energy, nutrients, and water in order to grow. Photosynthetic algae use the sun as their energy source, while heterotrophic (organisms that cannot make their own food) algae use a carbon-rich chemical energy source to grow just as animals do. Researchers in the Pacific Northwest have suggested using both types of algae so that biomass can be grown year round—even when there is less sun. Both types of algae need heat and large amounts of carbon dioxide (CO_2) and nutrients like nitrogen and phosphorous. Because of this, algae cultivation would ideally be situated near power stations, cement plants, wastewater plants, dairy farms, pulp or paper plants, or other industrial areas that produce CO_2, heat, and nutrients. This has the added benefit of preventing the release of some of these waste products into the environment, especially CO_2, that would otherwise contribute to climate change.

Algae can be grown in open ponds or in closed bioreactors. Both methods require land and water. One study showed that 530,000 gallons of water were needed to fill a 20-centimeter deep 2.5 acre pond. Open ponds are exposed to changes in temperature and humidity and can be contaminated by outside algae species. Growing algae in a bioreactor instead of an open pond is generally more water efficient, but bioreactors are more expensive than open pond systems. On the positive side, algae doesn't need freshwater to grow; it can grow in wastewater or salt water. Growing algae also requires less land than other energy crops and it can often be grown on land not suited for agriculture. This means that freshwater and arable land can be saved for food crops.

Collection and Extraction

Algae grow quickly and can be harvested every day or every week. Because microalgae are so small, they stay suspended in their water source and must be filtered from the water and concentrated before the oil can be removed from algal cells. This step, known as drying or dewatering, takes a large amount of energy.[10]

Feedstock Fact Sheet: Algae *continued*

Conversion and Co-products

After the algae are removed and concentrated, three components are extracted from them: oil, carbohydrates, and proteins. The oil can then be refined into biofuels like jet fuel using already existing petroleum refineries. Carbohydrates and proteins can be converted into and sold as co-products such as animal feed, chemicals, and food. Some researchers also suggest converting the carbohydrates into fuel using a different processing method. These conversion processes require energy, chemicals, and equipment. If algae-based biofuels are to be commercially successful on a large scale, more research is needed to find ways to reduce the amount of energy needed for extraction and conversion processes.

Distribution and Consumption

It is likely that transporting biofuels to airports would be done using the same infrastructure that is used for fossil fuel transport. The Pacific Northwest has five main oil refineries in Washington State and petroleum products are transported via pipelines, barges, and trucks. Jet fuel is heavier than other fuels and is best shipped via trucks and barges. These transportation networks take refined fuels to storage facilities near airports or fuel terminals. This is where biofuels would be blended with petroleum-based jet fuel. Blended jet fuel would then be sent to airports using existing distribution systems.

Sustainability Factors: Algae	
Greenhouse Gas Emissions (GHG)	The amount of GHG produced in the algae-to-fuel supply chain is still unknown and depends on the processes used to convert algae and the fuels used to run machinery needed to cultivate and harvest algae. Studies have suggested that the production of biojet fuel from algae can create anywhere from one-fifth to twice the amount of GHG of petroleum-based jet fuel.
Food Security	Algae cultivation does not need land that could be used for food crops and its co-products can be used for animal feed.
Conservation	Large-scale cultivation of algae on sensitive lands could decrease the biodiversity of the area and harm ecosystems. If genetically modified algae are used, there is a risk that they might escape into surrounding ecosystems and become invasive species. Producers would have to comply with laws on genetically modified organisms.
Soil	Chemicals leaking into soil could be a concern if chemicals are used during the conversion process.
Water	It is possible to grow algae without freshwater, so this feedstock may not compete with food production for freshwater resources. Algae can be grown in wastewater or salt water and can in fact help clean these waters. However, growing algae requires a very large amount of water and after algae have been harvested the water might need to be treated to remove chemicals, fertilizers, salts, or other pollutants.
Air	Algae cultivation presents few air quality concerns.
Other Concerns	Additional research is needed to explore how to effectively use algae to produce fuel. The amount that could be produced in the Pacific Northwest and the cost of production are still unknown. Toxic chemicals used in conversion have significant impacts and are expensive. However, researchers are exploring more natural alternative methods.

Feedstock Fact Sheet: Oilseed (Camelina)[11]

As the name suggests, oilseeds are plants that produce seeds that contain lots of oil. Soybeans, sunflowers, canola, cotton, and peanuts are common types of oilseed that produce edible oils.[12] While many oilseeds thrive in the Midwest prairies, not all thrive in the Pacific Northwest. One oilseed that can grow in the Pacific Northwest is *Camelina sativa.* The oil content of camelina seeds ranges from 29-42%, making it a promising feedstock for biofuels.

