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Assessing the Potential for Conversion to Biomass Fuels in Interior Alaska

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Abstract

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In rural Alaskan communities, high economic, social, and ecological costs are associated with fossil fuel use for power generation. Local concerns regarding fuel prices, environmental contamination, and the effects of global climate change have resulted in increased interest in renewable energy sources. In this study we assessed the feasibility of switching from fossil fuels to wood energy in rural Alaskan villages in forested regions of interior Alaska. Modeling results based on recent data on rural energy use, demographics, economics, and forest dynamics indicated that the installation costs of biomass systems would be recouped within 10 years for at least 21 communities in the region. In addition, results showed that all but the largest remote communities in the interior could meet all their electrical demand and some heating needs with a sustainable harvest of biomass within a radius of 10 km of the village. Marketable carbon credits may add an additional incentive for fuel conversion, particularly if U.S. prices eventually rise to match European levels. Biomass conversion also offers potential social benefits of providing local employment, retaining money locally, and reducing the risk of catastrophic wildfire near human habitation. This analysis demonstrated that conversion to biomass fuels is economically viable and socially beneficial for many villages across interior Alaska.

Keywords: Biomass fuel, carbon offset, interior Alaska, wood energy.

Summary

Rural Alaskan communities are faced with the concurrent problems of high fuel prices for electricity and heating, high fire risk owing to increasing fire severity and fuel buildup around communities, and environmental contamination from extensive use of diesel fuel. In this study we sought partial solutions for all of these problems through use of wood energy in rural Alaskan villages in forested regions of interior Alaska. We assessed the feasibility of this fuel substitution from an ecological, economic, and social viewpoint using separate submodels, then analyzed our results as a whole.

Owing to the high costs of fuel transport and storage in rural Alaska, energy prices are extremely high. Consumers pay an effective rate of up to 35 cents per kWh in some regions, despite substantial state subsidies. Our focus was on use of black spruce (*Picea mariana* (Mill.) B.S.P.) in relatively simple small-scale boilers for electrical power generation, with the possibility of using waste heat in combined heat and power systems. In addition, we explored the possibility of communities obtaining carbon offset credits that could be traded on the open market.

The ecological submodel estimated the maximum travel distance necessary for biomass harvest for wood energy around each of the 36 villages studied. This submodel took into account village population, per capita energy use, the fraction of total energy use to be replaced with biomass energy, rotation length for forest harvest, biomass density for black spruce at harvest age, wood energy density, electrical efficiency, and percentage of forest cover.

The economic submodel explored the short- and long-term costs and benefits of switching from diesel energy to wood energy in these remote communities, and estimated the period needed to pay back capital investments. In our calculations, we used the installed cost of a biomass power system per kilowatt of generation capacity, the total biomass capacity installed, the actual energy offset, diesel efficiency, diesel price, the fraction of nonfuel costs offset by use of biomass, total nonfuel costs, biomass energy generated, biomass energy costs, and the value of carbon credits available owing to fuel offset.

We explored the effects of model input selection and model parameter uncertainty on model outputs by performing sensitivity analyses on both the ecological and the economic submodels.

Our social analysis was qualitative, and focused on factors likely to affect the feasibility of fuel substitution, including threshold requirements for success in any one community. We also examined potential feedback between ecological, economic, and social factors, and assessed ways in which they might in combination affect the feasibility of wood biomass fuel use in Alaska villages.

Our analysis was intentionally conservative, and may therefore have underestimated potential advantages of conversion to biomass fuels. Nevertheless, modeling results indicated that the installation costs of biomass systems would be recouped within 10 years for at least 21 communities in the region. In addition, results showed that all but the largest remote communities in the interior could meet all their electrical demand and some heating needs with a sustainable harvest of biomass within a radius of 10 km of the village. The greatest economic feasibility is demonstrated by villages that are not easily reached by either road or river networks. The greatest ecological feasibility occurs in communities of small to medium size, where the wood resources needed are available within a relatively small radius. Marketable carbon credits may add an additional incentive for fuel conversion, particularly if U.S. prices eventually rise to match European levels. Biomass conversion also offers potential social benefits of providing local employment, retaining money locally, and reducing the risk of catastrophic wildfire near human habitation. Success of a fuel conversion project in a community is likely to depend upon the existence of local advocates and participants; sufficient local technological skills; and collaboration among communities, funders, and electrical cooperatives.

This analysis demonstrated that conversion to biomass fuels would be economically viable and socially beneficial for many villages across interior Alaska. Pilot projects offer the next step in testing feasibility.

Introduction

The excess carbon dioxide released into the atmosphere by the burning of fossil fuels is having measurable impacts on the Earth's climate, with even more profound impacts likely in the future (Hansen et al. 2005a, Houghton et al. 2001, Karl and Trenberth 2003, Prentice et al. 2000). Moreover, fossil fuels are a non-renewable resource with uncertain future prices and availability owing to limited supplies and fragile international trade agreements. Thus, academic, industrial, and governmental researchers are increasingly exploring renewable sources of energy.

Potential sources of sustainable energy include solar, geothermal, hydroelectric, wind, and biomass. Although each of these options has positive and negative attributes, biomass energy holds immediate promise because it is broadly available, fairly well developed technologically, and in some cases can be linked to other benefit streams in addition to the production of energy. In the United States, interest in woody biomass as a fuel is increasing as both an alternative fuel and a means of reducing fire risk near forested communities (GAO 2005).

The two primary obstacles that currently limit the use of woody biomass in the United States are low cost-effectiveness and lack of reliable supply (GAO 2005). For example, the cost of producing electricity from woody biomass using current technologies in the United States is currently 7.5 cents per kWh, whereas the market price for this electricity is only 5.3 cents per kWh (GAO 2005).

These obstacles might be overcome if selected communities can institute pilot projects that demonstrate the efficacy of biomass energy, provide a testing ground for improvements, and at the same time enjoy immediate economic and social benefits locally. We propose that the ideal locations for such pilot projects might be in communities with the following attributes:

- Relatively small and self-contained with simple infrastructure
- High current cost of power and/or heat
- Proximity to sustainable supplies of woody biomass
- Lack of social opposition to use of biomass fuel
- Strong social impetus to mitigate global climate change
- Interest in obtaining marketable carbon credits
- Existence of other social and economic considerations that make biomass harvest and use a desirable option.

Many villages and towns in interior Alaska fit all of these criteria. Rural Alaskans are disproportionately exposed to the effects of climate change, which is most pronounced at high latitudes (ACIA 2005), and struggle with rising fuel costs in a mixed economy characterized by high transportation costs. In rural

Alaskan communities, mainstream fossil fuel technologies are prohibitively expensive. Large quantities of alternative fuels in the form of woody biomass (chiefly black spruce, *Picea mariana* (Mill.) B.S.P.) are available in this region, and the technology to use these fuels is relatively simple. Moreover, positive economic externalities may be realized through forest thinning or clearing, given the risks of forest fires to life and property, the direct costs of fire suppression, and the negative impacts of fire suppression on long-term ecosystem services. The advent of carbon trading markets in both the public and private sectors provides a source of additional revenue for alternative energy projects that could potentially tip the balance toward renewable energy sources (Duval 2004), although because such markets are slow to develop, this analysis does not depend upon their existence. Biomass can be used for heating, for energy generation, or for combined heat and power. This paper's focus is at the village level rather than the household level at which many heating choices are made; thus we chose to explore the possibility of conversion of village diesel generation facilities to renewable energy sources as one way in which villages might partially mitigate climate change, earn tradable carbon credits, reduce fuel costs, reduce fire risk, and increase local autonomy, thereby reducing vulnerability to external social and economic change.

In many regions both in the United States and abroad, immediate transition to alternate fuels is limited for economic, technological, or sociopolitical reasons. However, in much of interior Alaska, economic drivers, governmental infrastructure, available natural resources, and social imperatives all point toward the viability of conversion to new energy sources. We suggest that fuel conversion programs could be implemented in such a manner as to have positive effects on these systems. We further suggest that interior Alaska has the opportunity to provide leadership in this arena.

Previous studies have examined the feasibility of using wood fuel for energy generation in particular communities, including Dot Lake (AEA 2000a) and McGrath (Crimp and Adamian 2001). However, these studies cannot easily be extrapolated to other communities, and do not examine such factors as fire risk reduction and job creation. In this paper we provide a more comprehensive assessment. We analyze the feasibility and sustainability of potential biomass energy programs in rural Alaska by creating a social, biological, and political model framework within which we evaluate not only a wider range of financial costs and benefits, but also the interactions of ecological feasibility, social acceptability, community interest, and leadership commitment.

Background: System Components

Energy Systems in Rural Alaska

Approximately 200 villages in Alaska have no connection to the electrical grid that links Alaska's largest communities. Prior to the 1960s, electricity was not available to most rural Alaskans (AVEC 2005). Now, these villages are generally supplied with electricity by diesel generators ranging from about 15 to 3100 kW in energy output (AEA 2000b). In total, 382 971 145 kWh of power were produced through diesel generation in Alaska in 2004, and 28,476,898 gal (107 459 992 L) of diesel fuel were consumed (AEA 2004). Many rural communities are part of regional cooperatives, including the Alaska Village Electrical Cooperative, Inc. (AVEC), which operates more than 150 diesel generators in 51 communities that run a cumulative 414,822 hours a year (AVEC 2005).

Because most rural Alaskan communities are not on the road system, fuel for these generators must be transported by barge or airplane. Thus, in most cases, fuel can only be transported during summer, and enough fuel to last a full year must be stored on site (Colt et al. 2003). Maintaining this large storage capacity for fuel has posed significant environmental problems and incurred hundreds of million dollars of expenses (Colt et al. 2003, Duval 2004).

Because of the high costs of fuel transport and storage in rural Alaska, energy prices are extremely high. Consumers pay an effective rate of up to 35 cents per kWh in some regions. Less than half the total cost of electricity in rural Alaska can be directly attributed to fuel costs (Colt et al. 2003). Storage alone adds an estimated $0.40/L, owing to capital expenses and spill response capability—which itself may add as much as $0.16/L (UAF 2005).

Even in urban areas, electricity is more expensive in Alaska than in other parts of the country. In Fairbanks, the largest community in the interior and Alaska's second-largest city, residential power costs over 11.6 cents per kWh, not counting additional charges (GVEA 2005), 35 percent more than the nationwide average cost of residential electricity (EIA 2005).

In rural areas, much higher costs occur despite substantial subsidies. Alaska's Power Cost Equalization Program (PCE) provides assistance based on an algorithm that discounts costs between 12.0 and 52.5 cents per kWh by 95 percent (AEA 2004). Average residential rates without the subsidy would be more than 60 cents per kWh in some communities. Even so, the combined costs borne by consumers and the PCE program still do not account for a large proportion of the real costs of the system, which are funded by government grants, mostly for infrastructure. For small independent villages that are not AVEC members, these grants cover more than half (55 percent) of the real costs; for AVEC members, they cover approximately 26 percent (Colt et al. 2003). As the umbrella group for all village energy programs, the Alaska Energy Authority (AEA) administers and/or funds rural power system upgrades, the PCE program, energy conservation and alternative energy development, circuit rider maintenance and emergency response, utility operator training, a bulk fuel revolving loan fund, a power project loan fund, and maintenance of AEA-owned facilities. Although AEA has its own capital fund, recent capital project funding for bulk fuel storage upgrades and rural power system upgrades has come primarily from the Denali Commission, a federal-state partnership established by Congress in 1998 to provide critical utilities, infrastructure, and economic support throughout Alaska. It has been supplemented by other federal grants from agencies such as the Environmental Protection Agency (EPA) and the Department of Housing and Urban Development (HUD), as well as by state appropriations for capital expenditures.

Rising fuel price is likely to be the single greatest driver for a change from diesel-only systems. Diesel power generation is expensive in both direct and hidden costs. Among these are air pollution; problems with effective storage, resulting in soil and groundwater contamination from spills; spills during transport or transfer, resulting in larger scale contamination and risks to humans and wildlife; risk of non-delivery of fuel under adverse conditions, resulting in loss of power; and dependency on the PCE program (Colt et al. 2003). A typical rural village has separate tank farms owned and operated by the city government, the tribal government, the village corporation, the local school, the electric utility, and other public or private entities. As of 1999, the EPA considered 97 percent of these tank farms to have serious deficiencies, including inadequate foundations, dikes, joints, and piping; improper siting near water sources; and rust and corrosion (EPA 1999, Poe 2002).

Biomass Investment and Technology

Developing village biomass projects is timely, given new interest and potential funding for wood energy in interior Alaska. The Alaska Wood Energy Development Task Group, a recently formed coalition of federal and state agencies and other not-for-profit organizations, is now actively coordinating the state's efforts to increase the use of biomass for energy in Alaska. Since 2004, the task group has been soliciting biomass energy project proposals from communities for funding with AEA-earmarked funding. As of 2007, AEA had budgeted $669,674 for wood energy activities (AEA 2005, AEA 2007).

Wood fuel has traditionally been converted into energy via open burning, fireplaces, and wood stoves. In traditional applications, the energy efficiency of biomass fuels for heating, cooking, and energy production is very low—in some cases as low as 10 percent (Kishore et al. 2004). However, biomass technology has improved over the past decade and has enjoyed success in other parts of the world, including Scandinavia and India. New biomass technologies allow for both more efficient energy conversion and—owing to a hotter and more complete burn—greatly reduced emissions of particulates and carbon monoxide. Biomass fuels can include whole trees, cut firewood, chunk-wood, compressed sawdust pellets or briquettes, or gasified wood. These fuels can be used for electricity generation, heating, or a combination of both. Modern methods that offer greater combustion efficiency and lower emissions of air pollutants include combustion in a modern boiler/steam turbine system, direct wood gasification, or pyrolysis (Bain et al. 1996). Although energy release is highly efficient in all of these systems, considerable energy is lost in converting that energy to electricity. Typically, the overall efficiency of a system that is only used to generate electricity is a mere 25 to 30 percent (Bain et al. 2003). However, much of the energy lost is converted to heat. If heat is also a desirable product, as is the case for most of the year in interior Alaska, the boiler system can be configured for the simultaneous production of heat and electricity. More than 50 rural Alaska communities—or approximately 27 percent—already have combined heat and power (CHP) systems (Crimp and Adamian 2001, MAFA 2004) and therefore have the infrastructure for heat and power distribution. Although system configurations range widely, a preliminary assessment of the market indicates that 70 percent of rural Alaska communities could make cost-effective use of combined heat and power systems (MAFA 2004).

Boiler systems are the simplest choice for biomass heat and power generation. In such a system, whole-tree wood chips or chunks are oxidized with excess air circulation, either in a stoker or a fluidized bed, and the hot flue gases released produce steam in the heat-exchange sections of a boiler. Some of this steam produces electricity via a turbine in a Rankine cycle, and the excess steam is used for heat (Bain et al. 2003).

Wood gasification and pyrolysis are potentially 30 to 40 percent more efficient than direct combustion, require less water, and result in cheaper costs per kWh, but generally involve more complex operation and maintenance requirements and newer and less proven technology.[1] Wood gasification is the process of heating wood in an oxygen-limited chamber to a temperature range of 200 to 280 °C until volatile gases including carbon monoxide, hydrogen, and oxygen are released from

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[1] Scahill, J. 2003. Biomass to energy: present commercial strategies and future options. Presentation. Denver, CO. Healthy Landscapes and Thriving Communities: Bioenergy and Wood Products Conference. U.S. Department of the Interior. Jan. 21.

the wood and combusted (Bain et al. 2003). Several methods of gasification exist; however, updraft gasifiers are the simplest and most reliable (see footnote 1) and thus the only type considered in this analysis.

Carbon Markets

Although the United States is not a signatory to the Kyoto Protocol on Climate Change, and policy analysts predict that carbon dioxide (CO_2) reductions will not become mandatory in the United States in the near future (McNamara 2004), the ramifications of this international agreement, as well as the dialogue that led to its creation, have nonetheless altered the way in which U.S. carbon stocks and fluxes are likely to be managed in the future.

In signatory nations, long-term carbon sequestration has become a commodity that can be traded against carbon emissions based on a cap-and-trade system (McNamara 2004). Likewise, reduction of emissions from nonrenewable sources (generally fossil fuels) can be traded against increases in other sectors. In January 2005, the European Union—including all 25 of its member states—initiated the European Union Emissions Trading Scheme (ETS), a legally binding international trading market in greenhouse gas emissions. Russia, Canada, and Switzerland are working toward instituting parallel systems (Kirk 2004). The transferability of carbon credits has opened up international economic possibilities never before seen, although some parallels can be drawn to the successful mitigation of sulfur dioxide pollution in the United States through use of tradable pollution credits (CCX 2006).

Meanwhile, nongovernmental markets have already appeared, even in nonsignatory nations. In the United States, the Chicago Climate Exchange (CCX) is currently the most viable carbon credit market (McNamara 2004). It is acting as a self-regulating voluntary market, administering the world's first multisector and multinational emission-trading platform. By participating in trading through CCX, corporations, municipalities, and other institutions have made legally binding commitments to reduce net emissions of greenhouse gases. Carbon emitters as well as credit holders are banking on future increases in the price of credits because of either international agreements or state and local laws. By entering the market early, buyers are showing good will and environmental responsibility, as well as setting up relationships that may prove lucrative in the future (McNamara 2004).

Alaska has yet to participate in nascent carbon markets, although the passage into law of a bill promoting carbon credit research (Berkowitz 2004) demonstrates the state's interest in both climate change and carbon-credit trading. Some states and geographic regions are already making local commitments to reduce greenhouse emissions. For example, in August 2001, the New England Governors and

Eastern Canadian Premiers signed a regional climate change agreement aimed at reducing greenhouse gas emissions to 1990 levels by 2010, and reducing emissions to 10 percent below 1990 levels by 2020. To meet the requirements of this agreement, participatory states are creating local control mechanisms. In California, Governor Schwarzenegger signed Executive Order S-3-05 in June 2005, dictating that the state's greenhouse gas emissions would be reduced to 2000 levels by 2010, to 1990 levels by 2020, and to 80 percent of 1990 levels by 2050 (Schwarzenegger 2005).

Under the rules of the Kyoto Protocol—which are often used as guidelines, even in nonsignatory markets—tradable credits can be obtained in a number of ways, including afforestation, reforestation, and conversion from fossil fuel use to carbon-neutral fuels. For the purposes of carbon accounting, biomass can be considered carbon neutral: although carbon is emitted when biomass is burned, forest regrowth should, over time, take up an equal quantity of carbon. However, because the time scales of emissions and absorption differ, the sustainability of the forests from which biomass is harvested must be certified. All emission reductions and tradable carbon credits must be monitored, verified, and certified by a third party that provides both confirmation that the carbon exists and insurance that it will be sequestered for the duration of the commitment period. Marketable carbon offsets also require proof of additionality—an assurance that sequestration or emission reductions would not have occurred had the project not been implemented. Finally, projects must not lead to "leakage": emission increases in another sector that can be attributed to reductions in the credited sector (Innes and Peterson 2001, UN 1997).

