Opportunities for Woody Biomass Fuel Crops in Interior Alaska

Robbin Garber-Slaght[1], Stephen D. Sparrow[2], darleen t. masiak[2], and Gwen Holdmann[1]

1. Alaska Center for Energy and Power, University of Alaska Fairbanks

2. School of Natural Resources and Agricultural Sciences, Agricultural and Forestry Experiment Station, University of Alaska Fairbanks

1.0 Introduction

As the price of traditional fossil fuels escalates, there is increasing interest in using renewable resources, such as biomass, to meet our energy needs. Biomass resources are of particular interest to communities in interior Alaska, where they are abundant (Fresco, 2006). Biomass has the potential to partially replace heating oil, in addition to being a possible

Robbin Garber-Slaght in a Conservation Reserve Program field near Delta Junction, Alaska. Photo by Stephen D. Sparrow.

SNRAS

School of Natural Resources & Agricultural Sciences source for electric power generation (Crimp and Adamian, 2000; Nicholls and Crimp, 2002; Fresco, 2006). The communities of Tanana and Dot Lake have already installed small Garn boilers to provide space heating for homes and businesses (Alaska Energy Authority, 2009). A village-sized combined heat and power (CHP) demonstration project has been proposed in North Pole. In addition, several Fairbanks area organizations are interested in using biomass as a fuel source. For example, the Fairbanks North Star Borough is interested in using biomass to supplement coal in a proposed coal-to-liquids project, the Cold Climate Housing Research Center is planning to test a small biomass fired CHP unit, and the University of Alaska is planning an upgrade to its existing coal-fired power plant that could permit co-firing with biomass fuels. The challenge for all of these projects is in ensuring that biomass can be harvested on both an economically and ecologically sustainable basis.

One method of ensuring long-term sustainable production and harvest of biomass may be by growing short rotation woody biomass crops, such as willows (*Salix* spp.) and poplars (*Populus* spp.). This concept has generated interest locally, and has been demonstrated with some success in other locations around the world. Programs in Sweden and New York have been studying and cultivating willows as a biomass resource for the past thirty years (Nordh, 2005; Volk, et al., 2006.). While their information does not necessarily apply to the subarctic conditions of interior Alaska, their studies can be used as a starting point for local projects.

Interior Alaska has several potential plant genera that could be used as biomass energy crops, including willow, alder (*Alnus*), and poplar. Previous studies conducted on willows and alders in interior Alaska examined succession of these shrubs on river flood plains (Viereck, 1970; Van Cleve and Viereck, 1981; Krasny et al., 1988) while others investigated the use of shrubs to revegetate areas impacted by development (Densmore et al., 2000; McKendrick, 2005; Walter and Hughes, 2005). There is very little information on the growth rate and biomass production of native shrubs and trees in short rotation plantations in the subarctic, but such information is needed in order to assess the feasibility of growing them as an energy crop.

2.0 Existing Short Rotation Biomass Programs

There are many programs worldwide that are actively engaged in growing short rotation willow crops for use in biomass heat and power generation (Volk et al., 2004). The programs in Sweden and New York are among the longest running and provide a wealth of information about how to best manage short rotation woody species as agricultural crops for their particular geographic regions. While their experiences are very important and many aspects are relevant to crop production in other parts of the world, neither system is designed for subarctic conditions. Even in Sweden, most biomass crops are cultivated at latitudes significantly south of those of interior Alaska, and in a climate heavily influenced by the North Atlantic Current. This creates a warmer and wetter climate than is found in interior Alaska, resulting in longer growing seasons.

2.1 Willow Research and Production in Sweden

Swedish researchers have been studying short rotation willow coppice (SRWC) systems since the 1960s (Nordh, 2005). Originally the research focused on biomass for paper and pulp mills. As energy prices have increased, more research has gone into SRWC for use in energy production. Between 1990 and 1996 a huge expansion in the planting for SRWC brought approximately 37,000 acres (15,000 hectares) into cultivation for SRWC. This boom in SRWC plantings was fueled in part by government subsidies. Many of the plantations started in this period were on marginal land and were not well managed; their yields have been low and some were plowed under after 1996 when subsidies decreased (Helby et al., 2006). More recent research is looking into the use of willows for environmental applications such as phytoremediation (use of plants to decontaminate soils and water) (Nordh, 2005).

The plantation system for growing biomass in Sweden has a well-established, fully mechanized protocol for planting and harvesting. During the fall prior to planting, the field is treated with an herbicide and the field is plowed to prepare the soil for planting the subsequent spring. Cuttings are harvested from one-year-old shoots during winter when they are dormant and stored at temperatures slightly below freezing until planting time, in late April to early June. Cuttings are planted in double rows. Up to three double rows can be planted at a time, using a specially designed planting machine. The machine cuts the shoots into 6–8 inch (15–20 cm) lengths and pushes them into the soil. Controlling weeds is very important in the first year, and mechanized weed control is often used. During the winter of the first year the shoots are coppiced (cut back) to encourage the development of lots of shoots. During the second year the crop is fertilized and additional fertilization is recommended after the first harvest occurs. The plantations are harvested every three to five years in the winter when the soil is frozen. The harvester cuts and feeds the plants into a chipper. The chips are shipped green to a local user, usually a district heating plant. Well-maintained plantations can produce 4–5 oven-dry tons (odt) /acre/ year (9–11 metric tons /hectare/year) or about 30–45 MWh (102,000–153,000 Btu) of energy (Nordh, 2005). A plantation can last about 25 years and sustain 6–7 harvests before it must be replanted.

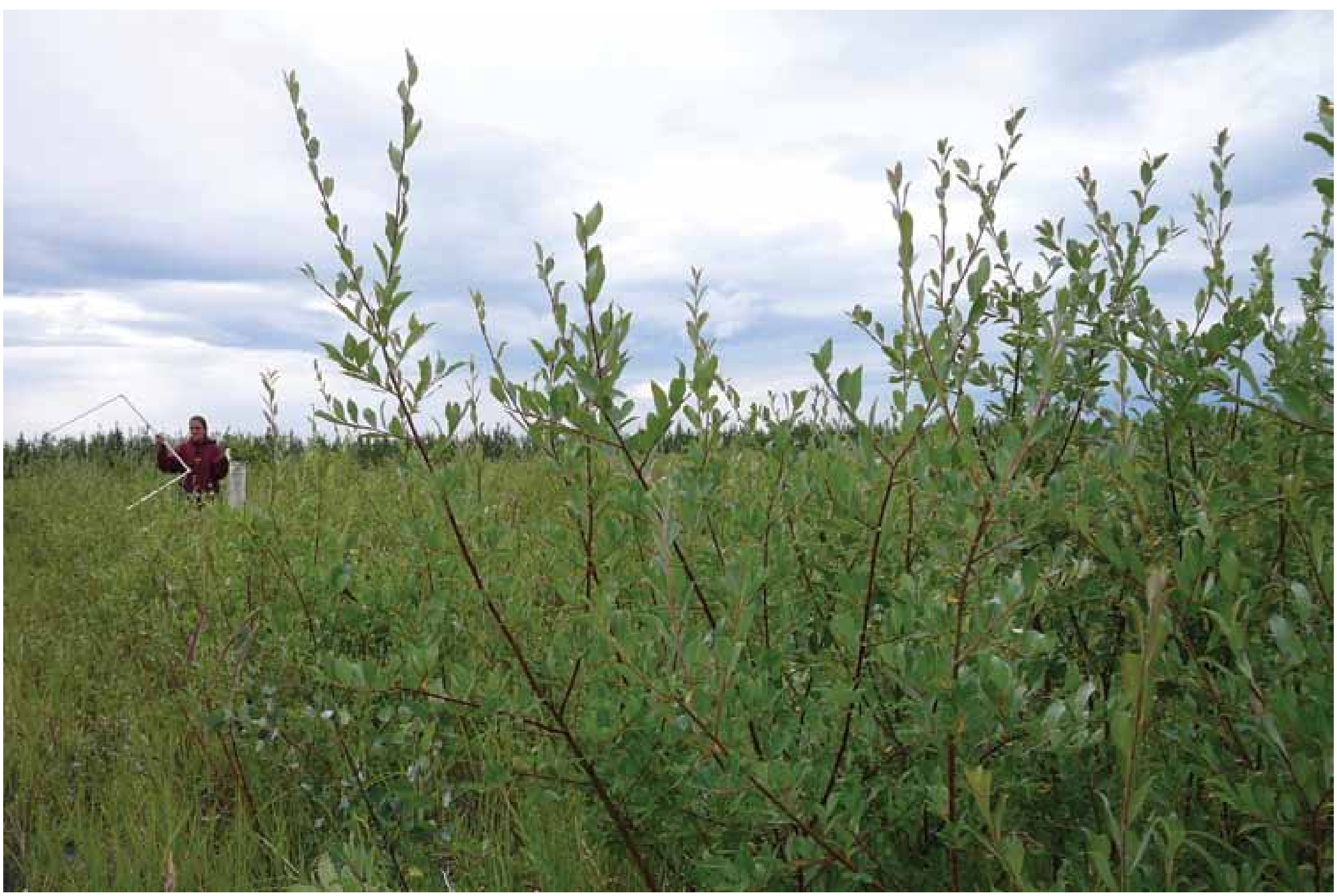
Much of the research in Sweden has gone into determining which willow species to plant and developing fast-growing clones and hybrids. Years of study have produced several willow clones which were chosen for particular characteristics such as fast growth rates, disease resistance, and other adaptations to their environment.

2.2 Willow Research and Production in New York State

The State University of New York, College of Environmental Science and Forestry (SUNY-ESF) began intense study and cultivation of willows as a renewable feedstock for bioenergy and bioproducts in the mid-1980s. In the mid-1990s SUNY-ESF and twenty other organizations banded together to form the Salix consortium with the goal of creating a way to commercialize willow production in the northeastern and the midwestern regions of the United States. By 2000 the consortium had 690 acres (280 ha) of land planted in willow biomass crops. These plots were studied for adaptability of clones, management of diseases and weeds, as well as planting, harvesting, and transportation logistics (Volk et al., 2006).

SUNY-ESF researchers have created a willow producers' handbook, which was first issued in 1997 and was revised in 2002 (Abrahamson et al., 2002). The recommended methods are similar to those used in Sweden. Recommendations call for mowing, spraying with herbicide, and plowing during the summer prior to planting the field. In the spring just before planting, the field is cultivated to kill any germinating weeds and to loosen the soil for planting. Dormant cuttings are planted 2.5 feet (0.76 meters) apart in double rows spaced 5 feet (1.5 meters) apart. SUNY-ESF has modified a step planter to push the cuttings into the soil. A pre-emergent herbicide is applied right after planting. Mechanical weed control is often necessary during the first growing season. The plants are coppiced during the first winter after the leaves have fallen. Fertilizer is applied during the second growing season. The first harvest occurs at the end of the fourth growing season once the willows are dormant. The harvester cuts and then chips the willows. The field is fertilized the year after harvest. One planting should last approximately 23 years (Abrahamson et al., 2002). SUNY-ESF's unirrigated research fields yield 4–5 odt/acre/year (9–11 metric tons/hectare/year) while their fertilized and irrigated fields yield up to 12 odt/acre/year (27 metric tons/hectare/year).

Researcher darleen t. masiak harvesting willows in a CRP field near Delta Junction. Photo by Stephen D. Sparrow.



2.3 Lessons Learned

The following lessons from Sweden and New York are important to potential biomass crop production in Alaska:

- Planting procedures and harvesting are similar in the temperate climates of Sweden and North America.
- Early weed control is important for establishing a good crop, as willows do not compete well with grasses and broad-leafed weeds.
- Fertilization is important for highly productive biomass systems.

While browsing by wildlife has not usually been mentioned as a factor in the Swedish and New York studies, it could reduce productivity in Alaska if steps are not taken to minimize it.

