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Life Cycle Assessment of Wood Energy for Residential Heating—Opportunities for Wood Pellet Production in Southeast Alaska

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Abstract

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Southeast Alaska is a remote area, located approximately 700 miles north of Seattle, Washington. Most of the region's goods are imported by barge, creating logistical and economic challenges not faced by many other parts of the United States. In this context, we used life cycle assessment (LCA) to evaluate the potential environmental impact on global warming potential (GWP) of converting home heating systems from heating oil to wood pellets in southeast Alaska. Once the current level (status quo) was established, we evaluated imported pellet utilization at 20-, 40- and 100-percent penetration into the residential heating oil markets. We also modeled local production of wood pellets in southeast Alaska, assuming a 20-percent penetration. Our research found that reductions in GWP resulting from the conversion to wood pellets ranged from 10 to 51 percent, with the greatest reductions being associated with the highest levels of imported pellets. The scenario of producing wood pellets in southeast Alaska to meet local needs had a reduction in GWP of 14 percent (versus the status quo).

Keywords: Pellets, wood energy, residential heating, global warming potential, water transportation.

Introduction

Climate change is an environmental issue of worldwide significance that has focused attention on the quantity of greenhouse gases released into the environment from the burning of fossil fuels. When planning wood-energy applications, it is critical to quantify the complete environmental impacts of harvesting, transporting, and combusting woody biomass for energy production, then compare these impacts to those of alternative fuel sources (often fossil fuels). Within this context, the conversion from fossil-fuel energy systems to biomass fuel sources is gaining momentum in southeast Alaska. Until recently, the increasing cost of petroleum-based heating fuel has biomass fuels such as wood pellets, wood chips, and firewood more cost-competitive, creating economic advantages for biomass. This is especially true in southeast Alaska, given the high cost of transportation to import heating oil into the region. Over the past 10 years, more than a dozen small-industrial-scale wood-energy systems have been installed in southeast Alaska. Although most of these systems are small (typically burning fewer than 100 cords of wood or 1,000 tons of chips per year), their cumulative impact motivated us to conduct life cycle assessment (LCA) research to quantify important decision variables as new wood-energy installations are brought online and new fuel-supply chains are established. To our knowledge, this research is the first to perform LCA on regionwide use of wood energy for residential heating that includes a substantial transportation component.

Southeast Alaska is a rugged and sparsely populated island chain, rich in natural resources but isolated from the highway and rail systems that serve the mainland areas of North America. A limited industrial base makes it necessary to import almost all goods into the region, primarily by barge. In this report, we developed a baseline analysis that compares the environmental impact of heating oil versus wood pellets for residential heating. Total life cycle emissions result from the energy needed to collect, transport, process, and combust wood fuels. Accounting for these energy flows is critical to comparing alternatives in an LCA, such as the use of heating oil versus wood for residential heating.

Life cycle assessment quantifies every stage in a product's life and its interaction with the environment (fig. 1). The outcomes of an LCA can accurately target the source of environmental impacts throughout a product's life. LCAs can be used to support development of more "environmentally friendly" products or sustainable production methods, and to provide insights regarding raw material conservation whether for wood energy or other products. Rigorous, quantitative LCAs can be valuable management tools to help formulate policies promoting environmental gains. Such assessments have evolved as an internationally accepted method to

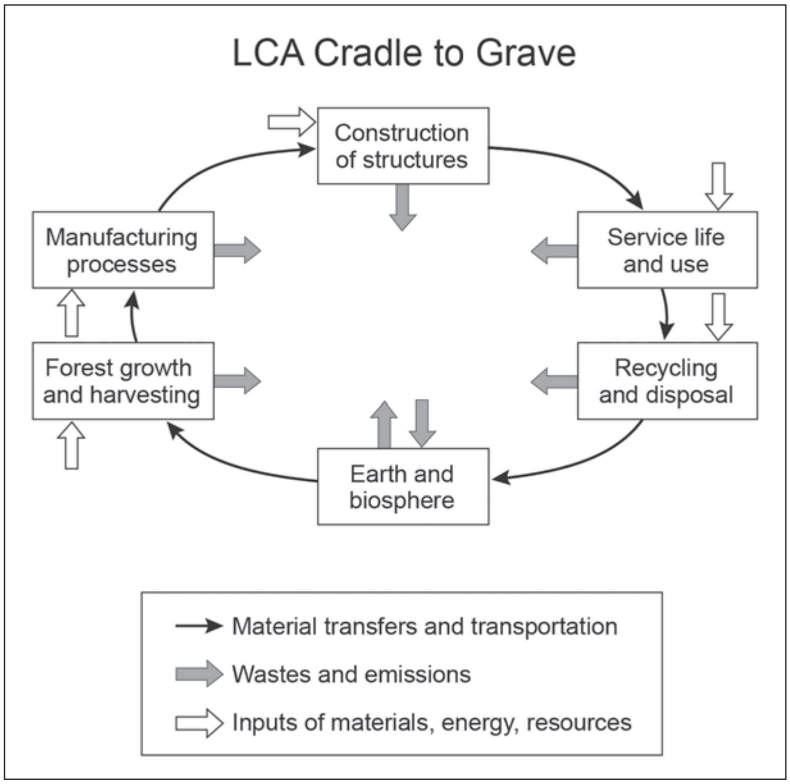

Figure 1—Life cycle of a biological material.

analyze complex impacts and outputs of a product or process and their environmental effects. As defined by the International Standards Organization (ISO 2006), an LCA is a multiphase process consisting of a life cycle inventory (LCI), life cycle impact assessment (LCIA), and life cycle interpretation. In this report, we used LCA to evaluate residential heating scenarios that included heating oil, cordwood, and wood pellets.

