Growing Our Energy at Home:
Biomass Crops in Alaska

introduction by Stephen D. Sparrow

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Alaska is home to vast energy resources and is a net exporter of energy in the form of crude oil. Yet Alaskans, especially those residing in remote communities, pay some of the highest energy prices in the country. Energy experts are working to identify opportunities for developing cheaper, renewable energy sources for Alaskans. Alaska has vast quantities of biomass, mostly in the form of trees, which provide an excellent and often cheap fuel source for many communities in the forested regions of the state. However, there are concerns over the long-term sustainability of repeated harvests of forests, especially if the harvest repeat rate is short. Also, many communities in Alaska do not have ready access to forest biomass. Growing biomass crops for energy may be a feasible way to sustainably produce renewable energy in some parts of Alaska.

Scientists at the University of Alaska Fairbanks Agricultural and Forestry Experiment Station are researching the cropping potential of several types of plants for biomass, as well as different methods for converting the energy contained in biomass into usable energy. We report here on research on growing barley, a commonly grown feed grain in Alaska, as a product that can be directly burned and converted to heat energy; on the feasibility of growing canola, an oilseed crop, and using the oil directly as a fuel or converting it to biodiesel; on growing indigenous and introduced grasses and woody shrubs as biomass crops; and on converting waste forest or agricultural products, such as sawdust or cull potatoes, into bio-oil which can be used as a liquid fuel.

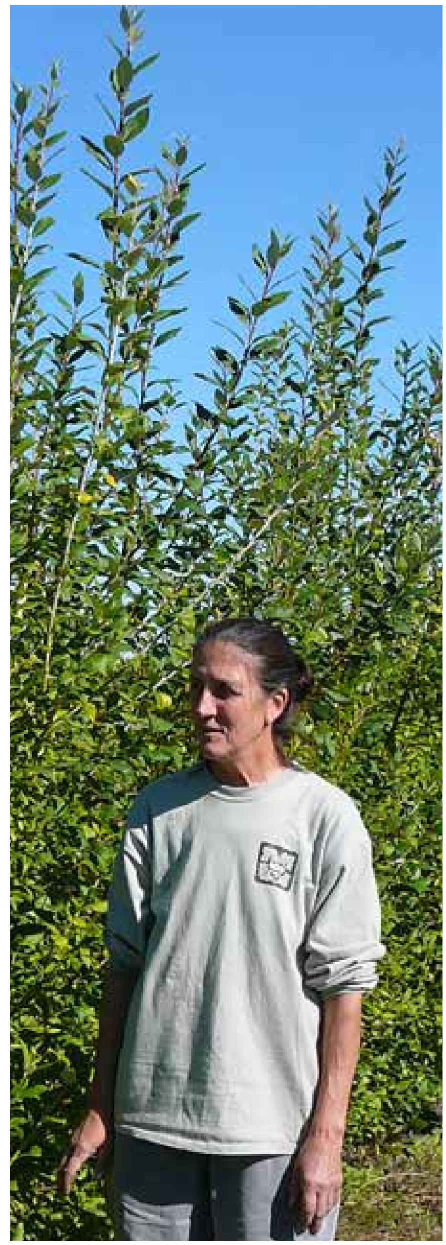
Potential Perennial Lignocellulosic Energy Crops for Alaska

Stephen D. Sparrow, Amanda Byrd, darleen masiak, Mingchu Zhang, Robert van Veldhuizen, William Schnabel

With interest spurred in alternative, locally available renewable energy sources, chief among the resources AFES is investigating is lignocellulosic biomass, which include the primary fiber types making up wood and the stems of grasses. It is used as an energy source through direct burning or by first converting it to liquid or gaseous fuels through various chemical and physical procedures. The former is, of course, "low-tech," and is currently the most common use of fibrous biomass for fuel. The latter, which require sophisticated and often expensive technology, not yet widely used.

In Alaska, the most common source of fibrous biomass is trees harvested from native forests. The rotation period is long (decades) and energy yields per unit of land per year are often low. There has been a great deal of research across the globe on the potential use of both grasses and woody species as short-rotation energy crops. Plants receiving the most interest are fast growing, heat-loving grasses (such as switchgrass and *Miscanthus*) and fast-growing shrubs or trees, most notably willows and poplars. Warm-season grasses, such as switchgrass, do not grow well in Alaska. However, research in Northern Europe has indicated that some species of cool-season grasses may have potential as energy crops. Both willows and poplars are indigenous to and widespread in Alaska, so there is a great deal of interest in their use as energy crops.

Over the past decade, we have studied the potential of growing lignocellulosic biomass crops at several locations in Alaska, including Anchorage, Yakutat, Palmer, Delta Junction, and Fairbanks. These locations represent a wide range of climate and soil conditions.



Darleen masiak, now retired, worked on biomass cropping potential for woody shrubs such as these willows (Feltleaf willow, Salix alaxansis*) growing on the Fairbanks Experiment Farm at UAF. This stand was only two years old and already almost twice as tall as masiak, illustrating why woody species such as these excite such interest.*
—Photo by Stephen D. Sparrow

We converted a six-year-old planted balsam poplar plot to a biomass study at Anchorage (61.25°N, 149.80°W); the location has a mean annual temperature (MAT) of 35°F and mean annual precipitation (MAP) of 16 inches. The entire plot area was harvested and divided into four quadrants, two of which received nitrogen fertilizer (N) at 100 lbs per acre, and two of which received none. Tree regrowth was harvested after two growing seasons and analyzed for energy, ash, and nutrient contents.