3.0 Alaska Studies

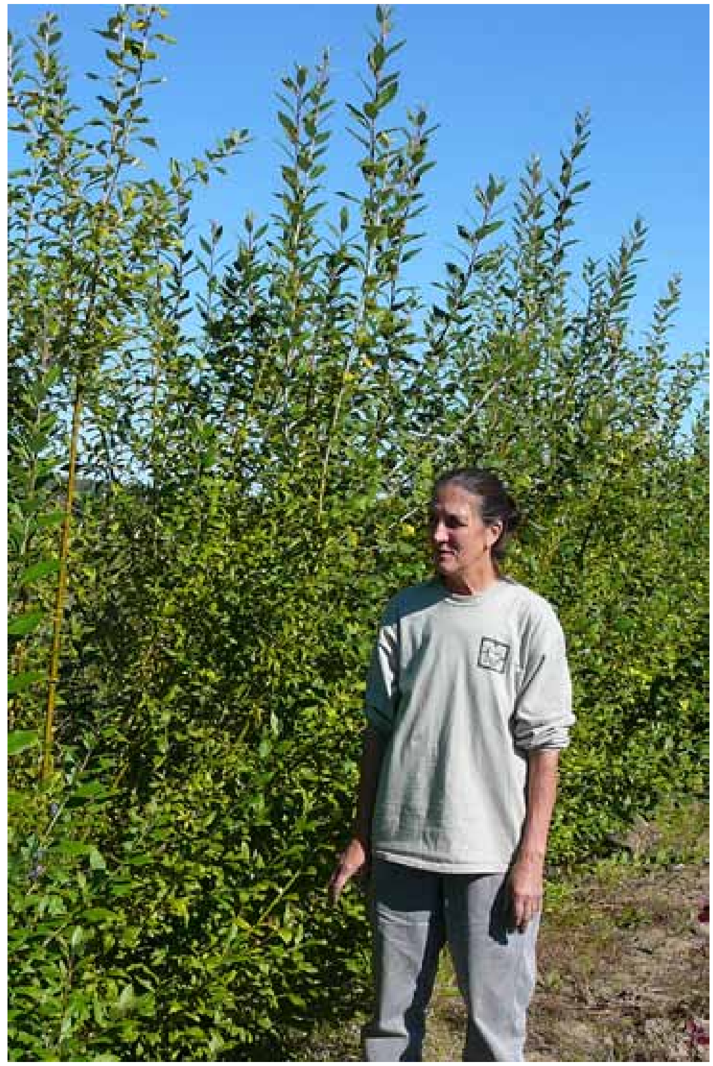
Willows are pervasive in Alaska (Argus, 1973), and quite a bit of study has gone into them. The more pertinent studies deal with species succession and revegetation. Successional studies provide information on the type of conditions where Alaska shrubs thrive. The revegetation studies provide knowledge about how to plant Alaska willows and which ones survive best.

3.1 Flood Plain Succession

Willows are among the first woody species to colonize newly created or freshly washed flood plains (Viereck et al., 1993). They grow prolifically for the first four to five years. Willows are followed by alders, which dominate for five to ten years. Balsam poplar mixes with the alder and the forest persists for approximately 100 years after flooding. If there is no new flooding, white spruce are dominant for 200 to 300 years and are followed by black spruce (Viereck et al.,1993).

3.2 Forest Fires

Vegetation recovery after severe fire tends to be slow in Alaska and often starts with non-woody plants, such as fireweed and grasses. If grasses get well established, willows or other woody species do not really take over for several years. After approximately seven years willow and alder can be well established (Knapman, 1982). Zasada et al. (1987) planted spruce, aspen, alder, and willow following a prescribed burn. The spruce had the best survival rate, but the broad-leafed species grew taller and faster. Planted seedlings survived better than unrooted cuttings.



Researcher darleen t. masiak by a two-year-old stand of feltleaf willow at the Fairbanks Experiment Farm, on the UAF campus. Photo by Stephen D. Sparrow.

3.3 The Trans-Alaska Pipeline

Following the construction of the trans-Alaska oil pipeline there were several large studies to determine how best to revegetate affected areas. Many of the studies researched revegetating with grasses, which tend to out-compete willows. In 1977 Alyeska Pipeline Service Co., operator of the pipeline, began a program to plant 1.5 million willow cuttings on 890 acres (360 ha) of disturbed willow habitat in the areas of the Sagavanirktok, Atigun, and Dietrich River valleys. The program was an expensive failure, which led Alyeska to commission a study to determine the best ways to revegetate willow habitat in the Arctic (Zasada et al., 1981). That study provides the most comprehensive look at planting willows for revegetation in Alaska.

Feltleaf willow (*Salix alaxensis*) cuttings were planted on a variety of different sites for three years. The cuttings were harvested from the local area while they were dormant and kept frozen until their planting. Planting consisted of placing a shovel in the ground, opening a hole, and putting the cutting in the hole at an angle to get as much of the cutting below ground as possible. The plots were treated with a variety of different fertilizer treatments (Zasada et al., 1981).

The pipeline study found that feltleaf willow responds well to high fertilization levels, but can survive with low nutrient conditions provided there is not much competition (Zasada et al., 1981). Grasses are detrimental to the growth of willows. The grasses limit the light the willows receive, hindering growth, and may kill the willows if grass stands are thick enough (Zasada et al., 1981). Cuttings will survive the best of any planting system when in competition with grasses; however, seedlings have a higher survival rate overall.

The study indicated feltleaf willow survives best when planted early in the summer; mid-to-late summer plantings do not survive well. Also, plants cut back in the summer do not recover and often die. However, taking cuttings in early April when they are dormant does not seem to affect their growth the following summer (Zasada et al., 1981).

Densmore et al. (1987) studied the establishment of willow for moose browse along the pipeline and concluded that cuttings needed to be .25 to .5 in (0.6 to 1.5 cm) in diameter and 12–15 inches (30–38 cm) long for best survival.

These studies were put to good use when the pipeline was vandalized in 2001. The resulting oil spill clean-up required the use of revegetation techniques. The revegetation started with two short-lived grass species (*Puccinelliu borealis* and *Lolium temulentum*) to prevent soil erosion followed by the planting of 11,500 willow cuttings and 200 spruce trees. The entire area was well fertilized with 10-10-20 fertilizer at about 360 lb/acre (400 kg/hectare). Three years after planting the willow cuttings were 4 to 5 feet (1.2 to 1.5 meters) tall and had an 80–88% survival rate (McKendrick, 2005).

3.4 Revegetation Manuals

In the past twenty years, state and federal organizations in Alaska have published several manuals for revegetation of disturbed sites, particularly streambanks. Introduced grasses were a major part of most revegetation projects, but more and more agencies are looking to use local plants. Seeding local grasses and legumes is not very difficult when the seeds are readily available. However, willows are ideal because they are found locally, are easy to harvest and plant, and they establish rapidly.

Revegetation using willows is simple but takes some advanced planning. The revegetation manuals for Alaska present the same basic steps for revegetating with willows (Miller et al., 1983; Alaska Department of Fish and Game, 1986; Densmore et al., 2000; Walter and Hughes, 2005) and all provide detailed information on collecting, storing, and planting cuttings.

3.5 Lessons Learned

The following lessons from prior experience cultivating willows in Alaska are important to establishing biomass crops:

- Local Alaska willows (particularly feltleaf willow) can easily be grown from cuttings if proper handling procedures are used and field conditions are conducive to cutting survival.
- Moist soil conditions are important for dormant cutting survival. Watering for the first several weeks is important.
- Fertilizers will increase growth during the first few growing seasons.
- Weeds and grasses can severely stunt the growth of willows in the first year. Competition from grasses can even kill willow plantings.
- Cuttings should be harvested during the dormant season and planted as early as possible in the spring.

3.6 Non-Willow Woody Species

Willows are among the fastest growing woody shrubs in interior Alaska, but there are other species that may have potential as biomass crops. Balsam poplar (*Populus balsamifera* L.) and quaking aspen (*Populus tremuloides* Michx.) are two relatively fast-growing trees in interior Alaska. Researchers in other regions have studied both species as potential biomass crops. Aspen requires longer rotations between harvesting; at least eight years, but ten is better to minimize die-off following harvest (Perala, 1979). Balsam poplar is much more likely to succeed in a short rotation coppice system similar to the willow system, as it can survive the three-year harvest cycle better than aspen. Poplar can yield 3 to 8 tons/acre/year (7 to 18 metric tons/hectare/year) (Dickmann et al., 2001).

Alder is another woody shrub that may have potential as a biomass crop. Alders, particularly black alder (*Alnus glutinosa* L.) and gray alder (*Alnus incana* (L)), have been studied in Europe and the Lower 48 states as potential biomass crops. Both species can compete successfully with willows as potential short rotation coppiced crops, and alders are also nitrogen fixers so they enhance the soil where they grow.

Because of their nitrogen-fixing ability alders have been studied in Alaska as potential revegetation species for abandoned mines. Mitchell and Mitchell (1981) did an extensive study of green alders (*Alnus crispa*) for mine land restoration and found with the proper planting techniques alders can thrive on marginal land. However, alders are more difficult to plant than willows; transplanting seedlings produced the highest survival rates.

Alders do not seem to grow well from cuttings like many willow species do, and thus must be established from seeds. This means that alders are more labor intensive to plant, but alders fix nitrogen and produce slightly more energy per pound than willows: 8820 to 8460 Btu/lb (4900 cal/g compared to 4700 cal/g) for five-year-old plants (Van Cleve, 1973). The revegetation manual for Denali National Park and Preserve provides steps for the successful large-scale planting of alder (Densmore et al., 2000). It recommends collecting seeds in the late fall, being sure to collect a root nodule as well, and growing the seeds in a greenhouse for at least three months before planting. The seedlings will require fertilizer during this time, as well as when they are first put in the ground. The Denali process has had 95% survival rates and the alders grow about 1 m (3 ft) in the first three years (Densmore et al., 2000).

3.7 Growth Rates and Biomass Production on Non-intensively Managed Land

Very few Alaska studies investigated growth rates and biomass production of woody shrubs. Moose forage studies measured the number of twigs per acre (Weixelman et al., 1998), and some other studies weighed individual plants (Cole et al., 1999), but there is no published information on biomass yield per unit area over time. To establish a baseline, we conducted five biomass surveys on unmanaged fields of known and unknown ages.

A field which had been mowed three years before sampling and a four-year-old field near Delta Junction were chosen for the initial survey. Twenty-four randomly selected 1m^2 (10.8 ft^2) plots were sampled in each field. All of the standing woody species in each square were cut at ground level. The woody samples were oven-dried and weighed. The three-year-old field averaged 1045 lb/acre (1171 kg/ha), and the four-year-old field averaged 1000 lb/acre (1125 kg/ha). The fields are part of the federal Conservation Reserve Program (CRP), a program which pays farmers to place acreage aside to conserve topsoil and wildlife habitat. The fields are not treated in any way except that they are mowed, usually on three-year rotations. The small difference in biomass yields in the three- and four-year-old fields could be the result of many factors: soil quality, grass and weed competition, wetness of the area, and the large variability of the CRP lands. The yields in sample plots ranged from 0 g/m^2 to 478 g/m^2 (0-0.1 lb/ft^2). Three samples were collected from another CRP field that was on wetter soils and yielded 1600 lb/acre (1790 kg/ha) (due to the small sample size the results may be misleading). In any case, allowing willows to grow with little to no management will likely yield less than 1 ton oven-dry biomass/acre (2.24 metric tons/hectare).

Three similar surveys were conducted at the Chena River Lakes Flood Control Project. One field, judged to be at least five years old from growth rings, yielded about 1047 lbs/acre (1173 kg/ha). Two other fields, each estimated to be two years old, yielded 464 lbs/acre (519 kg/ha) and 590 lbs/acre (660 kg/ha). It would be worthwhile to conduct a study of the same fields next year to determine the actual increase in biomass over the course of a year.