The LCI is an objective, data-based process of quantifying energy and raw material requirements, air emissions, waterborne effluents, solid waste, and other environmental releases occurring within the system boundaries. The LCIA process characterizes environmental releases identified in the LCI into impact categories such as global warming, acidification, carcinogenics, respiratory effects, eutrophication, ozone depletion, ecotoxicity, and smog. The tool for the reduction and assessment of chemical and other environmental impacts (TRACI) can be used to assess LCA environmental impacts, including those of pellet and heating oil production for the southeast Alaska model. This tool is a midpoint method developed by the U.S. Environmental Protection Agency (EPA) specifically for U.S. locations.

Research Objectives

Our primary objective was to compare the environmental impacts of current levels of heating oil and cordwood use (the status quo) with the impact of using wood pellets as a replacement for fuel oil for residential heating in southeast Alaska. The emphasis of this analysis is the impact on the relative global warming potential (GWP) of these alternatives. Specifically, our research objectives were to develop a cradle-to-grave (extraction to combustion) LCA on the environmental impacts of: (1) importing wood pellets into southeast Alaska from the Pacific Northwest, versus

(2) local production of wood pellets in southeast Alaska to supplement current cordwood use.

We compared heating oil, current cordwood use in southeast Alaska (the status quo), and the substitution of heating oil versus use of wood pellets. Additional assessments were performed on the availability of resources to sustain pellet production in southeast Alaska and meet local needs without importing pellets.

Residential Heating in Southeast Alaska

Southeast Alaska is characterized by remote communities, long transportation distances, high energy costs, and long heating seasons. Increased awareness among area residents of biomass energy and its potential cost savings has led to greater demand for heating products such as wood pellets, chips, and firewood. Wood energy has primarily been used in thermal applications (as opposed to electric power generation), and now includes several small-scale projects to heat governmental or institutional buildings, in addition to residential use. Several initiatives, including the southeast Alaska "bioenergy roadmap," as well as funding initiatives to conduct feasibility studies, have provided support to potential wood-energy users.

Residential heating could soon benefit from forestry-related alliances in southeast Alaska. Viking Lumber Company (a wood products mill) and Sealaska Corporation (an Alaska Native corporation) have collaborated to promote regional biomass projects. As is commonly accepted, they have determined that the lowest cost wood feedstocks would come from lumber manufacturing residues. Aided by declining pulpwood markets, an estimated 25,000 green tons of wood residues would be available for wood pellet production regionally (Sealaska 2010). In addition to sawmill residues, higher cost woody feedstocks could be obtained from forest operations, including improved timber harvest log utilization and silvicultural treatments.

Residential heating in southeast Alaska includes several fuel types (table 1). Heating oil represents the predominant use, with 64 percent of households,

Table 1—Current fuel use and household use for residential heating in southeast Alaska

Community	Southeast Alaska households		Fuel type								
			Utility gas	LP gas	Electricity	Heating oil	Coal	Wood	Solar energy	Other	None
	Number	*Percentage of total*	*Number of households*								
Ketchikan	5,367	19.9	96	150	1,152	3,513	—	389	—	58	9
Wrangell	1,160	4.3	24	22	392	422	—	287	—	11	2
Petersburg	1,671	6.2	77	17	401	900	—	273	—	3	—
Sitka	3,623	13.5	37	159	1,058	2,121	5	209	—	25	9
Juneau	12,323	45.8	225	347	2,688	8,414	12	501	—	96	40
Hoonah	999	3.7	31	22	4	651	—	282	5	4	—
Haines	1,139	4.2	46	—	25	687	—	381	—	—	—
Skagway	395	1.5	17	23	8	313	—	30	—	4	—
Prince of Wales Island	250	0.9	—	13	4	108	—	121	—	4	—
Total	26,927	100	553	753	5,732	17,129	17	2,473	5	205	60
Percentage of total			2.1	2.8	21.3	63.6	0.06	9.2	0.02	0.76	0.22

LP = liquefied petroleum.

Source: USDC CB (2012).

followed by electricity, wood, and gas (including liquefied petroleum (LP) (21, 9, and 5 percent of households, respectively) (USDC CB 2012). Southeast Alaska's largest city, Juneau, contains 46 percent of the total households in southeast Alaska, and 68 percent of these are heated with heating oil. The largest percentage of wood use based on population is on Prince of Wales Island, where 48 percent of households use wood for home heating. Prince of Wales Island, however, has a relatively small population. Across southeast Alaska, households heating with heating oil outnumber those heated with biomass by nearly to 7:1 (table 2).

National and Regional Wood Pellet Production

In 2009, North America produced about 7 million tons of wood pellets, of which almost 5 million tons were exported to Europe (Pirraglia et al. 2010). In contrast, U.S. wood pellet producers supplied domestic markets with nearly 80 percent of their production. Wood pellet production in the lower 48 United States is centered near large sources of wood residue from primary wood products facilities.

In southeast Alaska, forest products production infrastructure is generally lacking, allowing only small volumes of pellets to be produced economically. Currently, there is one small wood pellet manufacturer in southeast Alaska, producing about 800 tons annually. Expanded pellet production in the region will

Table 2—Current energy use by household in southeast Alaska for heating oil and biomass

Community	Average annual energy use	Households in southeast Alaska		Number of households heating with fuel type		Percentage of households heating with fuel type	
	BTUs per household ($\times 10^6$)	*Number*	*Percentage of total*	*Heating oil*	*Biomass*	*Heating oil*	*Biomass*
Ketchikan	71.56	5,367	19.9	3,513	389	20.5	15.7
Wrangell	77.07	1,160	4.3	422	287	2.5	11.6
Petersburg	77.07	1,671	6.2	900	273	5.3	11.0
Sitka	72.24	3,623	13.5	2,121	209	12.4	8.5
Juneau	85.75	12,323	45.8	8,414	501	49.1	20.3
Hoonah	86.44	999	3.7	651	282	3.8	11.4
Haines	86.44	1,139	4.2	687	381	4.0	15.4
Skagway	86.44	395	1.5	313	30	1.8	1.2
Prince of Wales Island	71.56	250	0.9	108	121	0.6	4.9
Total	714.60	26,927	100	17,129	2,473	100	100

BTUs = British thermal units.

