

A PACIFIC NORTHWEST EXTENSION PUBLICATION

Washington State  
University

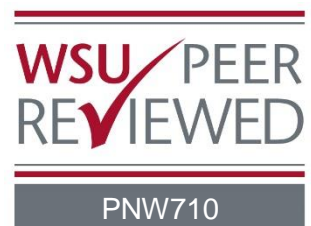
Oregon State  
University

University of  
Idaho



# ETHANOL IN THE PACIFIC NORTHWEST

**Noelle M. Hart**, Extension Coordinator, WSU Extension, Washington State University; **Keaton L. Lesnik**, Department of Biological and Ecological Engineering, Oregon State University; and **Patricia A. Townsend**, Regional Extension Specialist, WSU Extension, Washington State University



# ETHANOL IN THE PACIFIC NORTHWEST

## Abstract

This factsheet provides background on ethanol as a transportation biofuel and discusses the role ethanol plays in the Pacific Northwest (PNW) states of Washington, Oregon, and Idaho. This includes describing relevant policies, consumption, availability of ethanol blends, production facilities, feedstock sources, and economic and environmental impacts. Ethanol is commonly blended into gasoline across the United States, including the PNW. National and state-level policies encourage biofuel production and consumption in Washington and Oregon. Possible benefits of using ethanol as a biofuel include reducing greenhouse gas emissions and stimulating rural economies, in addition to increasing fuel octane ratings. Concerns include potential land use change and impacts on food prices. The PNW consumed 523 million gallons of fuel ethanol in 2015. As of 2018, three ethanol refineries are operating in the PNW and a large-scale facility stands idle. Most ethanol consumed and produced in the PNW is made from imported corn, but food waste, sugar beets, poplar trees, wheat/barley/grass straw, and forestry residues are also potential feedstock options for the region. If cellulosic ethanol reaches a wide-spread commercial scale, the PNW could utilize considerable quantities of cellulosic feedstocks. Ethanol production has grown over the past decade and may continue to increase with scientific advancements and policy support.

## Introduction

Ethanol's potential to be a widespread transportation fuel has long been recognized, if not realized until recently. An ethanol-powered engine was designed in the 1800s, Henry Ford called ethanol the "fuel of the future" in 1925, and ethanol was popular during the oil crisis of the 1970s (Kovarik 1998). Today, demand for ethanol blends is largely driven by federal policies enacted in the years 2005 and 2007 to increase energy independence and encourage clean, renewable transportation fuels. Gasoline sold at the pump contains ethanol, usually as a blend of 10% ethanol

and 90% gasoline (i.e., E10). Approximately 523 million gallons of fuel ethanol were consumed in the Pacific Northwest (PNW) states of Washington, Oregon, and Idaho in 2015 (U.S. EIA 2016a).

Ethanol is produced at three refineries in the PNW, with a combined capacity of 102 million gallons per year (Ethanol Producer Magazine 2017; Renewable Fuels Association 2017). Corn (imported from the midwestern U.S.) is the primary feedstock, but food waste is used as well. The PNW's ethanol production could meet 20% of the PNW's current ethanol demand if operating at full capacity. Additionally, a facility capable of producing 113 million gallons per year is idle but could more than double the region's production capacity.

This factsheet provides background on ethanol as a transportation biofuel and discusses the role ethanol plays in the PNW. This includes describing relevant policies, consumption and availability of ethanol blends, production facilities, feedstock sources, and economic and environmental impacts.

## Basics of Ethanol

Ethanol, or ethyl alcohol, is a clear, colorless liquid that can be derived through the fermentation of plant/biomass materials (AFDC 2016a). Primarily used as a transportation fuel, ethanol is one of the few biofuels produced on an industrial scale. Ethanol is also commonly used as a solvent for industrial and medical purposes, and it is the alcohol component of alcoholic beverages.

All gasoline vehicles can safely use E10 (10% ethanol–90% gasoline), which is the typical gasoline fuel sold in the U.S. (U.S. EIA 2016b). Equipment with small engines can also use E10. However, if the equipment will not be used for several months, the fuel should be removed or mixed with a fuel stabilizer to prevent the ethanol from absorbing water into the fuel tank (Veal 2014).

A slightly higher blend, E15 (gasoline blended with 10.5% to 15% ethanol) is approved by the U.S. Environmental Protection Agency (EPA) for vehicles built after 2001 (U.S. EPA 2011). Currently, adoption is limited by summertime use

restrictions. At higher temperatures gasoline vaporizes faster and releases evaporates that contribute to smog formation. To protect air quality, the EPA regulates gasoline's vapor pressure (i.e., "Reid vapor pressure" [RVP]) (U.S. EPA 2018). Although both E10 and E15 raise vapor pressure over the limit, only E10 receives a waiver to allow continued sale in the summer months (EESI 2016a).

High concentration blends, namely E85 (up to 85% ethanol), are available, but vehicles must be equipped with corrosion-resistant fuel tanks and lines. Many models of cars and trucks are

manufactured with the capability to use E85 and are termed flexible fuel vehicles (FFVs), which can be identified by Flex Fuel/E85 logos or a yellow fuel tank cap (Figure 1). The ethanol content of E85 varies seasonally, with less ethanol used in colder months to improve vehicle starting and performance (U.S. DOE 2016). The actual percentage of ethanol in fuel marked E85 ranges from 51% to 83%, and therefore "E85" is often simply called "flex fuel" (U.S. DOE 2016). There are approximately 2,900 E85 fueling stations throughout the U.S., primarily located in the Midwest (AFDC 2017a).



Figure 1. The "Flex Fuel" logo (left) and yellow ring around the fuel insertion point (right) on a flexible fuel vehicle.

## Impacts

### *Environmental*

The greatest environmental concern associated with petroleum transportation fuels is the emission of greenhouse gases (GHG), such as carbon dioxide, which contribute to climate change. GHG emissions are reduced by displacing petroleum consumption with ethanol produced from biomass. Although burning ethanol fuel emits GHG just like petroleum fuels, the net GHG emissions are lower because atmospheric carbon dioxide is captured as the biomass grows. Life cycle assessments (LCA) are a tool for evaluating the net GHG emissions or other

environmental impacts (e.g., effects on water quality) of the whole biofuels system, from biomass production to biofuel consumption. Estimates of net GHG emissions vary widely across LCA and are dependent on the type of biomass feedstock, biofuel conversion process, selected system boundaries, data quality, and assumptions about land use changes associated with an increase in ethanol production.

Land use impacts and effects on crop prices (i.e., food vs. fuel) are commonly-expressed concerns about using corn-based ethanol. Energy crops, like corn, can compete with food crops for the use of arable land. Committing additional land to food or energy crop production due to ethanol demand (i.e.,

indirect land use change) may destroy natural habitats, reduce biodiversity, and increase GHG

emissions if disrupting ecosystems that stored carbon (e.g., forests) (Hoekman and Broch 2018). However, the global trend between 2004 and 2012 was toward increasing efficiency of current croplands rather than using additional land, suggesting that ethanol demand leads to less indirect land use change than previously predicted (Babcock and Iqbal 2014; Flugge et al. 2017).

Estimates for net GHG emission reductions for corn starch ethanol range between 19% and 48% (Wang et al. 2012). A 2017 USDA report found a 43% reduction for U.S.-produced corn ethanol compared to gasoline (Flugge et al. 2017; USDA 2017). The use of alternative feedstocks, such as cellulosic and waste materials, could result in emission decreases of 34–92% compared to gasoline (Wang et al. 2012; Budsberg et al. 2015) but these advanced biofuels are not cost-competitive.