4.0 The Potential

Yields of about a half-ton of biomass per acre (1.1 metric tons/ha) after three or more years growth are disappointing compared to about 5 tons/acre (12 metric tons/ha) or more over three years in the New York biomass energy program. A yield of half a ton of willow wood per acre contains an energy yield of about 8 million BTU which is equivalent to about 1.4 barrels of crude oil.

A biomass burner power plant capable of producing 200 KW power has been proposed near North Pole, Alaska. This would produce enough electricity to power about 150 average American homes (Energy Information Administration, 2009). The amount of willow biomass required in a year to power a 200 kW power plant at 30% efficiency is about 1100 tons (1000 metric tons) or about 2200 acres (900 ha). There are 25,000 acres (10,000 ha) of CRP land in the Delta Junction area, and a third of it is mowed every year. That is potentially 8000 acres (3,000 ha), which could produce 4000 tons (3,600 metric tons) of biomass in any given year. Current rules for CRP holders do not allow for the harvest of biomass as a fuel crop, but there is the possibility of changing the federal laws to allow for this type of harvest; New York state has such an exemption (Timothy Volk, SUNY-ESF, personal communication, 2008). While a thorough economic analysis would be required to determine how much biomass is needed per acre to be profitable, low yields on CRP land in Alaska likely make use of biomass uneconomical because cost of harvest may exceed the value of the woody biomass.

The Chena River Lakes Flood Control Project may also provide a potential source of biomass near Fairbanks. In the past it has had contracts with farmers to plant and harvest hay; this could easily be transferred to harvesting woody biomass. The flood plain is also mowed on a three-year rotation and it produces similarly to the CRP land. The flood control project is probably not large enough to be the sole source of biomass, only maintaining about 3000 acres (1200 ha) in shrubs. Again, low yields may limit the use of this resource without management to improve yields.

In addition to the CRP land and the Chena flood control project, there are other areas that could be harvested or are currently harvested in some fashion. The Golden Valley Electric Association (GVEA) spends time each summer clearing its power lines of trees and shrubs that could potentially be turned into a biomass resource. The actual biomass production along the power lines will need to be studied with the help of GVEA. The Fairbanks area also has new firebreaks or defensible-space clearings that could provide up to 100,000 green tons (90,000 metric tons) of biomass (Nicholls et al., 2006). These defensible-space clearings are expected to cover 3000 acres (1200 ha) and will be completed by 2010, so they are only a short-term solution unless they are managed for biomass production.

Harvesting and transporting biomass from natural stands can potentially be logistically intensive. Harvesting 2200 acres (890 ha) will require a lot of energy in the form of mowers and chippers. If biomass species could be farmed in a fashion similar to the New York program, 1100 tons (1000 metric tons) of biomass could come from 220 acres (90 ha), assuming yields similar to those produced in New York. However, it is unknown whether the New York system will work in interior Alaska. Most likely the willow clones that have been established for New York will not survive well here. The growing season in Alaska is much shorter than New York's and the harvest rotations may have to be extended. Before starting a short-rotation coppicing program in interior Alaska, the following questions need to be addressed:

- Which species will grow the fastest and produce the largest amount of biomass?
- How long should the plants grow before coppicing?
- How much biomass will they produce in 3, 5, 8 years?
- What types and levels of fertilizers will they need?
- What is the best way to plant the chosen species?
- How much weed control is required? Which weed control systems will not harm the biomass species?
- When is the best time to harvest the biomass? In the fourth year? During the fall or winter?
- How much is a power plant willing to pay per ton? Is it cost effective to grow?

We have begun looking into some of these questions on small test plots at UAF's Fairbanks Experiment Farm. Very preliminary results with a few plants in single row plots on highly productive soil showed average yields of about 4.5 odt/acre/yr (10 metric tons/ha) with feltleaf willow and about 1 odt/acre/yr (2.2 metric tons/ha) with other indigenous species (unpublished data). Thus, feltleaf willow looks promising; but it is too early to recommend it for use as a bio-energy crop. Several growing seasons will be required before conclusive information can be obtained.

5.0 Conclusion

Use of farmed biomass for power generation in interior Alaska may be feasible, but more research is needed on biomass production potential and costs of production, harvesting, transportation, and processing before a full assessment of the feasibility of biomass power generation can be determined. While woody shrubs may not produce as fast in Alaska as they do in New York, Alaska has much more space to harvest from. Natural growth of a half-ton per acre (1.1 metric ton/ha) is not spectacular, but it is expected that managed biomass would produce much more per acre. In an area of the world where solar power is seasonal, wind power is intermittent, and geothermal power is localized, biomass may be a viable option for interior Alaska.

Acknowledgements: Support for Garber-Slaght for this project was provided by an Alaska EPSCoR Undergraduate Research Grant.

Works Cited

Abrahamson, L., T. Volk, R. Knopp, E. White, and J. Ballard. 2002. *Willow Biomass Producer's Handbook.* State University of New York. Syracuse, New York.

Alaska Department of Fish and Game. 1986. *Streambank Revegetation: Field Guide for Streambank Revegetation.* Alaska Department of Fish and Game Habitat Division and Alaska Department of Natural Resources.

Alaska Energy Authority. 2009. *Alaska Energy – A First Step Toward Energy Independence. A Guide for Alaskan Communities to Utilize Local Energy Resources.* Alaska Energy Authority. Anchorage, Alaska.

Argus, G. 1973. *The genus* Salix *in Alaska and the Yukon.* National Museum of Natural Sciences Publications in Botany No. 2. National Museum of Canada, Ottawa, Canada.

Cole, E.C., M. Newton, and A. Youngblood. 1999. Regenerating white spruce, paper birch, and willow in south-central Alaska. *Canadian Journal of Forest Research* 29:993–1001.

Crimp, P.M. and S.V. Adamian. 2000. Biomass energy alternatives for a remote Alaskan community. In: *Proceedings of the 9th Biennial Bioenergy Conference,* Buffalo, New York.

Densmore, R., J.C. Zasada, B. Neiland, and M. Masters. 1987. Planting willow for moose habitat restoration on the north slope of Alaska, U.S.A. *Arctic and Alpine Research* 19(4):537–543.

Densmore, R., M.E. Vander Meer, and N.G. Dunkle. 2000. *Native Plant Revegetation Manual for Denali National Park and Preserve.* US Geological Survey, Biological Resources Division. USGS/BDR/ITR-2000-0006.

Dickmann D.I., J.G. Isebrands, J.E. Eckenwalder, and J. Richardson. 2001. *Poplar Culture of North America.* NRC Research Press. Ottawa, Canada.

Energy Information Administration. 2009. Official energy statistics from the U.S. Government: Electricity. Energy Information Administration, US Department of Energy. On line at: www.eia.doe.gov/cneaf/electricity/esr/table5.html.

Fresco, N. 2006. Carbon sequestration in Alaska's boreal forest: Planning for resilience in a changing landscape. PhD dissertation, University of Alaska Fairbanks, Fairbanks, Alaska.

Helby, P., H. Rosenqvist, and A. Roos. 2006. Retreat from *Salix* – Swedish experience with energy crops in the 1990s. *Biomass and Bioenergy* 30:422–427.

Knapman, L. 1982. Fireline Reclamation on Two Fire Sites in Interior Alaska. US Department of the Interior Bureau of Land Management. BLM/AK/RMN-82/01.

Krasny, M.E., K.A. Vogt, and J.C. Zasada. 1988. Establishment of four Salicaceae species on river bars in interior Alaska. *Holarctic Ecology* 11:210–219.

McKendrick, J. 2005. Final Monitoring Inspection Report Mile Post 400 Revegetation Site, 2005. Alyeska Pipeline Service Company. Fairbanks, Alaska.

Miller, C.R., R. Parkerson, J. Zasada, A. Epps, and J.A. Smith. 1983. *A Revegetation Guide for Alaska.* Alaska Rural Development Council. 2.

Mitchell, G.A., and W.W. Mitchell. 1980. *Alder for mineland restoration in cold-dominated climates.* Final Report to Industrial Environmental Research Laboratory. Office of Research and Development, US Environmental Protection Agency, 45268 SEA/CR IAG No. 1706–15–10, Cincinnati.

Nicholls, D.L. and P.M. Crimp. 2002. Feasibility of using wood wastes to meet local heating requirements in the Kenai Peninsula, Alaska. US Department of Agriculture, US Forest Service, Pacific Northwest Experiment Station Report No. PNW-GTR-533.

Nicholls, D.L., S.E. Patterson, and E. Uloth. 2006. Wood and Coal Cofiring in Interior Alaska: Utilizing Woody Biomass From Wildland Defensible-Space Fire Treatments and Other Sources. Pacific Northwest Research Station. PNW-RN-551.

Nordh, N.-E. 2005. Long Term Changes in Stand Structure and Biomass Production in Short Rotation Willow Coppice. PhD dissertation. Department of Crop Production Ecology, Swedish University of Agricultural Sciences, Uppsala, Sweden.

Perala, D.A. 1979. Regeneration and Productivity of Aspen Grown on Repeated Short Rotations. US Department of Agriculture Forest Service. NV-176.

Van Cleve, K. 1973. Energy and biomass relationships in alder (*Alnus*) ecosystems developing on the Tanana River floodplain near Fairbanks, Alaska. *Arctic and Alpine Research* 5:253–260.

Van Cleve, K. and L.A. Viereck. 1981. Forest succession in relation to nutrient cycling in the boreal forest of Alaska. pp. 185–211. In: West, D.C., Shugart, H.H., and Botkin, D.B. (editors). *Forest Succession: Concepts and Application.* Springer-Verlag, New York.

Viereck, L.A. 1970. Forest succession and soil development adjacent to the Chena River in interior Alaska. *Arctic and Alpine Research* 2:1–26.

Viereck, L.A., C.T. Dyrness, and M.J. Foote. 1993. An overview of the vegetation and soils of the floodplain ecosystem of the Tanana River, Interior Alaska. *Canadian Journal of Forest Research* 23:889–898.

Volk, T.A., L.P. Abrahamson, C.A. Nowak, L.B. Smart, P.J. Tharakan, and E.H. White. 2006. The development of short-rotation willow in the northeastern United States for bioenergy and bioproducts agroforestry and phytoremediation. *Biomass and Bioenergy* 30:715–727.

Volk, T.A., T. Verwijst, P.J. Tharakan, L.P. Abrahamson, and E.H. White. 2004. Growing fuel: a sustainability assessment of willow biomass crops. *Frontiers in Ecology and the Environment* 2:411–418.

Walter, J., and D. Hughes. 2005. *Streambank Revegetation and Protection; a Guide for Alaska.* Alaska Department of Fish and Game. Report No. 98-3.

Weixelman, D., R.T. Bowyer, and V. Van Ballenberghe. 1998. Diet selection by Alaskan moose during winter: effects of fire and forest succession. *ALCES* 34(1):213–238.

Zasada, J., B. Neiland, and R. Densmore. 1981. Investigations of Techniques for Large-Scale Reintroduction of Willows in Arctic Alaska. Agricultural Experiment Station, School of Agriculture and Land Resources Management, University of Alaska. Fairbanks, Alaska. Contract Taps/41 Task Order No. 27.

Zasada, J., R.A. Norum, C.E. Teutsch, and R. Densmore. 1987. Survival and growth of planted black spruce, alder, aspen, and willow after fire on black spruce/feather moss sites in interior Alaska. *The Forestry Chronicle* 63:84–88.

SNRAS

School of Natural Resources & Agricultural Sciences

UAF™ University of Alaska Fairbanks

Appendix 1: Annotated Bibliography for Biomass Shrubs in Alaska

Robbin Garber-Slaght, Alaska Center for Energy and Power, UAF

Included in this appendix are all identified publications related to the growth of biomass shrubs in Alaska, as related to growing a biomass energy crop.