Source: Brackley et al. (2010).

require an expansion of the local forest products industry to supply waste residues from lumber manufacturing (including utility logs), combined with future opportunities to improve forests through thinning and other silvicultural practices. The possibility of establishing an economically viable local pellet mill is tenuous at best.

Wood Pellet Market Potential for Southeast Alaska

An estimated 2,473 households in southeast Alaska currently use firewood for heating (Brackley et al. 2010). This demand translates to more than 17,000 tons of wood annually, assuming a wood moisture content of 14.5 percent and average woodstove efficiency of 75 percent. However, retail sales of wood pellets in Alaska have thus far met only a fraction of this demand. An estimated 32 retail stores in Alaska sold 2,359 tons of bagged pellets in 2009 (Sealaska 2010). For wood pellets to penetrate even 20 percent of the heating oil market in southeast Alaska (3,426 households), a minimum of 22,000 tons of pellets annually would be required (based on pellet moisture content of 6.5 percent and average stove efficiency of 75 percent). Current regional pellet consumption is roughly 10 percent of this level.

As new wood-energy facilities become established in southeast Alaska, the type and form of wood fuel used will become an important determinant of delivered fuel cost, and in turn project economics. Some of the possible wood procurement strategies for southeast Alaska include: (1) using harvesting residues from forestry activities, (2) identifying firewood harvesting scenarios, or (3) importing wood pellets from the lower 48 states. As economies of scale become more fully developed, a wood pellet or other densified fuel facility could become established in southeast Alaska.

Prince of Wales Island, the largest land mass in the Alexander Archipelago (fig. 2), is the site of the largest sawmill in southeast Alaska, has extensive forest resources, and also has a well-developed road network. Our model considers Prince of Wales Island to be the region's optimal location for pellet production, despite being located some distance from population centers such as Juneau and Sitka.

Because most markets in southeast Alaska can be served only by ship or air, many goods (including wood fuel) are more economical to import than to produce locally. This is likely to remain so until a wood-products infrastructure develops, one that is capable of processing the second-growth timber resources of the Tongass National Forest, in tandem with public acceptance of this harvest. The costs of importing pellets 700 miles from Seattle appear high unless they are compared with the high cost of producing goods within southeast Alaska, which in many cases can be even higher.

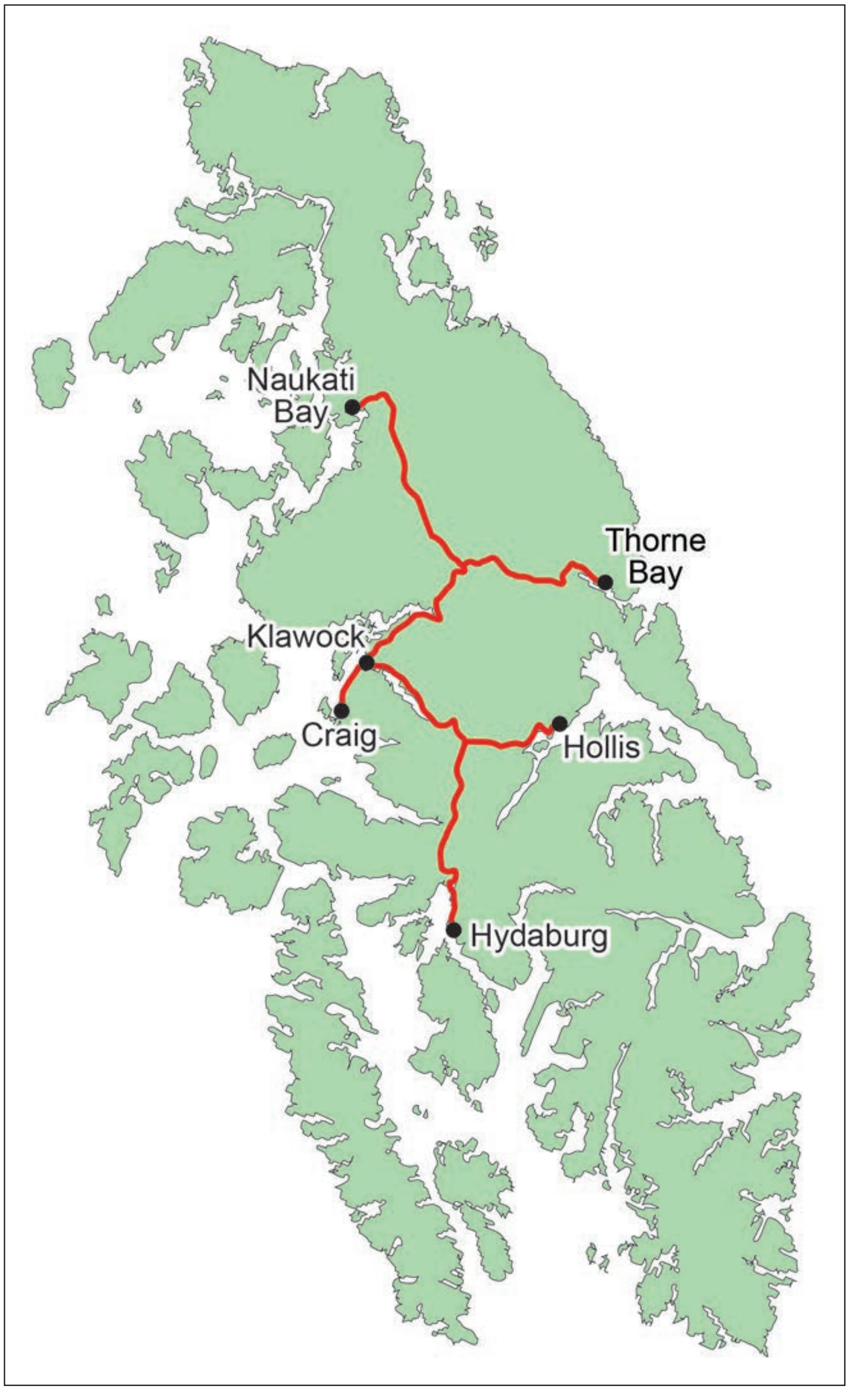

Figure 2—Map of Prince of Wales Island communities and primary roads.