In interior Alaska, fuel substitution may hold the greatest promise for attaining marketable carbon credits. Unlike credits based on afforestation, reforestation, or increased forest stocking, fuel offset credits are not one-time credits; as more fossil fuel use is offset over time, more credits can be earned. In addition, biomass energy generation can theoretically be developed on a wide range of scales. Finally, as described above, fuel offsets may be possible within a framework that generates other positive outcomes in addition to reduction of carbon emissions.

Forest Ecology and Ecosystem Services

The ecological sustainability of any proposed biomass fuels project will be pertinent not only from the point of view of achieving certifiable forestry practices in order to verify carbon sequestration credits, but also from the perspective of maintaining other ecosystem services. Historically, naturally occurring fires in interior Alaska have created a variegated landscape with multiple age classes of forest succession (Dyrness et al. 1986), each of which provides different resources (e.g., berries, moose browse, cover for furbearing mammals, and habitat for woodland caribou). However, fire suppression around inhabited areas tends to decrease average annual area burned (Dewilde and Chapin 2006), which over time will tend to increase average forest stand age and reduce this variability while also increasing the risk of future fires. Although harvest and fire do not result in identical post-disturbance trajectories (Rees and Juday 2002), harvest does offer a means of introducing age-class variability and reducing fire risk around communities.

Goals and Objectives

The purpose of this study is to assess the feasibility of switching from fossil fuels to wood energy in rural Alaska villages located in forested regions of interior Alaska (fig. 1) that are not supplied with electricity via the railbelt (the centralized power grid connecting Anchorage, Fairbanks, and other relatively large communities). More specifically, the study's objectives were to:

1. Create a quantitative ecological model of the footprint of potential biomass harvest for wood energy around interior Alaska villages.
2. Create a quantitative economic model of the short- and long-term costs and benefits of switching from diesel energy to wood energy in these remote communities.

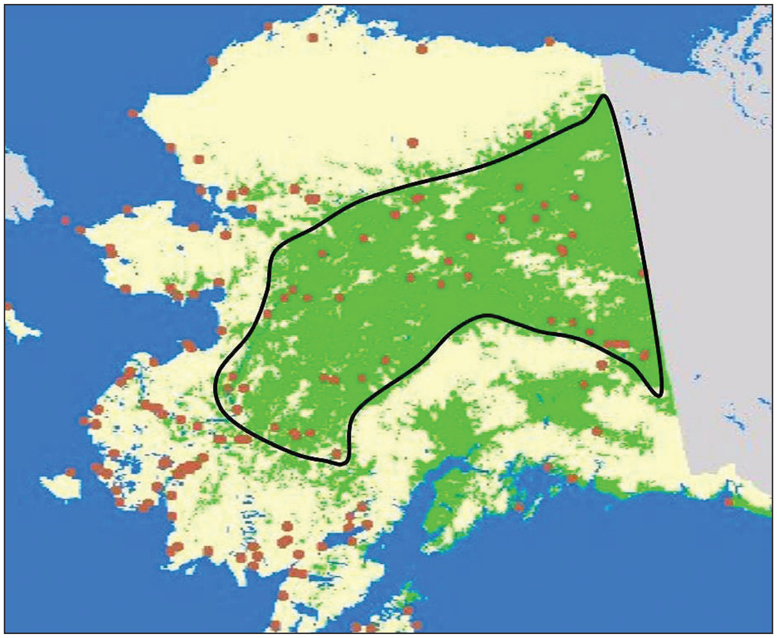

Figure 1—Remote Alaska communities. About 90 communities (represented by dots) lie in forested regions (green-shaded area). Approximately half of these are in the Interior region considered in this study (roughly demarcated by black line). Adapted from Crimp and Adamian 2000.

3. Explore the effects of model input selection and model parameter uncertainty on model outputs.
4. Qualitatively assess the effects of social factors on the feasibility of fuel substitution.
5. Examine potential feedback between ecological, economic, and social factors, and assess ways in which they might in combination affect the feasibility of wood biomass fuel use in Alaska villages.

Methods

Ecological Feasibility

For selected interior Alaskan villages, we created a simple model to estimate the area required to supply aboveground tree biomass over a rotation length that would mimic natural fire cycles while reducing fire risk in communities, optimizing aesthetic and subsistence values, and protecting ecosystem integrity. The biomass required was calculated from input variables and model parameters selected based on published data. Input variables included village size, village per capita energy needs, and optimal harvest rotation length. Parameters internal to the model included forest cover, forest volume, predicted biomass growth curves, and energy outputs by harvest volume.

Model output was expressed as maximum travel distance to obtain wood fuel—in other words, the distance between a village and the perimeter of the circle circumscribing the area of sustainable yield necessary to meet the needs described by the input variables. The radius (r) of a circle of area A is defined as

$$\mathrm{r} = \sqrt{\frac{A}{\pi}}\ .$$

The area (A) necessary for fuel collection around a village would be a function of the population and its energy needs, the percentage of those needs to be met by biomass, the percentage of land included as productive for black spruce, the energy available per acre of wood harvested, and the frequency with which any particular acre could be harvested. Thus, the general formula used was

$$Dmax = \sqrt{\frac{P \times Epc \times Eo \times R \times 0.01}{Bd \times Ad \times Ew \times Ee \times Fc \times \pi}}$$

Where:

Dmax = maximum travel distance (km)

P = village population

Epc = per capita energy use (kWh/yr)

Eo = Energy offset (fraction of total energy use replaced with biomass energy)

R = Rotation length for forest harvest (years)
Bd = biomass density (t/ha) for black spruce at harvest age (green weight)
Ad = correction factor for converting green to air-dried wood (t air-dry/t green)
Ew = energy available from air-dried wood (kW/t)
Ee = electrical efficiency (fraction of gross heating value converted to electrical energy)
Fc = Forest cover (black spruce forest as fraction of total land area)
0.01 = the correction factor to convert from hectares to square kilometers

We first obtained model results for villages within the study area by using mean, median, or generally accepted values as initial model parameters, hereafter referred to as "nominal" values. Nominal parameter values were selected conservatively, so as to overestimate rather than underestimate the footprint of harvest for biomass fuels around any particular village. Likewise, parameter ranges were selected to represent a relatively broad set of possible outcomes. Because all model inputs and parameters were part of a single first-order equation, and because all variables were multiplicative, the sensitivity of the model to variability in each parameter depended only on the magnitude of the range of possible values for that parameter. However, some of these ranges were quite large, resulting in a substantial cumulative effect of parameter uncertainty. We examined the sensitivity of the model to uncertainty in both model inputs and model parameters by performing 300 stochastic model runs—100 each for minimum, mean, and maximum community sizes—using parameter values randomly selected from within each parameter range.

Model inputs reflected known or predicted values for village sizes and energy usage based on Alaska census data and information published by the AEA (AEA 2000b, 2002, 2004; ADCED 2005) (table 1). Mean population for the communities we focused on was 106, with a range from 21 to 1,439. We considered energy use at current levels, based on kWh generated rather than kWh actually used in order to account for inevitable waste. The mean value was 3758 kWh per capita, close to the 4000 kWh estimated by Colt et al. (2003). Communities with the highest usage were similar to the U.S. average of 10,000 kWh per capita (Colt et al. 2003).

Rotation length was also treated as a model input, as it depends on community preference. We assumed that communities would seek to reduce wildfire risk as a byproduct of their harvest strategy and that they would therefore only harvest mature black spruce stands (the most fire-prone landscape type). An 80-year rotation would allow for harvest in early maturity, whereas a 200-year rotation would yield trees in late senescence; very few stands older than 200 years can be found for any species in interior Alaska (Yarie and Billings 2002). Thus, we bounded the

Table 1—Energy use and costs in forested interior Alaska communities not on the railbelt electrical grid

Community	Population[a]	Per capita electrical use[b]	Fuel use[c]	Average price[b]	Installed generator capacity	Residential rate without PCE[b]	Actual residential rate w/PCE[b]
		kWh	*Gallons*	*Dollars per gallon*	*kW*	*Dollars per kWh*	*Dollars per kWh*
Alatna and Allakaket	122	5318	53,773	2.19	430	0.48	0.27
Aniak	532	4640	192,576	1.32	2865	0.49	0.32
Anvik	101	4644	38,474	1.32	337	0.46	0.28
Beaver	67	4379	31,436	1.92	137	0.42	0.26
Evansville and Bettles	51	13 800	58,368	1.41	650	0.41	0.20
Central	102	4921	50,104	1.22	640	0.51	0.28
Chuathbaluk	105	2036	20,200	1.70	n/a	0.56	0.32
Circle	99	3758	34,750	1.24	200	0.50	0.27
Crooked Creek	147	1731	25,258	1.69	n/a	0.56	0.32
Dot Lake	29		n/a	n/a	325	0.23	0.17
Eagle and Eagle Village	183	4270	58,474	1.20	477	0.41	0.26
Fort Yukon	594	4781	207,698	1.66	2400	0.34	0.23
Galena	717	13 203	724,076	1.46	6000	0.25	0.18
Grayling	182	3235	46,352	1.52	546	0.44	0.28
Healy Lake	34	4500	14,339	1.25	105	0.40	0.24
Holy Cross	206	3437	54,340	1.51	585	0.42	0.27
Hughes	72		37,325	3.27	323	0.51	0.30
Huslia	269	3409	77,648	1.79	680	0.46	0.28
Kaltag	211	3143	57,498	1.58	573	0.46	0.28
Koyukuk	109	3241	20,830	1.89	244	0.45	0.36
Lime Village	34	2920	9,101	4.44	77	0.80	0.56
Manley Hot Springs	73	4029	26,772	1.14	480	0.60	0.36
McGrath	367	8074	221,650	1.40	2685	0.43	0.29
Minto	207	3491	56,366	1.13	558	0.40	0.26
Nikolai	121	3317	38,182	1.81	362	0.50	0.34
Northway and Northway Village	195	8123	121,569	1.29	1165	0.43	0.25
Nulato	320	3590	85,982	1.59	897	0.44	0.28
Red Devil	35	3612	14,490	1.83	173	0.56	0.32
Ruby	190		24,861	1.76	654	0.46	0.33
Shageluk	132	3073	31,506	1.69	370	0.46	0.28
Sleetmute	78	2939	25,314	1.69	208	0.56	0.32
Stony River	54	2156	13,994	1.69	139	0.56	0.32
Takotna	47	5292	28,219	1.72	297	0.48	0.32
Tanana	304	4533	104,270	1.34	1456	0.49	0.31
Tetlin	129	3669	40,782	1.46	280	0.47	0.27
Tok	1,439	8700	861,311	1.25	4960	0.23	0.17

Note: The penultimate column indicates what electrical rates would be in each community if Power Cost Equalization (PCE) subsidies were not provided by the state, and the final column shows the actual rates paid by householders.

n/a = not available.

[a] Data from ADCED 2005.

[b] Data from AEA 2004.

[c] Data from UAA 2003.

range of inputs with these values. The nominal value was set at 110, just prior to apparent age- and/or fire-related decreases in stand frequency (Hollingsworth 2004, Yarie and Billings 2002).

Across the interior, black spruce stands account for approximately 44 percent of the landscape (Sharratt 1997). This was used as a nominal value, although the actual mean is likely to be higher because of undercounting of early-succession stands that would be classified as black spruce in a later successional stage. Because villages in areas with less than 10 percent forest cover were not considered, 10 percent was set as the low value, and 75 percent was selected as an upper limit (Fitzsimmons 2003). Although forest cover approaches 100 percent in some regions of the interior, land around villages often contains considerable areas of rivers and other wetlands, so a conservative estimate was chosen.

The energy value of dry spruce chips was bracketed within a relatively small range by different authors (Maker 2004, Somashekhar et al. 2000, Zerbin 1984), making our model relatively insensitive to changes in this parameter. Based on these estimates, we selected a nominal value of 8,500 btu/lb (5480 kWh/t), with low and high boundaries of 7,780 and 8,920 btu/lb (5018 and 5753 kWh/t). However, differences in moisture content substantially affect energy output, because in the case of high-moisture fuel, some of the energy released by combustion is used to evaporate water (table 2). Although many wood burner systems can be used with a wide range of fuel types and fuel moistures, air-dry black spruce was selected as the nominal fuel, owing to the general availability of the species and the relative technological ease of air-drying as compared to kiln-drying.

Table 2—The heating value of wood

Moisture content	Gross heating value		
	Low	**Medium**	**High**
Percent		*kWh/t*	
0	5025	5490	5761
25	3769	4118	4321
30	3518	3843	4033
35	3266	3569	3745
40	3015	3294	3457
45	2764	3020	3169
50	2513	2745	2881
55	2261	2471	2593
60	2010	2196	2305

Note: Values for a wide selection of hardwoods, softwoods, and wood residues fall in a relatively narrow range, with black spruce near the high end. Gross heating value depends primarily on moisture content.

Green black spruce has a moisture content (MC) of approximately 60 percent (Yarie and Mead 1982), whereas air-dried wood has approximately 12 to 15 percent moisture (Prestemon 1998, Yarie and Mead 1982). Although this figure may in some cases be lower in Alaska's dry climate, we assumed an air-dried moisture content of 15 percent, and thus a typical weight loss of 28 percent during the drying process, and a final gross heating value (GHV) of 85 percent of the oven-dry value. Boundary values for these parameters were set at 0 percent weight loss and 40 percent GHV for green wood (table 2), and 31 percent weight loss and 90 percent GHV for wood at 10 percent moisture.

Average aboveground tree biomass (including the fresh weights of bole, branches, and foliage) for 80-, 110-, and 200-year-old black spruce stands in interior Alaska are approximately 25, 28, and 10 t/ha, respectively (Yarie and Billings 2002). It is likely that the low value for 200-year-old stands reflects the result of slow growth on shallow saturated soils; such stands would be less than optimal for biomass fuel management. We selected 28 t/ha as both the nominal and the maximum value, and 10 t/ha as the minimum value.

We assumed a nominal efficiency of 28 percent for electrical production, with a range of 20 to 40 percent, based on the estimates shown in Table 3. Overall efficiencies for combined heat and power systems are significantly higher. However, we chose to focus on the feasibility of wood-fired electrical generation and thus treated heat energy as a positive externality.

Table 3—Electrical and total efficiency of wood-fired systems

Type of process	Electrical efficiency	Combined heat and power efficiency	Source
Hot gasification/fuel cell	0.23	0.6	Osmosun et al. 2004
Downdraft gasification	0.40	0.9	Zerbin 1984
Gasification		0.7	Wu et al. 2003
Gasification	0.35		Willeboer 1998
Gasification/fuel cell	0.24	0.6	McIlveen-Wright et al. 2003
Combustion	0.25		USDA 2004
Biomass integrated gasification combined-cycle	0.33		Haq 2002
Gasification	0.21		Somashekhar et al. 2000
Combustion	0.20	0.6	Bain et al. 2003
Mean	0.28	0.68	

Note: Most authors report greater efficiency from gasification systems than from direct combustion.

Economic Feasibility

Rural Alaskan villages have mixed economies that include significant market and nonmarket components, and the costs of current village energy programs are borne not only by community members but also by external entities. Thus, in order to analyze the economic sustainability of potential fuel offset programs, we considered not only the costs and benefits of construction, operation, maintenance, fuel, employment, and carbon sequestration credits for diesel versus biomass systems, but also circulation of cash income and noncash commodities within communities, and the effects of subsidies. We examined economic feasibility based on published estimates and projections for:

- Village energy consumption
- Fossil fuel cost
- Nonfuel expenses specific to diesel systems
- Existing subsidies for fossil fuels, infrastructure, and maintenance
- Installation and maintenance costs for biomass systems
- Labor and mechanical costs for wood procurement
- Existing village economies, cash flows, and employment
- Current and potential future prices for carbon credits

We created a quantitative model incorporating the above components to assess whether fuel conversion would be likely to have a positive economic outcome for each village, and over what period initial investments in biomass infrastructure might be recouped.

The model input was the biomass generation capacity installed. Parameters internal to the model included diesel prices, nonfuel expenses specific to diesel systems, nonfuel expenses common to both systems, installed diesel capacity, actual kWh of power generated, installation costs for biomass systems, and annual operation costs for biomass systems. For each of these parameters we either used published village-by-village values or determined nominal values based on mean, median, or generally accepted values from the literature. Nominal parameter values were selected conservatively, so as to overestimate rather than underestimate the costs of fuel conversion. Likewise, parameter ranges were selected to represent a relatively broad set of possible outcomes.

We examined the sensitivity of the model by randomly selecting parameter values for key variables (diesel price, biomass system installation costs, annual biomass operation and maintenance costs, and carbon credit prices) from the full range of uncertainty expressed in the literature. Using these random values, we analyzed the results of 10 stochastic model runs for each of the 31 villages for which adequate data were available.

The general formula used in the economic submodel was:

$$Y = \frac{CapitolCosts}{AnnualSavings}$$

$$= \frac{CapitolCosts}{AnnualCostsOffset - AnnualBiomassCosts + AnnualCarbonCreditValue}$$

$$= \frac{Ic \times El}{(Ao \times De \times Dp) + (NFo \times NFc) - (Bg \times Bc) + (De \times Ao \times Cc)}$$

Where:

Y = years to pay back investment

Ic = installed cost of a biomass power system, per kW generation capacity

El = electrical load (total biomass capacity installed, in kW)

Ao = actual offset, in kWh (based on relationship between installed biomass capacity and mean electrical load)

De = diesel efficiency (gallons of diesel fuel per kWh generated)

Dp = diesel price ($/gallon for diesel fuel)

NFo = estimated nonfuel offset (fraction of nonfuel costs, e.g., fuel storage and spill prevention, offset by use of biomass)

NFc = total nonfuel costs (including diesel-specific costs and those common to biomass or diesel systems) (total $)

Bg = biomass energy generated (kWh/yr)

Bc = Biomass energy costs ($/kWh)

Cc = carbon credits available owing to fuel offset ($/gallon fuel)

Total capacity installed in each village, total annual energy use in each village, and much of the data on nonfuel costs and existing costs and funding sources for power systems was available through state Department of Community and Economic Development budget requests (Poe 2001, 2002) budget reports (Alaska 2001, 2002), the University of Alaska Anchorage Institute of Social and Economic Research (UAA 2003), and the AEA (AEA 2000b, 2002, 2004, 2005). For the most part, these parameters were incorporated in the model as given. However, the proportion of nonfuel costs incurred prior to or during generation (e.g., the costs of fuel storage and boiler operation and maintenance) were not always separated from those incurred after generation (e.g., the costs of distribution and customer service). This breakdown had to be estimated based on partial data. Average fuel prices were based on 2004 figures, despite the steep rise in prices over the following years. However, we assessed the sensitivity of this parameter within the range of -50 to +150 percent to account for this volatility.