Abrahamson, L., Timothy Volk, Richard Knopp, Edwin White, and Jennifer Ballard (2002). *Willow Biomass Producer's Handbook*. Syracuse, NY, State University of New York.

> "The Willow Biomass Producer's Handbook describes the willow biomass production system, which is based on a combination of agricultural and forestry practices. The system simultaneously produces a renewable cellulosic feedstock and provides a wide range of environmental and rural development benefits. The system described is operational, but is being optimized on more than 500 acres in central and western New York. This revision of the handbook provides information that has been gained from research and operational trials since the first edition of the handbook was produced in 1997." (3)

Alaska Department of Fish and Game (1986). *Streambank Revegetation: Field Guide for Streambank Revegetation*. Alaska Department of Fish and Game Habitat Division and Alaska Department of Natural Resources.

> Presents how to revegetate a streambank; including how to collect the plantings. Three methods are presented: dormant cuttings, bundles, and rooted cuttings. There is also an example exercise showing how to plan for a particular stream.

Alaska House Resource Agency (1982). *Import Substitution in Rural Alaska*. Alaska State Legislature: House Resource Agency Report 81-6.

> This presents potential ways to change the economics in rural Alaska by substituting local commodities for imports based on the following:
> 1. Energy changes - mainly conservation, but with higher oil prices coal and wood gasification are a possibility
> 2. Building materials
> 3. Agriculture

Argus, G. W. (1973). *The Genus Salix in Alaska and the Yukon*. Ottawa, Canada. National Museums of Canada.

> This detailed description of all of the willow species in Alaska and the Yukon provides the best identification manual for willows.

Argus, G. W. (2004). *A Guide to the Identification of Salix (willows) in Alaska, the Yukon Territory, and Adjacent Regions*. Ontario, Canada. Retrieved June 6, 2008 from, http://aknhp.uaa.alaska.edu/willow/pdfs/GuideSalixAK-YT11May05.pdf.

“This guide to the identification of *Salix* (willows) in Alaska and Yukon was written to accompany a workshop in *Salix* identification given at the University of Alaska in the summer of 2004. It provides a number of resources to aid in the identification of *Salix* in the field and the herbarium. These include a dichotomous key, access to a computerized interactive key, descriptions of the species, information on flowering time, habitat, general distribution, distribution maps, and taxonomic comments.” (5)

In addition to the printed guide, there is also a downloadable program to help with the identification process at http://aknhp.uaa.alaska.edu/willow/index.htm.

Babb, M. F. (1959). *Propagation of Woody Plants by Seed with Notes on Other Methods of Reproduction*. Palmer, Alaska, University of Alaska, Alaska Agricultural Experiment Station Bulletin 26.

Presents a discussion of how to grow woody plants in Alaska, mostly grown from seeds. How to treat the seeds and the best times to plant them.

Bishop, S. C., and F. Stuart Chapin III (1989). "Patterns of natural revegetation on abandoned gravel pads in Arctic Alaska." *Journal of Applied Ecology* 26: 1073-1081.

Studied the natural revegetation of human made gravel pads in Arctic Alaska . Found that legumes are very important to revegetation for their nitrogen fixing ability.

Bliss, L. C., and J. E. Cantlon (1957). "Succession on river alluvium in northern Alaska." *American Midland Naturalist* 58(2): 452-469.

Presents the successional stages of alluvial vegetation on the North Slope: perennial herbs, vigorous feltleaf willows, deteriorating feltleaf willow, and finally alder-willow mix.

Bochmel, C., Iris Lewandowski, and Wilhelm Calupein (2008). "Comparing annual and perennial energy cropping systems with different management intensities." *Agricultural Systems* 96: 224-236.

They studied several energy crops and their biomass potential in southern Germany. Miscanthus had the greatest yield. Fertilization was important to yield.

Borjesson, P. (1999). "Environmental effects of energy crop cultivation in Sweden-I: Identification and quantification." *Biomass and Bioenergy* 19: 137-154.

“This paper presents an analysis of how energy crop cultivations in Sweden, consisting of short-rotation forest (*Salix*) and energy grass (reed canary grass), can be located and managed to maximize environmental benefits. The overall conclusion is that substantial environmental benefits, ranging from global to site-specific, could be achieved when traditional annual food crops produced with current agriculture practices are replaced by dedicated perennial energy crops. The emission of greenhouse gases could be reduced by

reduced carbon dioxide emissions from organic soils, by reduced nitrous oxide emissions caused by the use of fertilizers and through accumulation of soil carbon in mineral soils, which also leads to increased soil fertility. Nutrient leaching could be reduced by using energy crop cultivations as buffer strips along open streams and wind erosion could be reduced by using *Salix* plantations as shelter belts. Cultivation of *Salix* and energy grass can also be used to purify municipal waste, such as wastewater, landfill leachate, and sewage sludge. Furthermore, the content of heavy metals in the soil can be reduced through *Salix* cultivation. The biodiversity is estimated to be almost unchanged, or slightly increased in open farmland. These environmental benefits, which could be achieved on up to 60% of current Swedish arable land and last for 25 years or more, will increase the value of the energy crops. The economic value of these benefits is calculated in Part II of the analysis, which is presented in a second paper." (137)

Borjesson, P. (1999). "Environmental effects of energy crop cultivation in Sweden-II: Economic valuation." *Biomass and Bioenergy* 16: 155-170.

"In this paper, environmental benefits of the cultivation of perennial energy crops in Sweden, which have been identified and quantified in an earlier paper, are evaluated economically. Several different benefits, ranging from global to site-specific, could be achieved by replacing annual food crops with perennial energy crops. The economic value of these environmental benefits, including reductions in costs to farmers (direct costs) and to society as a whole (external costs), has been estimated to be from US $ 0.1 up to US $ 5/GJ biomass. For comparison, the production costs (excluding transport) of *Salix* and reed canary grass are about US $ 4.4 and US $ 5.0/GJ, respectively. Purification of waste water in energy crop cultivation has the highest economic value, followed by reduced nutrient leaching through riparian buffer strips, recirculation of sewage sludge, and reduced wind erosion through shelter belts consisting of *Salix*. The value of other environmental benefits is estimated to be less than US $ 0.7/GJ. If 200,000 ha of Sweden's totally available arable land of 2.8 Mha were available for energy crop cultivation, around 45 PJ biomass could theoretically be produced per year, at an average cost of about US $ 0.7/GJ, including the value of environmental benefits. It is assumed that priority is given to cultivations with the highest total value, as several different environmental effects could be achieved on the same cultivation site. If 800,000 ha were to be available, the corresponding cost of some 150 GJ biomass per year would be around US $ 2.8/GJ." (155)

Brown, J. K. (1976). "Estimating shrub biomass from basal stem diameters." *Canadian Journal of Forest Research* 6: 153-158.

This article assumes that allometric equations can be applied to shrubs. It provides equations and constants for willows, taking the diameter at the ground.

ln (weight, g)=a + b*ln (basal diameter, cm)
for willows a= 3.303 and b=2.762
This is the total above ground weight. (154)

Brna, Phillip, and Nancy Moore (1987). "Streambank revegetation with woody plants." *Alaska Fish and Game* (March-April): 34-37.

Discusses how to use woody plants to revegetate a streambank. Looks at four methods: dormant cuttings, rooted cuttings, bundles, and transplants.

Cannel, M., L. J. Sheppard, and R. Milne (1988). "Light use efficiency and woody biomass production of poplar and willow." *Forestry* 61: 125-137.

A study in Scotland that analyzed biomass production of popular and willow grown in containers. Willow has more above ground biomass.

Chan, S., Steven R. Radosevich, and Amy T. Grotta (2003). "Effects of contrasting light and soil moisture availability on the growth and biomass allocation of Douglas-fir and red alder." *Canadian Journal of Forest Researc*h 33: 106-117.

"We examined growth and biomass allocation of individual Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and red alder (*Alnus rubra* Bong.) seedlings grown for 3 years under contrasting combinations of light and water. Alder growth was always greater than Douglas-fir. Full sunlight and soil moisture at field capacity caused large differences in size between the two species. With limited light and water, differences were smaller. Under full light and limited water, Douglas-fir allocated a high portion of its biomass to roots, whereas red alder allocated a high percentage to aboveground biomass components. Under light and water resource-limiting situations, red alder allocated more mass to stem, whereas Douglas-fir allocated more to roots. Red alder growth responded negatively to water limitation, whereas Douglas-fir did not. Red alder exhibited greater foliage plasticity to light. Species differences in size and allocation in response to resource availability may determine pathways by which Douglas-fir and red alder interact in a mixed community. Our findings support the hypothesis that the potential of species to use growth-limiting resources is an indicator of competitive ability. We suggest that red alder and Douglas-fir can co-exist under conditions of full light and limiting soil moisture availability. Furthermore, when contrasted with red alder, Douglas-fir's relatively greater tolerances to low light allow it to better persist in the understory. Red alder's rapid early growth and competitive ability will be superior under full light and nonlimiting soil moisture conditions." (106)

Cole, E. C., M. Newton, and A. Youngblood (1999). "Regenerating white spruce, paper birch, and willow in south-central Alaska." *Canadian Journal of Forest Research* 29: 993-1001.

This study did controlled plantings in the Anchorage area following spruce bark beetle kills; for willows, moose browse was a major factor in growth rates. The survival of rooted cuttings after 5 years was high and did not vary with treatments (997).

Collet, D. M. (2004). *Willows of Interior Alaska*, Department of the Interior, U. S. Fish and Wildlife Service.

This field guide describes the willows in interior Alaska in winter and summer.

Crimp, P., and Serge Adamian (2000). *Biomass Energy Alternative for a Remote Alaska Community*, Alaska Energy Authority, Ecotrade Inc.

Looked at three options for McGrath: 1. a wood-fired boiler at the school, 2. a diesel combined heat and power (CHP) district heating and wood chip-fired boiler system, and 3. a wood-fired power system. The corporation decided on the option #2. The study discusses costs and amount of wood available.

Dabbs, D., Wihelm Friesen, and Shane Mitchell (1974). *Pipeline Revegetation*. Arctic Gas, Biological Report Series, Northern Engineering Services Company Limited. Vol. 2.

This study looked at the revegetation around a buried pipeline test site in the Mackenzie River area. It is mainly a study of grasses with a small part on low shrubs. Shrubs were planted with 10.3 cuttings/m^2, which equates to 1650 man hours/hectare (660 hours/acre). The *Salix alaxensis* species had high survival rates 83-96% after one year. The *Alnus crispa* had very high survival rates 78-100%. The *Salix planifolia* and *Alnus incana* did not survive nearly as well (22 to 75%). (20-21)

Densmore, R., and John C. Zasada (1978). "Rooting potential of Alaskan willow cuttings." *Canadian Journal of Forest Research* 8: 477-479.

"Rooting potential of cuttings of two riparian and three non-riparian taiga willows was tested under laboratory condition, and survival of a riparian and a non-riparian species was observed under field conditions. The riparian species, *S. alaxensis and S. novae-angliae* rapidly produced roots on all submerged portions of the cuttings. Only a few cutting of the non-riparian species, *S. scouleriana* and *S. glauca* produced roots, and only at the basal end of the cuttings. *S. bebbiana* did not produce roots." (477)

Densmore, R., and John C. Zasada (1983). "Seed dispersal and dormancy patterns in northern willows; ecological and evolutionary significance." *Canadian Journal of Botany* 61: 3207-3216.

"Seeds of 24 common *Salix* species of the Alaskan boreal forest and tundra were set to germinate in laboratory and field experiments, and seed dispersal times were observed." (3207)

Willows that disperse early in the growing season have non-dormant seeds that germinate rapidly at temps from 5 to 25°C. These early seeds are nonviable within 1 week. Late seeds germinate at higher temperatures and start out dormant.