In the PNW, gasoline is blended with imported corn ethanol or, to a much lesser degree, regionally-produced ethanol from imported corn. Given ethanol constitutes only 10% of gasoline and that the PNW relies on imports from the Midwest (Borrud 2016), significant increases in regional production would need to be realized to have a meaningful impact on GHG emissions in the PNW.

On a more local scale, the use of ethanol has likely improved environmental and public health. Ethanol replaced MTBE (methyl tertiary butyl ether) as the fuel additive used to raise the octane number of gasoline, when several states banned MTBE in the early 2000s due to groundwater contamination concerns (American Cancer Society 2014, EESI 2016b). The high octane rating, higher evaporation rate, and flammability temperature of ethanol fuels has a positive effect on engine efficiency, further reducing emissions of carbon monoxide, smog-forming nitrogen oxides, and hydrocarbons such as benzene and butadiene (Demirbas 2009; Speth et al. 2014). However, definitive long-term public health effects due to increased ethanol use are not clear as ethanol use is associated with higher emissions of formaldehyde and acetaldehyde (Jacobson 2007).

Other environmental effects are dependent on the feedstock and growing region. Corn, for example, is associated with significant environmental concerns, such as nutrient run-off from fertilizer that degrades downstream water quality and high irrigation requirements (Hoekman et al. 2018). Some feedstocks actually provide additional ecosystem services. For example, poplar trees have been used to clean contaminated sites, aid in wastewater treatment, and cover landfills. (Isebrands and Richardson 2012). Biofuel crops may increase or decrease water usage depending on the type of crop and what the crop is replacing on the landscape. This will be important in parts of the PNW with limited water availability.

### **Economic**

Bioenergy has the potential to support local rural economies and rural development by diversifying agricultural markets and generating manufacturing jobs at biofuel production facilities (Demirbas 2009). The majority of ethanol fuel used in the United States is produced domestically, thereby supporting rural industries and energy security. Independence of ethanol prices from volatile international petroleum markets is also a potential benefit to the economy.

However, the PNW is currently experiencing little benefit from the regional ethanol industry, as evidenced by substantial importation of ethanol and use of imported feedstock for most PNW production. This is despite awarding millions of dollars in business energy tax credits to ethanol companies since 2008 (Borrud 2016).

### **Ethanol Fuel Policies**

The most significant national legislation concerning biofuels such as ethanol are the Energy Policy Act of 2005 and the Energy Independence and Security Act (EISA) of 2007. The Energy Policy Act of 2005 established Renewable Fuel Standards (RFS) which set a volume quota of 7.5 billion gallons per year (BGY) of biofuels that must be blended with U.S. gasoline and diesel fuel by 2012. The EISA updated the RFS and mandated biofuel production of up to 36 BGY by 2022 (U.S. EPA 2016). Under the EISA, corn starch ethanol, also referred to as

"conventional" biofuel, can only contribute 15 BGY toward the 36 BGY target. This restriction is to encourage the use of other feedstocks, especially those that do not compete directly with food production. However, given projections of a limited supply of cellulosic ethanol, waivers can be purchased to meet the mandate in lieu of using cellulosic biofuel. Experts argue that the comparatively cheap cellulosic ethanol waivers has hampered the development of a PNW cellulosic industry (Galinato et al. 2016).

There is current state legislation within the PNW, specifically in Oregon, pertaining to ethanol in transportation fuel. Oregon’s Renewable Fuel Standard, which is separate from the national RFS, mandates that all gasoline sold in the state be blended with 10% ethanol (E10) (ORS 646.913 2015). E10 is both the minimum and maximum allowed, with the exception of E85 for use in flex fuel vehicles. E15 is not allowed under the current legislation (Wind, personal communication).

Oregon also has a Clean Fuels Program that provides a market-based approach to reduce the carbon emissions from transportation fuels relative to a 2015 baseline (DEQ 2017). The 2015 baseline for gasoline was E10 using Midwest corn-based ethanol. Ethanol could play a significant role in meeting the Clean Fuels Program reduction goals as corn ethanol evolves into more efficient production methods (e.g., reducing energy consumption of corn and ethanol production) and as different feedstocks, such as waste-based or cellulosic materials, become economically feasible.

### Ethanol Consumption

Ethanol’s potential as a transportation fuel has long been recognized, if not realized. An ethanol-powered engine was designed in the 1800s, Henry Ford called ethanol the “fuel of the future” in 1925, and ethanol was popular during the oil crisis of the 1970s (Kovarik 1998). Current demand for ethanol blends is largely driven by the RFS. Total consumption of ethanol has steadily increased over the past ten years (U.S. EIA 2017a).



Figure 2. There are ten public fueling stations offering E85 in the PNW. Eugene, OR has two stations. (Source: Alternative Fuels Data Center [2017a].)

In 2015, PNW regional fuel ethanol consumption was estimated at 523 million gallons per year (MGY), which is about 4% of fuel ethanol consumption nationally (U.S. EIA 2016a)<sup>1</sup>. This breaks down by state to 289 MGY in Washington, 160 MGY in Oregon, and 74 MGY in Idaho.

In the PNW, there are 36 fueling stations (10 public and 26 private) that distribute E85 (Figure 2). A resource to find E85 fuel stations near you is the [DOE’s Alternative Fuels Data Center](#).

## Ethanol Feedstocks

Nearly all plant materials can be used as an ethanol feedstock, even residues left over from harvested

crops. The future sustainability of ethanol production depends heavily on the choice and development of various feedstocks. Categories of feedstocks can be broken down into purpose grown sugar/starch-based energy crops, cellulosic-based feedstocks, and wastes (Table 1). In the PNW, current or potential feedstocks (Figure 3) include: corn, sugar beets, sorghum, poplar trees, wheat/barley/grass straw residues, and biomass waste from food, forestry, paper, and other industries. Other feedstocks could theoretically be imported (e.g., corn stover), but this fact sheet focuses on what is currently imported and feedstocks that show the most promise for sourcing within the PNW.

Table 1. Advantages and disadvantages of different feedstock categories and relevant biomass sources in the PNW.

Available Feedstocks in PNW	Advantages	Disadvantages
<b>Starch/Sugar-based</b> Corn, Sugar Beets, Sorghum	Easily extractable sugars Established crop/commodity High ethanol yields	Direct competition with food Energy intensive to grow
<b>Cellulosic</b> Poplar Trees, Straw Residues	Abundant resources Marginal land can be used Low energy inputs to grow	Hard to extract sugars Difficult to harvest/collect/deliver
<b>Other Waste Residues</b> Forestry Residues, Paper Industry Waste, Food Processing Wastes	Inexpensive Value-added product Greatest reduction in emissions	Inconsistent composition Dependence on other industries Low yields

<sup>1</sup> Fuel ethanol data in thousand barrels was converted to million gallons by multiplying by 0.042. See [https://www.eia.gov/totalenergy/data/monthly/pdf/sec10\\_7.pdf](https://www.eia.gov/totalenergy/data/monthly/pdf/sec10_7.pdf)



Figure 3. The current most common feedstock for ethanol production, corn (upper left), and three feedstocks with potential in the PNW, sugar beets (upper right), poplar trees (lower left), and wheat straw (lower right).