As a nominal model input, we assigned biomass capacity installed in each village a value equal to the mean electrical load for that community. Under this assumption, existing diesel systems would be at least partially retained and maintained to meet peak loads, while allowing biomass systems to run at full capacity for much of the time. In the communities we assessed, mean load was only 8 to 29 percent of installed capacity (appendix), demonstrating overcapitalization that would probably not be necessary to replicate with biomass systems. Load profiles are not available for most rural Alaskan communities. However, available information from six villages of varying sizes shows combined daily and seasonal variation yielding peak loads that are approximately twice mean loads and threefold the minimum loads (Devine et al. 2005). Installation of biomass generation capacity greater than minimum loads would result in some unused capacity; at a capacity equal to mean loads unused capacity would be about 30 percent, and at a capacity equal to twice mean loads it would be approximately 60 percent (figure 2).

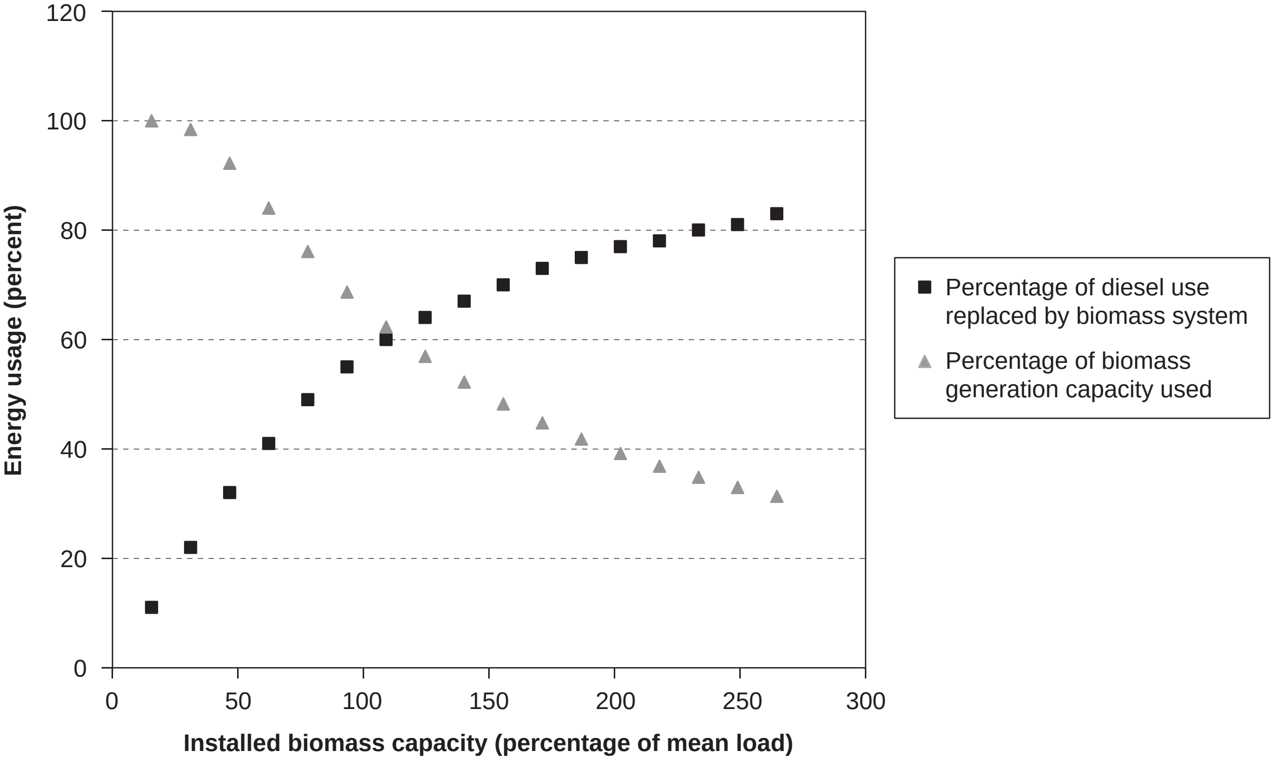

Figure 2—Biomass generation capacity and diesel fuel savings. Owing to daily and seasonal variability in energy demands, total system capacity is designed to greatly exceed average loads (adapted from data on substitution of diesel systems with wind power, Devine et al. 2005).

Diesel fuel costs would be directly offset according to the number of kilowatt-hours actually generated by the biomass system. Nonfuel expenses would be offset by the percentage of these costs associated only with diesel systems and by the total capacity replaced. Nonfuel generation expenses for diesel systems are steep because they include construction and maintenance of fuel tanks as well as spill response capabilities, although not all of these costs are currently internalized (Colt et al. 2003). We estimated that continuous operation of biomass systems at mean load levels would offset 60 percent of the village's diesel fuel use, but reduce nonfuel expenses associated with existing systems by only 25 percent. To assess the sensitivity of the model to our assumptions, we compared the results with a model run in which biomass generation capacity replaced only 50 percent of mean loads, replacing 40 percent of diesel fuel use and 10 percent of nonfuel expenses (Devine et al. 2005).

We compiled estimates of capital costs for purchase and installation of biomass systems from a range of available sources (table 4). To present conservative approximations in estimating feasibility of fuel conversion, and to allow for the potentially

Table 4—Capital costs and annual operation and maintenance (O&M) costs for biomass systems as compared to diesel generators

System type	Estimated installed cost		Estimated O&M costs					
	Low	**High**	**Low**	**High**	**Plant size**	**Plant type**	**Location**	**Source**
	Dollars per kW		*Dollars per kWh*		*kW*			
Biomass systems:								
	1,536	1,536	0.17	0.17	100,000	BIGGC[a]	U.S.	Haq 2002
	914	914	n/a	n/a	35,000	BIGGC	Brazil	Waldheim and Carpentieri 2001
	2,000	2,000	0.12	0.12	Up to 15	BIGGC	U.S.	ENR 2001
	1,230	1,488	n/a	n/a	5,000–10,000	FBC[b]	U.S., Finland	Bain et al 1996
	1,400	2,000	0.09	0.14	25,000–150,000	BIGGC	U.S.	Bain et al. 2003
	1,275	2,000	0.17	0.17	25,000–150,000	FBC	U.S.	Bain et al. 2003
	2,000	2,000	0.06	0.12	2,000–25,000	Unspecified	U.S.	USDA 2004
	980	2,500	0.15	0.20	1,000–110,000	GS[c] or FBC	U.S.	Scahil[d]
	900	2,200	0.15	0.20	15–650	BIGGC	U.S.	Scahill[d]
Mean	1,359	1,849	0.13	0.16				
Diesel generators (rural interior Alaska):								
	800	1,500	0.14	1.04	>100kW		U.S.	EIC 2002, AEA 2004

n/a = not available.

[a] BIGGC = Biomass integrated gasification combined cycle. Wood chips or chunks are heated in an oxygen-limited chamber to a temperature range of 200 to 280 °C until volatile gases including carbon monoxide, hydrogen, and oxygen are released and combusted.

[b] FBC = Fluidized bed combustion. Wood chips or chunks are directly combusted with excess air flow that circulates through the fuel bed.

[c] GS = Grate stoker. Wood chips or chunks are combusted in a simple stoker.

[d] Scahill, J. 2003. Biomass to energy: present commercial strategies and future options. Presentation. Denver, CO. Healthy Landscapes and Thriving Communities: Bioenergy and Wood Products Conference. U.S. Department of the Interior. Jan. 21.

higher costs of installation and operation in remote Alaskan sites, we used the mean of the authors' high-end estimates, $1,849/kW, as the nominal value in our model. For the purposes of sensitivity analysis, we considered the range of values between the minimum published value ($980/kW) and 125 percent of the maximum published value ($2,500 x 1.25) = $3,125.

Generation costs (including fuel, operation, and maintenance costs) for wood-powered systems are difficult to accurately estimate, as they depend on location, wages, ease of fuel procurement, mechanization of harvest, and ease of maintenance. A national estimate of 7.5 cents/kWh (GAO 2005) seems far too optimistic for our purposes; in rural Alaska, travel costs and lack of local technical expertise would be expected to drive up the costs of system maintenance. However, this is already the case for diesel systems. Small-scale relatively nonmechanized methods for gathering and chipping wood might increase labor costs per ton of fuel, but the ready availability of both wood fuel and labor might partially balance these effects. We estimated generation costs based on actual costs of clearing and thinning projects in rural communities (table 5) (Hanson 2005, Lee 2005, USDI BLM 2005). In all cases, local crews were used, and the work was extremely labor-intensive and low-tech. Although these projects did not entail using the harvested wood for electrical generation, they did include manual disposal through piling and burning or chipping, as well as overhead and equipment costs. Translating these costs into equivalent energy costs resulted in a mean or nominal value of $0.16/kWh (rounded

Table 5—Costs per acre for forest clearing projects in rural Alaska villages

Fuel treatment project site	Type of treatment	Overhead and equipment cost per acre	Wages per acre	Total cost per acre	Cost per metric ton[a]	Operating cost per kWh[b]
		Dollars				
Healy Lake[c]	Fire break	640	2,560	3,200	282	0.22
Tanacross[c]	Parklike clearing to spacing of ~12 ft	800	3,200	4,000	353	0.27
Delta Junction[d]	Fire break	n/a	n/a	1,100	97	0.07
Stevens Village[c]	Light thinning of spruce understory	100	400	500	44	0.03
Fairbanks[e]	Fire break	n/a	n/a	2,700	238	0.18
Mean		513	2,053	2,300	203	0.16

Note: Costs vary depending on how labor-intensive the work is and how the project is managed.

n/a = Not available.

[a] Assuming 28t/ha, 405ha/acre.

[b] Assuming 5,480 × 0.85 = 4658 kWh/t (green weight)

[c] Data from Hanson 2005.

[d] Data from USDI BLM 2005.

[e] Data from Lee 2005, hand-felling method only.

up to \$0.17/kWh). To provide a more conservative estimate of feasibility in our sensitivity analysis and avoid reliance on a potentially anomalous value, we raised the lower end of this range to four times the costs recorded for Stevens Village (to \$0.12/kWh), and rounded the upper limit to \$0.28. Projected total generation costs (including fuel, operating, and maintenance) are similar to estimates of between \$0.06 and \$0.20/kWh (mean = \$0.16/kWh) noted by various sources for small-scale or rural biomass projects (Bain et al. 2003, ENR 2001, Haq 2002, USDA FS 2004; see footnote 1) (table 4). This is substantially less than the real cost of diesel power in most villages, although it does not include the cost of distribution.

We gathered information on village-by-village fuel use, energy use, fuel costs, and subsidies primarily from annual statistical reports on the PCE Program (AEA 2000b, 2002, 2004) and Alaska Electric Power Statistics for 1960–2001 prepared by the Institute of Social and Economic Research at the University of Alaska Anchorage for the AEA, the Regulatory Commission of Alaska, and the Denali Commission (UAA 2003). Some of these data have already been shown in table 1; the full data set appears in the appendix.

We estimated model parameters for the value of carbon sequestration credits by gathering data on existing markets in the United States and Europe and calculating the tons of carbon offset for each 1,000 gal (3,774 L) of diesel replaced by biomass fuel. The estimated value of these credits covers a wide range, owing to market fluctuations and future uncertainty. Prior to the Kyoto Protocol taking effect in signatory nations, the trading price of carbon was typically slightly over \$1 per metric ton. In 2005, prices fluctuated around the \$2 mark, and we used a value of \$1.90 in our analysis, despite the fact that more recent values have spiked as high as about \$4. Although the international agreement had no direct effect on U.S. markets, it appears to have had an indirect effect (McNamara 2004). However, the prices of these voluntary credits remain far below the prices for verified emissions reductions in signatory nations. On the European Carbon Exchange (ECX), the European trading market, prices rose from approximately €8 (\$9) at the beginning of 2005 to almost €30 (\$38) in July 2005, and in August 2005 settled back down to about €20 (\$24) (McCrone 2005).

Carbon credits represent a benefit stream from outside the village economy, with a value additive to all other benefit streams. We analyzed the potential value of the credits that could be obtained on a village-by-village basis, based on the number of tons of diesel offset, as determined by village energy use and biomass capacity installed (model input) (table 6). Although derived via different algorithms, our results, which estimate a total of 32,609 t of CO_2 emissions from diesel power generation in rural interior forested communities, are congruent with those obtained by

Table 6—Estimated annual quantity and value of potential carbon offset credits obtainable via fuel substitution in rural Alaska

	Diesel fuel				Value of carbon credits	
	Volume[a]	Weight[b]	Carbon weight[c]	CO_2 emissions[d]	CCX[e]	ECX[f]
	Liters	*Kilograms*	*Kilograms*	*Tonnes*	*Dollars*	*Dollars*
All PCE communities	107 796 786	84 081 493	72 049 266	263 700	501,031	6,328,807
Forested PCE communities in interior Alaska	13 329 974	10 397 380	8 909 494	32 609	61,957	782,610
Per 1,000 gallons of diesel	3785	2952	2530	9	18	222

CCX = Chicago Carbon Exchange, ECX = European Carbon Exchange, PCE = Power Cost Equalization Program.

[a] AEA 2004.

[b] Diesel fuel weighs approximately 0.78 kg/L.

[c] Diesel fuel is a mixture of hydrocarbons with an average weight ratio of 12 parts carbon to 2 parts hydrogen, with small amounts of other elements such as sulfur.

[d] When combusted, each carbon atom combines with two oxygen atoms at weight ratio of $C/CO_2 = 3/11$.

[e] 2006 vintage, $1.90/t, September 2005 (CCX 2006).

[f] 20 €/t = $24/t August 2005 (McCrone 2005).

Duval (2004), who estimated a total of 274 263 metric tons of CO_2 emissions for all PCE communities, with 52 047 of these tons from “forested Alaska.” Our somewhat lower figures for forested interior Alaska reflect the fact that some rural forested communities are in the southeastern or south-central parts of the state, which are not considered in our analysis.

Social Feasibility

Analysis of social feasibility was primarily qualitative rather than quantitative, and included assessment of:

- Existing social infrastructure related to village electrical utility management and funding, fire prevention, and biomass harvest
- Threshold requirements (make-or-break factors needed within a particular community or at a broader scale, e.g., a minimum level of local technological expertise)
- Existing institutional barriers to change
- Potential positive social feedback (e.g., autonomy, employment)
- Potential negative social feedback (e.g., reactions to system quirks or failures)
- Lessons learned from existing biomass projects in rural Alaska

Although funding for village power systems is provided to a large degree by state and federal subsidies via AEA programs, ownership and operating responsibility for many of these projects is placed entirely with local grantees (Poe 2002). Thus, we assumed that most ultimate decisionmaking would take place at the village level, although financing, training, infrastructure, and technological expertise might all come from farther afield.

In addition, we drew information from past and ongoing projects with goals and objectives similar to those proposed in this study. These include wood fuel projects such as the existing boiler at Dot Lake and the proposed biomass system in McGrath (Adamian et al. 1998, AEA 2000a, Crimp 2005, Crimp and Adamian 2001); other alternative fuel projects such as wind-diesel hybrid systems (AEA 2005, Devine et al. 2005, MAFA 2004) and fire prevention efforts that include forest clearing (Hanson 2005, Putnam 2005).

Several fuel treatment projects aimed at reducing the risk of catastrophic wildfire have already taken place in village settings, under a combination of local leadership and assistance from entities such as the Alaska Department of Natural Resources (DNR) Division of Forestry and Tanana Chiefs Conference (TCC). The immediate costs of these projects were noted in table 5. However, to further ascertain the impacts of these efforts at the village level, we spoke with Doug Hanson of DNR (2005) and Will Putnam of TCC (2005). In particular, we questioned the importance of local hire; the role of key leaders, elders, or crew bosses; and the relationship between fire crews, harvest crews, and local opinions regarding fire protection.

Although for the purposes of the economic submodel we calculated costs and benefits irrespective of the impacts on different funding sources and beneficiaries, analysis of benefit streams was necessary for a more indepth understanding of the social submodels. Thus, we qualitatively assessed the current discrepancy between the real cost of power and the cost borne by consumers, the potential impacts of shifting funding and changing subsidies, and the potential economic value of local jobs generated by the harvest of biomass fuels. Our analysis was based on data on existing sources of funding for Alaska rural energy projects (table 7), data from the PCE Program (appendix) (AEA 2004); and financial information from past forest clearing projects (table 5)

Table 7—Annual funds for rural Alaska energy projects, including loans and grants

Funded item/activity	Federal funds (EPA, HUD, CDBG, DOE)	State appropriations	State revolving loan[a]	Alaska Energy Authority capital funds[b]	Denali Commission	Local funds	Unspecified	Total funding	Reference year
				Dollars					
Circuit rider maintenance and emergency response	100,000	200,000						300,000	2001
Utility operator training								n/a	
Rural power system upgrades							2,300,000	2,300,000	2000
Rural power operations	68,300	269,600					2,400,200	2,738,100	
Tank farm upgrades	4,900,000	2,450,000			15,350,000	550,000		23,250,000	2002
Bulk fuel revolving loan fund			51,000					51,000	2003
AEA power project loan fund			835,000					835,000	2003
Power cost equalization		15,617,225						15,617,225	2004
Energy cost reduction program[c]					2,500,000			2,500,000	2006
Village end use efficiency program[c]					722,000			722,000	2005
Wind energy assessment[c]	70,000			37,000	390,000			497,000	2005
Wood energy development program[c]	84,000			16,000				100,000	2005
Energy efficiency technical assistance[c]	137,500			62,500				200,000	2005
AEA operation and maintenance							1,067,100	1,067,100	2005
Total	5,359,800	18,536,825	886,000	115,500	18,962,000	550,000	5,767,300	50,177,425	

Note: All of these funds are managed by the Alaska Energy Authority (AEA).

EPA = Environmental Protection Agency, HUD = Housing and Urban Development, CDBG = Community Development Block Grant, DOE = Department of Energy.

[a] These funds are expressed as annual outlays. They are generally expected to be recouped and recirculated, but at zero or reduced interest rates.

[b] As of 2002, assets in the AEA fund were worth $800 million.