Densmore, R., John C. Zasada, B. Neiland, M. Masters (1987). "Planting willow for moose habitat restoration on the north slope of Alaska, U.S.A." *Arctic and Alpine Research* 19(4): 537-543.

Studied how to plant willows on the tundra after TAPS construction. *S. alaxensis* was planted from both frozen-dormant and fresh cuttings, the two cutting types were equally successful. The plantings were evaluated 9 years later and after 9 years there was 53% percent survival except for the mid-season plantings (2% survival) (540). The thicker cuttings (> 0.6 cm) survived better (541). The most vigorous growth occurred when the cuttings were planted 15-20 cm deep with 15 cm above the ground (541). Fertilizer had no visible effect 9 years out (542).

Densmore, R., Mark E. Vander Meer, and Nancy G. Dunkle (2000). *Native Plant Revegetation Manual for Denali National Park and Preserve*. U.S. Geological Survey, Biological Resources Division: USGS/BDR/ITR-2000-0006.

Describes revegetation techniques used in the park. Looks at many varieties of plants that can be used in revegetation.

Alders grow best when container-grown seedlings are used. Their first 3-6 years are slow growth. Collecting a root nodule (soil inoculant) is important when collecting alder seeds. (26) They had 95% survival of alder after 5 years and a height of 1 m within 3 years (27).

Salix alaxensis, *S. arbusculoides*, *S. barclayi*, and *S. pulchra* root well from cuttings (28). Most willows need nutrients, primarily nitrogen (29). To collect willow cuttings, cut them 25-45 cm in length and get 1-2.5 cm in diameter young stems with at least one leaf node. They needed to be planted soon after cutting or taken dormant. Plant in shallow holes at 45 degree angle, 5-8 cm above soil, fertilize and water (29). Willows will root in 1-3 weeks and grow 0.5m/year (30).

Fresco, N. (2006). *Carbon Sequestration in Alaska's Boreal Forest: Planning for Resilience in a Changing Landscape*. Fairbanks, University of Alaska Fairbanks. Ph. D: 198pp.

Chapter 3 is devoted to biomass potential in rural interior Alaska. Provides estimates of the distance traveled by the community to harvest biomass sustainably. Concludes that smaller villages can do this, but larger towns will not have enough biomass on the 80 year rotations.

Galliett, H., Joe Marks, and Dan Renshaw (1980). *Wood to Gas to Power; a Feasibility Report on Conversion of Village Power Generation and Heating to Fuels Other than Oil*. The Alaska Village Electric Cooperative, Inc. and The Alaska Power Authority. Vol. 1.

AVEC village sites can feasibly use gasified wood chips to power electrical generators. They would only consume 10% of wood available. Looks only at large tree species. Wood chips were an estimated $6.25 / million BTU, diesel was $14.38 per million BTU in 1980 (5).

Gillespie, A. R., and Phillip E. Pope (1994). "Intensive culture of European black alder in central Indiana, U.S.A.: Biomass yield and potential returns to farmers." *Biomass and Bioenergy* 6(6): 419-430.

> Studied alder growth in Indiana and concluded biomass production only feasible with aid. Alder in Indiana yielded 10 dry Mg/ha/year (4.5 tons/acre) (dependent on spacing) (425).

Gregory, R. A., and Paul M. Haack (1964). *Equations and Tables for Estimating Cubic-Foot Volume of Interior Alaska Tree Species*. Juneau, AK, U.S. Department of Agriculture, Forest Service: Research Note NOR-6.

> Presents equations and tables that can be used to estimate the volume of Alaska tree species.

Grigal, D. F., and Lewis F. Ohmann (1977). *Biomass Estimation for Some Shrubs from Northeastern Minnesota*. St. Paul, MN, U.S. Department of Agriculture. Forest Service: Research Note NC-226.

> Presents allometric equations to use when measuring shrub stems at 15 cm above the ground.

y=ax^b
where y= biomass in grams dry weight, x=diameter in cm
for red alder a=31.328, b=3.050
for green alder a=39.684, b=2.696
for willows a= 17.815, b=4.919

Grunzweig, J. M., Stephen D. Sparrow, Dan Yakir, and F. Stuart Chapin III (2004). "Impact of agricultural land-use change on carbon storage in boreal Alaska." *Global Change Biology* 10: 452-472.

> “Climate warming is most pronounced at high latitudes, which could result in the intensification of the extensively cultivated areas in the boreal zone and could further enhance rates of forest clearing in the coming decades. Using paired forest-field sampling and a chronosequence approach, we investigated the effect of conversion of boreal forest to agriculture on carbon (C) and nitrogen (N) dynamics in interior Alaska. Chronosequences showed large soil C losses during the first two decades following deforestation, with mean C stocks in agricultural soils being 44% or 8.3 kg/m^2 lower than C stocks in original forest soils. This suggests that soil C losses from land-use change in the boreal region may be greater than those in other biomes. Analyses of changes in stable C isotopes and in quality of soil organic matter showed that organic C was lost from soils by combustion of cleared forest material, decomposition of organic matter and possibly erosion. Chronosequences indicated an increase in C storage during later decades after forest clearing, with 60-year-old grassland showing net ecosystem C gain of 2.1 kg/m^2 over the original forest. This increase in C stock resulted probably from a combination of large C inputs from belowground biomass and low C losses due to a

small original forest soil C stock and low tillage frequency. Reductions in soil N stocks caused by land-use change were smaller than reductions in C stocks (34% or 0.31 kg/m^2, resulting in lower C/N ratios in field compared with forest mineral soils, despite the occasional incorporation of high-C forest-floor material into field soils. Carbon mineralization per unit of mineralized N was considerably higher in forests than in fields, which could indicate that decomposition rates are more sensitive in forest soils than in field soils to inorganic N addition (e.g. by increased N deposition from the atmosphere). If forest conversion to agriculture becomes more widespread in the boreal region, the resulting C losses (51% or 11.2 kg/m^2 at the ecosystem level in this study) will induce a positive feedback to climatic warming and additional land-use change. However, by selecting relatively C-poor soils and by implementing management practices that preserve C, losses of C from soils can be reduced." (452)

Hansen, E., Lincoln Moore, Daniel Netzer, Michael Ostry, Howard Phipps, and Jaroslav Zavitkovski (1983). *Establishing Intensive Cultured Hybrid Poplar Plantation for Fuel and Fiber*. U.S. Department of Agriculture. Forest Service. St. Paul, MN: Gen. Tech. Rep. NC-78.

"The paper describes a step-by-step procedure for establishing commercial size intensively cultured plantation of hybrid poplar and summarizes the state-of-knowledge as developed during 10 years of field research at Rhinelander, Wisconsin." (summary)

Heilman, P., and R. F. Stettler (1985). "Mixed, short-rotation culture of red alder and black cottonwood: growth, coppicing, nitrogen fixation, and alleopathy." *Forestry Science* 31(3): 607-616.

Alder and cottonwood were mixed and grown together in Washington State. The harvest at 4 years of growth average 15.9 Mg/ha/yr (7 tons/acre). The mixture was ultimately less productive than the pure cottonwood stand.

Helby, P., Hakan Rosenqvist, and Anderso Roos (2006). "Retreat from *Salix*-Swedish experience with energy crops in the 1990s." *Biomass and Bioenergy* 30: 422-427.

Studied why Swedish farmers had stopped growing willow for biomass. Surveyed farmers and determined that crop management problems had been the major cause.

Heller, M. C., Gregory A. Keoleian, and Timothy Volk (2003). "Life cycle assessment of a willow bioenergy cropping system." *Biomass and Bioenergy* 25: 147-165.

"The environmental performance of willow biomass crop production systems in New York (NY) is analyzed using life cycle assessment (LCA) methodology. The base-case, which represents current practices in NY, produces 55 units of biomass energy per unit of fossil energy consumed over the biomass crop's 23-year lifetime. Inorganic nitrogen fertilizer inputs have a strong influence on overall system performance, accounting for 37% of the non-renewable fossil energy input into the system. Net energy ratio varies from 58 to below 40 as a function of fertilizer application rate, but application rate also has implications on the system nutrient balance. Substituting inorganic N fertilizer with

sewage sludge biosolids increases the net energy ratio of the willow biomass crop production system by more than 40%. While CO_2 emitted in combusting dedicated biomass is balanced by CO_2 adsorbed in the growing biomass, production processes contribute to the system's net global warming potential. Taking into account direct and indirect fuel use, N_2O emissions from applied fertilizer and leaf litter, and carbon sequestration in below ground biomass and soil carbon, the net greenhouse gas emissions total 0.68 g CO_2 eq. /MJ of biomass produced. Site specific parameters such as soil carbon sequestration could easily offset these emissions resulting in a net reduction of greenhouse gases. Assuming reasonable biomass transportation distance and energy conversion efficiencies, this study implies that generating electricity from willow biomass crops could produce 11 units of electricity per unit of fossil energy consumed. Results from the LCA support the assertion that willow biomass crops are sustainable from an energy balance perspective and contribute additional environmental benefits." (147)

Holloway, P., and John Zasada (1979). *Vegetative Propagation of 11 Common Alaska Woody Plants*. U.S. Department of Agriculture, Forest Service: PNW-334.

11 species were planted from cuttings in the Fairbanks area. Poplar rooted best when just stem cuttings were planted. Willow also rooted well; alder did not root much at all. Root and rhizome cuttings of all species rooted.

Holmes, K. W. (1982). *Natural Revegetation of Gold Dredge Tailing at Fox, Alaska*. School of Agriculture and Land Resources Management. Fairbanks, University of Alaska Fairbanks. Master of Science: 197pp.

An in-depth look at natural revegetation in the gold dredge tailings 20 to 60 years after the dredging.

Hytonen, J., Hari Lumme, and Timo Tormala (1987). "Comparison of methods for estimating biomass." *Biomass* 14: 39-49.

Compared several methods for measuring willow biomass: the harvest method, mean stool method, regression method, and ratio methods. The regression method seems to perform the best, but the article does not explain any method very well.

Johansson, B., Pal Borjesson, Karin Ericsson, Lars J. Nilsson, and Per Svenningsson (2002). *The Use of Biomass for Energy in Sweden - Critical Factors and Lessons Learned*. Environmental and Energy System Studies. Lund, Sweden, Lund University: report no. 35.

The article presents an overview of Sweden's energy systems. Well-maintained willow plantations should yield 8-10 dry tonnes/ha (4-5 tons/acre).

Johnson, L., and Keith Van Cleve (1976). *Revegetation in Arctic and Subarctic North America; a Literature Review*. Hanover, New Hampshire, Cold Regions Research and Engineering Laboratory: CRREL report 76-15.

A comprehensive review of all literature dealing with revegetation in the Arctic, mostly grasses. Concludes that woody plants need more research.

Johnson, L., W. Quinn, and J. Brown (1977*). Revegetation and Erosion Control Observations Along the Trans-Alaska Pipeline*; *1975 Summer Construction Season*. Hanover, New Hampshire, Cold Regions Research and Engineering Laboratory: CRREL report 77-8.

Studied grasses as revegetation species along TAPS.

Johnstone, J. F., F.S. Chapin III, J. Foote, S. Kemmett, K. Price, and L. Viereck (2004). "Decadal observations of tree regeneration following fire in boreal forests." *Canadian Journal of Forest Research* 34: 267-273.