Feedstock

Like other plants, oilseed crops use sunlight, carbon dioxide (CO_2), and water in the process of photosynthesis to produce food. In this process, they release oxygen to the atmosphere. Camelina is a hardy plant that can grow on lands unsuitable for food and matures in a short time (85-100 days). It can tolerate low and high temperatures, and can be planted in fall, winter, and spring.

In drier areas of the Pacific Northwest, wheat is grown in the winter and fields are left fallow during the summer. Fallow fields are often sprayed with herbicides or tilled using farming equipment, and these uncovered soils may suffer soil erosion from wind and loss of moisture. Cover crops grown during the summer help retain soil moisture and nutrients, prevent soil erosion, break up pest breeding cycles, and maintain a biological diversity that supports healthy soils. Oilseeds like camelina are a possible cover crop that could improve the agricultural sustainability of the area while producing a new biofuel feedstock.

There are risks and costs to farmers who grow oilseed crops in rotation with wheat. Summer cover crops use inputs like fertilizers and chemicals. During particularly dry periods, these crops may absorb more moisture from the soil than if the fields had been left fallow, possibly reducing the amount of wheat produced the following winter.

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Pacific Northwest farmers who grow camelina face additional uncertainty. While camelina has been cultivated for years in Eastern Europe, it is relatively new to the United States and how productive and effective this crop could be in the Pacific Northwest is still unknown. Farmers may not be willing to plant camelina unless it is shown to be agriculturally successful and economically profitable.

Collection and Extraction

Oilseed crops can be harvested, transported, and stored using the same machinery and infrastructure used for wheat. Their seeds are fairly stable and do not break easily, which helps preserve them during the collection process. Once collected and stored, seeds will be crushed to extract the oil when needed. The Pacific Northwest has some small crushing facilities, but in order to produce oilseed-based biofuel on a large enough scale to make it economically viable, facilities for processing oilseed crops would need to be expanded.

Feedstock Fact Sheet: Oilseed (Camelina) *continued*

Conversion and Co-products

The process to convert oilseeds into biojet fuel requires hot water and energy. Apart from its oil content, around 70% of oilseed's volume by weight is meal. Converting this meal into a secondary product that can be sold is necessary to make this biofuel feedstock profitable. The biggest opportunity to use oilseed meal is in animal feed, but there are factors that may limit this use. Currently only a small portion of *Camelina sativa* meal can be added to animal feed because it contains a chemical that can interfere with an animal's metabolism and reproduction. Other co-products such as fuel pellets or soil enhancements could be made from the meal.

Distribution and Consumption

It is likely that transporting biofuels to airports would be done using the same infrastructure that is used for fossil fuel transport. The Pacific Northwest has five main oil refineries in Washington State and petroleum products are transported via pipelines, barges, and trucks. Jet fuel is heavier than other fuels and is best shipped via trucks and barges. These transportation networks take refined fuels to storage facilities near airports or fuel terminals. This is where biofuels would be blended with petroleum-based jet fuel. Blended jet fuel would then be sent to airports using existing distribution systems.

Sustainability Factors: Oilseeds	
Greenhouse Gas Emissions (GHG)	One study suggested that compared to petroleum-based fuels, an oilseed-to-fuel supply chain could reduce GHG by 80-85%. While this study included uses of nitrogen fertilizer for oilseed crops, it did not consider direct or indirect land use changes that might occur if oilseeds are not grown on fallow fields.
Food Security	It is still unknown how growing crops like camelina in rotation with wheat may impact the amount of wheat produced in the same field. Using camelina meal for animal feed could also impact demand for high protein feed bought from the Midwest or Canada.
Conservation	In addition to agricultural land where wheat is currently grown, oilseed crops can be planted on other lands that are at risk of erosion to support conservation aims. However, areas that are critical for biodiversity or water health should be avoided.
Soil	Oilseed cover crops have been shown to reduce soil erosion and add organic matter to the soil, increasing soil fertility in the long run. Although fertilizers and herbicides may be used to grow cover crops, they are usually also used on fallow fields.
Water	While fallow fields lose moisture to evaporation, oilseeds capture moisture and transfer it to the soil. However, oilseed cover crops do draw on the soil's moisture content, leaving less water available to fall wheat crops and possibly impacting wheat yields.
Air	Growing camelina in rotation with wheat reduces soil erosion in agricultural areas. As a result, less small particulate matter is released into the air, improving local air quality.
Other Concerns	Agricultural yields are still uncertain due to climate and rainfall variation, meaning the supply of this feedstock may not always be predictable. There is also a need for additional research to show economic viability of camelina and to identify varieties that could be better suited to animal feed or other co-products.