Background—Wood Pellet Production

Wood pellets are a renewable heating fuel produced from dried, compressed woody biomass, most commonly from primary and secondary wood manufacturing residues. Nearly 1 million U.S. homes use wood pellets for heat in free-standing stoves, fireplace inserts, furnaces, and boilers (Puettmann et al. 2015). Wood pellets are also used in larger scale applications such as schools, prisons, and government buildings. The Premium Grade Pellet Standard specifies a maximum inorganic ash content of 1 percent, a minimum specific gravity of 0.64 (40 pounds per cubic foot), and a maximum fines content of 0.5 percent by weight (PFI 2015). Standard Grade Pellets include the same criteria for fines, specific gravity, and dimensions but allow maximum ash content of 3 percent by weight. The energy content of wood pellets is approximately 8,000 to 8,500 BTUs per pound higher heating value depending on the composition of the wood and bark. Wood pellets are normally sold in 40-lb bags through local retailers.

Functional Units

Establishing the functional units is an important part of an LCA to allow for meaningful comparisons between different materials and alternatives. Functional units for residential fuel use in southeast Alaska are based on household annual energy requirements and higher heating values for each fuel used (cordwood, heating oil, or wood pellets) (table 3).

System Boundary—Cordwood

The system boundary for cordwood involves individuals harvesting the wood for personal use. It is assumed that either standing trees are felled or downed timber is used. Our model assumed that all cordwood (firewood) was processed using chainsaws, then hand-hauled to personal vehicles for transport to households (fig 3).

Table 3—Functional units for residential heating fuels used in southeast Alaska

Fuel type	Higher heating value	Factor	Functional unit	Units	Moisture content
					Percent
Cordwood	7,398	0.75	5,549	BTUs per pound	14.5
Heating oil	139,000	0.78	108,000	BTUs per gallon	—
Wood pellets	8,200	0.75	6,150	BTUs per pound	6.5

BTUs = British thermal units.

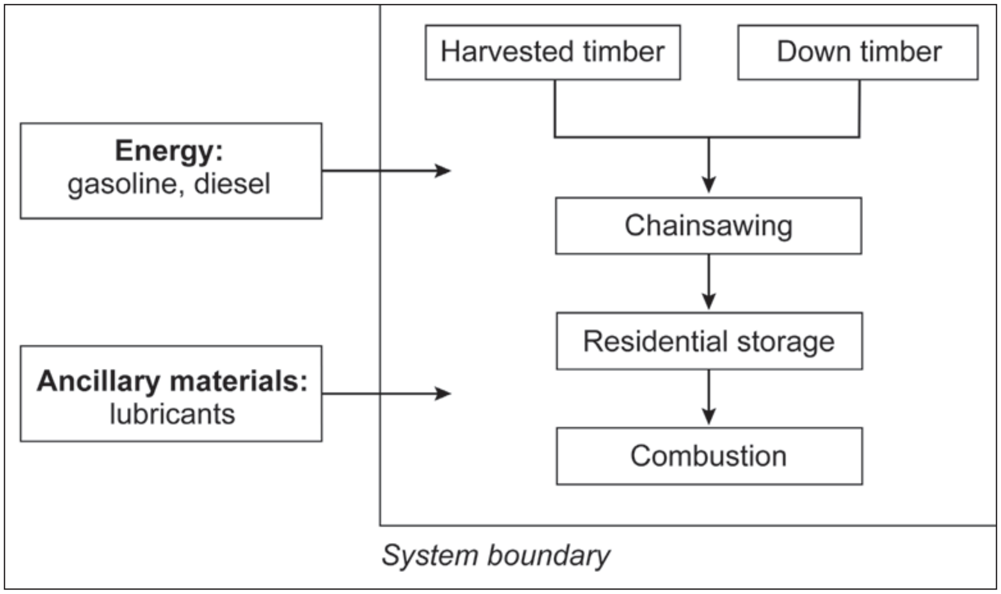

Figure 3—Cordwood life cycle assessment system boundary for residential heating in southeast Alaska.

System Boundary—Heating Oil

The system boundary for heating oil begins at extraction and ends with heating fuel combusted in residential oil heaters. We assumed that 100 percent of the heating oil was pumped from wells in Alaska, then delivered via pipeline to Valdez for loading onto ocean tankers, then shipped to the Seattle area for refining. The weighted average distance based on production used was 1,439 miles (2315 km). We assumed that heating oil would be shipped back to southeast Alaska (to the port of Ketchikan), reloaded onto smaller barges, and then transported to one of eight destination communities. The final step in this process would be truck delivery to individual households (often 15 miles or less).

System Boundary—Wood Pellet Production (Imported)

Two upstream feedstocks were used for the wood pellet production model; whole logs and sawmill residues (typically bark, slabs, edgings, and sawdust) (fig. 4). In the Pacific Northwest model, with pellet feedstocks originating from whole log chipping, the system boundary began with forest regeneration (Johnson et al. 2005) and ended with premium wood pellets. Upstream processes included planting seedlings, forest site preparation, fertilization, thinning, harvest, and log transportation for chipping to the pellet manufacturer (Johnson et al. 2005). For pellet feedstocks collected from sawmill residues, upstream processes for harvesting and lumber production and transportation of residues to the pellet mill are included. Pellet mill