[c] Part of the energy conservation and alternative energy development program.

Data adapted from AEA 2005; 2002; 2004, Alaska Department of Community and Economic Development 2001, 2002.

Results

Ecological Feasibility

Using nominal parameter values and a forest rotation length of 110 years, the maximum travel distance required to collect enough mature black spruce to meet average electrical loads (thus supplying approximately 60 percent of total village power) ranged from 1.1 to 12.8 km. (table 8).

Table 8—Estimated land area and maximum travel distance for sustainable harvest of black spruce for energy generation

Community	Population	Annual energy use	Load offset (biomass generation capacity = mean load)	Harvest area around village	Maximum travel distance
		kWh	*kWh*	*Hectares*	*Kilometers*
Alatna and Allakaket	122	648 861	389 317	2665	2.9
Aniak	532	2 468 700	1 481 220	10 140	5.7
Anvik	101	469 023	281 414	1927	2.5
Beaver	67	293 400	176 040	1205	2.0
Evansville and Bettles	51	703 820	422 292	2891	3.0
Central	102	501 896	301 138	2062	2.6
Chuathbaluk	105	213 737	128 242	878	1.7
Circle	99	372 000	223 200	1528	2.2
Crooked Creek	147	254 434	152 660	1045	1.8
Eagle and Eagle Village	183	781 344	468 806	3209	3.2
Fort Yukon	594	2 840 000	1 704 000	11 665	6.1
Galena	717	9 466 799	5 680 079	38 885	11.1
Grayling	182	588 761	353 257	2418	2.8
Healy Lake	34	152 986	91 792	628	1.4
Holy Cross	206	708 012	424 807	2908	3.0
Huslia	269	916 941	550 165	3766	3.5
Kaltag	211	663 172	397 903	2724	2.9
Koyukuk	109	353 250	211 950	1451	2.1
Lime Village	34	99 263	59 558	408	1.1
Manley Hot Springs	73	294 120	176 472	1208	2.0
McGrath	367	2 963 200	1 777 920	12 171	6.2
Minto	207	722 562	433 537	2968	3.1
Nikolai	121	401 400	240 840	1649	2.3
Northway and Northway Village	195	1 583 944	950 366	6506	4.6
Nulato	320	1 148 831	689 299	4719	3.9
Red Devil	35	126 434	75 860	519	1.3
Shageluk	132	405 639	243 383	1666	2.3
Sleetmute	78	229 258	137 555	942	1.7
Stony River	54	116 418	69 851	478	1.2
Takotna	47	248 705	149 223	1022	1.8
Tanana	304	1 378 060	826 836	5660	4.2
Tetlin	129	473 310	283 986	1944	2.5
Tok	1439	12 518 973	7 511 384	51 421	12.8

With the exception of the two largest communities, Tok and Galena, which have regional and local road systems, respectively, the maximum travel distance was calculated to be 6.2 km or less, a distance easily reachable by snowmachine or four-wheeler, allowing for relatively low-tech harvest using chainsaws and a portable chipper. Larger communities might still find biomass fuel conversion an attractive option if they are located in regions with sufficient forest cover or road access, and if per capita electrical use remains modest. Even if 100 percent of village energy needs were supplied by biomass, the maximum travel distance for communities of up to 600 inhabitants would be no more than 8 km (fig. 3). Selecting a rotation length of 80 rather than 110 years only modestly reduces the maximum travel distance (fig. 4), because shorter rotations are correlated with lower biomass densities. However, increasing the rotation length to 200 years greatly increases the harvest area and travel distance, owing to both the longer return interval before stands can be harvested again, and reduced spruce biomass per hectare in older stands.

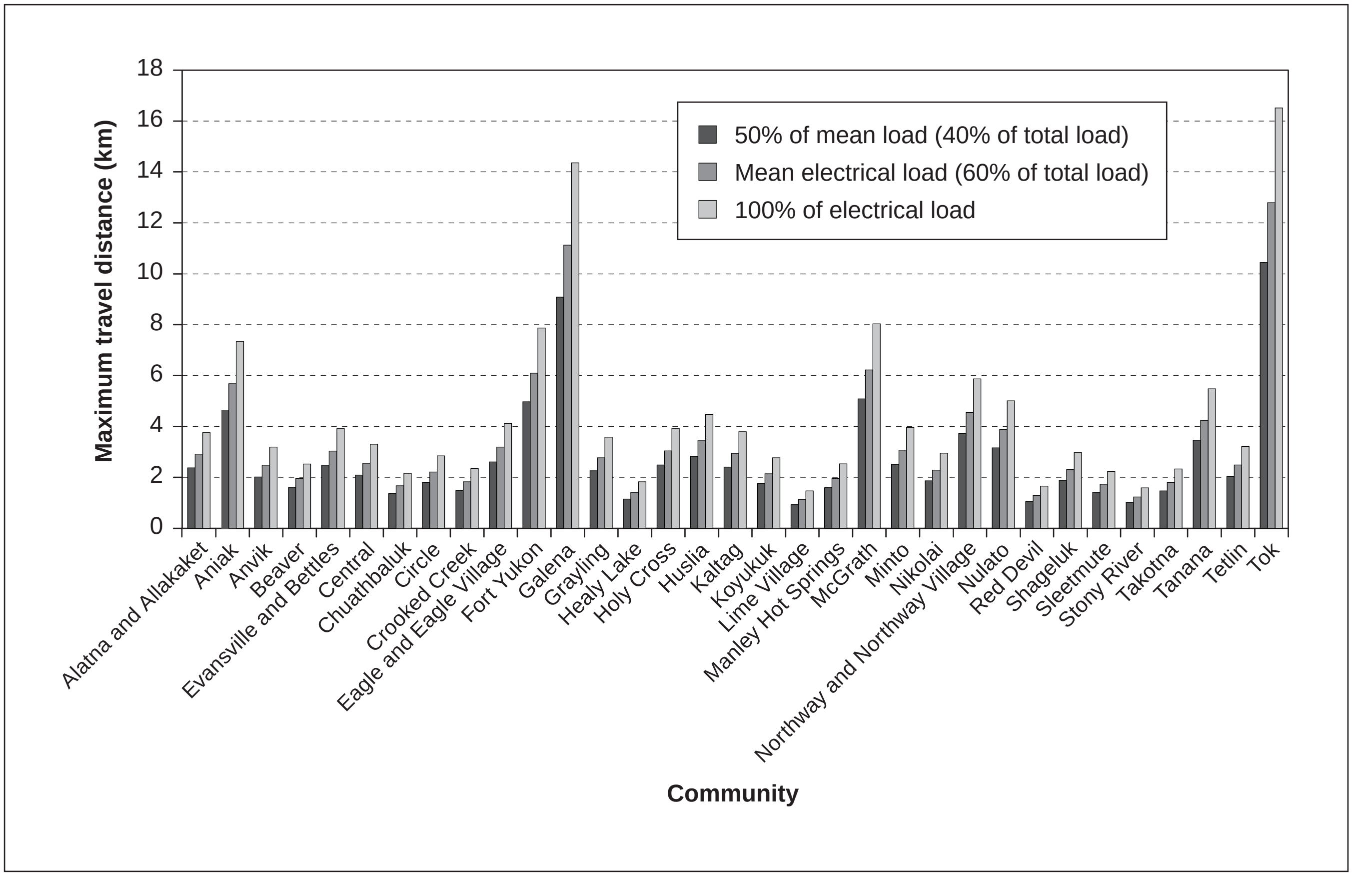

Figure 3—Maximum travel distance for meeting a given percentage of village energy needs by biomass fuels. Model outputs estimate sustainable harvest of black spruce for energy generation. If installed biomass generation capacity is equal to 50 percent of mean loads, approximately 40 percent of the community’s electrical demand will be offset. At a capacity equal to mean loads, this rises to 60 percent of demand. All data assume 110-year forest rotations.

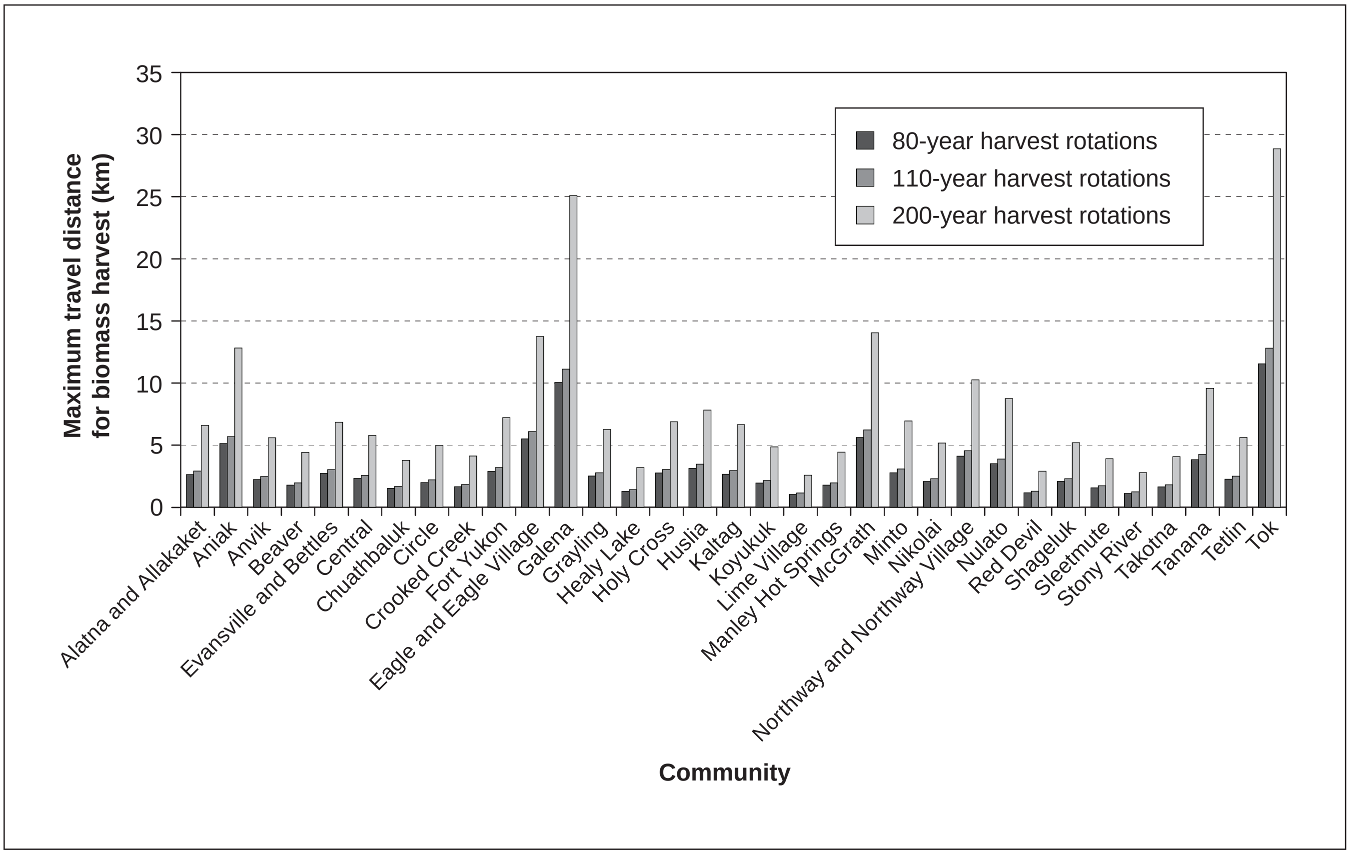

Figure 4—Maximum travel distance for sustainable harvest of black spruce for energy generation according to selected harvest rotations. Rotation lengths of 80, 110, or 200 years are shown. Black spruce biomass density per hectare increases between 80 and 110 years, and decreases between 110 and 200 years (Yarie and Billings 2002), resulting in a steep increase in travel distance with long rotations.

Model sensitivity analysis using randomly selected parameter values from within each parameter range yielded a distribution of results for each of three village sizes (fig. 5). For a village of 21 residents, no model runs yielded a maximum travel distance of over 3.8 km; the mean was 1.7 km. For a village of 106 residents, the range was 1.5 to 10.7, with a mean of 3.9 km. The distribution of results was broadest for the largest communities with a single outlier at 39.3 km. The remainder of the range fell between 5.5 and 27.5 km, with a mean of 14.2 km.

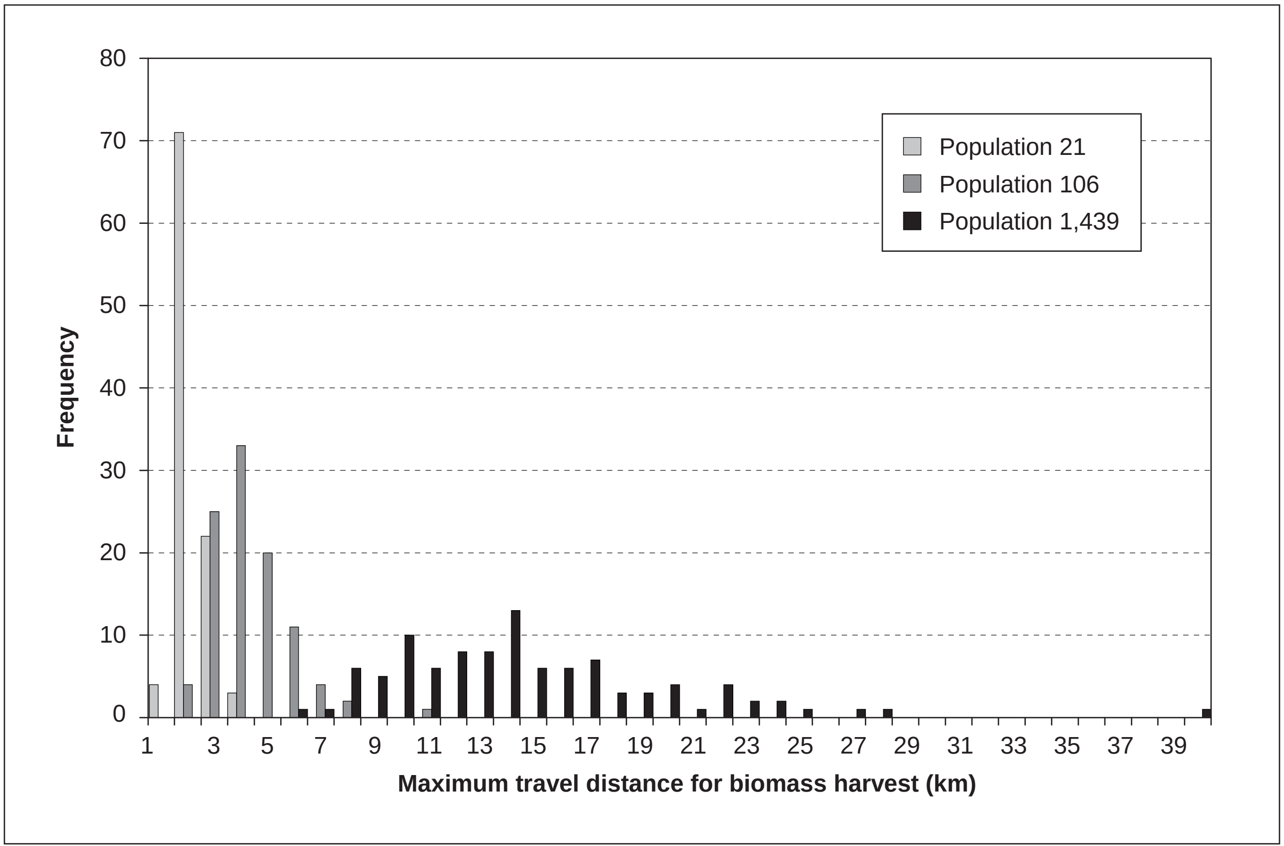

Figure 5—Distribution of results for 100 stochastic model runs for each of three village population sizes. In each model run, values for rotation length, biomass density, energy by moisture content, energy per ton, forest cover, and electrical efficiency were randomly selected from within broad accepted ranges.

Economic Feasibility

Because of missing data, not all economic calculations could be performed for all selected communities. For some villages, data were missing for fuel costs, nonfuel expenses, or energy generated (appendix), making it impossible to include these communities in model results. Thus, our results reflect a subset of forested off-grid villages in the interior. However, in addition to obtaining village-specific results, we were able to explore general relationships between village size, village accessibility, and economic feasibility.

For many of the communities in this analysis, total annual operating costs for electrical generation would be lower if part of the village's diesel power were converted to a biomass-fueled system (table 9). Tetlin, Tok, Northway, Koyukuk, Evansville and Bettles, and Eagle show consistently negative results; however, since Tok and Northway are both accessible via the Alaska Highway, one of the state's major thoroughfares, they may be considered anomalous as compared to more remote villages accessible only by minor roads or by rivers (major or minor)

Table 9—Annual savings in generation costs and total capital investment associated with two levels of fuel system replacement

	Annual savings		Capital investment	
	Biomass capacity = ½ mean load	Biomass capacity = mean load	Capacity to meet ½ mean load	Capacity to meet mean load
	Dollars			
Alatna and Allakaket	11,320	25,317	68,479	136,957
Aniak	7,342	84,547	260,538	521,076
Anvik	146	11,945	49,499	98,998
Beaver	n/a	n/a	30,964	61,929
Evansville and Bettles	-7,444	-3,669	74,279	148,557
Central	5,176	22,618	52,968	105,937
Chuathbaluk	6,150	16,173	22,557	45,114
Circle	601	9,562	39,260	78,519
Crooked Creek	6,615	16,765	26,852	53,704
Dot Lake	n/a	n/a	n/a	n/a
Eagle and Eagle Village	-12,195	-5,423	82,460	164,921
Fort Yukon	-18,945	7,847	299,724	599,447
Galena	n/a	n/a	999,093	1,998,186
Grayling	2,865	19,017	62,136	124,272
Healy Lake	1,120	6,035	16,146	32,291
Holy Cross	2,377	21,266	74,721	149,442
Hughes	n/a	n/a	n/a	n/a
Huslia	16,168	47,175	96,771	193,542
Kaltag	7,822	28,313	69,989	139,978
Koyukuk	-6,399	-7,724	37,281	74,562
Lime Village	15,665	29,749	10,476	20,952
Manley Hot Springs	2,590	14,268	31,040	62,081
McGrath	-21,238	24,279	312,726	625,452
Minto	-5,593	9,675	76,257	152,513
Nikolai	4,549	11,024	42,362	84,725
Northway and Northway Village	-36,149	-45,395	167,164	334,328
Nulato	5,285	36,648	121,244	242,487
Red Devil	8,855	20,129	13,343	26,687
Ruby	n/a	n/a	n/a	n/a
Shageluk	3,856	15,924	42,810	85,619
Sleetmute	8,465	19,640	24,195	48,390
Stony River	8,450	19,582	12,286	24,573
Takotna	5,892	12,228	26,247	52,495
Tanana	-5,207	24,803	145,436	290,871
Tetlin	-4,680	-3,332	49,951	99,903
Tok	-353,480	-463,066	1,321,209	2,642,418

n/a = not available.