"This paper presents data on early postfire tree regeneration. The data were obtained from repeated observations of recently burned forest stands along the Yukon - British Columbia border and in interior Alaska. Postfire measurements of tree density were made periodically for 20-30 years, providing direct observations of early establishment patterns in boreal forest. Recruitment rates of the dominant tree species in both study areas were highest in the first 5 years after fire, and additional net establishment was not observed after 10 years. The postfire population of spruce (*Picea mariana* (Mill.) BSP and *Picea glauca* (Moench) Voss s.l.) remained constant after the first decade in the two study areas. Populations of aspen (*Populus tremuloides* Michx.) and lodgepole pine (*Pinus contorta* Dougl. ex Loud. var. *latifolia* Engelm.) both declined after 10 years in mixed-species stands along the Yukon-British Columbia border. Mortality rates of aspen and pine were positively correlated with their initial densities, indicating that thinning occurred as a density-dependent process. At all sites, measurements of stand density and composition made early were highly correlated with those made late in the monitoring period, indicating that patterns of stand structure initiated within a few years after fire are maintained through subsequent decades of stand development." (267)

Keoleian, G. A., and Timothy A. Volk (2005). "Renewable energy from willow biomass crops: life cycle energy, environment and economic performance." *Critical Reviews in Plant Sciences* 24: 385-406.

"Short-rotation woody crops (SRWC) along with other woody biomass feedstocks will play a significant role in a more secure and sustainable energy future for the United States and around the world. In temperate regions, shrub willows are being developed as a SRWC because of their potential for high biomass production in short time periods, ease of vegetative propagation, broad genetic base, and ability to resprout after multiple harvests. Understanding and working with willow's biology is important for the agricultural and economic success of the system. The energy, environmental, and economic performance of willow biomass production and conversion to electricity is evaluated using life cycle modeling methods. The net energy ratio (electricity generated/life cycle fossil fuel consumed) for willow ranges from 10 to 13 for direct firing and gasification processes. Reductions of 70 to 98 percent (compared to U.S. grid generated electricity) in greenhouse gas emissions as well as NOx, SO_2, and particulate emissions are achieved. Despite willow's multiple environmental and rural development benefits, its high cost of production has limited deployment. Costs will be lowered by significant improvements in yields and production efficiency and by valuing the system's environmental and rural development benefits. Policies like the Conservation Reserve Program (CRP), federal biomass tax credits and renewable portfolio standards will make willow cost competitive in the near term. The avoided air pollution from the substitution of willow for conventional fossil fuel generated electricity has an estimated damage cost of $0.02 to $0.06 /kWh. The land intensity of about 4.9 X 10^5 ha-yr/kWh is greater than other renewable energy sources. This may be considered the most significant limitation of willow, but unlike other biomass crops such as corn it can be cultivated on the millions of hectares of marginal agricultural lands, improving site conditions, soil quality and landscape diversity. A clear advantage of willow biomass compared to other renewables is that it is a stock resource whereas wind and PV are intermittent. With only 6 percent of the current U.S. energy consumption met by renewable sources the accelerated development of willow biomass and other renewable energy sources is critical to address concerns of energy security and environmental impacts associated with fossil fuels." (386)

Knapman, L. (1982). *Fireline Reclamation on Two Fire Sites in Interior Alaska.* U.S Department of the Interior, Bureau of Land Management: BLM/AK/RMN-82/01.

An "unscientific" look at natural re-growth following two fires in the White Mountains Recreation Area. Takes observations of what happened along the firelines for the seven years following the plowing of them. In most cases the grasses take over for the first several years. Willow and alder are well established by seven years out.

Kopp, R., Lawrence Abrahamson, Edwin White, and Timothy Volk (1997). *Willow Bioenergy Producer's Handbook*. Syracuse, NY, State University of New York.

This is the original manual of how to plant, maintain, and harvest willow as an energy crop. Most of the data is for New York state and similar latitudes.

Kopp, R., Lawrence Abrahamson, Edwin White, Timothy Volk, C.A. Nowak, and R.C. Fillhart (2001). "Willow biomass production during ten successive annual harvests." *Biomass and Bioenergy* 20: 1-7.

"Five willow clones and one hybrid poplar clone were planted during 1987 at 0.3x0.3m spacing and harvested annually for 10 years. Half of the trees were fertilized annually with N, P and K and all trees were irrigated beginning in the third growing season. Annual biomass production fit the logistic growth curve well for four of the clones with r^2 values ranging from 0.91 to 0.54, suggesting that well-adapted willow clones can be consistently productive for at least 10 years with annual harvesting. Fertilizer did not increase the maximum biomass production level attained, but it reduced the time required to reach maximum production by 1 year. The correlation between annual biomass production and the number of growing degree days during years 4-10 was high, ranging

from 0.95 to 0.66.” (1)

Willows can be consistently productive for ten years with annual harvesting. Production can depend on the temperature and fertilization.

Krasny, M. E., Kristiina A. Vogt and John C. Zasada (1988). "Establishment of four Salicaceae species on river bars in interior Alaska." *Holarctic Ecology* 11: 210-219.

“Patterns of seed and vegetative reproduction were investigated for three flood plain species, balsam poplar *Populus balsamifera* L., feltleaf willow *Salix alaxensis* (Anderss.) Cov. and sandbar willow *Salix interior* Rowlee, and one upland species, trembling aspen *Populus tremuloides* Michx., in interior Alaska. All four species have similar patterns of seed germination in response to moisture stress and high salt concentrations when tested under laboratory conditions. In field experiments, percent germination of all four species was also very similar, ranging from 0% on dry sandy sites, to greater than 60% on mesic silty sites. Germination on salt crusts ranged from 0-40% for all species, depending on the physical characteristics of the soil surface. Colonization of mesic silty sites was almost exclusively by seed, whereas colonization of dry sandy sites was limited to those species which were able to root sucker under floodplain conditions. Root suckering was also an important means of establishment on frequently inundated sites where establishment by seed was limited by flooding. Differences between the species in their distribution on the floodplain were related to differences in patterns of vegetative reproduction, but not seed germination.” (210)

Kuzovkina, Yulia and Martin F. Quigley. (2005). "Willows beyond wetlands: uses of *Salix* l. species for environmental projects." *Water, Air, and Soil Pollution* 162: 183-204.

Willows are used for ecosystem restoration, phytoremediation, bioengineering, and biomass production.

Labrecque, M., and Traian I. Teodorescu (2003). "High biomass yield achieved by *Salix* clones in SRIC following two 3-year coppice rotation on abandoned farmland in southern Quebec, Canada." *Biomass and Bioenergy* 25: 135-146.

“Two species of willow, *Salix discolor* and *S. viminalis*, were planted in 1995 under short-rotation intensive culture on two abandoned farmland sites: sandy site (S1) and clay site (S2). After three seasons of growth the two species were coppiced. In the spring of the first season following coppicing, one dose of composted sludge equivalent to 100 kg of “available” N /ha, was applied to some plots (T1) while others were left unfertilized (T0). The aims of the experiment were to compare the growth performance and nutrients exported by willow species planted on marginal sites with different soil characteristics and to assess the impact of fertilization with wastewater sludge on yields during a second rotation cycle.

Over three seasons, willow height, diameter and aboveground biomass were greater for *S. viminalis* than for *S. discolor* on all fertilized plots. The best growth performance of two

willows was obtained on the clay site. *S. viminalis*, planted on the fertilized plots of the clay site, had the highest biomass yield (70.36 tDM /ha). The application of a dose of wastewater sludge (100 kg of 'available' N /ha) was not enough to satisfy all nutritional requirements of willows for the period of growth. Over the second rotation the nutrients removed from the soil by willows (in kg per ton of dry mass harvested) were: from 5.3 to 7.5 for N; from 0.6 to 0.9 for P; from 1.8 to 3 for K; from 4.2 to 7.2 for Ca and from 0.4 to 0.7 for Mg." (135)

MacPherson, G. (1995). *Home-grown Energy from Short-rotation Coppice*. Ipswich, United Kingdom, Farming Press Books.

How to get started with short rotation farming, specifics for the United Kingdom. Provides a good overview of Sweden's clones and soil types. The chapters include: "The market for woodchips, Why energy crops could fill more than a million hectares of UK farmland, Suitable situations, Soils and climates for short-rotation coppice, Will it pay?, Planting material, Establishing the crop, Protecting the crop, Cheap to feed, Harvest: to chip or not to chip?, Storage, drying and utilization, Getting started, and Setting up farm energy marketing groups.

Marshall, H. G. W. (1981). *Use of Wood Energy in Remote Interior Alaskan Communities*. C. A. I. Reid. Anchorage, AK, State of Alaska Department of Commerce and Economic Development, Division of Energy and Power Development.

Looked at the potential of wood energy in rural Alaska. Studied the availability of wood biomass and possibility of growing it. It deals mostly with large trees, however it addresses woody shrubs a little bit.

> "Woody shrub vegetation could suitably be harvest if chipped on-site because this is a particularly difficult material to handle and transport in its original form. Many of the river islands and banks are covered with willow which is fast-growing and which quickly re-sprouts when cut. This could be a highly productive source of fuel cut on rotations of, say, 10 years. However, it is a source of food for moose on which rural communities depend for meat so this has to be an important consideration. The willow sites close to or on the river banks also protect the soil surface from eroding under high flood levels. Its use a s a fuel source must be approached with care and could be tried on an experimental basis initially." (24)

The study concludes that replanting harvested sites is the best way to keep biomass available, and silviculture of quick growing crops is the best way to harvest biomass (31).

McKendrick, J. D. (2005). *Final Monitoring Inspection Report Mile Post 400 Revegetation Site, 2005*. Fairbanks, Alaska, Alyeska Pipeline Service Company.

"The final required inspection of the Mile Post (MP) 400 (N 65° 26.228';W 148°35.078'') oil spill rehabilitation is reported in this document. In July, 2005 the site was a shrub-dominated plan community (cover) with an understory of forbs, grasses and seedlings of forest trees. The two species of grass seeded on the site had died, as anticipated in the rehabilitation plan. There is no evidence of the oil spill on vegetation surrounding the site. There are no signs of oil either in the soil or on water surfaces at this location. There was neither signs of thermokarst nor the prospects of thermokarst in the future on this site. It is anticipated that natural trees will over take the site in a matter of a few years, perhaps 10 to 15 years. The rehabilitation objective was to remove the hydrocarbon contamination and leave the site in a condition conducive for the natural regeneration of the indigenous forest plant community. All evidence found at the site indicated the site is developing in accordance with the rehabilitation plan objectives." (i)

Miller, Calvin R., Robert Parkerson, John Zasada, Alan Epps, and James A. Smith (1983*). A Revegetation Guide for Alaska.* Alaska Rural Development Council: A-00146.

How to grow revegetation plants and which type of plants to grow. Mostly deals with grasses, but makes suggestions about woody plants as well.

Mitchell, G. A., and W. W. Mitchell (1981). *Alder for mineland restoration in cold-dominated climates*. Alaska Department of Agronomy. Palmer, Alaska.

"Principal objectives of this study were: (1) evaluation of procedures for treatment and stratification of seed from native alder populations, (2) establishment of trial seedling with variables of soil manipulation and amendments, (3) establishment of seedling transplants for fertilizer evaluation at Palmer and for survival characteristics on mine spoils at two locations, and (4) documentation and chemical and physical characteristics of selected spoil materials and determination of changes resulting from alder invasion." (introduction)

The study concluded that broadcasting seeds not a viable option on old mine sites, that the planting of seedlings requires a wet time of year, but is possible, and that the collection of seeds should be in early to mid autumn.

Moore, N. (1986). "Recommendations for reclamation species and techniques." *Alaska Miner* (April): 14, 18.

Provides information to miners on what the Plant Materials Center in Palmer does for reclamation of mining lands.

Nicholls, D., and Peter M. Crimp (2002*). Feasibility of Using Wood Wastes to Meet Local Heating Requirements of Communities in the Kenai Peninsula in Alaska*. U. S. Dept. of Agriculture: PNW-GTR-533.