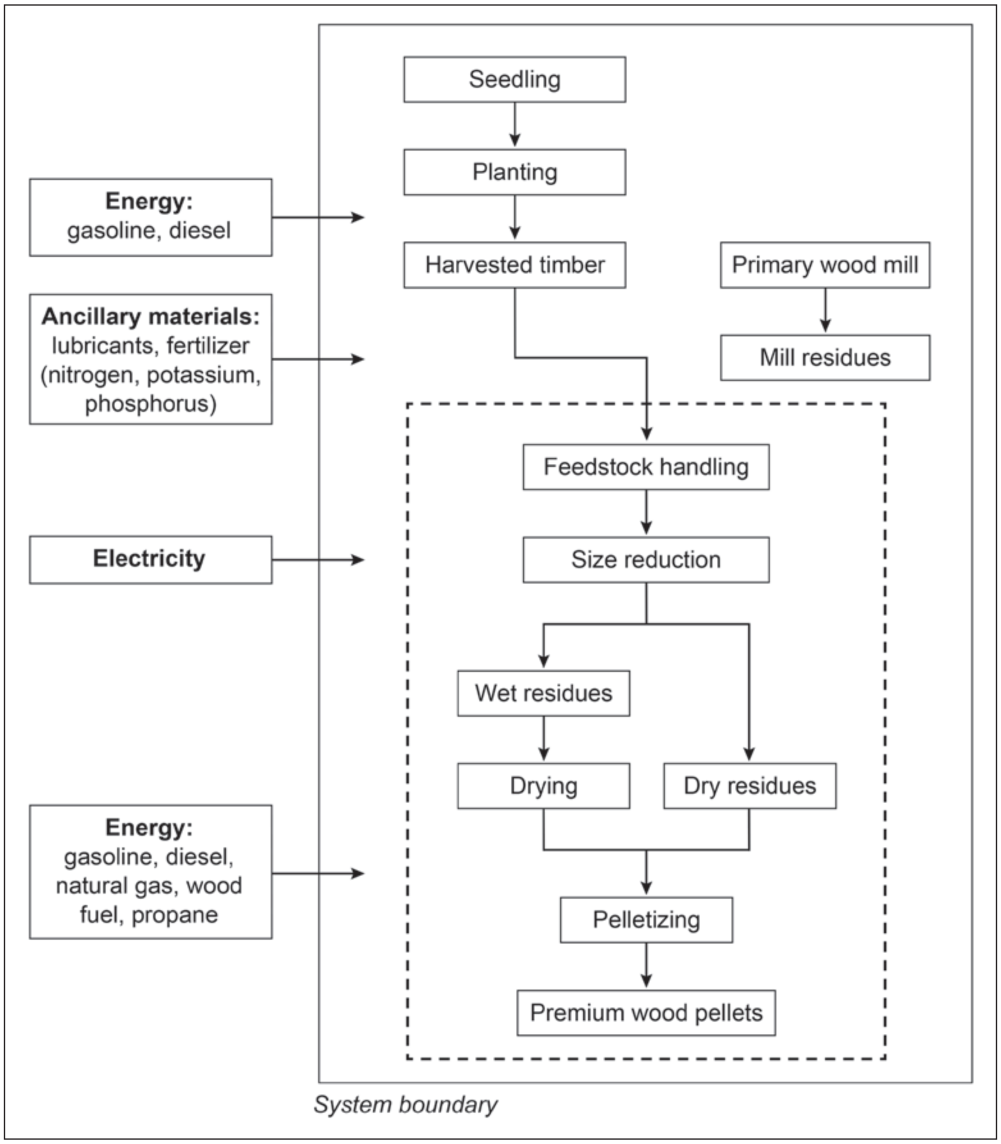

Figure 4—Life cycle assessment system boundary for imported wood-pellet production.

production includes unit processes for feedstock handling, size reduction, drying, screening, pelletizing, bagging, and pellet transport to the Port of Seattle (fig. 4). Our model assumed that pellets were transported by barge to the port of Ketchikan, then shipped by barge to one of eight destination communities, followed by road transport to retailers and finally end users.

System Boundary—Wood Pellet Production (Local)

For premium wood pellets produced in southeast Alaska, we assumed that feedstocks would be obtained from either sawmill residues or whole logs (lower grade logs from sort yards or utility-grade logs from sawmills (fig. 5). In this model, the