### ***Starch/Sugar-based Feedstocks***

Starch- and sugar-based feedstocks, like corn grain, are the most dominant feedstocks for domestic ethanol production. Ethanol production from these feedstocks is well-developed. However, these crops tend to be energy-intensive to grow, requiring large amounts of inputs (e.g., nutrients, water). The energy used to provide these inputs results in GHG emissions, which limits the GHG reduction benefits

of ethanol from these crops (Table 2). Sugars and starches are easy to extract and ferment from these feedstocks, but these crops can also be used for food production (e.g., as livestock feed), placing ethanol production in direct competition with food production. Consequently, the RFS set by the EISA limits ethanol production from starch- and sugar-based crop feedstocks, referred to as “conventional” biofuel, to 15 BGY.

Table 2. Comparison of GHG reductions and ethanol yields for starch- and sugar-based feedstocks (blue) and cellulosic feedstocks (green). Sources cited within the text.

Feedstock	GHG Reductions	Ethanol Yields (gallon/acre)
Corn Starch	19–48%	660
Sugar Beets	71%	1,095
Sweet Sorghum	71%	1,133
Wheat Straw	> 73%*	173
Poplar	92%	805**

\* Reduction based on E85. Others based on E100.

\*\* This is a per year average value provided for comparison across feedstocks. In actuality, poplar is harvested every three years, so ethanol yield from harvested poplar would be 2,416 gallons per acre.

**Corn—**

Similar to national trends, the primary feedstock for producing ethanol in the PNW is corn starch (*Zea mays*). The corn used for ethanol is field corn, which is otherwise used for animal feed and different from sweet corn, which is what people eat. Field corn is mostly starch (rather than sugar) and is harvested later in the growing season to let it dry as much as possible on the stalk. About 37% of corn grown nationally is used for ethanol production (USDA ERS 2017).

The PNW is not a major corn-producing region. Corn production is related to the regional dairy industry (Brown et al. 2010). In 2016, 48 million bushels of corn were produced in the PNW (20 million in Washington, 19 million in Idaho, and 9 million in Oregon), which is only 0.3% of the 15 billion bushels produced nationally (USDA National Agricultural Statistics Service 2017). Therefore, corn-based ethanol production in the PNW relies on corn grown outside the PNW.

**Sugar Beets—**

Sugar beets (*Beta vulgaris*) may also be used as a feedstock for ethanol production. The root of sugar

beets typically contains anywhere between 13–21% sucrose that can be fermented into ethanol (Šantek et al. 2010). Sugar beet processing also leads to pulp and molasses by-products, which can be used as a nutritious livestock feed (Lardy and Schafer 2016). Idaho (172,000 acres planted), Oregon (10,700 acres planted), and Washington (2,000 acres planted) are three of eleven states that produce sugar beets (USDA National Agricultural Statistics Service 2017). Idaho produces the 3rd most nationally behind Minnesota and North Dakota.

Compared to other crops such as corn, a large yield in tons per acre can be achieved. In the PNW, sugar beet yield averages 43.8 tons per acre compared to approximately 6 tons of corn grain per acre (USDA National Agricultural Statistics Service 2017). However, a ton of corn grain can produce 110 gallons of ethanol, while a ton of sugar beets can only produce approximately 25 gallons of ethanol (USDA 2006). Therefore, sugar beets could produce about 1,095 gallons of ethanol per acre, while corn

could produce 660 gallons per acre<sup>2</sup>. Looking at the life cycle from crop production through ethanol use, sugar beet ethanol reduces GHG emissions by 71% compared to gasoline (Alexiades et al. 2018).

An analysis in the state of Washington indicated that there are numerous market challenges to a sugar beet ethanol industry, including competition with cheaper corn ethanol and comparatively unfavorable growing conditions (Yoder et al. 2009). Idaho, however, is successfully growing sugar beets and would be better suited for sugar beet ethanol production. This would require sugar beet ethanol being cost-competitive with corn ethanol and more profitable than sugar. An opportunity may emerge in the future, as large sugar buyers abandon genetically modified sugar beets in favor of non-GMO sugar cane (Dan 2016), and sugar beet growers look for a new market.

### **Sweet Sorghum—**

While not grown extensively in the PNW, sweet sorghum (*Sorghum bicolor*) is a potential energy crop that contains high levels of carbohydrates, is more drought-resistant, and requires less fertilizer than corn (Almodares and Hadi 2009). A sorghum-based, paper-processing facility is currently being planned in Parma, ID, establishing a market for the crop in the region (Ellis 2016). Experience with growing sorghum as a rotation crop could lead to potential future use as a biofuel feedstock. Sweet sorghum can produce 1,133 gallons of ethanol per acre (Castro et al. 2017) and reduce GHG by 71% (Cai et al. 2013).

### **Cellulosic Feedstocks**

Cellulosic ethanol is produced from fibrous, woody, inedible plant biomass. This biomass comes from dedicated non-food energy crops, crop residues, and other waste resources. Compared to starch- and sugar-based crops, more intensive processing is needed to access the fermentable sugars but ultimately results in fewer net GHG emissions because these feedstocks are abundant and require fewer inputs (e.g., fertilizer) to grow

(AFDC 2017b). Additionally, cellulosic ethanol made from crop residues and other wastes avoids placing fuel production in direct competition with food production, compared to starch/sugar-based feedstocks. Improvements in soil quality and provision of wildlife habitat may also result if traditional row crops are replaced with perennial cellulosic crops (Lynd et al. 2009).

### **Poplar—**

[Advanced Hardwood Biofuels Northwest](#), a federally-funded consortium of universities and industry partners, has been investigating the potential for a PNW hybrid poplar-based biofuels and chemicals industry since 2011. Hybrid poplar trees (*Populus* spp.) are an attractive feedstock for biofuel production due to their fast growth rates, adaptability, genetic variability, and high cellulose/low lignin wood (Townsend et al. 2014). At a demonstration farm, hybrid poplar yielded 16 bone-dry tons per acre after three-years growth (Stanton 2017). One bone-dry ton of poplar yields approximately 450 kg (151 gallons)<sup>3</sup> of ethanol (Crawford et al. 2016). Therefore, an acre of poplar could produce an estimated 2,416 gallons of ethanol upon harvest every three years (~805 gallons/acre/year). Poplar ethanol can reduce GHG emissions by 92%, using certain production pathways (Budsberg et al. 2015).

The use of poplars also provides additional environmental benefits (Isebrands and Richardson 2012). They can be grown on poor or degraded soils and even improve soil quality over time through the accumulation of soil carbon. Poplars are able to take up large amounts of nitrogen and phosphorus, making them suitable as part of wastewater treatment systems (Minogue et al. 2012). Poplar trees can also be used to extract or stabilize pollutants (i.e., phytoextraction or phytostabilization) due to poplar's high tolerance to various toxic factors, including many heavy metals (Burken and Schnoor 1999).