"Wood energy can be important in meeting the energy needs of Alaska communities that have access to abundant biomass resources. In the Kenai Peninsula, a continuing spruce bark beetle (*Dendroctonus rufipennis* (Kirby)) infestation has created large volumes of standing dead spruce trees (*Picea spp*.). For this evaluation, a site in the Kenai-Soldotna area was chosen for a small, industrial-scale (4 million British thermal units (BTUs) per hour) wood-fired hot water heating system, which could be fueled by salvaged spruce timber and also by saw-milling residues. Thirty-six different scenarios were evaluated by using wood fuel costs ranging from $10 to $50 per delivered ton, alternative fuel costs from $1 to $2 per gallon, and fuel moisture contents of either 20 percent or 50 percent (green basis). In addition, two different capital costs were considered. Internal rates of return varied from less than 0 to about 31 percent, and project payback periods varied from 4 years to greater than 20 years. Potential barrier to the long-term sustainability of a wood energy system in the Kenai Peninsula include the availability of biomass material once current spruce salvage activities subside. The estimated wood fuel requirements of about 2,000 tons per year are expected to be easily met by spruce salvage operations over the short term and by sawmill residues after salvage inventories diminish. It is expected that a wood energy system this size would not significantly reduce overall fuel loads in the area, but instead would be a good demonstration of this type of system while providing other community benefits and energy savings." (abstract)

Nicholls, D. L., Stephen E. Patterson, and Erin Uloth (2006). *Wood and Coal Cofiring in Interior Alaska: Utilizing Woody Biomass From Wildland Defensible-Space Fire Treatments and Other Sources.* Pacific Northwest Research Station: PNW-RN-551.

"Cofiring wood and coal at Fairbanks, Alaska, area electrical generation facilities represents an opportunity to use woody biomass from clearings within the borough, wildland-urban interface and from other sources, such as sawmill residues and woody material intended for landfills. Potential benefits of cofiring include air quality improvements, reduced greenhouse gas emissions, market and employment development opportunities, and reduction of municipal wood residues at area landfills. Important issues that must be addressed to enable cofiring include wood chip uniformity and quality, fuel mixing procedures, transportation and wood chip processing costs, infrastructure requirements, and long-term biomass supply. Additional steps in implementing successful cofiring programs could include test burns, an assessment of area biomass supply and treatment needs, and a detailed economic and technical feasibility study. Although Fairbanks North Star Borough is well positioned to use biomass for cofiring at coal burning facilities, long-term cofiring operations would require expansion of biomass sources beyond defensible-space-related clearings alone. Long-term sources could potentially include a range of woody materials including forest harvesting residues, sawmill residues, and municipal wastes." (1)

Coal costs $2.58/ million BTU, green wood costs $3.89 / million BTU in 2006; these estimates include transportation costs. (8)

In the next 5-10 years, "defensible-space clearings within the Fairbanks area WUI could provide up to 100,000 tons of biomass" harvesting is estimated to be $150/acre (10)

Nilsson, L.-O. (1982). *Determination of Current Energy Forest Growth and Biomass Production*. Uppsala, Sweden, Swedish University of Agricultural Sciences: S-750 07.

Details a non-destructive way to estimate of biomass of willows, but does not provide all of the parameters.

Nordh, N.-E. (2005). *Long Term Changes in Stand Structure and Biomass Production in Short Rotation Willow Coppice.* Uppsala, Sweden, Swedish University of Agricultural Sciences. Ph. D: 26 pp.

Looked at biomass production in later cutting cycles. Determined that "sustainability in SRWC systems is enhanced by matching clone and site and adapting fertilization and harvest timing to actual stand development" (3).

Nordh, N.-E., and Theo Verwijst (2004). "Above-ground biomass assessments and first cutting cycle production in willow (*Salix sp*.) coppice - a comparison between destructive and non-destructive methods." *Biomass and Bioenergy* 27: 1-8.

“To assess non-destructive above-ground biomass measurements in comparison to destructive measurements in willow (*Salix sp*.) coppice plantations, individual plant weights of twelve 4-year old willow clones (*Salix viminalis* L., *S. dasyclados* Wimm.) were estimated by constructing allometric relationships between stem diameter and shoot dry weight. The plants were also measured with a destructive method, i.e. harvest, weighing, and determination of wood dry matter content. The allometric relationships between shoot dry weight and stem diameter at 55, 85 and 105 cm from the shoot base, were compared. Mean differences between the destructively and non-destructively measured plant weights were small and only significant for two of the clones. For nine of the clones, the non-destructive assessments deviated less than 3% from destructively measured weights. The maximum deviation was a 7% underestimation of the mean plant weight. However, the resulting differences between methods increased with increasing plant weight for six of the clones. For most clones, the best fit of the model relating shoot dry weight and stem diameter was found at 105 cm above shoot base ($r^2 > 0.987$) but high model fits also were found at 55 cm(r^2>0.973) and 85 cm(r^2>0.961) above shoot base. Plant survival was determined to obtain production assessments per unit area. Standing woody biomass after 4 years ranged from 24.6 to 38.1 t dry matter/ha and plant survival from 71% to 98%. We conclude that non-destructive methods are reliable for a range of clones in commercial practice, while improvement is needed for purposes in which detection of small growth differences is crucial.” (1)

Oak Ridge National Laboratory, "Bioenergy Feedstock Information Network (BFIN)." Retrieved July 25, 2008, from http://bioenergy.ornl.gov/main.aspx.

Provides information on government research into biomass energy, it has much to do with ethanol, but there is some on other energy crops.

Perala, D. A. "*Populus tremuloides* Michx. Quaking Aspen." Retrieved July 24, 2008, from http://www.na.fs.fed.us/spfo/pubs/silvics_manual/volume_2/populus/tremuloides.htm.

This article provides a comprehensive life history of the aspen in most forms throughout the northern U.S.

Perala, D. A. (1979). *Regeneration and Productivity of Aspen Grown on Repeated Short Rotations*. U.S. Department of Agriculture, Forest Service: NV-176.

Aspen do not produce well on rotations shorter than 10 years in Minnesota. Rotations of at least 15 years are unlikely to impair aspen regenerative and productive capacity

Regeneration and yields declined steadily through the fourth harvest (on 1 year rotations) and drastically after that (2). The decline is less in 4 and 8 year rotations, but it is still a problem (3).

Pohjonen, V. (1991). "Selection of species and clones for biomass willow forestry in Finland." *Acta Forestalia Fennica* 221.

Detailed history of the development of willow clones for biomass production in Finland, almost 20 years of history.

Pontailler (1999). "Biomass yield of poplar after five 2-year coppice rotations." *Forestry* 72(2): 157-163.

A European study that determined the biomass of four poplar clones after fiver 2-year coppice rotations. There are several charts of the biomass measurements.

Racine, C. A., Lawrence A. Johnson, and Leslie Viereck (1987). "Patterns of vegetation recovery after tundra fires in Northwestern Alaska, U.S.A." *Arctic and Alpine Research* 19: 461-469.

Studied natural plant recovery after tundra fires in Northwestern Alaska, grasses are the majority of the research.

Rafaschieri, A., Mario Rapaccini, and Giampaolo Manfrida (1999). "Life cycle assessment of electricity production from poplar energy crops compared with conventional fossil fuels." *Energy Conversion and Management* 40: 1477-1493.

"The environmental impact of electric power production through an Integrated Gasification Combined Cycle (IGCC) cofired by dedicated energy crops (poplar Short Rotation Forestry (SRF)) is analyzed by a Life Cycle Assessment approach. The results are compared with the alternative option of producing power by conventional fossil fueled power plants. The energy and raw materials consumption and polluting emissions data both come from experimental cases. Thermodynamic models are applied for simulation of the energy conversion system. The results establish relative proportions for both consumption and emissions of the two energy systems, in detail. Considerable differences emerge about the environmental impact caused by the different gasification conditions. The evaluation of the environmental effects of residues of the pesticides in ground/surface water and in the soil required a particular care, as well as the characterization of all chemicals (herbicides, fungicides and insecticides) used for the crops." (1477)

Rytter, L. (1994). *The Possible Use of Gray Alder in Plantation Forestry*. Silviculture tuned to nature and wood and energy production, Geneva and Lausanne ,Switzerland, Science and Sustainable Development. 33-39.

Alder has high productivity rate, which is especially impressive on less favorable sites (33).

Rytter, L. (1996). “The potential of grey alder plantation forestry.” In *Short Rotation Willow Coppice for Renewable Energy and Improved Environment*. Uppsala, Sweden: 89-94.

“A survey concerning the potential use of grey alder in short rotation forestry is performed. It is concluded that grey alder is an interesting contributor in plantation forestry, because it has a high woody biomass production, is more or less self-supporting with nitrogen, and is a well adapted to conditions in Fennoscandian and Balticum.” (89)

The initial growth of alder is rapid, but slower than willows. They reach a maximum growth in 6-7 years. Harvest can be 5 Mg/ha/year, and with additional watering and nutrients it can reach 8 Mg/ha/year (3.5 tons/acre). (90) The recommended rotation for alder is 10-20 years (91).

Sampson, G. R., Allen P. Richmond, Gary A. Brewster, and Anthony F. Gasbarro (1991). "Cofiring of wood chips with coal in interior Alaska." *Forest Products Journal* 41(5): 53-56.

Looked at the potential of woods in interior for cofiring with coal. There is information about the heating capacity of interior spruce, aspen, and birch.

Siren, G. "Silviculture for Energy." *Unasylva* 138. Retrieved April 3, 2007 from, http://www.foa.org/docrep/p8870e/p8870e03.htm.

The basic needs of an intensive energy plantation, without specifics on any particular species.

Smart, L. B. (2005). "Genetic improvement of shrub willow (*Salix spp*.) crops for bioenergy and environmental application in the United States." *Unasylva* 221(56): 51-55.

How New York has been breeding willows for certain characteristics.

Stiell, W. M., and A.B. Berry (1986). "Productivity of short-rotation aspen stands." *The Forestry Chronicle*: 10-14.

The study was in Petawawa National Forestry Institute, near Ottawa, Canada. It looked at aspen production from suckers. It was concluded that 10 years is the shortest rotation for Aspen to ensure survival.

Szczukowski, S., J. Tworkowski, A. Klasa, and M. Stolarski (2002). "Productivity and chemical composition of wood tissues of short rotation willow coppice cultivated on arable land." *Rostlinna Vyroba* 48: 413-417.

Various species of willows were grown in Northern Poland and their biomass potential was measured with harvests at one, two and three year intervals. There are very good data tables on biomass and BTU per species. The longer between cuttings the better biomass and BTU production, up to 3 years.

Uri, V., Hardi Tullus, and Drista Lohmus (2002). "Biomass production and nutrient accumulation in short-rotation grey alder (*Alnus incana* (L.) Moench) plantation on abandoned agricultural land." *Forest Ecology and Management* 161: 169-179.

A study in Estonia on grey alder that yielded 1.6 tonnes/hectare (0.7 tons/acre) at 5 years out.

Van Cleve, K., Leslie A. Viereck, and Robert L. Schlentner (1971). "Accumulation of nitrogen in alder (*Alnus*) ecosystems near Fairbanks, Alaska." *Arctic and Alpine Research* 3: 101-114.

Studied biomass production of floodplain shrubs by age. Provides charts of the size of plants and the biomass production. Sites were sampled at 5, 15, and 20 years old along the Tanana river flood plain. At 5 years the alders are dense, 49,699 stems/hectare and 2 cm diameter; at 15 years alder are 4,563 stems/hectare and 6.6 cm diameter; at 20 years alder are 7,142 stems/hectare and 7.1 cm diameter (105). The weighed biomass (kg/ha OD) with the roots included was at 5 years alder-8,750.7, willow-663.3; at 15 years alder-27,810.4, willow-5,584.1; at 20 years alder-42,740.6, willow-5,127.4 (108).