(appendix). Minto, Fort Yukon, and Tanana show benefits from conversion to wood fuel under some conditions but not under others, depending on the scale of the biomass generation capacity installed.

When the added benefit stream of potential carbon sequestration credits is added to the potential annual savings gained by biomass fuel conversion, wood-fired electrical generation becomes more favorable. Even without taking carbon credits into account, 23 communities show a payback period of less than 25 years for the initial capital investment of installing a biomass electrical generation system adequate to meet mean electrical loads (fig. 6). A 25-year payback corresponds roughly to a real discount rate of 2.4 percent if the benefit stream continues for another 15 years. The projected time before a net positive economic balance is reached without carbon credits ranges from a mere 0.7 years for Lime Village and 1.3 years each for Stony River and Red Devil, to 11.7 years for Tanana and 15.8 years for Minto. If communities were able to sell carbon offset credits at 2005 U.S. prices, the payback periods for Tanana and Minto would drop to 11.3 and 14.9 years, respectively. At European carbon prices, these figures would dip to 7.8 and 9.2 years. Villages for which it would take longer than 25 years to recoup the investment and communities for which the benefit stream is negative are not shown in this figure. However, both McGrath and Fort Yukon, two of the larger communities analyzed, show a payback period of less than 25 years when carbon credits are taken into consideration, but not when carbon credits are included.

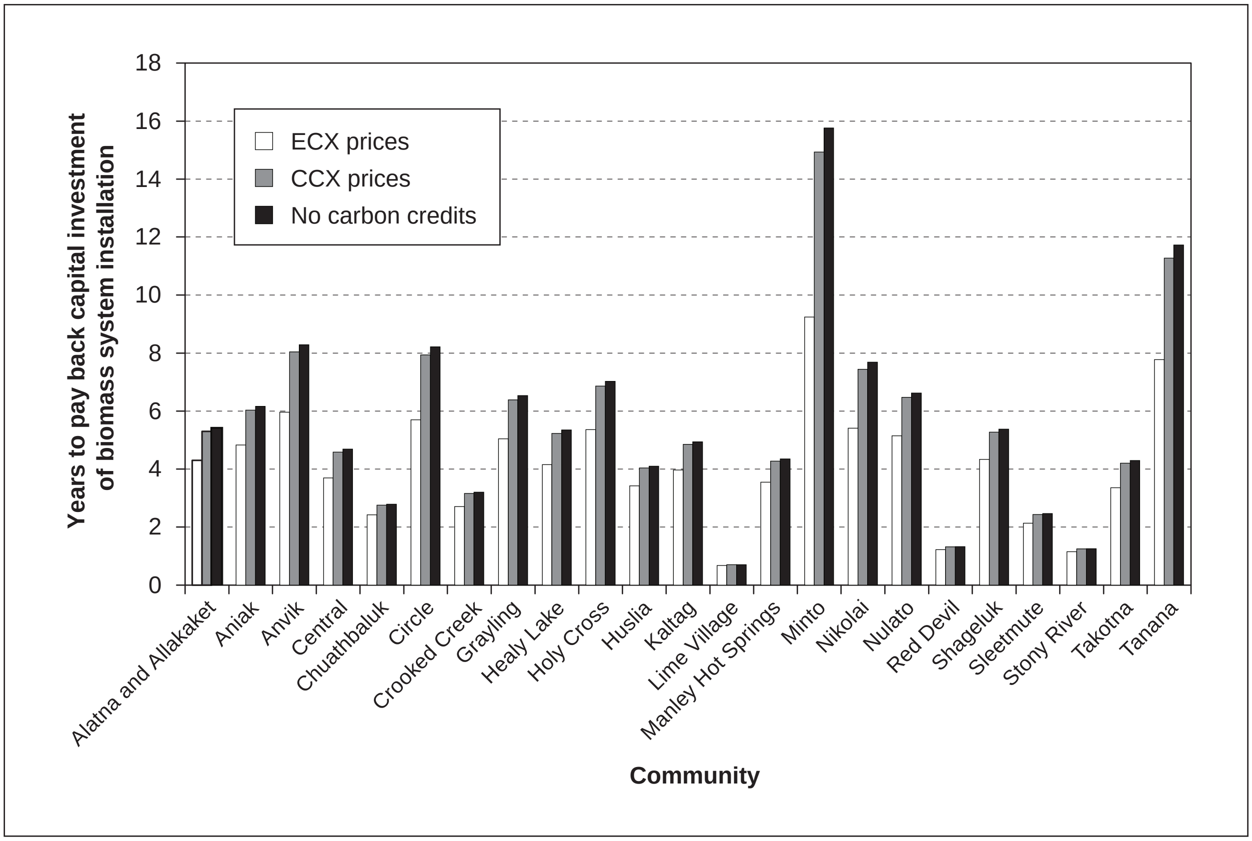

Figure 6—Years necessary to recoup an investment in wood-powered electrical generation capacity equal to mean electrical loads. For each selected village, three carbon-credit trading scenarios are shown: one in which no carbon credits are sold, one in which available fuel-offset credits are traded at Chicago Climate Exchange (CCX) prices, and one in which credits are traded at European Climate Exchange (ECX) prices.

It should be noted that, although villages for which data are absent have been necessarily omitted from this analysis, these communities should not be assumed to have a poor cost-benefit balance from potential biomass projects. In general, communities not accessible via a major road showed positive results based on biomass generation at mean load levels (fig. 7). This relationship was particularly robust for communities with fewer than 100 residents.

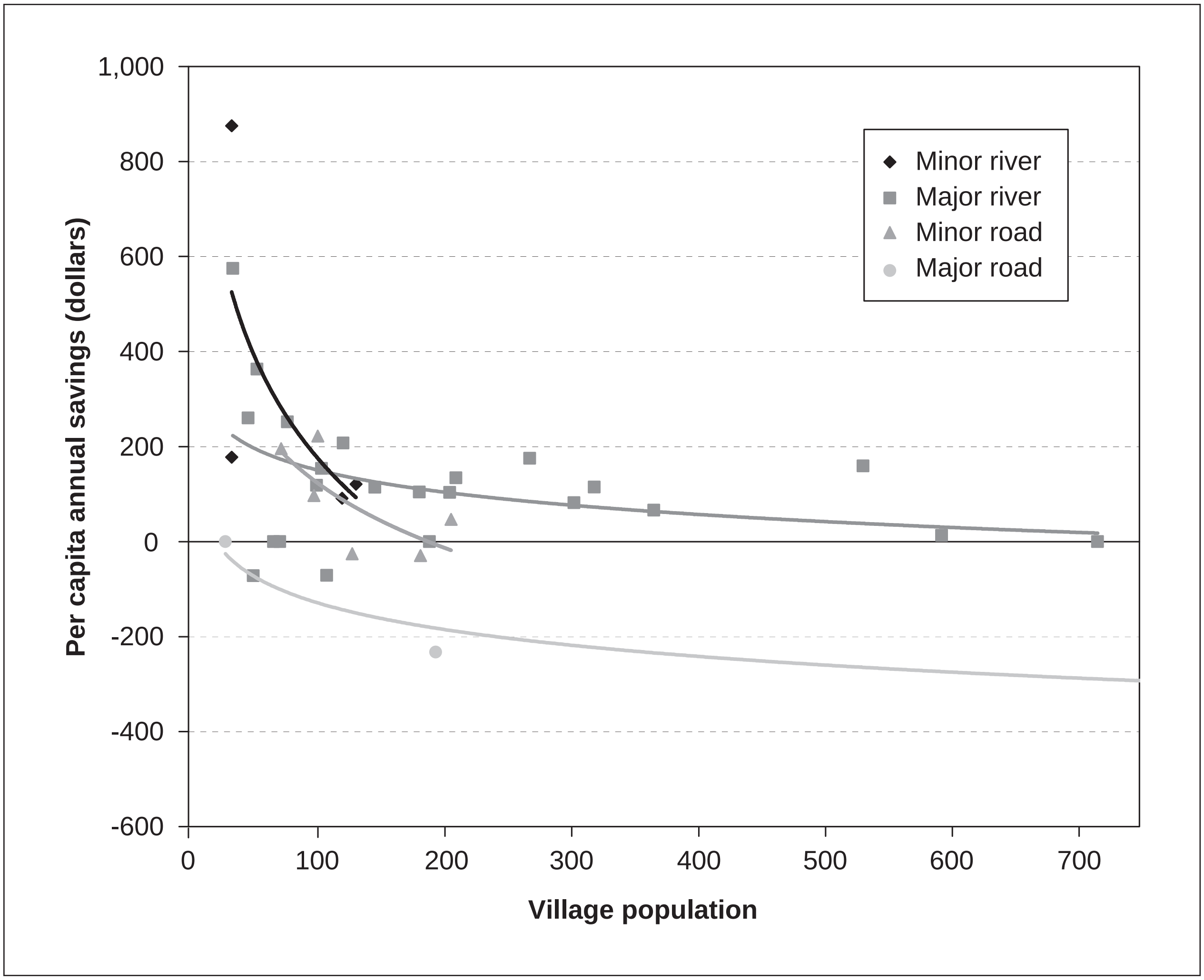

Figure 7—Per capita savings by village size and accessibility for biomass generation at mean loads. Logarithmic regression curves are fitted to four categories of accessibility. Only those villages that can be reached on major roads show consistently negative results for replacement of fossil fuel with biomass fuels at mean load capacity. For all villages, smaller population size is correlated with greater per capita benefits from fuel conversion.

For many communities, our model placed biomass conversion close to the economic break-even point when nominal parameters were used. Stochastic model runs using randomly selected parameter values from within broad possible ranges yielded mixed economic outcomes for almost all the villages analyzed (fig. 8). Only 10 villages—Aniak, Central, Chuathbaluk, Crooked Creek, Lime Village, Manley Hot Springs, Red Devil, Sleetmute, Stony River, and Takotna—showed net annual savings on generation costs for all 10 model runs. However, only two communities—Fort Yukon and Tok—yielded unfavorable results in 50 percent or more of model runs for replacement of mean load capacity. As the largest community with the greatest power usage, Tok also yielded the broadest range of potential annual costs or savings.

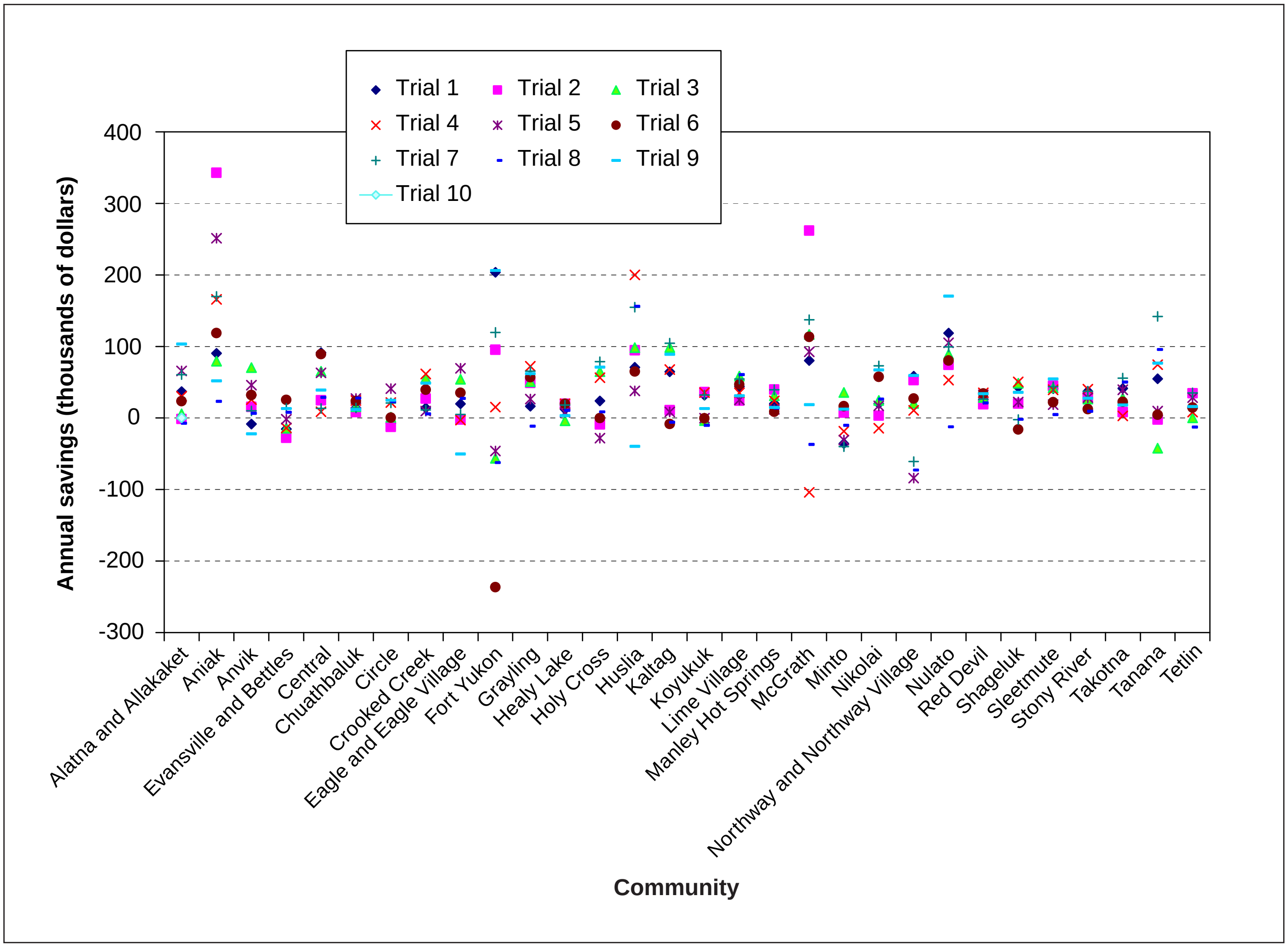

Figure 8—Sensitivity analysis for replacement of diesel systems with biomass electrical generation sufficient to meet peak loads. Data points show the results of 10 model runs using parameters randomly selected from within broad possible ranges. Tok has been excluded for reasons of scale; results for Tok ranged from -$1.9 million to +$1.5 million.

The ranges used in this analysis included installed costs between $980 and $3,125 per kW, annual operation and maintenance costs for biomass systems between $0.12 and $0.28 per kWh, carbon credits between $0 and $222 per 1,000 gal (3774 L) of fuel offset; and fuel prices between 50 and 250 percent of 2004 prices. It should be noted, however, that 2006 fuel prices were close to 200 percent of 2004 prices in many areas (DeMarban 2006b). If 2006 prices were used as a baseline, model runs would become consistently favorable in almost all communities.

When capital cost for biomass system installation was considered as a random stochastic variable and results were calculated for expected project payback time, results showed a similar pattern (fig. 9). Seven of the ten villages for which all model runs yielded annual savings showed a payback time of less than 25 years for all model runs. Only Tok showed a consistently poor ability to recoup the investment costs associated with biomass conversion, although other communities, including Evansville and Bettles, Fort Yukon, Koyukuk, Minto, and Northway yielded mixed results.

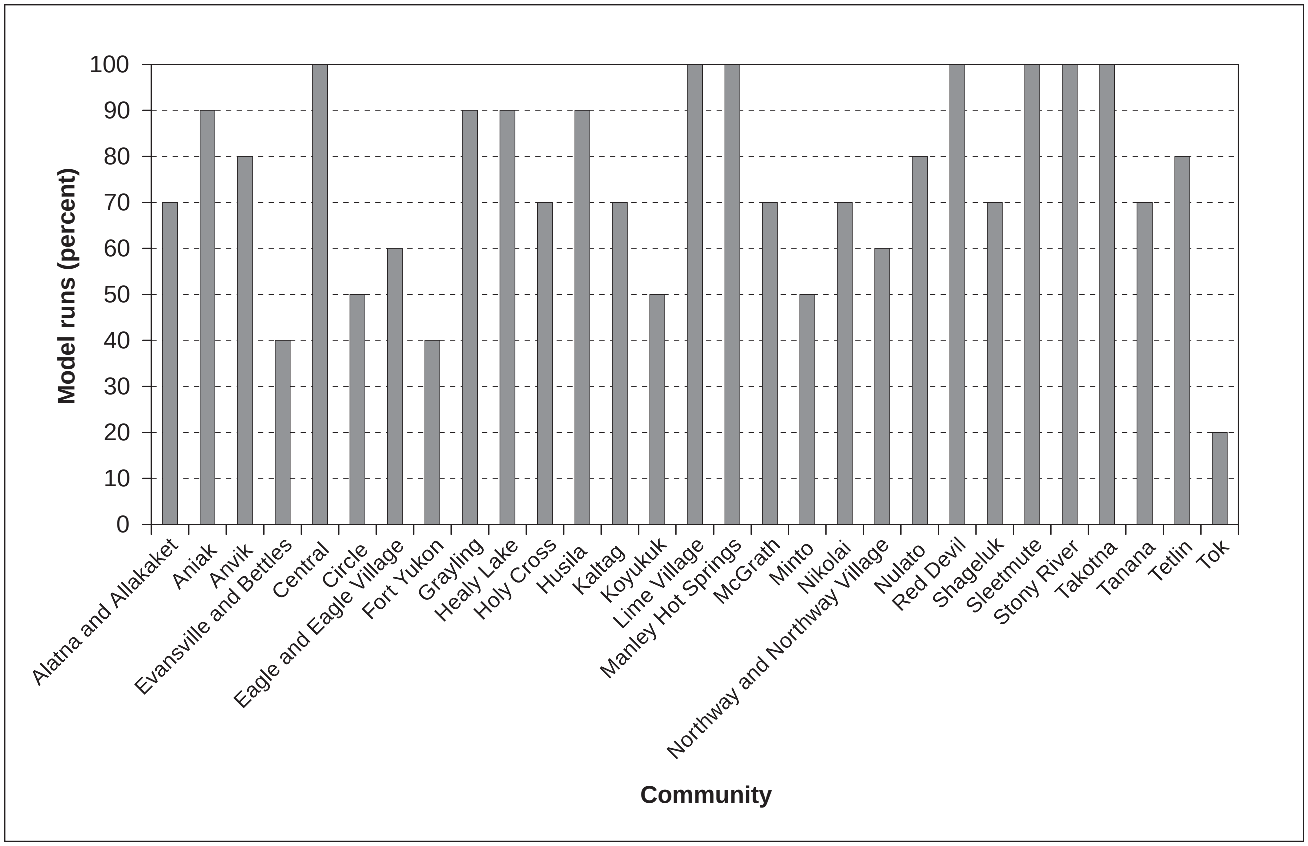

Figure 9—Sensitivity analysis of time necessary to recoup capital investment with biomass capacity of mean load. For each village, the graph illustrates the percentage of stochastic model runs for which randomly selected parameter values yielded a payback time of less than 25 years.