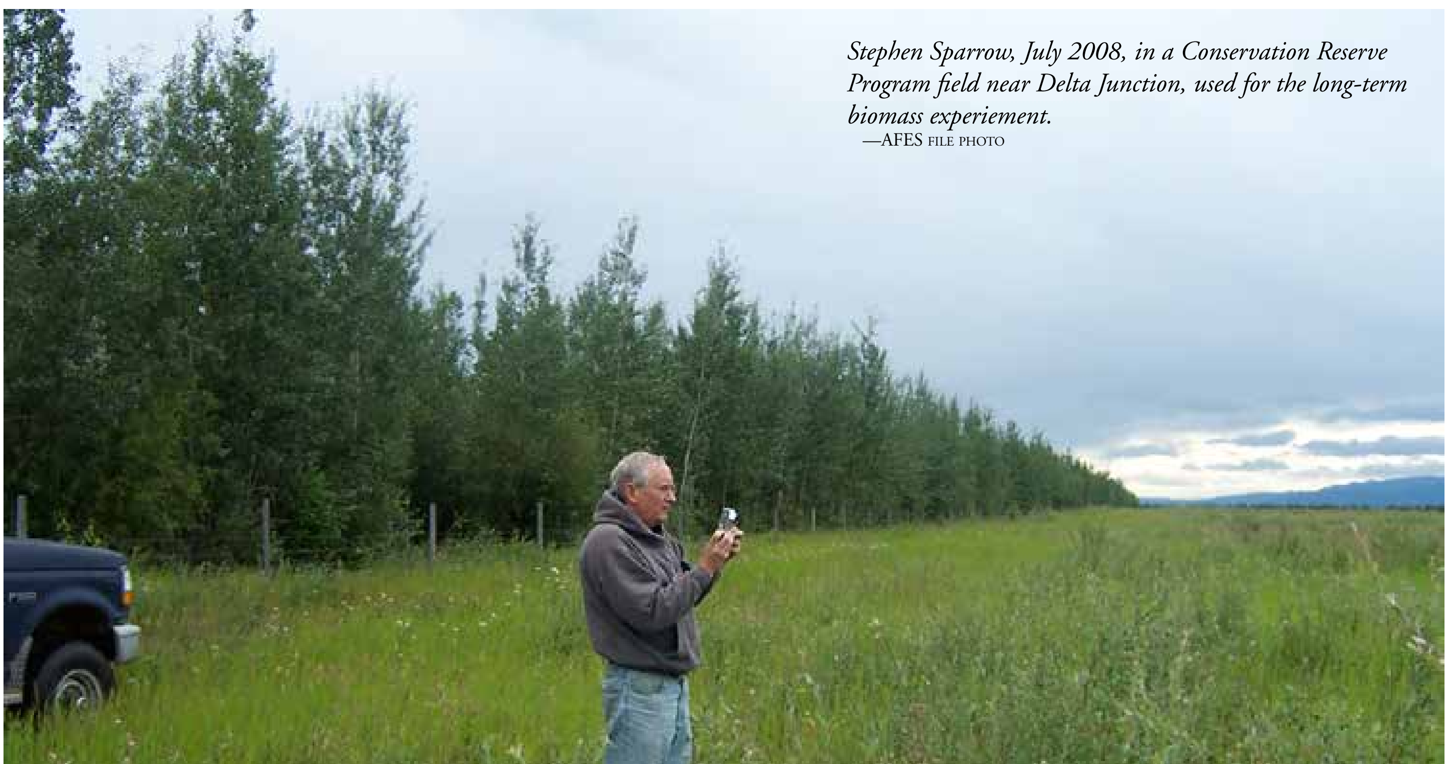
At Yakutat (59.55°N, 139.73°W), located in a north temperate maritime climate (MAT of 39°F and MAP of 151 in), we planted dormant cuttings of 10 willow species and two poplar species and transplants of one alder species. Plots at Yakutat have not yet reached harvest stage.

We planted dormant cuttings of two willow species and one poplar species at Palmer (61.53°N, 149.08°W) and two locations at Fairbanks (64.82°N, 147.87°W). Plots at Palmer (MAT, 37°F; MAP, 12 in), were overtaken by weeds and were destroyed in their second year. Plots at Fairbanks (MAT 27°F; MAP, 11 in) were fertilized with 90 lb N/ac in the second year after establishment. Willow/poplar plots at Fairbanks were harvested at the end of the fourth year after establishment.

Grass plots, both native and introduced, were established in Delta Junction (64.04°N, 145.72°W) (MAT, 29°F; MAP, 11 in) and Fairbanks by seeding and were harvested annually beginning in their second year of growth. Three harvest regimes, consisting of a double harvest (midsummer and autumn), a single fall harvest, and an early spring harvest while still dormant were imposed, as were three nitrogen fertilizer treatments (10, 45, and 90 lb N/ac).

At Anchorage, poplar regrowth produced 2.45 tons biomass per acre per year over the two-year period, with no effect from the nitrogen fertilizer addition, likely because weeds absorbed most of the added nitrogen. The energy in an acre of harvested biomass was equivalent to the energy in approximately 610 gallons of diesel fuel. At Fairbanks, on a moderately drained site, the highest yielding species, feltleaf willow, produced <½ ton per acre per year and at a wet site, it produced 1 ton per acre per year.

Annual grass yields at both Fairbanks and Delta Junction varied greatly among species. Overall, smooth bromegrass produced the highest yields, with annual yields exceeding three tons per acre in some years at Fairbanks, and with yields for other grasses typically less than two tons per acre per year. Yields at Delta Junction were considerably lower than those at Fairbanks, probably because the site tends to be droughty, so water deficiency limits growth. Grasses generally responded to application of nitrogen fertilizer with the highest yields at the highest N rate. Moisture content of grasses was lowest for spring harvests, but highest dry matter yields were at fall harvest. The loss of biomass for spring harvest was due to loss of leaves and lodging, caused by snow load, to the point that the harvester could not recover the downed stems.



Stephen Sparrow, July 2008, in a Conservation Reserve Program field near Delta Junction, used for the long-term biomass experiement.
—AFES file photo

Amanda Byrd standing amidst poplars in an experiment plot for the biomass study.
—AFES FILE PHOTO

The grass yields were lower than usually reported in warmer climates for fast growing grasses, but were comparable to those reported for cool-season grasses in other high-latitude regions. Our woody biomass yields at Anchorage were within the range usually reported for willows and poplars in other regions; our yields at Fairbanks were quite low compared to most other studies. We do not know if the low yields were because the shrubs/trees had not become well enough established to produce rapid growth or if climatic or soil factors limited growth potential. We have not yet done assessments to determine the economic feasibility of growing bioenergy crops in Alaska.