Feedstock Fact Sheet: Solid Waste[13]

People and industries produce a lot of waste, or garbage. Municipal solid waste refers to the waste that comes from homes, schools, hospitals, and businesses. This includes packaging, yard clippings, clothing, old furniture, bottles, and food scraps.[14] Industrial solid waste refers to the waste that comes from industry and commercial operations such as food processing plants.[15]

Feedstock

Even when cities recycle and compost, a large amount of organic waste ends up in landfills. Many people in the biofuels industry see organic waste as a potential feedstock for biofuel. Paper, packaging, wood waste from construction sites, and yard waste all contain chemical energy that could be converted into fuel. Using solid waste as a feedstock could divert some waste from landfills that are quickly filling up and are often quite costly. In the state of Washington alone, over 2 million tons of organic solid waste ends up in landfills—even after waste has been diverted to recycling or composting facilities.

Collection and Extraction

Unlike with other feedstocks, there are already systems and infrastructure in place for the collection, transport, and storage of solid waste. Conversion systems to create solid waste-based biofuels could be set up near this infrastructure. A significant amount of waste is hauled to landfills by train. If organic waste was instead converted into biofuels in facilities near collection networks, the amount of transportation fuel needed and related greenhouse gas emissions could be reduced. One challenge is that current policy requires that waste streams going to recycling and composting do not decrease because of the interest in producing biofuel from waste.

Conversion and Co-products

There are many different processes used to convert organic waste to jet fuel. One of the biggest challenges is filtering out waste that contains pollutants or toxins. Communities where conversion facilities are located are often concerned

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about possible contamination of air, water, and soil by these pollutants.

The technology exists to convert waste into ethanol and studies show that this process is economically viable. Converting waste into aviation fuel, which is more energy dense, would be more expensive. There are a variety of ways to turn waste into fuel and most would require heat, chemicals or microorganisms, and acids or enzymes. Large, bulky waste may require technology to make it smaller before conversion. Co-products generated from converting waste to fuel could include chemicals, bio-oils, biochar (which can be used to enhance soils) and syngas (which can be burned as a fuel). It is also possible to make insulation, roof tiles, and road-making materials from the byproducts of the conversion process.

Distribution and Consumption

It is likely that transporting biofuels to airports would be done using the same infrastructure that is used for fossil fuel transport. The Pacific Northwest has five main oil refineries in Washington State and petroleum products are transported via pipelines, barges, and trucks. Jet fuel is heavier than other fuels and is best shipped via trucks and barges. These transportation networks take refined fuels to storage facilities near airports or fuel terminals. This is where biofuels would be blended with petroleum-based jet fuel. Blended fuels would then be sent to airports using existing distribution systems.

Sustainability Factors: Solid Waste	
Greenhouse Gas Emissions (GHG)	One study comparing gasoline and ethanol produced from waste found that ethanol reduced GHG by 81%. This study did not include emissions reductions due to shipping less waste to landfills. Of course, jet fuel is different than ethanol, but this provides some point of comparison.
Food Security	Using solid waste for fuel presents few concerns about food security.
Conservation	Due to the potential for contamination by pollutants, fuel plants should be located in areas where they will not pose a risk to critical species, ecosystems, or water systems.
Soil	Some leakage may occur from solid waste facilities and landfills into surrounding soils and water. Surface and groundwater quality around these facilities should be monitored and maintained. Diverting some solid waste from landfills to biofuel production could potentially reduce leakage from landfills into soils.
Water	Some leakage may occur from solid waste facilities and landfills into surrounding soils and water. Surface and groundwater quality around these facilities should be monitored and maintained.
Air	Community members are often concerned about the emission of toxins during the conversion of waste to fuel. Biofuel plants should follow all laws regulating air pollution.
Other Concerns	Fuel plants must take steps to prevent the release of toxins and hazardous materials. There also exists some competition and debate about the best use of waste streams especially when considered alongside recycling, composting, and electricity production.