Social Feasibility

Our qualitative analysis of the potential social role of biomass fuel conversion in rural interior Alaska yielded a conceptual map of where wood fuel might fit into village economies (fig. 10). Harvest of biomass fuels would provide local jobs, which in turn would bolster the local cash economy by recirculating money within each village. In contrast, payments for fossil fuels represent a monetary flow out of communities. Currently, economic multipliers in village economies are small. Income from carbon credits would create a cash flow into the community from an outside source—something that is often in short supply in rural Alaska. Fire is linked to many aspects of community wealth, in both monetary and subsistence categories. Thus, natural forest succession, protection of life and property, local wages, and subsistence foods are all linked through the presence—or absence—of fire on the landscape.

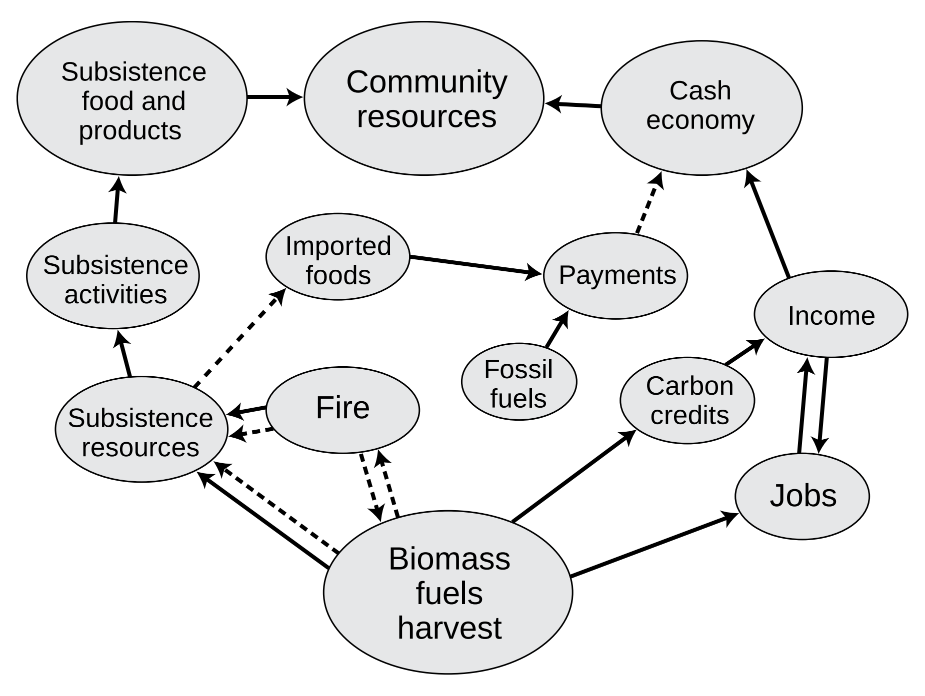

Figure 10—A conceptual model of economic feedback interactions. Village market and nonmarket economies are potentially linked to biomass fuels programs. Solid arrows indicate positive effects and dashed arrows indicate negative effects. Note that fire can have both positive and negative impacts on subsistence resources, depending on time scale.

Analysis of the impacts of subsidies and grants on village energy choices revealed a substantial gap between the real costs of electrical power and the prices being charged to consumers (fig. 11). Moreover, the real costs of village power make up a substantial proportion of village income, ranging from 7.1 to 70.0 percent (fig. 12). Because we have included the electricity used in shared facilities such as washeterias, schools, and offices in our totals, our figures are much higher than those for household use only (Colt et al. 2003). In reality, however, the discrepancy between realized costs and real costs may be even larger, owing to hidden (off-book) costs covered by transfer payments other than those made via the PCE Program. These include government-funded construction and upgrades, many of which were listed in table 7. Such off-book costs account for roughly 25 percent of the real cost of power (Colt et al. 2003), but are not accounted for in our economic analysis.

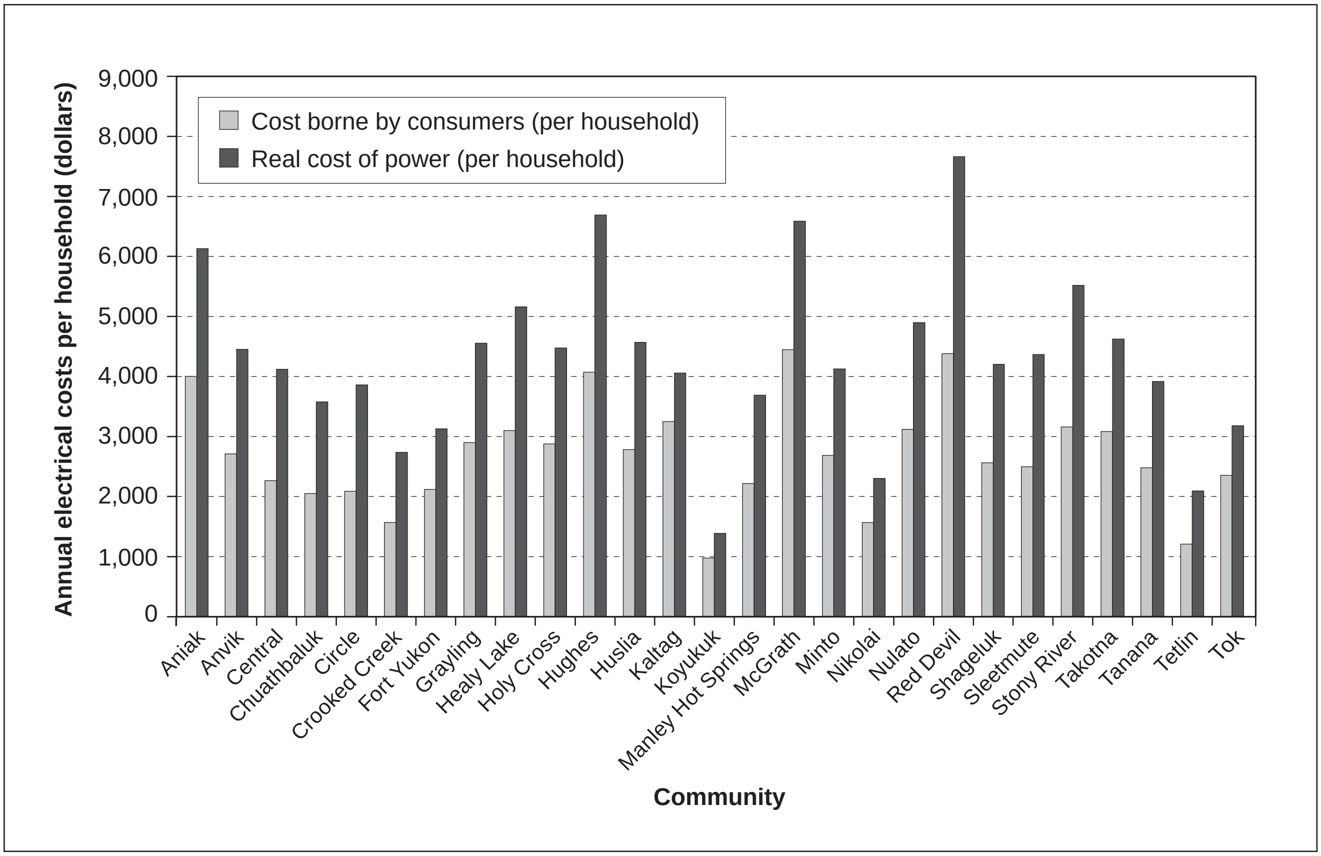

Figure 11—Annual village electrical costs, expressed on a per-household basis. These figures include costs incurred for electrical use in private homes as well as in shared facilities such as schools, tribal offices, and washeterias. The discrepancy between the cost borne by consumers and the real cost of power is covered by government funding, primarily via the Power Cost Equalization Program.

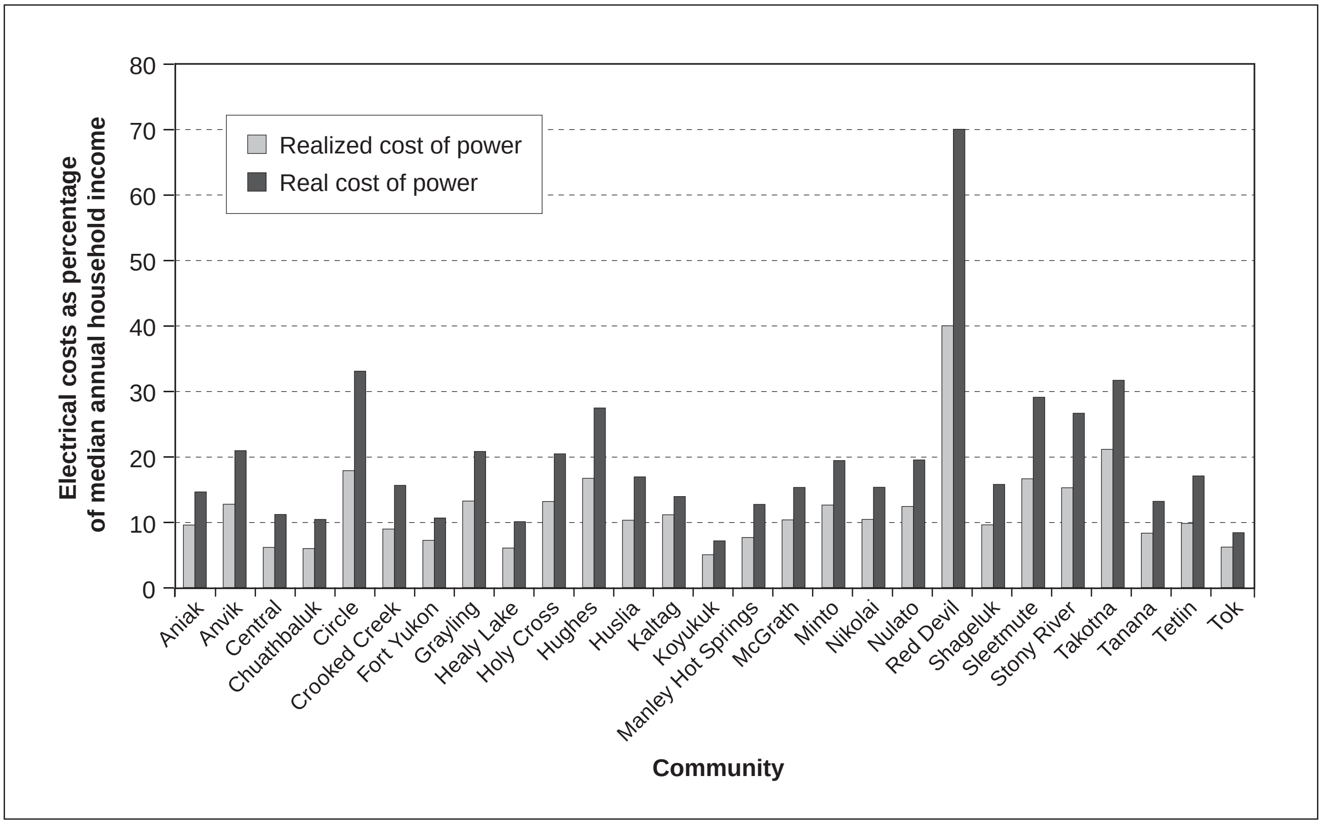

Figure 12—Village electrical costs per household expressed as a percentage of median household income for each community. Figures include costs incurred for electrical use in private homes as well as in shared facilities such as schools, tribal offices, and washeterias. The discrepancy between the costs borne by consumers ("realized costs") and the total unsubsidized costs ("real cost of power") is covered by government funding, primarily via the Power Cost Equalization Program.

The gap between real and realized costs has negative social ramifications, creating disincentives for locally based efficiency improvements, sustainable community planning, and innovative use of capital (Colt et al. 2003). Even if biomass fuel use can be shown to be an option that is feasible in a given community, village residents may lack the necessary economic incentive to catalyze change. Moreover, the small population base of most villages has in the past proven to be an obstacle to reliably securing the necessary human resources for governance, operation, and maintenance of utilities (Colt et al. 2003). On the other hand, although government entities may have a financial incentive to promote change and may have the necessary technical expertise and human resources, they may suffer from bureaucratic inertia and lack of social impetus. Based on the financial power wielded at higher levels of governance and the social power contained within communities, there are potential advantages and disadvantages associated with both top-down or bottom-up approaches to managing potential village biomass projects (table 10)

Table 10—Advantages and disadvantages of top-down vs. bottom-up strategies for implementing a fuel-conversion program

	Advantages	Disadvantages
Federal government	Power to limit carbon emission laws and treaties	Poor understanding of Alaska
State government	Power to create a statewide program	Emphasis on state rather than commmunity needs
Native corporations	Available capital; interest in village investments	Limited to for-profit activities; no statewide mission
Power cooperatives	Technical knowledge; statewide linkages	Commitment to existing diesel infrastructure
Village councils	Understanding of community needs	Lack of economic and human resources

At the state and federal levels, grants and other sources of funding are available to cover startup costs, and technical expertise is available for design and implementation work, including funds specifically allocated to renewable energy and alternative power (AEA 2005). Most of these funds would likely be channeled through the AEA, as detailed in table 7.

The advantages of the infrastructural assistance and funding available through AEA give rural Alaska a potential edge over rural communities in less developed nations, where capital and technological inputs are more uniformly scarce. Even in India, a nation with a stronger economy than many developing nations, lack of financial support for technology improvements has been cited as the primary reason for failure of an early attempt at instituting a small-scale biomass energy project (Kishore et al. 2004). A national-level analysis in India showed that biomass gasifiers 20 to 200 kW in capacity could entirely meet rural electricity needs (Somashekhar et al. 2000). Some demonstration projects have proven relatively successful (Somashekhar et al. 2000) whereas others have not (Kishore et al. 2004). There are several reasons for project failure, including subsidized power available from the existing grid, extremely low purchasing power among village residents, and poor technology for burning biomass other than wood chips (such as rice husks and other plant residues) (Kishore et al. 2004). Because Alaska's villages are largely removed from the power grid, have greater cash flows than rural Indian communities, and have wood as the primary source of potential biomass, these problems are unlikely to be applicable.

In addition to providing funding and know-how, governments may be the most effective managers of some aspects of on-the-ground efforts. Some degree of centralization and top-down effort are predicated by the tiny size of some of the communities in question. For example, specialized skills such as boiler design and installation and engineering of combined heat and power grid systems would not be found in every community of 50 to 100 individuals.

However, direct management from the state or federal level is rife with potential problems. The same remoteness that makes the cost of diesel fuel in villages so high also demands that village power and heating systems be internally rather than externally managed whenever possible. Cultural considerations bolster this assertion. Village residents, most of them Alaska Natives, strongly prefer local control of village affairs (Hanson 2005, Putnam 2005).

Not only is local autonomy culturally preferable, it is also likely to be crucial for the long-term viability of biomass projects. State and federal officials are unlikely to be knowledgeable concerning important details such as interpersonal dynamics in the community, traditional use in the area around the village slated for harvest, and local concerns regarding fire risk. For example, during community studies preliminary to the installation of a biomass energy system in the village of McGrath, residents expressed concerns about the technical and economic feasibility of the project; the impacts of increased wood harvest on subsistence activities, aesthetics, and future wood supply; and overall system complexity (Crimp and Adamian 2001). Alaska Natives are often suspicious of solutions derived by governmental groups that are perceived to be part of the problem, and without community support, trust, and buy-in, programs instituted by outside entities are doomed to failure (Reiger et al. 2002).

In addition, local residents are likely to be able to provide realistic assessments of what type of employment would be considered desirable, and on what time scale it might be undertaken. For example, wood harvest, chipping, and transport might be shared informally among several individuals, and might be timed not only to coincide with adequate snowpack for easy transport, but also to fit in with seasonal subsistence activities and other seasonal employment. In most communities, gathering wood fuel is already part of subsistence activities; community members would be best equipped to decide how and when to expand fuel collection and how to pay individuals for the wood they gather. Since fuel gathering would be coupled with fire prevention, and because fuel collection would be most likely to occur in the winter via snowmachine rather than in the summer fire season, existing fire crews would be an obvious choice of labor force. Hanson (2005) noted that fire crews were involved in fuel clearing projects in Healy Lake, Tanacross, and Stevens Village, and that these groups generally work well together and are actively interested in fire protection. However, he also commented that work crews vary, and that having a good crew boss or leader is crucial to success.

Village councils, local light and power cooperatives, and Native corporations have greater power to implement projects than do individuals. For example, these entities are eligible for state or federal grants such as those being made available through the Alaska Wood Energy Development Task Group. These grants, however, are being channeled via AEA. At an intermediate level of governance, organizations such as AEA, AVEC, and other regional light and power cooperatives have the potential to help link the resources of governmental agencies with the resources of communities. These organizations have already taken a lead in proposing, funding, and implementing alternative energy projects (AEA 2005, AVEC 2005). Thus far, AVEC has focused on wind and hydroelectric power, as many of its customer communities are coastal. Also, AEA has taken a lead in biomass demonstration projects, including installation of a wood-fired boiler in Dot Lake, and a proposal for a larger system in McGrath. The AEA has garnered funding for such projects from state and federal levels, but is implementing them using criteria that take into account local needs and local capacities.

In the long run, a combined approach seems likely to provide the greatest resilience to the system. Power sharing and co-management are ideas that are starting to take hold in a range of rural applications and are likely to be appropriate in an Alaskan context (Reiger et al. 2002). For example, although overarching assessments of fuel supply and demand around a village might be performed by forestry professionals, annual harvest areas might be chosen by local village councils, based on community preferences.

Based on the above information, we identified the following barriers and thresholds to change.

Barriers:

- The majority of AEA funding is traditionally allocated to existing system components, not to renewable energy or new technology startup.
- In some cases, state or AEA capital funds are designated for programs such as PCE and bulk fuel revolving loans, which create negative economic externalities favoring the status quo.
- Many power cooperatives are managed regionally, not at the village level.
- No forest certification system is in place whereby carbon credits could immediately be secured (although the potential for development of such a program exists within either the Alaska DNR or native corporation programs such as the TCC Forestry Program).
- Failure by the United States to sign onto binding climate-change agreements may keep carbon credit prices an order of magnitude lower here than overseas.