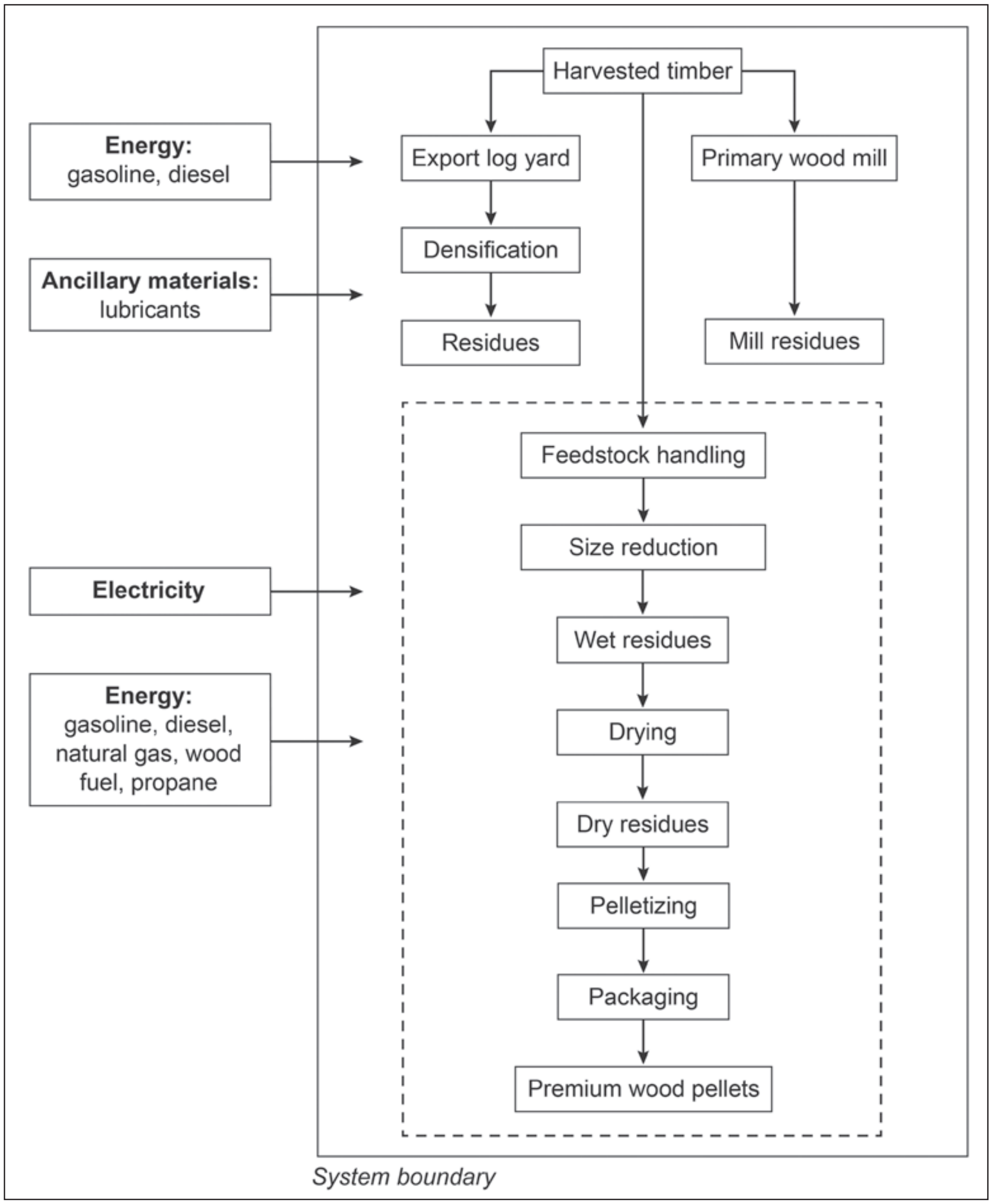

Figure 5—System boundary for southeast Alaska pellet production.

whole-log system boundary began with harvesting and ended with premium wood pellets. Pellet feedstocks collected from sawmill residues include the upstream processes of harvesting, lumber production, and transportation of residues to the pellet mill. All sawmill and whole-log chipping residues are considered to be green (i.e., undried). Our model assumed that pellet-mill production would include the following operations: feedstock handling, size reduction, drying, screening, pelletizing, bagging, and transportation to residential destinations (fig. 5).

Methods

Once the status quo usage of heating oil and cordwood was established, our scenarios assumed that pellet manufacture occurred either in the Seattle, Washington, area or in southeast Alaska. Because current wood pellet use in southeast Alaska is assumed to be minimal, we simulated changes to the status quo at pellet usage levels of 20, 40, and 100 percent penetration using imported pellets (table 4). We also modeled 20-percent market penetration of the heating oil market for residential heating based on pellets produced in southeast Alaska.

Residential heating was evaluated in nine communities: Haines, Hoonah, Juneau, Ketchikan, Petersburg, Prince of Wales Island, Sitka, Skagway, and Wrangell. Residential energy requirements are based on several interrelated variables, including quality of construction, amount and type of insulation, size of residence, average temperature, type of fuel used for heating, and type and efficiency of the heating system (Brackley et al. 2010). Our model is based on the average annual home heating requirements for each region as determined by the number of housing units for each community (table 5).

Nearly half the households in southeast Alaska are located in Juneau (46 percent of total), while Prince of Wales Island has the fewest, spread over several communities (1 percent of total). The highest heating demands are for households

Table 4—Life cycle assessment modeling scenarios for energy system comparisons

Scenario	Cordwood use	Wood pellet use[a]	Wood pellet source	Heating oil use[b]
1	Current (status quo)	0	NA	100
2	Current (status quo)	20	Imported (from Pacific Northwest)	80
3	Current (status quo)	40	Imported (from Pacific Northwest)	60
4	Current (status quo)	100	Imported (from Pacific Northwest)	0
5	Current (status quo)	20	Locally produced (southeast Alaska)	80

NA = not applicable.

[a] As a percentage of non-cordwood energy use for residential heating.

[b] As a percentage of Scenario 1 heating oil use for residential heating.

Table 5—Southeast Alaska cordwood use and energy consumption, by community

Location	Total number of households	Number of households heating with cordwood[a]	Household cordwood use	Energy use	Cordwood use	Cordwood use	Cordwood use
			Percentage of total households	*BTUs per household per year × 10^6* [b]	*BTUs per location per year × 10^9* [c]	*Tons per location per year*	*Average tons per household*
Haines	1,139	381	33	86.44	32.94	2,986	7.84
Hoonah	999	282	28	86.44	24.38	2,210	7.84
Juneau	12,323	501	4	85.75	42.96	3,895	7.77
Ketchikan	5,367	389	7	71.56	27.84	2,524	6.49
Petersburg	1,671	273	16	77.07	21.04	1,908	6.99
Prince of Wales Island	250	121	48	71.56	8.66	785	6.49
Sitka	3,623	209	6	72.24	15.10	1,369	6.55
Skagway	395	30	8	86.44	2.59	235	7.84
Wrangell	1,160	287	25	77.07	22.12	2,006	6.99
Total	26,927	2,473				17,918	7.25

BTU = British thermal unit.

[a] B25040: House heating fuel—Universe: occupied housing units. 2008–2012 American community survey 5-year estimates. http://factfinder2.census.gov/faces/tableservices/jsf/pages/productview.xhtml?pid=ACS_12_5YR_B25040&prodType=table.

[b] Higher heating value (HHV) = 8600 BTU/lb (0 percent MC); energy content of cordwood = 8,600–8,700 BTU/lb Alaska species.

[c] HHV = 7353 BTU/lb (14.5 percent MC_w) (Ince 1979); woodstove efficiency = 75 percent; actual heat output = 5549 BTU/lb (14.5 percent MC_{db}).

in the northern part of southeast Alaska, including Haines, Skagway, and Hoonah, requiring 86 million BTUs per household per year. The lowest household heating demand is on Prince of Wales Island and in Ketchikan, two southern locations, at 71 million BTUs per household per year. Average residential energy consumption per household in southeast Alaska is estimated to be 79 million BTUs per household (Brackley et al. 2010).