Stooling Beds: Poplars as a sustainable biomass energy resource

Valerie Barber

Poplar cuttings soaking in a bucket to sprout. Cuttings are brought out of cold storage and soaked for a week to induce sprouting before planting.

—Photo by Jeff Graham, Alaska Department of Forestry

Woody biomass systems financed through the Alaska Energy Authority are being installed in more and more communities for heat and in some places for combined heat and power (CHP). Some of the biomass facilities are supported by mill waste, imported (or local) pellets, or driftwood, but many locations rely on local forest harvesting. Forest regeneration is an important element of sustainable forest management and with a changing climate, there is much uncertainty about natural forest regeneration and planting trees in remote locations could be cost prohibitive. Poplar, aspen, and willows stump sprout abundantly after harvest and can be fast growing, while spruce and birch do not stump sprout and grow more slowly. Most of the woody biomass needed for energy will likely be harvested in winter, and if lacking reforestation efforts, spruce and birch forest types can become dominated by smothering grass and herbaceous vegetation for decades. The Alaska Forest Resources and Practices Act requires reforestation within seven years of timber harvest. Hence, inexpensive reforestation is critical to support woody biomass energy sustainably in Alaska.

Stooling beds are perennial hedgerows commonly used for stem cuttings (whips) to grow trees in the nursery industry. Stooling beds can be harvested each year and will grow back from stump sprouts. The harvested whips can be planted directly into the ground, providing a low-cost and technically simple way to reforest. Stooling beds might be a solution for reforestation after harvesting in Alaska but more research is needed to see if the technique of directly planting cut whips will work in Alaska. Demonstration stooling beds should be near research facilities that are easily accessible for demonstration access.

The Alaska Energy Authority Emerging Energy Technology Fund program provided funding for the stooling beds project being conducted by the State of Alaska's Division of Forestry (in the Department of Natural Resources) and the UAF Forest Products Program, with a goal to adapt, demonstrate, and disseminate inexpensive reforestation methods applicable following woody biomass harvest.

The project's staff harvested more than 4,000 stem cuttings from balsam poplar (*Populus balsamifera*) growing in Palmer and Delta Junction in March of 2013 and stored in a freezer. We soaked the unrooted stem cuttings for a week in late May/early June and planted them in mid-June 2013. We planted logged sites in Matanuska-Susitna Valley (five) and Delta Junction (five) with cuttings. We planted stooling beds that will serve as parent material for future cuttings at two locations, one each in Delta Junction and Palmer, where UAF has research sites with available land. At the Delta Junction and Palmer sites, we planted stooling beds of hyprid poplar, using cultivars of Green Giant, Okanese, and Hill obtained from Canada. We evaluated all planted stems for growth and survival at the end of the growing season.

Anomalous weather conditions during the spring and summer of 2013 didn't bode well for the propagation and survival of the whips. A late spring snowstorm and cold conditions delayed planting in the spring, and record-breaking heat and low precipitation induced drought stress over the growing season. Later, an early frost in Delta Junction adversely affected the planted hybrids.

Most of the planted whips started sprouting early in the summer but many were shriveled and brown by the end of the summer. Survival overall on the logged sites was about 10%. Sites that had more moisture had a higher success rate and one site had 45% survival.

The stooling beds at the research sites were watered periodically and many survived the heat. Most of the hybrid whips sprouted and were growing much faster than the local balsam poplar throughout the growing season, but Delta Junction had an early frost and most of the hybrids were killed.

The study will continue this year (2014). Cuttings were taken in March from Delta Junction, Fairbanks, Palmer, and Glennallen. The thought is to expand the collection area to

Delta Junction Research Site, first week of June 2014. Cutting origin was marked by colored flags. In addition to balsam poplar cuttings from Delta Junction, Fairbanks, Glennallen, and Palmer, and Alberta, Canada, hybrid poplars from Alberta were also planted, for a total of five different balsam poplar provenances and one hybrid.
—Photo by Valerie Barber

try to get more plasticity in the gene pool. Whips collected from each area will be planted at the Delta Junction and Palmer logged sites and at the research sites. A collection of all provenances will also be sent to Galena where a graduate student will plant the cuttings, develop a research project, and monitor survivability. A new biomass CHP system will be installed in Galena in 2015 that will be fueled by local logging efforts so low-cost and simple reforestation techniques are needed there.

We will also collect some survivors from each of the sites and take them back to Palmer. These might have greater gene plasticity that allowed them to survive drought, heat, and unpredictable frost, and if we can grow them, we might have trees that are better adapted for a warming Alaska. It might also be possible to create a hybrid poplar that can withstand the greater heat and drought that we are experiencing in Alaska.

While the hybrids used in Alaska grew better than the local balsam poplar, there is still a problem with phenology (budset and senescence) and with photoperiod. The light regime in Alaska is very different than lower latitudes. The hybrids that were damaged by the early frost did not harden off as early as the Alaska balsam poplar and thus still retained their leaves when the temperature dropped, while the Alaska trees had already lost theirs.

To alleviate this problem, we plan to develop an Alaska balsam poplar hybrid that will better adapt to the changing climate. The results will be documented, published, presented, and available for demonstration site visits. Results will be applicable to communities in boreal forest regions worldwide.