Thresholds:

- Existence of individuals within a given village who are willing and able to participate in fuel conversion projects, particularly village leaders who are willing to advocate for a biomass program, fire crews or other individuals actively interested in employment and fire prevention, and one or more crew leaders who can take responsibility for followthrough.
- Existence of necessary skills within village and the willingness of system operators to receive training in new technologies.
- Formation of effective cross-level collaboration, particularly between AEA (the likely funding agency and potential overarching project manager), village electrical companies or cooperatives (the likely applicants for funding and local managers), and individuals employed on the ground at the village level.

Discussion

The transition to renewable energy sources is constrained by a number of economic, social, technological, and political factors. These include startup costs for research and new infrastructure; social inertia and risk aversion; inadequately developed technologies; lack of availability of all energy sources in all regions; and artificially low costs of existing fossil-fuel systems owing to subsidies, lack of accounting for economic externalities, and current infrastructure. Nevertheless, our results indicate that even with conservative assumptions for ecological, economic, and social parameters, conversion to wood biomass energy is likely to be a feasible and attractive option for many communities in interior Alaska. A successful fuel-conversion program must fulfill the social, economic, and ecological needs of the system as a whole (fig.13).

Based on our model, the communities likely to show the greatest ecological feasibility for biomass conversion are those in the small to medium size categories. Only the largest communities—those with populations over about 300—potentially lack adequate wood resources for complete fuel conversion within an easily accessible radius. This pattern runs counter to the trend whereby other services such as schools, clinics, and airports are more cost-effective in larger communities, leading to governmental pressure toward consolidation of small villages. Ironically, many villages have shrunk in part because of the high costs of fuel (DeMarban 2006b).

The greatest economic feasibility is demonstrated by villages with the highest benefit/cost ratio, which tend to be those not easily reached by either road or river networks. For these villages, even high estimates of costs for biomass fuel systems show an advantage over existing high costs for fuel transportation and storage.

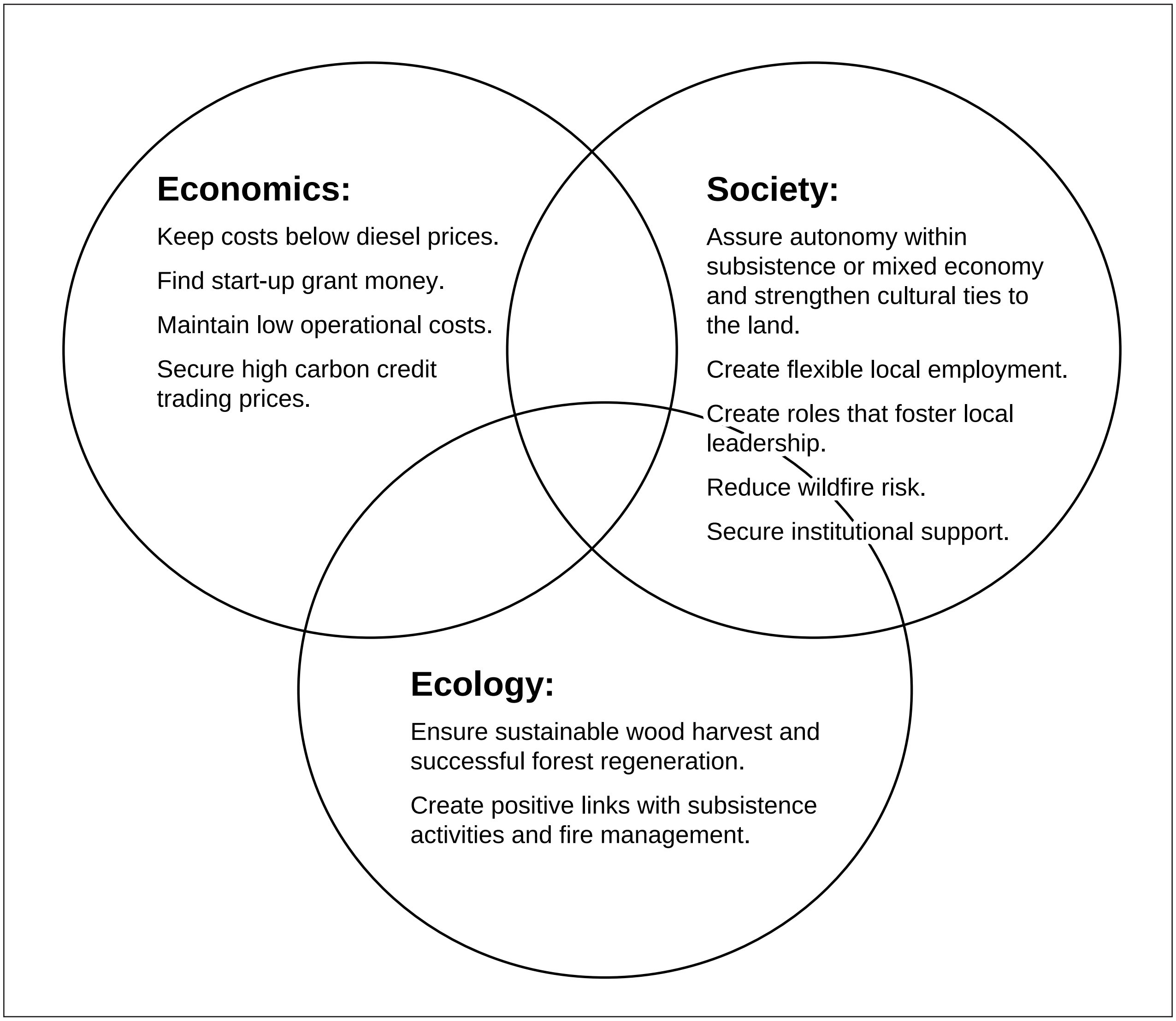

Figure 13—Social, economic, and ecological parameters affecting a potential fuel conversion program. These parameters are interconnected and subject to change over time.

Social feasibility, because it is so dependent on individuals, has yet to be determined on a village-by-village basis. However, it is likely to be greatest in communities with strong leadership, close ties to the land and its resources, and a core group of individuals—perhaps an existing fire crew—willing and able to work consistently on fuels harvest and associated tasks. These requirements tend to point toward medium or larger communities in remote areas.

Villages that fit both the ecological and the economic criteria include Alatna and Allakaket, Anvik, Central, Chuathbaluk, Circle, Crooked Creek, Grayling, Healy Lake, Holy Cross, Huslia, Kaltag, Lime Village, Manley Hot Springs, Minto, Nikolai, Nulato, Red Devil, Shageluk, Sleetmute, Stony River, and Takotna. In the smallest communities in this group, the presence or absence of strong leadership and willing workforce would be particularly critical in determining the success of conversion. For example, Takotna lists zero unemployed individuals from its 29 residents over the age of 16 (appendix). On the other hand, Aniak and Tanana show a positive benefit/cost ratio, but have populations above 300. Projects in these communities would have to be more cautious regarding wood supply, harvest area, and overall energy use, or might optimally be based on only partial conversion to wood fuel. Meanwhile Evansville and Bettles, Koyukuk, and Tetlin easily met ecological criteria but were on the borderline in the economic analysis. Fort Yukon, McGrath, Northway, and Tok all showed mixed results. These four communities are all either much larger than the mean, or located on a readily accessible transportation corridor, or both. Although biomass conversion projects may be feasible in these locations, additional factors would need to be taken into account, including the possibility of procuring wood from slightly farther afield (via road or river), and the effects of biomass conversion on the larger and more complex economies of these communities. Finally, inadequate data were available to fully assess potential feasibility for Beaver, Dot Lake, Galena, Hughes, and Ruby.

Our analysis was intentionally conservative, and may therefore have underestimated potential advantages of conversion to biomass fuels. For example, 110-year forest rotations are longer than would likely be considered by communities seeking fire protection and habitat revitalization. Our estimates for biomass per acre, forest cover, and carbon credit prices were relatively low, and our estimates for biomass system installation costs were relatively high. Perhaps the greatest undercounting of potential system benefits stems from the fact that, although we assumed that installed systems would provide both power and heat, we accounted for only the savings afforded by replacing the existing power supply. Although heating could in most cases only be provided for centrally located buildings, the savings afforded would likely be substantial in communities that already have infrastructure to support combined heat and power distribution, and worth assessing even in those that do not. Including heat as a resource increases estimates of biomass generator efficiency from approximately 28 to 68 percent (table 3). Even if less than half of this additional benefit stream could be effectively captured, it would increase the overall energy realized by more than 50 percent. An increase in system benefits of this magnitude would make almost all fuel conversion options economically attractive. Another potential source of error may stem from the fact that off-book expenses associated with current diesel systems were not considered, although they are likely to account for approximately 26 percent of total costs (Colt et al. 2003).

Finally, all estimates were made using 2004 fuel costs, which are substantially lower than more recent costs (DeMarban 2006a, 2006b). Fuel costs may continue to rise, and federal and state subsidies may shrink or disappear. The incentives for fuel conversion at the village level are highest when fuel prices are highest, but lower fuel costs might trigger the removal of state subsidies, as state revenues are almost entirely dependent on oil prices. These changes would make fuel conversion increasingly appealing—including, in many cases, conversion of 100 percent of generation capacity rather than partial conversion.

In addition to the sources of uncertainty explored in this analysis, other factors could affect the feasibility and desirability of biomass conversion programs. New transportation corridors might lower the costs of fuel transport in some areas. Additional local employment opportunities might drive up local wages, thus raising harvest costs or reducing the potential workforce. Payback on capital investments could be affected by inflation, deflation, or rapid changes in interest rates.

On the other hand, grant money such as that available through the Wood Energy Task Force, the Denali Commission, or AEA’s Wood Energy Development Program could help jump-start projects, and might make infrastructure costs less of a concern. New technology might reduce the installation and operation costs for wood gasifiers below the range predicted, or international turmoil might cause fuel prices to skyrocket above predicted values. Carbon credit prices would eventually rise to match current ECX prices, even in the United States, if new binding international agreements are reached. Moreover, if fire on the landscape is perceived as an ever-increasing threat, and if state and federal firefighting resources become strained, then forest clearing might become more socially desirable and financially lucrative in its own right.

Many of these potential changes or surprises would tend to increase the economic viability of fuel conversion. However, model uncertainty not only means that economic outcomes are ambiguous for many villages, but also that social feasibility is uncertain. Thus, pilot projects offer the next step in testing feasibility. Such projects would help to validate our model, test technology under new conditions (e.g., remote location, cold climate), provide positive lessons that could be incorporated into future projects, and provide experience regarding errors to avoid.

When ecological, economic, and social parameters are considered in conjunction with one another, a pattern of hurdles and benefits emerges (table 11). Although many of these have been addressed in our analysis, others can only be truly tested through use of real-life project implementation.

Table 11—Potential hurdles and benefits associated with biomass fuel conversion in interior Alaska

	Hurdles	Benefits
Economic	Cost of new infrastructure Cost of biomass harvest	Wages from fuel gathering Reduced cost of diesel
Social/political	Political buy-in from agencies and power companies Ensuring local involvement and continuity	Health benefits from reduced pollution Greater autonomy of local communities
Technical/ecological	Technical challenges of biomass energy generation Ensuring long-term sustainability of harvest	Reduced fire risk Greater landscape diversity Creation of diverse wildlife habitat

Two existing pilot projects in interior Alaska demonstrate the feasibility of wood biomass systems and the efficacy of employing combined heat and power capabilities. The first, a wood-fired boiler used to heat and power eight residences and the washeteria in the 37-person community of Dot Lake, is already operational. The second, in McGrath, has not yet been completed but is slated to include a combined heat and power system based on continued use of diesel with a wood boiler providing additional energy to the system.

Dot Lake is not a typical interior village, as it is on the road system. As a result, diesel fuel in the community is far less expensive than in some villages, and our calculations show a strongly negative incentive for biomass fuels conversion. Nevertheless, Village Council President Bill Miller estimates that the village saves \$6,500 to \$13,000 in fuel costs per year using the wood-powered system (AEA 2000a). Capital costs were paid by external funding sources. However, wood prices in Dot Lake are not likely to be equivalent to prices in more remote villages, because in Dot Lake the boiler operates on wastes from nearby timber operations, which can be easily transported via road.

In McGrath, the option selected appeared economically preferable to three other possibilities: the status quo (all diesel); a wood boiler powering only the school; or a more comprehensive wood system, with diesel remaining as the backup fuel (Crimp and Adamian 2001). Crimp and Adamian (2001) also noted that the cost-effective use of biomass was highly dependent on the availability of inexpensive wood wastes; costs would be expected to rise sharply if roundwood harvest were required to operate the facility. However, at the time the analysis was done, it was assumed that the cost of bulk diesel would remain static at \$1.54/gal (\$0.41/L). In reality, prices have risen sharply, increasing by over 65 percent between 2003 and 2005, and potentially reaching \$6/gal (\$1.59/L) in 2008 (Bradner 2005, 2008).

As previously described, the potential income from sale of carbon credits from interior villages would be roughly $62,000 annually at 2005 market prices. In very small villages, the totals would be less than $300 per year. Even in larger communities, these sums represent only a very small percentage of the funds that would be necessary to operate and maintain combined heat and power systems of any kind. However, in some cases, these sums are enough to tip the balance toward biomass fuel conversion. If the value of carbon credits in the United States ever rises to meet world standards, perhaps because of future international agreements, the additive value of these credits could become a significant part of the cash economy at the village scale.

Conclusion

Given the combined drivers of rising fuel prices, ongoing climate change, increasing fire risk, and social pressures favoring fossil fuel independence, many communities may soon consider shifting to alternative fuels. The incentive of earning tradable carbon credits has added to potential benefit streams, and the monetary gains of participating in carbon markets may increase tenfold or more in the long term if the United States eventually implements programs congruent with those being used by Kyoto Protocol signatory nations.

In rural Alaska villages, economic conditions make fossil fuel use unusually expensive, and social conditions favor autonomy and local employment. Ecological conditions are likely to allow for harvesting a sustainable fuel source in a manner that enhances rather than detracts from ecological resilience, owing to the complex relationship between fire, forest succession, forest resources, fire suppression, and human settlements. Biomass fuels are likely to increase the long-term social and ecological resilience of village communities to externally-driven changes, including fluctuations in fossil fuel prices related to state, national, or international policies; variability in Alaska’s economic outlook, which might in turn affect subsidies; and changes in fire risk and fire management, driven by climate change and by state and federal fire budgets.

For all of these reasons, interior Alaska village communities are in a position to be at the forefront in developing biomass fuels programs. Villages selected based on our combined ecological and social model would almost certainly reap benefits from the transition. In addition, because of the existence of substantial economic and political infrastructure at the state and federal levels, Alaska’s rural communities are in a position to serve as pilot projects and leaders in a global movement toward rural biomass power.

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English Equivalents

When you know:	**Multiply by:**	**To find:**
Meters (m)	3.28	Feet
Kilometers (km)	0.621	Miles
Hectares (ha)	2.47	Acres
Liters (L)	0.265	Gallons (gal)
Kilograms (kg)	2.205	Pounds
Tonnes (t)	1.102	Tons
Tonnes per hectare (t/ha)	893	Pounds per acre
Square meters per hectare (m^2/ha)	4.37	Square feet per acre
Degrees Celsius (°C)	(1.8 × °C) + 32	Degrees Fahrenheit
Kilograms per cubic meter (kg/m^3)	0.0624	Pounds per cubic foot
Joules (J)	0.000948	British thermal units (Btu)
Kilowatts (kW)	1.34	Horsepower
Kilowatt-hours (kWh)	3412	British thermal units
Kilowatt-hours per tonne (kWh/t)	0.645	British thermal units per pound

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Appendix

Alaska communities

Community	Access	Population[a]	Electric utility[a]	Total households[a]	Average number in household	Median household income[a]	Population 16 and over
						Dollars	
Alatna and Allakaket	Koyukuk	122	Alaska Power Company	53	2.30	n/a	89
Aniak	Kuskokwim	532	Aniak Light & Power Company	174	3.29	41,875	398
Anvik	Yukon	101	AVEC	39	2.67	21,250	69
Beaver	Yukon	67	Beaver Joint Utilities	31	2.71	28,750	86
Evansville and Bettles	Koyukuk	51	Alaska Power Company	28	1.82	n/a	66
Central	Minor Road	102	Central Electric, Inc.	67	2.00	36,875	113
Chuathbaluk	Kuskokwim	105	Middle Kuskokwim Electric Cooperative	33	3.61	34,286	90
Circle	Minor Road	99	Circle Electric Utility	34	2.94	11,667	50
Crooked Creek	Kuskokwim	147	Middle Kuskokwim Electric Cooperative	38	3.61	17,500	90
Dot Lake	Major Road	29	Alaska Power Company	10	1.90	13,750	18
Eagle and Eagle Village	Minor Road	183	Alaska Power Company	90	2.03	n/a	140
Fort Yukon	Yukon	594	Gwitchyaa Zhee Utilities	225	2.62	29,375	449
Galena	Yukon	717	City of Galena	216	2.83	61,125	495
Grayling	Yukon	182	AVEC	51	3.80	21,875	105
Healy Lake	Minor River	34	Alaska Power Company	13	2.85	51,250	43
Holy Cross	Yukon	206	AVEC	64	3.55	21,875	165
Hughes	Koyukuk	72	Hughes Power & Light	26	3.00	24,375	50
Huslia	Koyukuk	269	AVEC	88	3.33	27,000	188
Kaltag	Yukon	211	AVEC	69	3.33	29,167	159
Koyukuk	Yukon	109	City of Koyukuk	39	2.59	19,375	68
Lime Village	Minor river	34	Lime Village Power System	19	1.79	n/a	n/a
Manley Hot Springs	Road	73	Manley Utility Company, Inc.	36	2.00	29,000	60
McGrath	Kuskokwim	367	McGrath Light & Power	145	2.77	43,056	286
Minto	Minor Road	207	AVEC	74	3.49	21,250	179
Nikolai	Minor River	121	Nikolai Light & Power Utility	40	2.50	15,000	60
Northway and Northway Village	Major Road	195	Alaska Power Company	62	3.15	n/a	159
Nulato	Yukon	320	AVEC	91	3.69	25,114	213
Red Devil	Kuskokwim	35	Middle Kuskokwim Electric Cooperative	17	2.82	10,938	29
Ruby	Yukon	190	City of Ruby	68	2.76	24,375	119
Shageluk	Minor River	132	AVEC	36	3.58	26,667	76
Sleetmute	Kuskokwim	78	Middle Kuskokwim Electric Cooperative	33	3.03	15,000	52
Stony River	Kuskokwim	54	Middle Kuskokwim Electric Cooperative	19	3.21	20,714	49
Takotna	Kuskokwim	47	Takotna Community Association Utilities	19	2.63	14,583	29
Tanana	Yukon	304	Tanana Power Company	121	2.55	29,750	210
Tetlin	Minor Road	129	Alaska Power Company	42	2.79	12,250	70
Tok	Major Road	1,439	Alaska Power Company	534	2.61	37,941	995

n/a = not available, AVEC = Alaska Village Electrical Cooperative.