<sup>2</sup> 43.8 ton/acre \* 25 gallon/ton = 1,095 gallon/acre

6 ton/acre \* 110 gallon/ton = 660 gallon/acre

<sup>3</sup> Based on a conversion factor of 6.57 lb/gallon and 2.20 lb/kg

## Straw Residues—

Agricultural residues represent a substantial source of readily-available biomass without the need for additional land cultivation (SunGrant Initiative 2008). It is estimated there are 5.1 billion dry tons of agricultural residues produced globally, 10–25% of which can be used for biofuel production (Eisentraut 2010). In the PNW, a techno-economic and life-cycle assessment of ethanol from straw residue found it could be competitive with other alternative ethanol feedstocks (Juneja et al. 2013). The primary crops in the region that generate residues suitable for ethanol production are wheat (*Triticum aestivum*) and barley (*Hordeum vulgare*). Throughout Washington, Oregon, and Idaho, wheat and barley yields are 9 million and 1.55 million tons per year, respectively (USDA National Agricultural Statistics Service 2017).

For each ton of wheat produced, 1.3 tons of straw residue is generated, and similarly 1.2 tons of straw is created per ton of barley (Singh et al. 2010). The 13.56 million tons of wheat and barley straw produced in the PNW annually would be enough to produce approximately 845 million gallons of ethanol<sup>4</sup>. (Given an average yield of 71 bushels per acre of wheat and 84 bushels per acre of barley in the PNW, an acre of wheat could yield 173 gallons of ethanol and an acre of barley could yield 145 gallons of ethanol.) This far exceeds the current production capacity of PNW ethanol plants. However, not all the residue can be removed for ethanol, as some residue is needed for soil conservation (Banowetz et al. 2008).

In addition to wheat and barley straw, grass straw in the Willamette Valley of Oregon shows potential as an ethanol feedstock (Kumar and Murthy 2012; Juneja et al. 2011). This region is called “the grass seed capital of the world” and produces two thirds of U.S. cool-season grasses (Oregon State University 2018). Grass straw can come from grass seed harvest, as well as from grass harvested from Conservation Reserve Program land (Juneja et al. 2011).

The primary disadvantages in the use of agricultural residues is the inconsistency of the residue composition and difficulties in breaking the residues down to sugar components (Ho et al. 2014). The long-term effects that the removal of residues has on soil health are also of particular interest, as crop residues protect against erosion, replenish mineral nutrients, and are a source of soil carbon that supports soil ecosystems (Youngs and Somerville 2014). How much crop residue can be sustainably removed and the effects of straw-based ethanol on GHG emissions are still being studied (Kumar and Murthy 2012; Bonner et al. 2014; Liska et al. 2014; Congreves et al. 2017). One estimate for wheat straw ethanol found a 73% reduction in greenhouse gas emission for E85 (Borrion et al. 2012).

## Additional Waste Residues

The food, forestry, and paper industries, all of which are well established in the PNW, produce a large number of residues and by-products that can potentially be used as biomass feedstock for ethanol production. Currently, Summit Natural Energy in Cornelius, OR is using sugar and starch waste from the food industry to make ethanol. In 2000, Georgia Pacific in Bellingham, WA was producing ethanol from a pulping by-product (Graf and Koehler 2000). Between 1985 and 2004, an ethanol facility in Idaho used potato peels to make ethanol (Cope 2015). Municipal solid waste (e.g., food and yard waste, soiled cardboard) is another potential feedstock (Schmitt et al. 2012; Jessen 2013). The variability of wastes and dependence on other industries can make adoption difficult, and should be analyzed on a case-by-case basis. However, the environmental benefits of such an approach include both substantial reductions in GHG emissions and reductions in landfill space and disposal costs (Ho et al. 2014).

<sup>4</sup> Based on Singh et al. 2010's Table 2: Barley – 1.2 res/crop; 81% dry mass; 0.31 L ethanol/kg DM | Wheat – 1.3 res/crop; 90.1% DM; 0.29 L ethanol/kg DM

## Ethanol Production

Compared to the corn-growing Midwest, ethanol production in the PNW is extremely low. The total capacity of active production facilities is 102 MGY, accounts for only 20% of current ethanol demand in the PNW (generated by E10 usage), and is less than 1% of total U.S. ethanol capacity (U.S. EIA 2017b).

The PNW has been producing ethanol since the 1980s, albeit at low quantities prior to 2007 (U.S. EIA 2017b). Washington State's ethanol production peaked in the late 1980s at 5.5 million gallons per year. Washington has not commercially produced fuel ethanol since 2006. With the exception of the years 2005 and 2006, Idaho has produced ethanol since 1984. In contrast, Oregon did not begin ethanol production until 2007, and it has been producing ever since.

Important considerations when determining the commercial viability of a local biofuel production system are the energy inputs and 'net energy' of the biofuel (i.e., how much energy is in the fuel minus the energy used to make the fuel). Energy inputs and associated costs are especially high when feedstocks must be transported from outside the region, as with corn-based ethanol made in the PNW with feedstock imported from the Midwest. Locally-produced feedstocks may become better long-term options. For example, model-based estimates of a hypothetical cellulosic ethanol plant utilizing locally-produced woody biomass from forest thinning, clearing invasive juniper, or waste from wood-processing operations would have a 400% higher net energy gain than a corn-based ethanol plant that imported corn grain by rail from the Midwest (Figure 4; Jaeger et al. 2007).

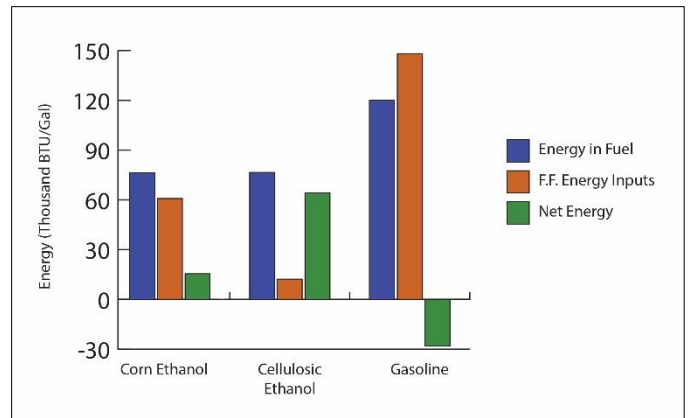


Figure 4. Energy values associated with regionally-produced fuel types. Included is the total energy contained in the fuel type, the fossil fuel (F.F.) energy inputs required for the processing of the fuel, and the net energy gained in the final fuel product. (Adapted from Jaeger et al. 2007)

## Coproducts

The production of ethanol creates coproducts that may generate additional revenues depending on market demand. Distillers grains, either dry grains and solubles (DDGS) or wet distillers grains (WGS), are a byproduct of milling during starch/sugar-based ethanol production. They are widely used as livestock feed by the dairy, beef, pork, and poultry industries (U.S. Grain Council 2012). There is an established PNW market for DDGS, with some distillers grains coming from ethanol plants in Boardman, OR and Burley, ID (Pacific Ethanol 2017a), and some imported from outside the region, e.g., South Dakota (Redfield Energy 2017).

One of the primary products of ethanol fermentation is carbon dioxide (CO<sub>2</sub>). Ethanol plants that capture CO<sub>2</sub> are a critical source for national CO<sub>2</sub> markets, and may be used as dry ice, in beverages, and for industrial applications (Mueller 2017). In many cases, alternative sources of CO<sub>2</sub> are higher emitting and less economical (Mueller 2017). Pacific Ethanol's Boardman, OR plant contributes to the 100,000 tons the company sells annually (Pacific Ethanol 2017a).