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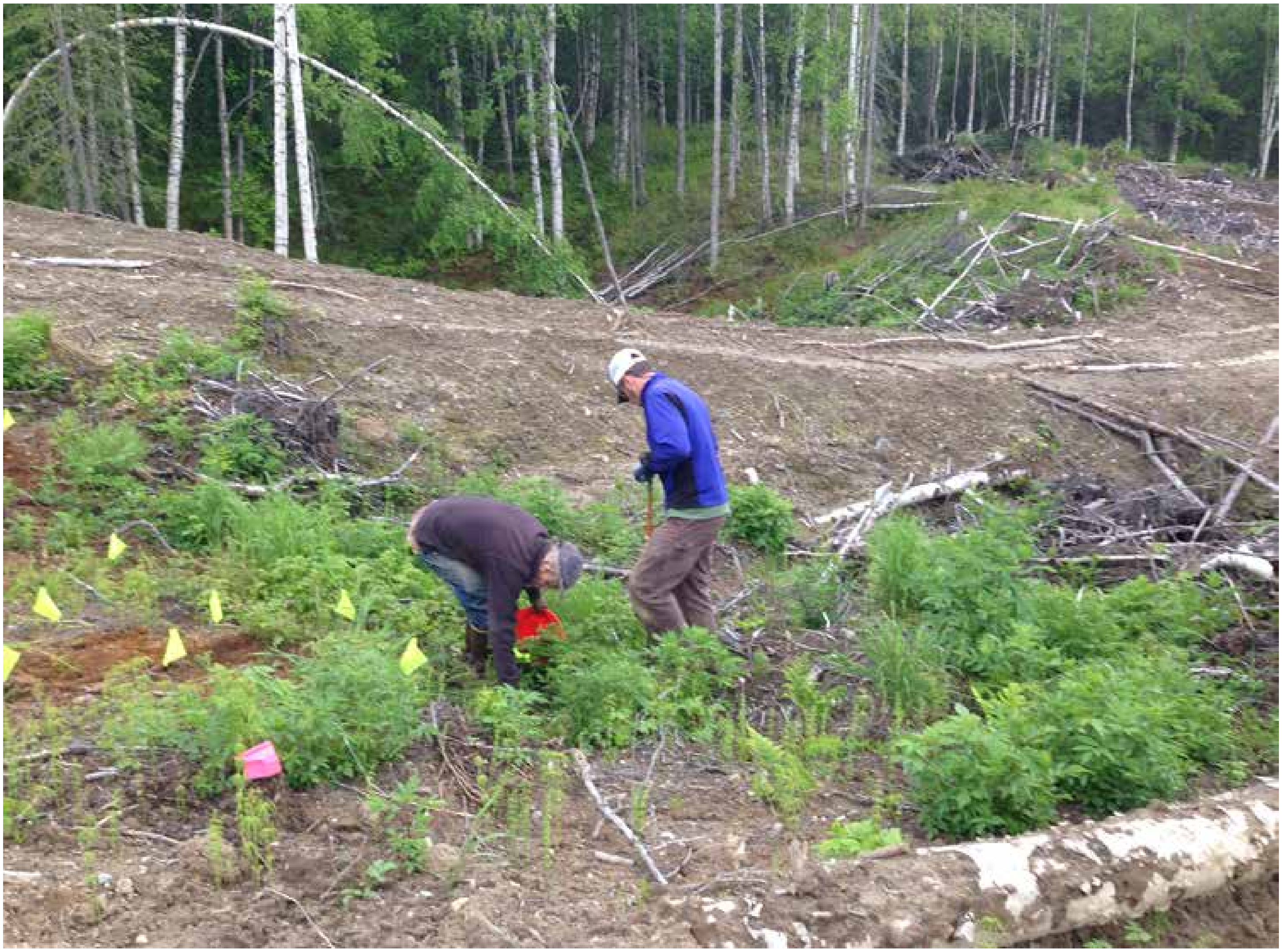

Planting whips at a logged site. Left, Jeff Graham. On the right, Jim Smith of the Alaska Department of Natural Resources.
—Photo by Valerie Barber

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Agronomic Crops for Biofuel Production in Alaska

Bob Van Veldhuizen and Mingchu Zhang

Barley for Biofuel Production

Barley is the most important cereal grain crop grown in Alaska and is well adapted to the state's long day length and short growing season. Although it is used primarily as an animal feed, both the harvested grain and straw can also be used as a biofuel source. An advantage of barley grain for biofuel is that it would require very little modification to typical pellet stoves for conversion to use grain as the biofuel source. There are several concerns with barley as a fuel source, however, such as moisture in the harvested grain, high ash content, high nitrogen content, and rough awns posing a hazard to animals.

Most barley varieties grown in Alaska have been the six-row types, which usually mature earlier and are more uniform at harvest than the two-row types. Early-maturing six-row barley varieties usually produce three to four tillers per plant that often reach maturity, increasing yields at harvest. Two-row varieties, which mature later, often produce many tillers, even late in the growing season. These late tillers may be immature at harvest when the main head is ripe. When the main head is harvested, the late tillers' wet plant material is mixed in with the ripe seed, increasing drying costs and reducing the quality of the grain for use as a biofuel.

The optimum moisture level in grain at harvest is around 14%, but this can range from as low as 12% to as high as 20%. Within this moisture range, barley grain will have a net heating value of between 6,000–8,200 BTU/lb (Clark et al. 2011). This moisture will volatilize during combustion, decreasing the energy produced. It will also have a negative impact on the metering of the grain from storage bins into the combustion chamber by bridging and plugging up transfer equipment. Higher moisture also means that the grain must be dried prior to storage.

After combustion, the material left over is the ash. Barley grain contains between 3.0–6.0% ash, much higher than wood products, which can range from 0.5–3.0% (Finnan and Caslin 2007). Contained in the ash are concentrated levels of potassium, sodium, chlorine, and silicon, as these elements do not volatilize during the combustion process. These elements tend to increase the ash content of grains and lower the melting temperature of the ash (Finnan and Caslin 2010). Barley grain has an ash melting temperature of between 1,300–1,800°F, compared with that of wood, which is around 2,300°F (Finnan and Caslin 2007). This lower temperature causes an increase in the formation of lumps of congealed ash or "clinkers" in the combustion chamber as well as condensing on the heat transfer surfaces in the boiler chamber, reducing the effectiveness of the boiler and requiring more boiler maintenance for proper efficiency.

Of additional concern is the nitrogen content of the grain. Nitrogen is the element needed in the highest concentrations for maximum yield and quality of the grain at harvest. During the combustion process these nitrogen compounds (proteins) are converted into nitrous oxides (NOx) and released into the atmosphere with the rest of the flue gasses. Immature, unripe grain will contain higher amounts of biomass nitrogen as well as a higher moisture content. This potentially reduces the efficiency of the combustion and increases the amount of ash and nitrous oxides.

Most barley varieties have a long rough awn attached to the hull surrounding the kernel. These rough awns are barbed in one direction, a holdover genetic trait from wild barley that may have helped to ensure seed dispersal by animals. If left on grain or found in straw, the awns do not have any impact on its use as a biofuel even though they are not desireable in a crop used as animal feed or bedding.