Southeast Alaska Cordwood Use

Residential use of cordwood (firewood) in southeast Alaska is still very limited and variable despite being abundantly available, and its source is often near communities. Regional use of cordwood for home heating ranged from 4 percent in Juneau to 48 percent on Prince of Wales Island (with an average of 9 percent), based on number of households (USDC CBs 2014). Using energy consumption values and taking stove efficiency and wood moisture content into account, we estimate total annual firewood consumption in southeast Alaska to be more than 17,000 tons (table 5).

Our models for cordwood extraction and use in southeast Alaska were based on surveys conducted in Wisconsin (Katers et al. 2012). The production processes were modified to reflect local (southeast Alaska) wood resources, access, and transportation distances. Collection of firewood in southeast Alaska assumed individual harvesting and transportation. Upstream processes regarding forest growth were also included. Natural regeneration was assumed because most harvesting scenarios would consider both standing and downedwood in old-growth forests. For individual harvest, we assumed that the only fuel consumption would be to operate chainsaws. Cordwood transportation was assumed to be done using personal vehicles with an average distance of 10 miles, for household consumption of 6.5 to 7.8 tons annually (table 5).

Our model assumed three different residential wood stoves: (1) EPA-certified wood stoves with catalytic converters, (2) EPA-certified wood stoves without catalytic converters, and (3) uncertified conventional stoves.

Heating Oil Production

Heating oil is the primary energy source for residential heating in southeast Alaska, numbering more than 17,000 households (64 percent of all households in the region (USDC CB 2014)). However, there is great variation within southeast Alaska, with heating oil being used by less than 1 percent of households on Prince of Wales Island and 49 percent in Juneau (USDC CB 2014), based on number of households. Total heating oil consumption in southeast Alaska is estimated to be more than 11 million gallons per year.

The heating oil LCI data was obtained from the USLCI database (NREL 2012), in which heating oil represented 4.89 percent of the products produced. Therefore, 4.89 percent of the burdens of all upstream processes (extraction and transportation) and the refinery process were assigned specifically to heating oil. Our model assumed that crude oil was shipped by oil tanker (ocean freighter) out of Valdez, Alaska, to refineries in Washington state. Because several ports exist in Washington, we used a weighted average based on production as a single mileage that was used in our model.

Pellets Imported From Washington

Our LCA evaluated pellet production using both wet and dry mill residues from softwood lumber production in the Pacific Northwest. The Washington pellet model was based on pellet production surveys conducted in Wisconsin (Katers et al. 2012).

The production processes initially used in Wisconsin were modified to reflect wood resources, electricity generation, and transportation distances typical of western Washington.

In our model, whole logs, wet mill residues, and dry mill residues were used to produce wood pellets in Washington. Final pellet furnish was derived from 41-percent wet mill residues (dried by the pellet mill) and 59-percent dry residues (purchased from outside sources). The residues were comprised of common Pacific Northwest softwoods (Johnson et al. 2005), and mill residues were from local softwood lumber production (Milota et al. 2005). Our model assumed that softwood whole logs were obtained from Pacific Northwest thinning regimes (Johnson et al. 2005), and chipped prior to drying. The SimaPro[1] input/output process for transportation and processing whole-log feedstocks was used (Pré Consultants B.V. 2014) (table 6). Our model also included wet and dry residues collected from softwood lumber mills (Milota et al. 2005) (table 7). All residue drying was by wood-fueled boilers, with wet wood residues dried to final moisture contents of between 12 and 17 percent (oven-dry basis).

Local Pellet Production

The forest resource in southeast Alaska, although abundant, is widely dispersed and is often located on steep slopes, thus is expensive to harvest and transport to manufacturing facilities as well as destination markets. Therefore, only high-value products can be produced economically. Because bioenergy products typically have low value, feedstocks must come to the manufacturing facility essentially free of charge, or they must be a waste product with an associated disposal cost, or the cost and market for the energy product must increase substantially in the future. These economic considerations dictated the system boundary for our LCA model and drove our assumptions for pellets manufactured in southeast Alaska as an alternative to heating oil.

Low-grade materials suitable for use in energy products exist in all harvested areas, but economic considerations and the need for barge transportation make most of the material economically unrecoverable. In contrast, mill residues are typically available at lower costs. In southeast Alaska these residues would be mostly green and require drying. Because only limited wood-drying facilities exist in southeast Alaska, we structured our analysis to include wet residues at sawmills and log-yard residues that do not meet the specifications for export-grade logs as inputs to pellet manufacturing (table 8).

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

Table 6—Unit process inputs/outputs for pellets produced in the Pacific Northwest and shipped to southeast Alaska (whole-log feedstocks)

Products	Value in U.S. units		Value in metric units	
Handling and transporting whole trees (per short ton of feedstock):				
Products				
Wet chips from processed whole logs (90-percent allocation)	1.00	Tons	907.18	Kilograms
Bark for wood fuel (10-percent allocation)	222.23	Pounds	100.80	Kilograms
Materials/fuels:				
Softwood logs with bark, harvested at average intensity site	78.75	Cubic feet	2.23	Cubic meters
Transport, single-unit truck, diesel powered	49.71	Ton-miles	72.58	Tonne-kilometers
Electricity/heat:				
Electricity, at grid	17.11	Kilowatt-hours	17.11	Kilowatt-hours
Diesel, combusted in industrial equipment	0.49	Gallons	1.86	Liters
Natural gas, combusted in industrial equipment	0.01	Gallons	0.02	Liters
Handling and transporting wet mill residues (per short ton of feedstock):				
Products:				
Wet mill residues	1.00	Tons	907.18	Kilograms
Materials/fuels:				
Pulp chips, softwood, green, at sawmill	1,000.00	Pounds	453.59	Kilograms
Sawdust, softwood, green, at sawmill	1,000.00	Pounds	453.59	Kilograms
Electricity/heat:				
Diesel, combusted in industrial equipment	0.41	Gallons	1.54	Liters
Electricity, at grid	2.48	Kilowatt-hours	2.48	Kilowatt-hours
Natural gas, combusted in industrial equipment	0.01	Gallons	0.02	Liters
Transport, single-unit truck, diesel powered	79.54	Ton-miles	116.13	Tonne-kilometers
Handling and transportation of dry mill residues (per short ton of feedstock):				
Products:				
Dry mill residues	1.00	Tons	907.18	Kilograms
Materials/fuels:				
Pulp chips, softwood, kiln dried, at planer	1,000.00	Pounds	453.59	Kilograms
Planer shavings, softwood, kiln dried, at planer	1,000.00	Pounds	453.59	Kilograms
Transport, combination truck, diesel powered	49.71	Ton-miles	72.57	Tonne-kilometers