Lignin is a major constituent of cellulosic biomass, making up 15 to 40% of terrestrial plants (Figure 5) (Ragauskas et al. 2014). Lignin is a structural component of plants and must be broken down in order to access the sugars (i.e., cellulose and

hemicellulose) used in ethanol production (Hamelinck et al. 2005). Utilizing lignin on a large scale is important for making cellulosic ethanol economically viable. Lignin can be burned for power or made into products like carbon fiber, plastics, and chemicals (Doherty et al. 2011), which are currently made from petroleum.

Other products that can be produced in tandem with ethanol include corn oil (with corn-based ethanol), xylose (with cellulosic ethanol), acetic acid, and other bio-based chemicals.

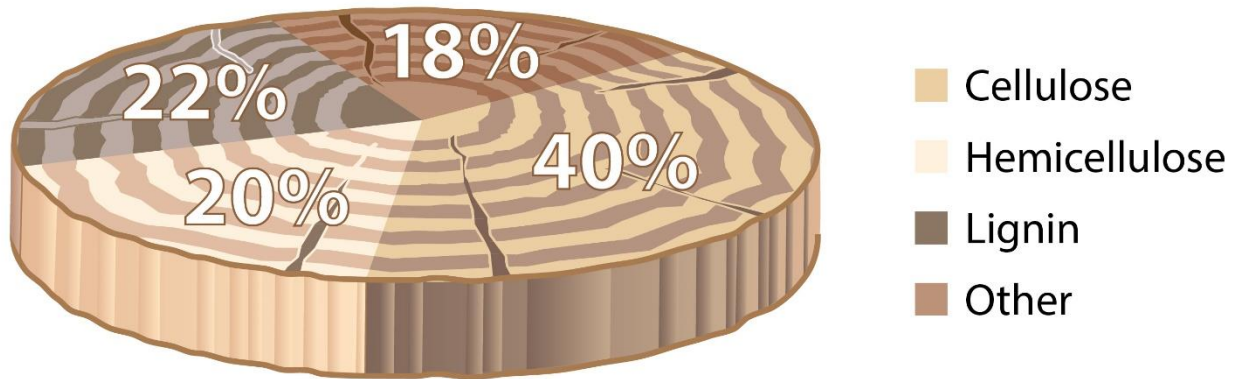


Figure 5. Percentage of lignin and other components in poplar wood; one example of a cellulosic feedstock.

**Ethanol Production Facilities**

Currently, there are three active ethanol biorefineries in the PNW (none currently in Washington; Figure 6). Additionally, there is an idle, large-capacity facility. The PNW has struggled to be competitive in the ethanol market. This is not surprising given: (a) the prominence of ethanol made from Midwest corn, (b) ethanol demand functionally capped at 10% of gasoline, and (c)

low-priced petroleum. If cellulosic ethanol ever reaches a commercial scale, the PNW would be in a better position to compete in the market, having considerable cellulosic feedstock options.

**Pacific Ethanol**

Pacific Ethanol is headquartered in Sacramento, CA. Of their eight locations throughout the U.S., two are in the PNW (Pacific Ethanol 2017b).

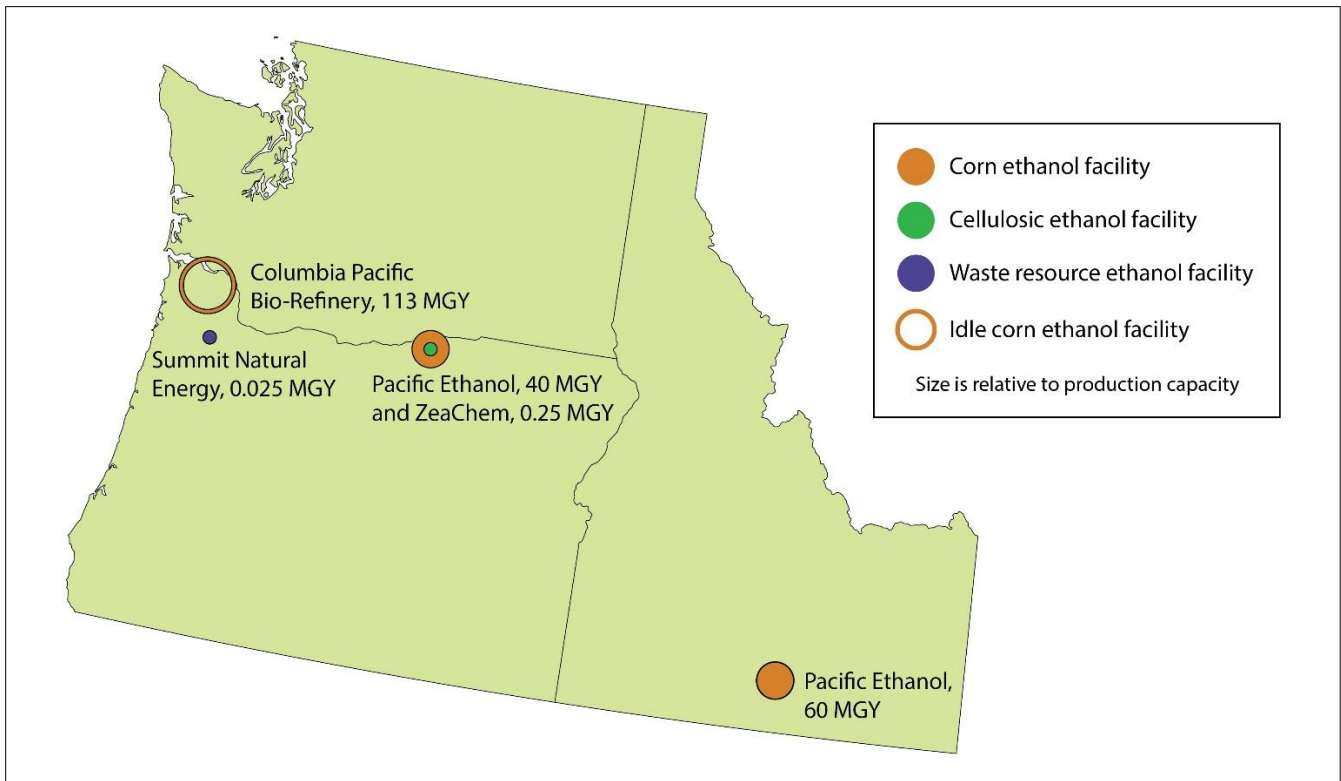


Figure 6. Existing and idle production facilities in the PNW.

This includes plants in Boardman, OR and Burley, ID that opened in August 2007 and April 2008, respectively. Corn grain is used as the feedstock for both plants and is imported by rail from the Midwest. The Oregon plant (a.k.a. Columbia biorefinery) has a capacity of 40 MGY while the Idaho plant (a.k.a. Magic Valley biorefinery) has a capacity of 60 MGY. In addition to ethanol, distillers grains, corn oil, and CO<sub>2</sub> are produced at both sites for additional value.

### Summit Natural Energy

Located in Cornelius, OR, Summit Natural Energy Corp. is a privately-held company that works closely with Summit Foods Inc., a dried fruit producer (Siemers 2009). The company uses food-waste sugars and starches from Summit Foods as well as products from food companies in the Portland, OR area, and converts them into ethanol. The ethanol produced onsite is sold to gasoline companies and also as racing fuel (Profita and Campbell 2014). Current ethanol production of Summit Natural Energy is around 25,000 to 30,000 gallons per year and may ramp up to 100,000 to

150,000 gallons per year in the near future, depending on availability of waste products.