Barley straw is around the same moisture content of the grain at harvest, but because it is less dense than the grain, it will have slightly lower net heating values of between 6,000–7,500 BTU/lb and similar ash content of between 4.8–5.9% (Caslin and Finnan 2010, Clark et.al. 2011). One advantage of straw over grain is the lower levels of potassium, sodium, chlorine, silicon, and nitrogen contained in the ash. There are still much higher levels of ash over that of wood products but the overall production of clinkers and scale deposits on the heat transfer surfaces will be lower than that produced by grain. The straw is usually left in the field for a time before it is baled and removed for future use. The weathering process tends to leach many of these elements out of the biomass, resulting in a lower incidence of clinker and scale formation. Unfortunately, the harvesting process for straw collection often accumulates significant amounts of soil in with the biomass. The mineral fraction of soil does not combust, leading to an increase in the formation of clinkers and residue accumulation, and thus increasing maintenance costs. Also, the straw would need to be processed into pellets to be fed into the combustion chamber, or the biomass furnace metering system would need to be modified to be able to feed straw bales. Either option would increase costs of operation.

'Wooding' barley growing at the Fairbanks Experiment Farm. Each grain is covered with a long rough awn.
—Photo by Robert Van Veldhuizen

Canola and Rapeseed for Biofuel Production

Rapeseed (from the Latin *rapum*, meaning turnip) is an annual or biennial industrial oilseed crop specifically developed for the lubrication and biofuel markets. There are two types of rapeseed, Polish or turnip rape (*Brassica rapa* or *Brassica campestris* L.) and Argentine rape (*Brassica napus* L.). Polish rapeseed is a mid tall, multibranched, annual, spring, cool-season, broadleaved oilseed plant. It is earlier maturing than the Argentine type by two to three weeks and requires about the same growing season length as barley. This makes the Polish types the best-suited oilseed for Alaska growing conditions. Rapeseed contains between 35–40% oil by weight. The oil contains high levels of erucic acid (30–60%) that can cause heart lesions and high levels of glucosinolates (30–40 micromoles per gram) that can cause goiters when fed to animals (Canola Council of Canada 2000). Because of the high levels of erucic acid and glucosinolates, rapeseed oil is valuable as a biofuel, but is unsuitable for the food and feed markets.

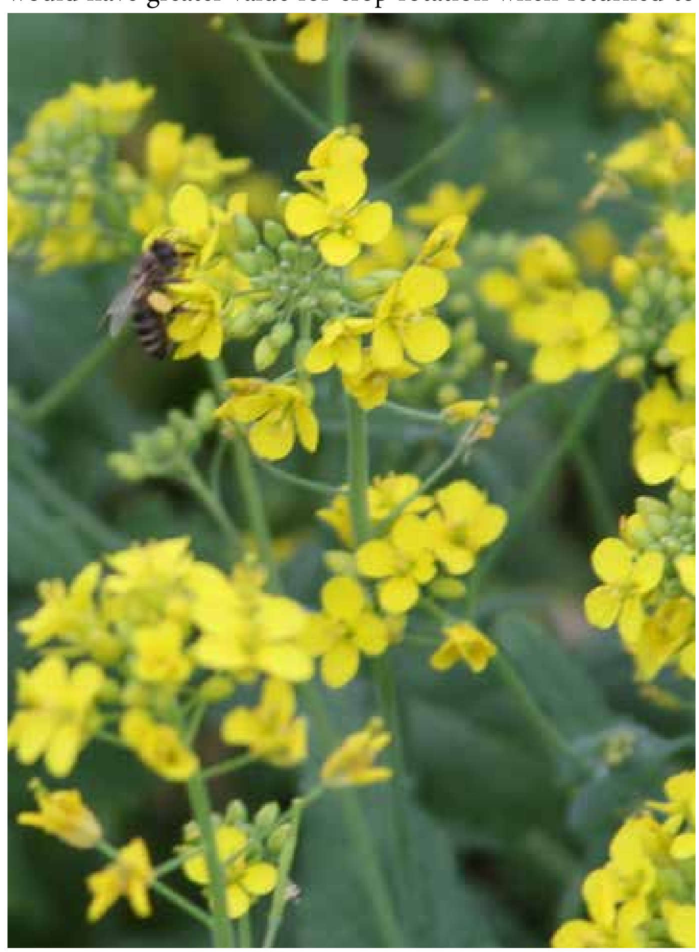
Canola is an edible oilseed crop specifically selected and bred from rapeseed to be low in erucic acid (2% or less) and glucosinolates (less than 30 micromoles per gram). In order to differentiate this new edible oil from the industrial oilseed rapeseed, the Canadian Oilseed Association used the first few letters of their association name, Can+Ol+A, or canola. Canola seed, like rapeseed, contains between 35–40% oil by weight. Canola oil is lower in saturated fats at 6% than any other vegetable oil with a favorable mix of mono- and polyunsaturated fats making it a high value cooking oil (Canola Council of Canada 2000).

Canola and rapeseed oil are obtained by a combination of pressing and solvent extraction of the mature seed. The best of the commercial oilseed presses is only capable of extracting about half of the oil contained in the canola seed, or about 20% by weight. The remaining half of the oil that remains in the meal is extracted with a hexane solvent process. The solvent is then removed from the oil, which is blended in with the pressed oil and everything is run through a filtration and cleaning process which yields about three quarters of the oil or about 30% by weight. Canola oil for the edible market can't contain more than 2% green seed. Green seed is immature seed containing chlorophyll which imparts a green color to the oil and shortens the shelf life by turning rancid quickly. Canola and rapeseed oil can be used after extraction as a biofuel either directly or after a chemical refining process that uses methanol and potassium hydroxide to remove water and glycerol from the oil. The biodiesel yield from this process is only about 80% of the oil yield.