Van Cleve, K. (1973). "Energy and biomass relationships in alder (*Alnus*) ecosystems developing on the Tanana River floodplain near Fairbanks, Alaska." *Arctic and Alpine Research* 5: 253-260.

Studied the energy content of several species in the alder ecosystem. Alder has a higher energy content at five years than most other shrubs.

(p. 255)	Energy Content calories/gram		
Species	5 years	15 years	20 years
Alder	5152	5118	5226
Willow	4578	5033	4845
Poplar	4679		
Birch	4841		

Viereck, L. A. (1970). "Forest succession and soil development adjacent to the Chena River in interior Alaska." *Arctic and Alpine Research* 2(1): 1-26.

They studied the freezing and thawing of soil in four different successional stands along the Chena.

Viereck, L. A., Elbert L. Little (1972). *Alaska Trees and Shrubs*. Washington, D.C., United States Department of Agriculture, Forest Service.

A field guide to trees and shrubs of Alaska. Willows are on pages 86-126 and alders are on pages 142-146.

Viereck, L. A., C. T. Dyrness, and M. J. Foote (1993). "An overview of the vegetation and soils of the floodplain ecosystem of the Tanana River, Interior Alaska." *Canadian Journal of Forest Research* 23: 889-898.

"The soils and vegetation of 12 stages of forest succession on the floodplain of the Tanana River are described. Succession begins with the invasion of newly deposited alluvium by willows (*Salix spp*.) and develops through a willow-alder *(Alnus tenuifolia* Nutt.) stage to forest stands of balsam poplar followed by white spruce and finally by black spruce." (889)

Describes the succession of plant species on the flood plain over a span of hundreds of years. Willows grow in slowly and only maintain themselves for 1 to 5 years, and then the alder takes over.

Volk, T. A., L. P. Abrahamson, C.A. Nowak, L.B. Smart, P.J. Tharakan, and E.H. White (2004). "Growing fuel: a sustainability assessment of willow biomass crops*." Frontier Ecology Environment* 2: 411-418.

Determines that growing willow for biomass is a sustainable project.

Volk, T. A., L. P. Abrahamson, C.A. Nowak, L.B. Smart, P.J. Tharakan, and E.H. White (2006). "The development of short-rotation willow in the northeastern United States for bioenergy and bioproducts agroforestry and phytoremediation." *Biomass and Bioenergy* 30: 715-727.

"Research on willow (*Salix spp*.) as a locally produced, renewable feedstock for bioenergy and bioproducts began in New York in the mid-1980s in response to growing concerns about environmental impacts associated with fossil fuels and declining rural economies. Simultaneous and integrated activities - including research, large-scale demonstrations, outreach and education, and market development - were initiated in the mid-1990s to facilitate the commercialization of willow biomass crops. Despite technological viability and associated environmental and local economic benefits, the high price of willow biomass relative to coal has been a barrier to wide-scale deployment of this system. The cost of willow biomass is currently $3.00 /GJ ($57.30 / odt) compared to $1.40- 1.90 /GJ for coal. Yield improvements from traditional breeding efforts and increases in harvesting efficiency that are currently being realized promise to reduce the price differential. Recent policy changes at the federal level, including the provision to harvest bioenergy crops from Conservation Reserve Program (CRP) land and a closed-loop biomass tax credit, and state-level initiatives such as Renewable Portfolio Standards (RPS) will help to further reduce the difference and foster markets for willow biomass. Years of work on willow biomass crop research and demonstration projects have increased our understanding of the biology, ecophysiology and management of willow biomass crops. Using an adaptive management model, this information has led to the deployment of willow for other applications such as phytoremediation, living snowfences, and riparian buffers across the northeastern US." (715)

When growing biomass on CRP land the production costs rival that of coal (722).

Walker, L. R., John C. Zasada, and F. Stuart Chapin III (1986). "The role of life history processed in primary succession on an Alaskan floodplain." *Ecology* 67(5): 1243-1253.

"The pattern of primary succession on the floodplain of the Tanana River in interior Alaska resulted largely from interactions between stochastic events and life history traits of the dominant species. Seed rain by willow (*Salix alaxensis*), alder (*Alnus tenuifolia*), poplar (*Populus balsamifera*), and spruce (*Picea glauca*) varied substantially among years but was highest in the successional stage dominated by that species. Some seeds of each species arrived in all stages, and seedlings of all species were initially present in early successional sites. The copious, wind-dispersed seeds and rapid seedling growth rates of willow and poplar resulted in their abundant establishment on early successional vegetated-silt bars. Heavier alder and spruce seeds were less widely distributed, yet rapid growth rates of alder resulted in dense alder thickets within 20 yr of silt bar formation. We found no evidence of buried seed of the four study species. Sown seeds of willow, alder, and poplar established only in early successional vegetated-silt and willow sites. Spruce established in these same sites and in alder sites. Spruce was the only species that naturally colonized mid and late successional sites. Removal of the litter and forest floor enabled all species to germinate in all sites. Flooding resulted in substantial mortality of seedlings in early successional sites. A combination of short life span, herbivory by hares, and shade intolerance eliminated willow from mid-successional alder-dominated sites. Thereafter differences in longevity explained successional change from alder to poplar to spruce. Facilitative interactions among species did not appear essential to explain changes in species composition in this primary successional sequence." (1243)

Walter, J., and Dean Hughes (2005). *Streambank Revegetation and Protection; a Guide for Alaska.* Alaska Dept. of Fish and Game. Retrieved July 24, 2008 from http://www.sf.adfg.state.ak.us/sarr/restoration/techniques/techniques.cfm

"Revegetation of riparian areas involves replanting native vegetation adjacent to lakes, streams, and creeks for the benefit of the species utilizing the system, watershed and associated uplands." (1)

How to revegetate a streambank. Gives suggestions on how to propagate willows and streambank shrubs. The techniques include: bundles, like staking, live siltation, brush mat, hedge brush layering, vegetated cribbing and grass rolls.

Warren, T. J. (1995). "Converting biomass to electricity on a farm-sized scale using downdraft gasification and a spark ignition engine." *Bioresource Technology* 52(1): 95-98.

A study that gasified biomass on a small scale to produce electricity. The system had many flaws that further studies were to work out.

Weih, M., Nils-Erik Nordh (2005). "Determinants of biomass production in hybrid willows and prediction of field performance from pot studies." *Tree Physiology* 25: 1197-1206.

Studied the biomass production of several varieties of hybrid willows in pots. Fertilizer is important to good production. (Sweden)

Weixelman, D., R. Terry Bowyer, and Victor Van Ballenberghe (1998). "Diet selection by Alaskan moose during winter: effects of fire and forest succession." *ALCES* 34(1): 213-238.

Discussed a little about revegetation after fires, but the article is mostly about moose selection of browse. Looked at twigs /m^2 between 7 and 80 years, willows had the greatest numbers between 20 and 30 years.

Wright, S. (2008). *A Revegetation Manual for Alaska*. Alaska Department of Natural Resources. Division of Agriculture Palmer, Alaska, Alaska Plant Materials Center. Retrieved July 24, 2008 from, http://www.dnr.state.ak.us/ag/RevegManual.pdf

Revegetation techniques and suggestions mostly with grasses.

Wright, S. J. (1985). *Willow Varieties for Alaska*. State of Alaska, Division of Agriculture, Plant Materials Center and USDA Soil Conservation Service: 7pp.

Looks at the potential uses of native Alaskan willows.

Wurtz, T. L. (1995). "Understory alder in three boreal forests of Alaska: local distribution and effect on soil fertility." *Canadian Journal of Forest Research* 25: 987-996.

Created allometric biomass models for Alaskan alders. The diameters were taken on the forest floor.

green alder, Standard Creek ln(biomass)=3.22+2.67ln(diam)
Trapper Creek ln(biomass)=3.43+2.64ln(diam)
mass is in grams, diameter is in centimeters

Yarie, J., and Delbert Mead (1982). *Aboveground Tree Biomass on Productive Forest Land in Alaska*. Portland, OR., U.S. Department of Agriculture, Forest Service: PNW-298.

The forestry biomass potential of coastal and interior Alaska. Includes tables of allometric equations.

Yarie, J., and Delbert Mead. (1988). Twig and Foliar Biomass Estimation Equations for Major Plant Species in the Tanana River Basin of Interior Alaska. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station: PNW-RP-401.

Estimates the biomass of shrubs and grasses using a percentage of plants at certain heights

Yemshanov, D., and Daniel McKenny (2008). "Fast-growing poplar plantations as a bioenergy supply source for Canada." *Biomass and Bioenergy* 32: 185-197.

"This study explores the economic feasibility of biomass for bioenergy from fast-growing hybrid poplar plantations established on agricultural lands in Canada. Using a spatial bioeconomic afforestation feasibility model, we report break-even supply costs for two broad scenarios: first with only merchantable fibre having value and secondly, a fibre-plus carbon scenario with carbon sequestered valued at $5 /t CO_2. Five levels of biomass processing capacities were examined in each scenario (90, 230, 450, 1500 and 3000 ktonnes per year) using 241 settlements across Canada as potential locations for bioenergy facilities. Supply costs here include plantation establishment, maintenance, agricultural land rent, harvest and transportation to nearest community. In relative terms three geographic regions had the most promise: the northern Prairies, central Ontario and parts of the Maritime Provinces. Smaller-scale bioenergy projects were attractive for Eastern Canada (Ontario and the Maritimes). The Prairie Provinces were most attractive for larger facilities with break-even supply costs exceeding $5 /GJ. Adding carbon incentives at $5 /t CO_2 decreases average costs of delivered biomass by $0.57-$1.38/GJ; however, these cost estimates are still above the current delivered costs of sub-bituminous coal." (185)

Zasada, J., and L. A. Viereck (1975). "The effect of temperature and stratification on germination in selected members of the Salicaceae in interior Alaska." *Canadian Journal of Forest Research* 5: 333-337.

They collected seeds from seven species of willow and determined what temperatures they required for germination.

Zasada, J. (1976). "Ecological and silvicultural considerations, Alaska's interior forests." *Journal of Forestry*: 333-337.

Looks at the timber potential of interior's forests in 1976.

Zasada, J., Bonita Neiland, and Roseann Densmore (1981). *Investigations of Techniques for Large-Scale Reintroduction of Willows in Arctic Alaska*. Fairbanks, Alaska, Agricultural Experiment Station, School of Agriculture and Land Resources Management, University of Alaska.

Studied *Salix alaxensis* on the North Slope in natural and planted revegetation plots after the construction of the pipeline. Takes a comprehensive look at planting and production of revegetion plants. *S. alaxensis* produces about 300 kg/ha (270 lbs/acre) dry weight in dense stands.

Zasada, J., L. A. Viereck, M. J. Foote, R. H. Parkenson, J. O. Wolff, and L. A. Lankford Jr. (1981). "Natural regeneration of balsam poplar following harvesting in the Susitna Valley, Alaska." *The Forestry Chronicle*: 57-65.

Studied regeneration after logging in the Susitna valley; the poplar came back well from stumps and branches; willow did not take over the area very well.

Zasada, J., Rodney A. Norum, Chrisitian E. Teutsch, and Roseann Densmore (1987). "Survival and growth of planted black spruce, alder, aspen, and willow after fire on black spruce/feather moss sites in interior Alaska." *The Forestry Chronicle*: 84-88.

"Seedlings of black spruce, aspen, green alder, and grayleaf willow planted on black spruce/feather moss sites in the boreal forest in interior Alaska survived and grew relatively well over a 6-year period after prescribed burning. Survival of black spruce was significantly greater than that of the broad-leaved species, but height growth was significantly less. Development of feltleaf willow and balsam poplar from unrooted cuttings was poor." (84)

Zasada, J., D.A. Douglas, and W. Buechler (unpublished). "*Salix* l., willow."

Provides the basics on willows, how to collect seeds and possible uses.