### ZeaChem

ZeaChem was formed in 2002 with the goal of developing biorefineries that would produce various products from the bacterial fermentation of cellulosic feedstocks, specifically locally-grown poplar and wheat straw. A demonstration plant with a capacity of 0.25 MGY has been completed and demonstrated ethanol production from hybrid poplar in 2013. However, no commercial ethanol is being produced at this time, and the future of the facility is uncertain.

### Columbia Pacific Bio-Refinery

Located at Port Westward, Clatskanie, OR, the Columbia Pacific Bio-Refinery is an ethanol shipment terminal and an idle ethanol production facility. With hefty financial support from the state of Oregon, the plant was opened in 2008 by Cascade Grains to produce 113 MGY of ethanol (Borrud 2016). Within a year, the company filed for bankruptcy (Learn 2013). Purchased by Global

Partners, LP, the site became a crude oil storage and transfer terminal in 2013. The company transitioned to moving ethanol when oil prices dropped (Luck 2016). Although the facility could more than double the PNW's ethanol production capacity, there is no indication that the ethanol production will resume.

## Future Perspectives and Conclusions

Ethanol is the most-used transportation biofuel on the planet, and the U.S. is a leading consumer (Vakkilainen et al. 2013). Due to scientific advancements and government incentives, ethanol production is increasing (U.S. EIA 2017a) and likely to continue to see growth. This growth offers opportunities for social-economic benefits, but careful evaluation must be made on a regional scale to identify feedstocks that provide net economic and environmental benefits.

In the PNW, ethanol production levels are low and Midwestern corn grain is the primary feedstock. Under different economic or political

circumstances, better options for the PNW include sugar beets, poplar trees, wheat straw, and industrial waste. From a broader industry, innovation perspective, researchers are investigating strategies that could alter ethanol production everywhere (e.g., improving conversion efficiency, using algal biomass, and direct fixing CO<sub>2</sub> into ethanol (Aikawa et al. 2013; Budsberg et al. 2015; Song et al. 2016). Opportunities for combined ecosystem services and biofuel feedstock production should be researched further, as this could provide win-win scenarios.

Increasing the feasibility of PNW ethanol production would require significant advances to improve the profitability of ethanol from regional feedstocks—technological breakthroughs, competitive fuel pricing, or policy changes. However, replacing petroleum fuels is a high priority when discussing climate change mitigation, and ethanol could be one of a suite of bioenergy options suitable for the PNW.

## Acknowledgments

This work was supported by Agriculture and Food Research Initiative (AFRI) Competitive Grant no. 2011-68005-30407 from the USDA National Institute of Food and Agriculture (NIFA). We would like to acknowledge Peter Moulton (Washington State Department of Commerce), Cory-Ann Wind (Oregon Department of Environmental Quality), and Summit Natural Energy for providing information and feedback for the development of this factsheet. Thank you to Shawn Freitas (OSU), Cat Gowan (WSU Extension), Nora Haider (WSU Extension), Marina Heppenstall (WSU Extension), Glen Li (OSU), Kevin Zobrist (WSU Extension), and an anonymous reviewer for commenting on previous drafts, and to Briana Nordaker (WSU Extension) for designing the figures.

## References

- Aikawa, S., A. Joseph, R. Yamada, Y. Izumi, T. Yamagishi, F. Matsuda, H. Kawai, J. Chang, T. Hasunuma, A. Kondo. 2013. Direct Conversion of *Spirulina* to Ethanol Without Pretreatment or Enzymatic Hydrolysis Processes. *Energy & Environmental Science* 6:1844–1849. DOI:10.1039/C3EE40305J.
- Alexiades, A., A. Kendall, K.S. Winans, and S.R. Kaffka. 2018. [Sugar Beet Ethanol \(\*Beta vulgaris\* L.\): A Promising Low-Carbon Pathway for Ethanol Production in California](#). *Journal of Cleaner Production* 172:3907–3917.
- Almodares, A., and M.R. Hadi. 2009. Production of Bioethanol from Sweet Sorghum: A Review. *African Journal of Agricultural Research* 4(9):772–780.

- Alternative Fuels Data Center (AFDC). 2016a. [Ethanol Fuel Basics](#).
- . 2017a. [Alternative Fueling Station Locator](#).
- . 2017b. [Ethanol Feedstocks](#).
- American Cancer Society. 2014. [MTBE and Cancer Risk](#).
- Babcock, B.A., and Z. Iqbal. 2014. [Using Recent Land Use Changes to Validate Land Use Change Models](#). *Staff Report 14-SR 109 of the Center for Agricultural and Rural Development: Iowa State University*.
- Banowitz, G.M., A. Boateng, J.J. Steiner, S.M. Griffith, V. Sethi, and H. El-Nashaar. 2008. [Assessment of Straw Biomass Feedstock Resources in the Pacific Northwest](#). *Biomass and Bioenergy* 32:629–634.
- Bonner, I.J., D.J. Muth Jr., J.B. Koch, and D.L. Karlen. 2014. Modeled Impacts of Cover Crops and Vegetative Barriers on Corn Stover Availability and Soil Quality. *BioEnergy Research* 7:576–589. DOI:10.1007/s12155-014-9423-y.
- Borrion, A.L., M.C. McManus, and G.P. Hammond. 2012. [Environmental Life Cycle Assessment of Bioethanol Production from Wheat Straw](#). *Biomass and Bioenergy* 47:9–19.
- Borrud, H. 2016. [Clean Fuels Law Brings Ethanol to Oregon – But Mostly from the Midwest](#). *The Oregonian* August 13, 2016.
- Brown, B., J. Hart, D. Horneck, and A. Moore. 2010. [Nutrient Management for Field Corn Silage and Grain in the Inland Pacific Northwest](#). *Pacific Northwest Extension Publication PNW 615*.
- Budsberg, E., J. Crawford, R. Gustafson, R. Bura, and M. Puettmann. 2015. [Ethanologens vs. Acetogens: Environmental Impacts of Two Ethanol Fermentation Pathways](#). *Biomass Bioenergy* 83:23–31.
- Burken, J., and J. Schnoor. 1999. [Distribution and Volatilization of Organic Compounds Following Uptake by Hybrid Poplar Trees](#). *International Journal of Phytoremediation* 1:139–151.
- Cai, H., J.B. Dunn, Z. Wang, J. Han, and M.Q. Wang. 2013. [Life-cycle energy use and greenhouse gas emissions of production of bioethanol from sorghum in the United States](#). *Biotechnology for Biofuels* 6:141.
- Castro, E., I.U. Nieves, V. Rondón, W.J. Sagues, M.T. Fernández-Sandoval, L.P. Yomano, S.W. York, J. Erickson, and W. Vermerris. 2017. Potential for Ethanol Production from Different Sorghum Cultivars. *Industrial Crops & Products* 109:367–373.
- Congreves, K.A., S.E. Brown, D.D. Németh, K.E. Dunfield, and C. Wagner-Riddle. 2017. Differences in Field-Scale N<sub>2</sub>O Flux Linked to Crop Residue Removal Under Two Tillage Systems in Cold Climates. *Global Change Biology Bioenergy* 9:666–680. DOI:10.1111/gcbb.12354.
- Cope, T. 2015. [Neighbors Come Out in Opposition of Proposed Ethanol Plant Near Caldwell](#). *Idaho Press-Tribune* May 3, 2015.
- Crawford, J.T., C.W. Shan, E. Budsberg, H. Morgan, R. Bura, and R. Gustafson. 2016. [Hydrocarbon Bio-Jet Fuel From Bioconversion of Poplar Biomass: Techno-Economic Assessment](#). *Biotechnology for Biofuels* 9:141.
- Dan, C. 2016. [As Big Candy Ditches GMOs, Sugar Beet Farmers Hit A Sour Patch](#). *NPR - The Salt* May 12, 2016.
- Demirbas, A. 2009. [Political, Economic and Environmental Impacts of Biofuels: A Review](#). *Applied Energy* 86:S108–S117.
- Doherty, W.O.S., P. Mousavioun, and C. Fellows. 2011. Value-adding to Cellulosic Ethanol: Lignin Polymers. *Industrial Crops and Products* 33:259–76.
- Eisentraut, A. 2010. [Sustainable Production of Second-Generation Biofuels](#). *Information Report of the International Energy Agency*.
- Ellis, S. 2016. [Sorghum Facility Would Provide Farmers with Stable Rotation Crop](#). *Capital Press* August 26, 2016.