Canola oil has a net heat value of between 16,000–17,500 BTU/lb depending on the maturity and quality of the harvested seed prior to pressing (Adams, et.al. 2006). The resulting canola meal after processing is a high-protein supplement for animal diets that contains around 5% oil by weight. The meal has a net heat value of between 8,700–12,200 BTU/lb (Porter and Crompton 2008, Clark et.al. 2011). Canola meal is higher in ash content than barley grain at about 6.0–6.5% ((Porter and Crompton 2008). In addition, there are comparable levels of potassium, sodium, chlorine, and silicon which tend to increase the ash content of the meal, lower the melting temperature of the ash (Finnan and Caslin 2010, Clark et.al. 2011), and increase the formation of clinkers in the combustion chamber as well as condensing on the heat transfer surfaces in the boiler chamber reducing the effectiveness of the boiler. Similar to barley grain, this will require more boiler maintenance for proper efficiency.

Depending on the percentage of green seed at harvest, the nitrogen content of canola meal is close to two times higher than for barley grain. This increases the amount of nitrous oxides (NOx) that can be formed and released into the atmosphere with the rest of the flue gases during the combustion process. More problematic than barley grain, immature, unripe canola will contain higher amounts of biomass nitrogen as well as a higher moisture content. This potentially reduces the efficiency of the combustion as well as increases the amount of ash and nitrous oxides.

Canola straw contains high levels of glucosinolates, around 5–20 micromoles per gram (Canola Council of Canada 2000). As mentioned previously, these glucosinolates can cause palatability and nutritional problems if fed to livestock or poultry. However, glucosinolates have a positive allelochemical effect that inhibits growth of some species of weeds, nematodes, insects, and soil-borne plant diseases in the field the following year. For this reason, the biomass would have greater value for crop rotation when returned to



Canola blossoms and honeybee at the Fairbanks Experiment Farm.
—Photo by Robert Van Veldhuizen

the soil rather than used as a biofuel source. Canola straw does have a net heat value of between 6,100–7,000 BTU/lb with an ash content of between 4.5–6.2% (Caslin and Finnan 2010, Clark et.al. 2011). Canola straw contains lower levels of potassium, sodium, chlorine, silicon, and nitrogen in the ash than grain straw. There will still be higher levels of ash over that of wood products but the overall production of clinkers and scale deposits on the heat transfer surfaces will be lower than that produced by grain straw. However, the same issues that affect the collection of barley straw for use as a biofuel also affect canola straw. There are additional problems with the collection of canola straw that further limit its use as a biofuel. Canola straw is very light in density compared to barley straw and can be blown across fields and lost before collection. The stems are much more brittle at maturity and tend to break into smaller pieces during combining. These small pieces are much more difficult to collect without also accumulating significant amounts of soil in the process.

Table 1. Average yield and quality of barley grown in interior Alaska

Barley Variety Name	Source	Seed Yield (lbs/acre)	Seed Yield (bu/acre)	Seed Test wt. (lbs/bu)	Net Heat Value[1] (BTU/lb)	Straw Yield (lbs/acre)	Net Heat Value[1] (BTU/lb)	Lodging (%)	Average Maturity Date	Average Maturity (GDD)[2]
Albright	Alberta	4,524	94	49	8,200	1,706	6,990	53	26 July	1,947
Finaska	Alaska	3,360	82	47	7,173	1,316	6,590	18	25 July	1,919
Otal	Alaska	3,841	80	48	8,100	1,113	6,590	35	27 July	1,975
Weal*	Alaska	3,282	68	43	7,007	7,874	7,500	35	26 July	1,647
Wooding	Alaska	3,783	79	48	8,076	1,774	7,000	40	25 July	1,919

1. Net Heat Values for barley seed and straw were not measured in this study. Values were calculated by multiplying yield data and average BTU/lb published in Finnan and Caslin (2007), and Caslin and Finnan (2010).

2. GDD, growing degree days are the cumulative average temperatures above 32°F to reach 50% maturity.

* 'Weal' is a hooded forage variety.

Table 2. Average yield and quality of Polish canola grown in interior Alaska

Canola Variety Name	Source	Seed Yield (lbs/acre)	Seed Yield (bu/acre)	Seed Test wt. (lbs/bu)	Net Heat Value[1] (BTU/lb)	Oil Yield (gal/acre)	Net Heat Value[1] (BTU/lb)	Lodging (%)	Average Maturity Date	Average Maturity (GDD)[2]
Deltana*	Alaska	1,583	32	49	11,150	41	13,422	40	16 Aug	2,511
Reward	Manitoba	1,522	30	48	11,111	39	13,353	77	14 Aug	2,460
Sunbeam	Alberta	1,432	29	50	11,189	37	13,665	93	5 Aug	2,225

1. Net Heat Values for canola were determined in Agricultural and Forestry Experiment Station research at the University of Alaska Fairbanks using a bomb calorimeter on the pressed oil and resulting meal which contained 10% oil by weight.

2. GDD, growing degree days are the cumulative average temperatures above 32°F to reach 50% maturity.

* 'Deltana' is an open pollinated experimental variety.

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Drop-in Biofuels

From the Department of Energy's Alternative Fuels Data Center website:

> "Drop-in biofuels are hydrocarbon fuels substantially similar to gasoline, diesel, or jet fuels. These fuels can be made from a variety of biomass feedstocks including crop residues, woody biomass, dedicated energy crops, and algae.The goal for drop-in fuels is to meet existing diesel, gasoline, and jet fuel quality specifications and be ready to "drop in" to existing infrastructure by being chemically indistinguishable from petroleum derived fuels. This minimizes infrastructure compatibility issues, which are a barrier to fast commercialization of biofuels like ethanol and biodiesel. Drop-in fuels are in a research and development phase with pilot- and demonstration-scale plants under construction. The current focus is aimed at replacing gasoline, diesel, and jet fuel, which may fuel vehicles that aren't good candidates for electrification."