Feedstock Fact Sheet: Woody Biomass[16]

Woody biomass is plant material that comes from trees and shrubs such as roots, bark, leaves, branches, trunks, and vines.[17] Just like other plants, trees and shrubs use sunlight, water, and carbon dioxide (CO_2) during the process of photosynthesis to make sugars and complex carbohydrates like cellulose and starch. These carbohydrates have chemical energy that, when burned, release CO_2 and heat energy. Researchers are currently investigating ways to convert the complex molecule cellulose found in woody biomass into aviation fuel and other co-products. Woody biomass could be a promising feedstock for the Pacific Northwest as almost half the region is covered by forests.[18]

Feedstock

In order for woody biomass to be a practical option as a feedstock, there must be a consistent and adequate supply available to biofuel producers. This means it is important to find a source of biomass that does not have a lot of competition with other markets. For instance, there are many sawmills in the Pacific Northwest that create wood waste from processing timber. While this biomass could be turned into fuel, it is currently used to generate electricity or provide feedstock for pulp and paper plants.

Another source of woody biomass is forest residuals. Forest residuals, also known as logging slash, are generally not used by other markets. Forest residuals like tree branches and bark are left behind when logs are cut and hauled away. They are usually left on site to decompose or are burned, returning nutrients to forest soils. Some stakeholders feel that removing forest residuals and using them for fuel would not be healthy for forest ecosystems.

Collection and Extraction

One major reason why forest residuals are currently underused is that they are bulky and spread out in forests, making this source of biomass expensive to collect and transport to processing plants. There are a couple of ways to make the collection process less expensive. One way is to collect forest residuals from the places where the logging industry has left them after cutting logs. Another is to put bulky woody biomass into a chipper before transporting it so that a more concentrated amount of biomass can fit onto each truck. Limiting the time and distance trucks must drive from a wood source to a refinery is another way to reduce costs. Researchers suggest a one-hour drive or a 50-mile driving radius as a reasonable limit. Along with trucks to transport forest residuals, extraction and collection requires machines such as loaders, chippers, and conveyors—all of which require fuel.

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Feedstock Fact Sheet: Woody Biomass *continued*

Conversion and Co-products

To make fuel from woody biomass, it is first broken down into its main chemical parts. Biomass contains cellulose, a complex carbohydrate that is the main source of energy for biofuels. Cellulose can be further broken down into simple sugars using a variety of methods involving heat, chemicals, acids, microorganisms, or enzymes. These sugars are then fermented using yeast or other microorganisms to produce alcohols like ethanol or isobutanol, the foundation for jet fuel.

During the conversion process, biomass that does not get turned into fuel can be converted into co-products such as chemicals or bio-plastics. The sale of these co-products can help make the whole process more economically sustainable.

Distribution and Consumption

It is likely that transporting biofuels to airports would be done using the same infrastructure that is used for fossil fuel transport. The Pacific Northwest has five main oil refineries in Washington State and petroleum products are transported via pipelines, barges, and trucks. Jet fuel is heavier than other fuels and is best shipped via trucks and barges. These transportation networks take refined fuels to storage facilities near airports or fuel terminals. This is where biofuels would be blended with petroleum-based jet fuel. Blended jet fuel would then be sent to airports using existing distribution systems.

Sustainability Factors: Woody Biomass	
Greenhouse Gas Emissions (GHG)	Some information suggests that using forest residuals for fuel emits less GHG than burning them or leaving them to decompose. One study showed that gathering forest residuals at the roadside and changing them into ethanol produced 2-3 times fewer GHG. This study included transportation and processing.
Food Security	Using woody biomass for fuel presents few concerns about food security.
Conservation	Collecting woody biomass may impact wildlife and ecosystems. Some stakeholders feel that using forest residuals for fuel does not create conservation issues if it only involves biomass from current logging operations.
Soil	Impacts on soil quality should be evaluated, especially potential soil compaction from equipment, nutrient removal, and increased erosion. Many stakeholders disagree on the soil impacts caused by removing forest residuals for biofuel production.
Water	Impacts on water quality should be evaluated, such as the effects of increased traffic on logging roads and how increased biomass removal might impact runoff and stream sedimentation.
Air	Converting logging slash and other biomass into biofuels has minimal air impacts. If slash is burnt, as is currently done in some logging operations, it produces fine particulate matter and hurts air quality.
Other Concerns	Forest products are also desired for other markets, meaning there is competition for woody biomass. Many are concerned that using forest products for biofuel is harmful to the forest ecosystem. The cutting and concentrating of woody biomass before shipping it must meet environmental regulations.