- Environmental and Energy Study Institute (EESI). 2016a. [Summertime, When the Living's Easy](#).
- . 2016b. [Fact Sheet - A Brief History of Octane in Gasoline: From Lead to Ethanol](#).
- Ethanol Producer Magazine. 2017. [U. S. Ethanol Plants](#).
- Flugge, M., J. Lewandrowski, J. Rosenfeld, C. Boland, T. Hendrickson, K. Jaglo, S. Kolansky, K. Moffroid, M. Riley-Gilbert, and D. Pape. 2017. [A Life-Cycle Analysis of the Greenhouse Gas Emissions of Corn-Based Ethanol](#). Report prepared by ICF under USDA Contract No. AG-3142-D-16-0243.
- Galinato, S.P., T.D. Skolrud, G.I. Galinato, C.R. Shumway, and J.K. Yoder. 2016. [Impacts of Federal Biofuel Policy and Market Structure on the PNW Cellulosic Ethanol Industry](#). Washington State University Extension TB25.
- Graf, A., and T. Koehler. 2000. [Oregon Cellulose-Ethanol Study: An Evaluation of the Potential for Ethanol Production in Oregon Using Cellulose-based Feedstocks](#). Report prepared by Bryan & Bryan, Inc. for the Oregon Office of Energy.
- Hamelinck, C.N., G.V. Hooijdonk, and A.P.C. Faaij. 2005. Ethanol from Lignocellulosic Biomass: Techno-Economic Performance in Short-, Middle- And Long-Term. *Biomass and Bioenergy* 28(4):384–410.
- Ho, D.P., H.H. Ngo, and W. Guo. 2014. [A Mini Review on Renewable Sources for Biofuel](#). *Bioresource Technology* 169:742–749.
- Hoekman, S.K., and A. Broch. 2018. Environmental Implications of Higher Ethanol Production and Use in the U.S.: A Literature Review. Part II - Biodiversity, Land Use Change, GHG Emissions, and Sustainability. *Renewable and Sustainable Energy Reviews* 81:3159–3177.
- Hoekman, S.K., A. Broch, and X. Liu. 2018. Environmental Implications of Higher Ethanol Production and Use in the U.S.: A Literature Review. Part I – Impacts on water, soil, and air quality. *Renewable and Sustainable Energy Reviews* 81:3140–3158.
- Isebrands, J.G., and J. Richardson (eds.). 2012. *Poplars and willows: trees for society and the environment*. CABI and FAO, Croydon, UK.
- Jacobson, M.Z. 2007. Effects of Ethanol (E85) versus Gasoline Vehicles on Cancer and Mortality in the United States. *Environmental Science & Technology*. 41:4150–4157. DOI:10.1021/es062085v.
- Jaeger, W.K., R. Cross, and T.M. Egelkraut. 2007. [Biofuel Potential in Oregon: Background and Evaluation of Options](#). Oregon State University Extension Service SR 1078.
- Jessen, H. 2013. [Trash to Bio-Treasure](#). *Ethanol Producer Magazine* October 11, 2013.
- Juneja, A., D. Kumar, and G.S. Murthy. 2013. Economic Feasibility and Environmental Life Cycle Assessment of Ethanol Production from Lignocellulosic Feedstock in Pacific Northwest U.S. *Journal of Renewable and Sustainable Energy* 5:023142.
- Juneja, A., D. Kumar, J.D. Williams, D.J. Wysocki, and G.S. Murthy. 2011. Potential for Ethanol Production from Conservation Reserve Program Lands in Oregon. *Journal of Renewable and Sustainable Energy* 3:063102.
- Kovarik, B. 1998. [Henry Ford, Charles Kettering and the Fuel of the Future](#). *Automotive History Review* 32:7–27.
- Kumar, D., and G.S. Murthy. 2012. Life Cycle Assessment of Energy and GHG Emissions During Ethanol Productions for Grass Straws Using Various Pretreatment Processes. *The International Journal of Life Cycle Assessment* 17:388–401.
- Lardy, G., and R. Schafer. 2016. [Feeding Sugar Beet Byproducts to Cattle](#). North Dakota State University AS1365.
- Learn, S. 2013. [Ethanol Plant in Clatskanie, Built with \\$36 Million in Oregon Loans and Credits, Now Shipping Crude Oil](#). *The Oregonian* May 13, 2013.