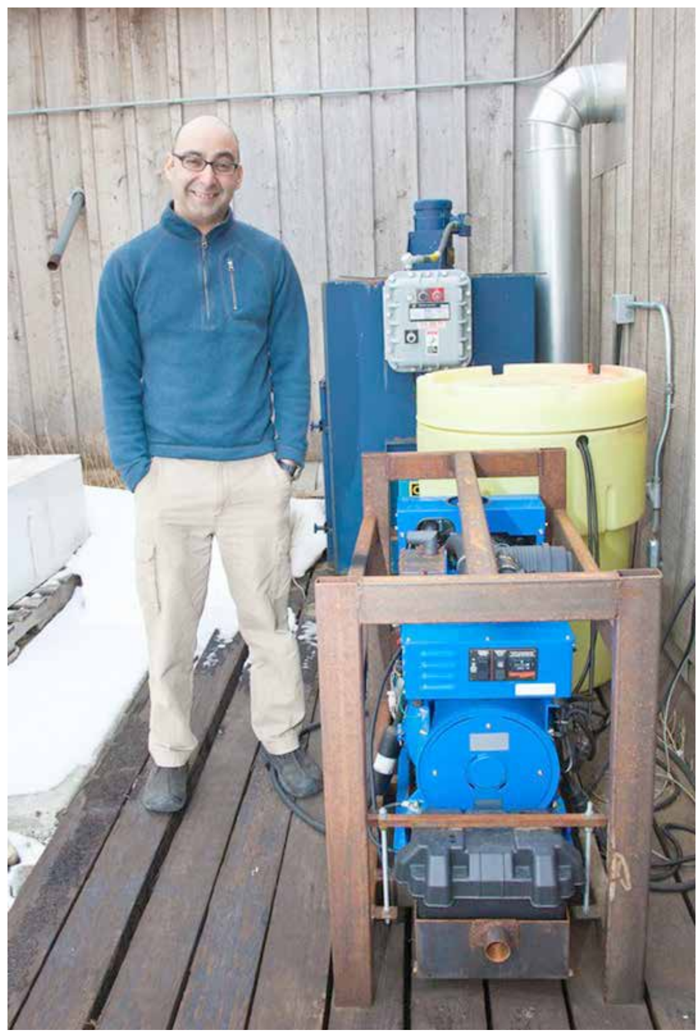
(See www.afdc.energy.gov for more information.)

Researchers are developing drop-in fuels using various methods, among them pyrolysis or liquefaction of biomass to bio-oil with hydroprocessing, catalytic conversion of sugars to hydrocarbons, fermenting sugars to hydrocarbons, hydrotreating algal oils, upgrading syngas from gasification, and upgrading alcohols to hydrocarbons. At the Matanuska Experiment Farm, former Associate Professor of Wood Chemistry and Applied Environmental Science and Technology J. Andres Soria* and graduate students employed catalytic pyrolysis and liquefaction procedures to create complex hydrocarbons for drop-in fuels.

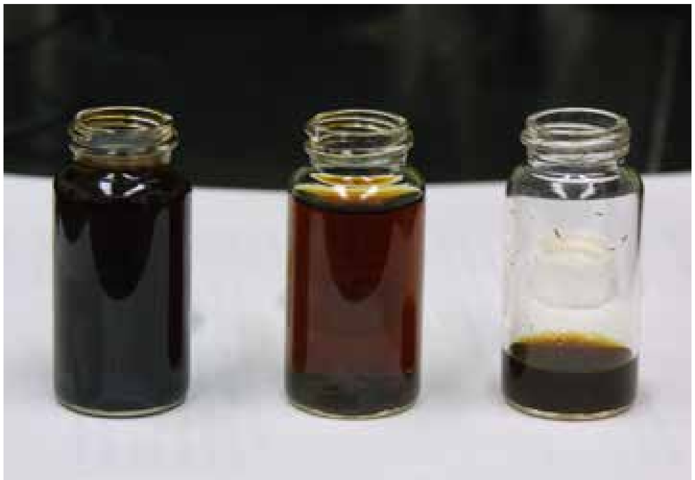
Catalytically Upgrading Bio-oil

J. Andres Soria, PhD and Theodore Dickerson, MSc

We carried out the conversion of different biomass streams into fuel products at the Palmer Center and included the transformation of lignocellulosic biomass into drop-in fuels, or direct alternatives to gasoline and diesel via catalytic pyrolysis pathways using a novel small-scale microreactor. The novel reactor system included a modified SGE Australia pyrojector unit that was fitted with a series of valves that allowed for different gases to be employed and investigated.



Andy Soria was a co-author on the 2011 National Academy of Sciences report, "Renewable Fuel Standard: Potential Economic and Environmental Effects of U.S. Biofuel Policy." He is shown here in 2011 with a 6KW generator that burned the biofuel produced from the bio-oil experiments. The generator powered the lab in Palmer.
—UAF PHOTO BY TODD PARIS



Bio-oils made from different Alaska trees, using supercritical fluid liquefaction. Left to right: birch, alder, and Sitka spruce.
—Photo by Juan Andres Soria

(An SGE pyrojector is a brand of microfurnace pyrolysis injector used for capillary gas chromatography.) The reaction chamber was fitted with a glass wool plug that kept the catalysts in place. The catalysts used were metallic forms of nickel, cobalt, palladium, and ruthenium (obtained from Acros Organics).

For our biomass, we used sawdust from locally sourced alder *(Alnus rubra)*, birch *(Betula neoalaskana)*, and black spruce *(Picea mariana)*, and introduced it into the reactor system by means of a sealed plunger unit. The reaction chamber, already containing the catalyst, was kept at 500°C by an electronically control system. The reaction chamber was purged and pressurized with hydrogen gas and maintained under these conditions for several minutes. Once the reaction time was completed, a valve allowed the gases to enter a gas chromatography/mass spectrometry unit that separated the chemicals produced based on their boiling point. We identified the compounds using computer software and compared the spectra that were produced to gasoline and diesel boiling point chemicals.

The results of this experimental setup are encouraging, as all Alaska species investigated were able to produce chemical profiles that matched the boiling point range of chemicals found in gasoline and diesel fuels. The small-scale reactor approach allowed the investigation to be done at a much reduced cost and with a faster response time than doing the work at scale. However, to validate the results we did scale up the alder wood upgrading using a pilot-scale pyrolysis unit to produce bio-oil. The bio-oil was then transferred into a Parr Instrument Company 7340 series vessel which was purged with hydrogen gas and sealed in the container containing the catalyst. The vessel was pressurized to 3,500 psig by raising its internal temperature to 400°C and kept there for several minutes. Once the reactor was quenched, the liquid content was removed and transferred to a gas chromatography/mass spectrometry vial.