[a] Data from ADCED 2005.

Alaska community fuel use and power generation

Community	Unemployed[a]	Fuel use (FY2004)[b]	Average price of diesel fuel (2004)[b]	Fuel costs	Installed capacity[c]	Power generated (2004)[b]	Average load	Average load/ installed capacity
		Gallons	*Dollars/gallon*	*Dollars*	*kW*	*kWh*	*kW*	
Alatna and Allakaket	20	53,773	2.19	117,763	430	648,861	74	0.17
Aniak	35	192,576	1.32	254,200	2,865	2,468,700	282	0.10
Anvik	11	38,474	1.32	50,786	337	469,023	54	0.16
Beaver	12	31,436	1.92	60,357	137	293,400	33	0.24
Evansville and Bettles	n/a	58,368	1.41	82,299	650	703,820	80	0.12
Central	8	50,104	1.22	61,127	640	501,896	57	0.09
Chuathbaluk	3	20,200	1.70	34,340	n/a	213,737	24	n/a
Circle	6	34,750	1.24	43,090	200	372,000	42	0.21
Crooked Creek	21	25,258	1.69	42,686	n/a	254,434	29	n/a
Dot Lake	2	n/a	n/a	n/a	325	n/a	n/a	n/a
Eagle and Eagle Village	25	58,474	1.20	70,169	477	781,344	89	0.19
Fort Yukon	52	207,698	1.66	344,779	2,400	2,840,000	324	0.14
Galena	32	724,076	1.46	1,057,151	6,000	9,466,799	1,081	0.18
Grayling	13	46,352	1.52	70,455	546	588,761	67	0.12
Healy Lake	5	14,339	1.25	17,924	105	152,986	17	0.17
Holy Cross	22	54,340	1.51	82,053	585	708,012	81	0.14
Hughes	3	37,325	3.27	122,053	323	n/a	n/a	n/a
Huslia	21	77,648	1.79	138,990	680	916,941	105	0.15
Kaltag	29	57,498	1.58	90,847	573	663,172	76	0.13
Koyukuk	12	20,830	1.89	39,369	244	353,250	40	0.17
Lime Village	n/a	9,101	4.44	40,408	77	99,263	11	0.15
Manley Hot Springs	4	26,772	1.14	30,520	480	294,120	34	0.07
McGrath	24	221,650	1.40	310,310	2,685	2,963,200	338	0.13
Minto	29	56,366	1.13	63,694	558	722,562	82	0.15
Nikolai	11	38,182	1.81	69,109	362	401,400	46	0.13
Northway and Northway Village	19	121,569	1.29	156,824	1,165	1,583,944	181	0.16
Nulato	52	85,982	1.59	136,711	897	1,148,831	131	0.15
Red Devil	4	14,490	1.83	26,517	173	126,434	14	0.08
Ruby	17	24,861	1.76	43,755	654	n/a	n/a	n/a
Shageluk	17	31,506	1.69	53,245	370	405,639	46	0.13
Sleetmute	8	25,314	1.69	42,781	208	229,258	26	0.13
Stony River	8	13,994	1.69	23,650	139	116,418	13	0.10
Takotna	0	28,219	1.72	48,537	297	248,705	28	0.10
Tanana	31	104,270	1.34	139,722	1,456	1,378,060	157	0.11
Tetlin	15	40,782	1.46	59,542	280	473,310	54	0.19
Tok	111	861,311	1.25	1,076,639	4,960	12,518,973	1,429	0.29

n/a = not available.

[a] Data from ADCED 2005.

[b] Data from AEA 2004; nonfuel expenses for Alaska Village Electrical Cooperative (AVEC) villages are calculated at the average rate for the cooperative.

[c] Data from UAA 2003.

Alaska community power costs

Community	Power per capita	Total nonfuel expenses (2004)[a]	PCE payments (2004)[a]	Residential rate without PCE[a]	Residential rate after subsidy[a]	Real cost of power	Real cost
	kWh	*Dollars*	*Dollars*	*Dollars per kWh*	*Dollars per kWh*	*Dollars*	*Dollars per kWh*
Alatna and Allakaket	5319	83,371	84,787	0.48	0.27	201,134	0.31
Aniak	4640	735,336	168,391	0.49	0.32	989,536	0.40
Anvik	4644	117,256	47,007	0.46	0.28	168,041	0.36
Beaver	4379	n/a	17,620	0.42	0.26	n/a	n/a
Evansville and Bettles	13 800	74,967	34,316	0.41	0.20	157,266	0.22
Central	4921	148,543	63,922	0.51	0.28	209,670	0.42
Chuathbaluk	2036	69,482	37,319	0.56	0.32	103,822	0.49
Circle	3758	86,608	37,593	0.50	0.27	129,698	0.35
Crooked Creek	1731	68,424	44,743	0.56	0.32	111,110	0.44
Dot Lake	n/a	15,551	9,751	0.23	0.17	n/a	n/a
Eagle and Eagle Village	4270	128,692	65,932	0.41	0.26	198,861	0.25
Fort Yukon	4781	362,638	142,391	0.34	0.23	707,417	0.25
Galena	13 203	n/a	124,170	0.25	0.18	n/a	n/a
Grayling	3235	147,190	69,919	0.44	0.28	217,645	0.37
Healy Lake	4500	43,540	13,490	0.40	0.24	61,464	0.40
Holy Cross	3437	177,003	83,911	0.42	0.27	259,056	0.37
Hughes	n/a	38,238	27,077	0.51	0.30	160,291	n/a
Huslia	3409	229,235	105,966	0.46	0.28	368,225	0.40
Kaltag	3143	165,793	70,921	0.46	0.28	256,640	0.39
Koyukuk	3241	18,747	12,804	0.45	0.36	58,116	0.16
Lime Village	2920	62,517	11,556	0.80	0.56	102,925	1.04
Manley Hot Springs	4029	103,826	34,735	0.60	0.36	134,346	0.46
McGrath	8074	561,359	162,757	0.43	0.29	871,669	0.29
Minto	3491	180,641	77,094	0.40	0.26	244,334	0.34
Nikolai	3317	42,004	47,474	0.50	0.34	111,113	0.28
Northway and Northway Village	8123	88,293	85,818	0.43	0.25	245,117	0.15
Nulato	3590	287,208	138,928	0.44	0.28	423,919	0.37
Red Devil	3612	68,461	16,839	0.56	0.32	94,978	0.75
Ruby	n/a	15,999	19,635	0.46	0.33	59,754	n/a
Shageluk	3073	101,410	42,971	0.46	0.28	154,655	0.38
Sleetmute	2939	69,424	41,057	0.56	0.32	112,205	0.49
Stony River	2156	69,067	16,594	0.56	0.32	92,717	0.80
Takotna	5292	33,897	20,849	0.48	0.32	82,434	0.33
Tanana	4533	326,127	109,284	0.49	0.31	465,849	0.34
Tetlin	3669	36,882	48,354	0.47	0.27	96,424	0.20
Tok	8700	671,543	212,194	0.23	0.17	1,748,182	0.14

Note: PCE = Power Cost Equalization program; n/a = not available.

[a] Data from AEA 2004; nonfuel expenses for Alaska Village Electrical Cooperative (AVEC) villages are calculated at the average rate for the cooperative.

Alaska community power cost per household and biomass system cost

			Estimated installed cost of biomass system ($1,849/kw)		
	Real cost of power per household	**Real cost of power per household as percentage of median household income**	**To meet 50 percent of mean load**	**To meet mean load**	**To replace 100 percent of existing generation capacity**
	Dollars	*Percent*	*Dollars*		
Alatna and Allakaket	n/a	n/a	68,479	136,957	795,070
Aniak	6,120	14.6	260,538	521,076	5,297,385
Anvik	4,442	20.9	49,499	98,998	623,113
Beaver	n/a	n/a	30,964	61,929	253,313
Evansville and Bettles	n/a	n/a	74,279	148,557	1,201,850
Central	4,111	11.1	52,968	105,937	1,183,360
Chuathbaluk	3,569	10.4	22,557	45,114	n/a
Circle	3,852	33.0	39,260	78,519	369,800
Crooked Creek	2,729	15.6	26,852	53,704	n/a
Dot Lake	n/a	n/a	n/a	n/a	600,925
Eagle and Eagle Village	n/a	n/a	82,460	164,921	881,973
Fort Yukon	3,120	10.6	299,724	599,447	4,437,600
Galena	n/a	n/a	999,093	1,998,186	11,094,000
Grayling	4,544	20.8	62,136	124,272	1,009,554
Healy Lake	5,152	10.1	16,146	32,291	194,145
Holy Cross	4,464	20.4	74,721	149,442	1,081,665
Hughes	6,679	27.4	n/a	n/a	597,227
Huslia	4,558	16.9	96,771	193,542	1,257,320
Kaltag	4,050	13.9	69,989	139,978	1,059,477
Koyukuk	1,381	7.1	37,281	74,562	451,156
Lime Village	n/a	n/a	10,476	20,952	142,373
Manley Hot Springs	3,681	12.7	31,040	62,081	887,520
McGrath	6,579	15.3	312,726	625,452	4,964,565
Minto	4,119	19.4	76,257	152,513	1,031,742
Nikolai	2,296	15.3	42,362	84,725	669,338
Northway and Northway Village	n/a	n/a	167,164	334,328	2,154,085
Nulato	4,888	19.5	121,244	242,487	1,658,553
Red Devil	7,652	70.0	13,343	26,687	319,877
Ruby	868	3.6	n/a	n/a	1,209,246
Shageluk	4,194	15.7	42,810	85,619	684,130
Sleetmute	4,359	29.1	24,195	48,390	384,592
Stony River	5,512	26.6	12,286	24,573	257,011
Takotna	4,613	31.6	26,247	52,495	549,153
Tanana	3,908	13.1	145,436	290,871	2,692,144
Tetlin	2,085	17.0	49,951	99,903	517,720
Tok	3,171	8.4	1,321,209	2,642,418	9,171,040

n/a = not available.

Alaska community power system annual costs

Community	Annual operating cost of biomass system ($0.17/kWh)		Annual diesel fuel cost offset		Annual nonfuel cost offset		Estimated annual savings (compared to real cost of diesel system), mean load	Per capita annual savings, mean load
	50 percent of mean load	Mean load	50 percent of mean load	Mean load	50 percent of mean load	Mean load		
				Dollars				
Alatna and Allakaket	44,123	66,184	47,105	70,658	8,337	20,843	25,317	208
Aniak	167,872	251,807	101,680	152,520	73,534	183,834	84,547	159
Anvik	31,894	47,840	20,314	30,471	11,726	29,314	11,945	118
Beaver	19,951	29,927	24,143	36,214	n/a	n/a	n/a	n/a
Evansville and Bettles	47,860	71,790	32,920	49,379	7,497	18,742	-3,669	-72
Central	34,129	51,193	24,451	36,676	14,854	37,136	22,618	222
Chuathbaluk	14,534	21,801	13,736	20,604	6,948	17,371	16,173	154
Circle	25,296	37,944	17,236	25,854	8,661	21,652	9,562	97
Crooked Creek	17,302	25,952	17,074	25,612	6,842	17,106	16,765	114
Dot Lake	n/a	n/a	n/a	n/a	1,555	3,888	n/a	n/a
Eagle and Eagle Village	53,131	79,697	28,068	42,101	12,869	32,173	-5,423	-30
Fort Yukon	193,120	289,680	137,911	206,867	36,264	90,660	7,847	13
Galena	643,742	965,613	422,860	634,291	n/a	n/a	n/a	n/a
Grayling	40,036	60,054	28,182	42,273	14,719	36,798	19,017	104
Healy Lake	10,403	15,605	7,170	10,754	4,354	10,885	6,035	177
Holy Cross	48,145	72,217	32,821	49,232	17,700	44,251	21,266	103
Hughes	n/a	n/a	n/a	n/a	3,824	9,560	n/a	n/a
Huslia	62,352	93,528	55,596	83,394	22,924	57,309	47,175	175
Kaltag	45,096	67,644	36,339	54,508	16,579	41,448	28,313	134
Koyukuk	24,021	36,032	15,747	23,621	1,875	4,687	-7,724	-71
Lime Village	6,750	10,125	16,163	24,245	6,252	15,629	29,749	875
Manley Hot Springs	20,000	30,000	12,208	18,312	10,383	25,957	14,268	195
McGrath	201,498	302,246	124,124	186,186	56,136	140,340	24,279	66
Minto	49,134	73,701	25,477	38,216	18,064	45,160	9,675	47
Nikolai	27,295	40,943	27,644	41,466	4,200	10,501	11,024	91
Northway and Northway Village	107,708	161,562	62,730	94,094	8,829	22,073	-45,395	-233
Nulato	78,121	117,181	54,685	82,027	28,721	71,802	36,648	115
Red Devil	8,598	12,896	10,607	15,910	6,846	17,115	20,129	575
Ruby	n/a	n/a	n/a	n/a	1,600	4,000	n/a	n/a
Shageluk	27,583	41,375	21,298	31,947	10,141	25,352	15,924	121
Sleetmute	15,590	23,384	17,112	25,668	6,942	17,356	19,640	252
Stony River	7,916	11,875	9,460	14,190	6,907	17,267	19,582	363
Takotna	16,912	25,368	19,415	29,122	3,390	8,474	12,228	260
Tanana	93,708	140,562	55,889	83,833	32,613	81,532	24,803	82
Tetlin	32,185	48,278	23,817	35,725	3,688	9,221	-3,332	-26
Tok	851,290	1,276,935	430,656	645,983	67,154	167,886	-463,066	-322

n/a = not available.

Alaska community years to break even on capital investment

Community	Years to pay back capital (mean load, no carbon credits)	Years to pay back capital (mean load, CCX)	Years to pay back capital (mean load, ECX)	Estimated annual savings compared to real costs of diesel system, ½ mean load	Years to pay back capital (½ mean load, no carbon credits)	Years to pay back capital (½ mean load, CCX)	Years to pay back capital (½ mean load, ECX)	Potential annual carbon credits	
								CCX prices	ECX prices
	- - - - - - - - - *Years* - - - - - - - -			*Dollars*	- - - - - - - - - *Years* - - - - - - - - -			*Dollars*	
Alatna and Allakaket	5.4	5.3	4.3	11,320	6.0	5.9	4.4	860	10,862
Aniak	6.2	6.0	4.8	7,342	35.5	30.4	11.4	3,081	38,900
Anvik	8.3	8.0	6.0	146	338.4	126.1	15.2	616	7,772
Beaver	n/a	n/a	n/a	n/a	n/a	n/a	n/a	503	6,350
Evansville and Bettles	-40.5	-47.8	43.6	-7,444	-10.0	-10.5	-27.2	934	11,790
Central	4.7	4.6	3.7	5,176	10.2	9.6	5.7	802	10,121
Chuathbaluk	2.8	2.8	2.4	6,150	3.7	3.6	2.9	323	4,080
Circle	8.2	7.9	5.7	601	65.3	47.7	11.5	556	7,020
Crooked Creek	3.2	3.2	2.7	6,615	4.1	4.0	3.1	404	5,102
Dot Lake	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Eagle and Eagle Village	-30.4	-33.9	99.1	-12,195	-6.8	-7.0	-11.0	936	11,812
Fort Yukon	76.4	60.9	18.2	-18,945	-15.8	-17.0	-138.6	3,323	41,955
Galena	n/a	n/a	n/a	n/a	n/a	n/a	n/a	11,585	146,263
Grayling	6.5	6.4	5.0	2,865	21.7	19.7	9.4	742	9,363
Healy Lake	5.4	5.2	4.2	1,120	14.4	13.3	7.1	229	2,896
Holy Cross	7.0	6.9	5.4	2,377	31.4	27.4	11.0	869	10,977
Hughes	n/a	n/a	n/a	n/a	n/a	n/a	n/a	597	7,540
Huslia	4.1	4.0	3.4	16,168	6.0	5.8	4.3	1,242	15,685
Kaltag	4.9	4.8	4.0	7,822	8.9	8.5	5.6	920	11,615
Koyukuk	-9.7	-9.9	-14.3	-6,399	-5.8	-6.0	-7.9	333	4,208
Lime Village	0.7	0.7	0.7	15,665	0.7	0.7	0.6	146	1,838
Manley Hot Springs	4.4	4.3	3.5	2,590	12.0	11.2	6.5	428	5,408
McGrath	25.8	23.7	12.2	-21,238	-14.7	-15.8	-94.0	3,546	44,773
Minto	15.8	14.9	9.2	-5,593	-13.6	-14.6	-73.4	902	11,386
Nikolai	7.7	7.4	5.4	4,549	9.3	8.8	5.5	611	7,713
Northway and Northway Village	-7.4	-7.6	-10.9	-36,149	-4.6	-4.7	-6.3	1,945	24,557
Nulato	6.6	6.5	5.2	5,285	22.9	20.8	9.9	1,376	17,368
Red Devil	1.3	1.3	1.2	8,855	1.5	1.5	1.3	232	2,927
Ruby	n/a	n/a	n/a	n/a	n/a	n/a	n/a	398	5,022
Shageluk	5.4	5.3	4.3	3,856	11.1	10.6	6.7	504	6,364
Sleetmute	2.5	2.4	2.1	8,465	2.9	2.8	2.3	405	5,113
Stony River	1.3	1.2	1.2	8,450	1.5	1.4	1.3	224	2,827
Takotna	4.3	4.2	3.4	5,892	4.5	4.3	3.2	452	5,700
Tanana	11.7	11.3	7.8	-5,207	-27.9	-32.0	45.2	1,668	21,063
Tetlin	-30.0	-34.0	62.0	-4,680	-10.7	-11.3	-36.1	653	8,238
Tok	-5.7	-5.8	-7.4	-353,480	-3.7	-3.8	-4.7	13,781	173,985

Note: CCX = Chicago Climate Exchange, ECX = European Climate Exchange, n/a = not available. Negative years for payback indicate that payback will never occur; in such cases the transition to biomass fuels would not be profitable.

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