- Liska, A.J., H. Yang, M. Milner, S. Goddard, H. Blanco-Canqui, M.P. Pelton, X.X. Fang, H. Zhu, and A.E. Suyker. 2014. Biofuels From Crop Residue Can Reduce Soil Carbon and Increase CO<sub>2</sub> Emissions. *Nature Climate Change* 4:398–401. DOI:10.1038/nclimate2187.
- Luck, M. 2016. [Ethanol Replaces Crude Oil at Clatskanie Port](#). *The Daily News, Longview, WA* September 3, 2016.
- Lynd, L.R., E. Larson, N. Greene, M. Laser, J. Sheehan, B.E. Dale, S. McLaughlin, M. Wang. 2009. The Role of Biomass in America's Energy Future: Framing the Analysis. *Biofuels, Bioproducts and Biorefining* 3(2):113–123. DOI:10.1002/bbb.134.
- Minogue, P.J., M. Miwa, D.L. Rockwood, and C.L. Mackowiak. 2012. Removal of Nitrogen and Phosphorus by Eucalyptus and Populus at a Tertiary Treated Municipal Wastewater Sprayfield. *International Journal of Phytoremediation* 14:1010–1023. DOI:10.1080/15226514.2011.649435.
- Mueller, S. 2017. [Ethanol Industry Provides Critical CO<sub>2</sub> Supply](#). *Ethanol Producer Magazine* February 8, 2017.
- Oregon Department of Environmental Quality (DEQ). 2017. [Overview of the Clean Fuels Program](#).
- Oregon State University. 2018. [Willamette Valley Field Crops: Grass Seed](#).
- Pacific Ethanol. 2017a. [Investor Presentation](#) May 31, 2017.
- Pacific Ethanol. 2017b. [Biorefineries and Locations](#).
- Profita, C., and K. Campbell. 2014. [3 Ways Northwest Companies Are Turning Food Waste Into Energy](#). *EarthFix* Nov. 19, 2014.
- Ragauskas, A.J., G.T. Beckham, M.J. Bidy, R. Chandra, F. Chen, M.F. Davis, B.H. Davison, R.A. Dixon, P. Gilna, M. Keller, P. Langan, A.K. Naskar, J.N. Saddler, T.J. Tschaplinski, G.A. Tuskan, C.E. Wyman. 2014. Lignin Valorization: Improving Lignin Processing in the Biorefinery. *Science* 344(6185):1246843. DOI:10.1126/science.1246843.
- Redfield Energy, LLC. 2017. [Corn Distillers Grain](#).
- Renewable Fuels Association. 2017. [Ethanol Biorefinery Locations](#).
- Šantek, B., G. Gwehenberger, M.I. Šantek, M. Narodoslavsky, and P. Horvat. 2010. [Evaluation of Energy Demand and the Sustainability of Different Bioethanol Production Processes from Sugar Beet](#). *Resources, Conservation and Recycling* 54:872–877.
- Schmitt, E., R. Bura, R. Gustafson, J. Cooper, and A. Vajzovic. 2012. Converting lignocellulosic Solid Waste into Ethanol for the State of Washington: An Investigation of Treatment Technologies and Environmental Impacts. *Bioresource Technology* 104:400–409.
- Siemers, E. 2009. [Firms Turn Trash Into Cash](#). *Portland Business Journal* April 26, 2009.
- Singh, A., D. Pant, N.E. Korres, A. Nizami, S. Prasad, and J.D. Murphy. 2010. [Key Issues in Life Cycle Assessment of Ethanol Production from Lignocellulosic Biomass: Challenges and Perspectives](#). *Bioresource Technology* 101(13):5003–5012.
- Song, Y., R. Peng, D.K. Hensley, P.V. Bonnesen, L. Liang, Z. Wu, H.M. Meyer III, M. Chi, C. Ma, B.G. Sumpter, and A.J. Rondinone. 2016. [High-Selectivity Electrochemical Conversion of CO<sub>2</sub> to Ethanol using a Copper Nanoparticle/N-Doped Graphene Electrode](#). *ChemistrySelect* 1(19):6055–6061.
- Speth, R.L., E.W. Chow, R. Malina, S.R.H. Barrett, J.B. Heywood, and W.H. Green. 2014. Economic and Environmental Benefits of Higher-Octane Gasoline. *Environmental Science & Technology* 48(12):6561–6568. DOI:10.1021/es405557p.

- Stanton, B. 2017. [Poplars for Bioenergy Harvested at Jefferson Demonstration Site](#). *AHB Newsletter Vol. 6, No. 1* April 2017.
- SunGrant Initiative. 2008. [Mapping Tools and Output: NASS Data](#).
- Townsend, P.A., S.P. Kar, and R.O. Miller. 2014. [Poplar \(Populus spp.\) Trees for Biofuel Production](#). *eXtension*.
- United States Department of Agriculture (USDA). 2006. [The Economic Feasibility of Ethanol Production from Sugar in the United States](#).
- . 2017. [USDA Releases New Report on Lifecycle Greenhouse Gas Balance of Ethanol](#). *Press Release No. 0007.17*.
- USDA Economic Research Service (ERS). 2017. [U.S. Bioenergy Statistics: Table 5--Corn Supply, Disappearance and Share of Total Corn Used for Ethanol](#).
- USDA National Agricultural Statistics Service. 2017. [Crop Production 2016 Summary](#).
- United States Department of Energy (U.S. DOE). 2016. [Handbook for Handling, Storing, and Dispensing E85 and Other Ethanol-Gasoline Blends](#).
- United States Energy Information Administration (U.S. EIA). 2016a. [Table F4: Fuel ethanol consumption estimates, 2015](#).
- . 2016b. [Almost All U.S. Gasoline is Blended with 10% Ethanol](#). *Today in Energy* May 4, 2016.
- . 2017a. [Biofuels: Ethanol and Biodiesel Explained – Use of Ethanol](#).
- . 2017b. [State Energy Data System \(SEDS\): 1960-2015 \(complete\)](#).
- United States Environmental Protection Agency (U.S. EPA). 2011. [EPA Announces E15 Partial Waiver Decision](#). EPA-420-F-11-003.
- . 2016. [Program Overview for Renewable Fuel Standard Program](#).
- . 2018. [Gasoline Reid Vapor Pressure](#).
- U. S. Grain Council. 2012. [A Guide to Distiller's Dried Grains with Solubles \(DDGS\)](#). Third Edition.
- Vakkilainen, E., K. Kuparinen, and J. Heinimö. 2013. [Large Industrial Users of Energy Biomass](#). *Report written for IEA Bioenergy Task 40*.
- Veal, M.W. 2014. [Ethanol and Two-Stroke Cycle Engines - Impacts of an Alternative Fuel in Small Engines](#). *North Carolina Cooperative Extension AG-784*.
- Wang, M., J. Han, J.B. Dunn, H. Cai, and A. Elgowainy. 2012. [Well-to-Wheels Energy Use and Greenhouse Gas Emissions of Ethanol from Corn, Sugarcane and Cellulosic Biomass for US Use](#). *Environmental Research Letters* 7:045905. 13pp.
- Wind, C.A. 2017. Personal communication. Oregon Department of Environmental Quality (DEQ) Clean Fuels Program Manager.
- Yoder, J., D. Young, K. Painter, J. Chen, J. Davenport, and S. Galinato. 2009. Potential for a Sugar Beet Ethanol Industry in Washington State. *Report to the Washington State Department of Agriculture*.
- Youngs, H., and C. Somerville. 2014. Best Practices for Biofuels. *Science* 344:1095–1096. DOI:10.1126/science.1255812.

Published and distributed in furtherance of the Acts of Congress of May 8 and June 30, 1914, by Washington State University Extension, Oregon State University Extension Service, University of Idaho Extension, and the U.S. Department of Agriculture cooperating. WSU Extension programs, activities, materials, and policies comply with federal and state laws and regulations on nondiscrimination regarding race, sex, religion, age, color, creed, and national or ethnic origin; physical, mental, or sensory disability; marital status or sexual orientation; and status as a Vietnam-era or disabled veteran. Washington State University Extension, Oregon State University Extension Service, and University of Idaho Extension are Equal Opportunity Employers. Evidence of noncompliance may be reported through your local Extension office. Trade names have been used to simplify information; no endorsement is intended.

Pacific Northwest Extension publications contain material written and produced for public distribution. You may reprint written material, provided you do not use it to endorse a commercial product. Please reference by title and credit Pacific Northwest Extension publications.

Order Information:

[WSU Extension](#)

Fax 509-335-3006

Toll-free phone 800-723-1763

[ext.pubs@wsu.edu](mailto:ext.pubs@wsu.edu)

[OSU Extension](#)

Fax 541-737-0817

Toll-free phone 800-561-6719

[puborders@oregonstate.edu](mailto:puborders@oregonstate.edu)

[UI Extension](#)

Fax 208-885-4648

Phone 208-885-7982

[calspubs@uidaho.edu](mailto:calspubs@uidaho.edu)

Copyright © Washington State University

Pacific Northwest Extension publications are produced cooperatively by the three Pacific Northwest land-grant universities: Washington State University, Oregon State University, and the University of Idaho. Similar crops, climate, and topography create a natural geographic unit that crosses state lines. Since 1949, the PNW program has published more than 650 titles, preventing duplication of effort, broadening the availability of faculty specialists, and substantially reducing costs for the participating states. Published September 2018.