The results show that the alder upgrading products match the boiling point range of diesel and gasoline, further vindicating the work of the microreactor. This is the first reported Alaska biomass-based drop-in fuel study and opens the door for further work to be done using the microreactor unit as well as the pilot-scale pyrolysis unit.

Liquefaction of Potatoes Using Supercritical Water

J. Andres Soria, PhD and Magdalena King, MSc

There are several possibilities for converting biomass into chemicals and fuels as well as using different sources of biomass for the conversion. In Alaska, we are capable of using various woody and lignocellulosic biomass streams for conversion, but also, we can use food matter that has gone bad. Using cull potatoes offers a unique opportunity to use an agronomic resource that can be grown locally, and that can be used to produce a drop-in fuel in the form of a chemical compound called 5 hydroxymethyl furfural (5HMF).

To produce this chemical we used supercritical water, which is pressurized and heated water that is raised to and above 374°C and 3,200 psig. (When a fluid reaches a supercritical state, the temperature and pressure are so high that distinct liquid and gas phases do not exist.) We used a Parr Instrument Company reactor and an electronically controlled heating unit to do this. We collected different potato varieties from the Matanuska Experiment Farm's fields and reacted the biomass with pure water under supercritical conditions. Under these conditions, the starch of potatoes dissociated into sugars, which further converted into the chemical 5HMF, as well as other secondary compounds. We found that the 5HMF was unstable once the supercritical reaction was stopped. The concentration of 5HMF reached the highest concentration seconds after the reaction stopped and then it reduced rapidly to zero within a few hours. The 5HMF polymerized, that is to say, it reacted with itself and the other secondary chemicals produced under the supercritical state to produce very large molecules that resembled tannin and humin compounds. So, as the 5HMF concentration dropped, the tannin and humin type compounds increased to the point that they precipitated out of solution.

From a fundamental perspective, this work shows a potential pathway for producing value-added chemicals from cull potatoes, but the approach requires further refinements to stop the precipitation reactions from occurring, and more work to enable starchy food wastes to become sources of drop-in fuels and chemicals.

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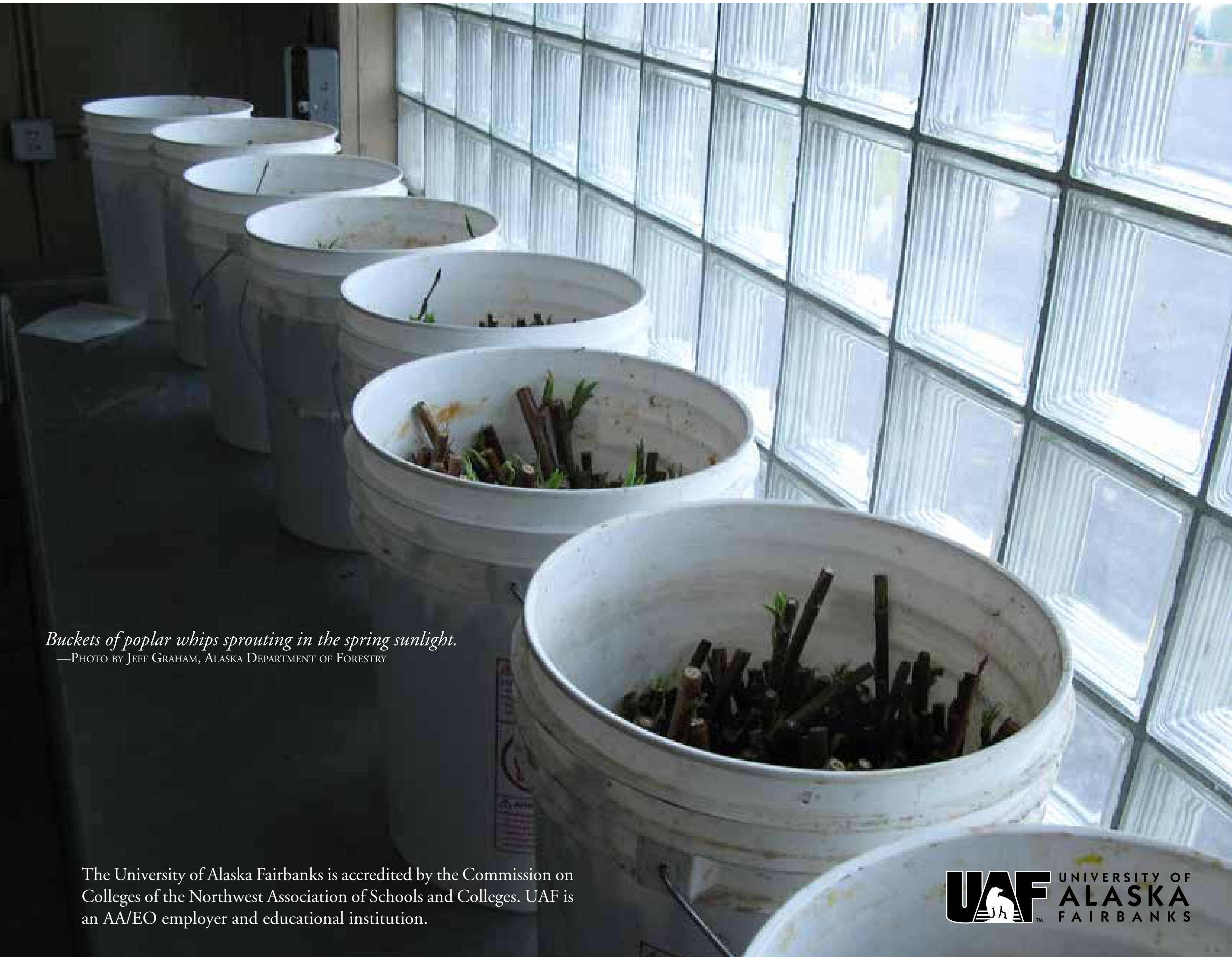

Buckets of poplar whips sprouting in the spring sunlight.
—Photo by Jeff Graham, Alaska Department of Forestry

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