Table 7—Unit process inputs/outputs for pellets produced in the Pacific Northwest and shipped to southeast Alaska (lumber mill residues)

Products	Value in U.S. units		Value in metric units	
For pellet furnish in pellet production:				
Products:				
Pellet furnish	1	Tons	907.2	Kilograms
Materials/fuels:				
Dry mill residues (dried onsite)	818.6	Pounds	371.3	Kilograms
Dry mill residues (purchased)	1,181.4	Pounds	453.6	Kilograms
Electricity/heat:				
Electricity (at grid)	45.5	Kilowatt-hours	45.5	Kilowatt-hours
For drying wet mill residues:				
Products:				
Washington dry mill residues, at dryer	1	Tons	907.2	Kilograms
Materials/fuels:				
Washington wet mill residues	1,000	Pounds	453.6	Kilograms
Washington wet chips from processed whole logs	1,000	Pounds	453.6	Kilograms
Electricity/heat:				
Electricity, at grid	30.0	Kilowatt-hours	30.0	Kilowatt-hours
Wood fuel/wet feedstock/industrial boiler	3,036,629.2	BTUs	3,203.8	Megajoules
For palletization:				
Products:				
Wood pellets	1	Tons	907.2	Kilograms
Materials/fuels:				
Pellet furnish	1	Tons	907.2	Kilograms
Low-density polyethylene resin, at plant	100.0	Pounds	45.4	Kilograms
Transport, ocean freighter, residual fuel-oil powered	5,500.0	Ton-miles	8,029.9	Tonne-kilometers
Transport, combination truck, diesel powered	10.0	Ton-miles	14.6	Tonne-kilometers
Electricity/heat:				
Electricity, at grid	100.3	Kilowatt-hours	100.3	Kilowatt-hours
Natural gas, combusted in industrial equipment	0.04	Gallons	0.14	Liters
Natural gas, combusted in industrial boiler	0.01	Gallons	0.03	Liters
Emissions to air:				
Particulates	0.21	Pounds	0.09	Kilograms
Particulates, <10 µm	0.21	Pounds	0.09	Kilograms
Volatile organic compounds	1.00	Pounds	0.45	Kilograms

BTU = British thermal units.

The energy content of pellets = 8200 BTU/od lb (Katers et al. 2012).

Efficiency of pellet stove = 75 percent.

Source: Adapted from Katers et al. (2012).

Table 8—Unit process inputs/outputs for local pellet production in southeast Alaska

Products	Value in U.S. units		Value in metric units	
Handling and transporting wet mill residues (per short ton of feedstock):				
Wet sawmill residues (Craig, Alaska)	1	Tons	907.18	Kilograms
Materials/fuels:				
Sawdust and chips, softwood, green, at sawmill (Craig, Alaska)	1481.5	Pounds	672	Kilograms
Electricity/heat:				
Diesel, combusted in industrial equipment	0.07	Gallons	0.28	Liters
Electricity hydropower	0.45	Kilowatt-hours	0.45	Kilowatt-hours
Natural gas, combusted in industrial equipment	0.001	Gallons	0.004	Liters
Drying wet mill residues (per short ton of feedstock):				
Dry pellet furnish (Craig, Alaska)	1.00	Tons	907.18	Kilograms
Materials/fuels:				
Wet sawmill residues (Craig, Alaska)	1347.99	Pounds	611.44	Kilograms
Wet chips from processed whole logs (Craig, Alaska)	651.99	Pounds	295.74	Kilograms
Electricity/heat:				
Electricity (hydropower)	75.57	Kilowatt-hours	75.57	Kilowatt-hours
Wood fuel/wet feedstock/industrial boiler	3,036,629.21	BTUs	3,203.81	Megajoules

Adapted from Katers et al. (2012).

Southeast Alaska Wood Products Residues as a Pellet Feedstock

The LCA model for production of wood pellets in southeast Alaska used 100-percent wet residues from softwood lumber production in Craig, Alaska (table 9). These residues were supplemented by whole pulpwood quality logs not suited for sawlogs or export. Our model, although based on Katers et al. 2012, was adjusted for local wood resource inputs, co-product allocation from sawmills, local electricity generation, and transportation. We assumed that one pellet mill located in the vicinity of Craig, Alaska would produce the pellets necessary for 20-percent substitution of the southeast Alaska heating oil residential market. Our model assumed that all residues would be chipped, screened, and dried in a horizontal drum dryer (table 8).

Wet mill residues represented 69 percent from softwood lumber production, with the remaining 31 percent coming directly from whole logs. Whole logs represented chipped utility logs (68 percent of total, based on scale) and recoverable residues (42 percent of total) at the export log yard. Lumber residues were a mix of sawdust and chips (51 percent of total), with lumber and bark comprising 39 and 9.4

Table 9—Local pellet production unit process inputs/outputs for pelletization, final step in pellet production

Products	Value in U.S. units		Value in metric units	
Wood pellets, bagged (Craig, Alaska)	1.00	Tons	907.1847	Kilograms
Materials/fuels:				
Pellet furnish (Craig, Alaska)	1.00	Tons	907.18	Kilograms
Low-density polyethylene resin, at plant	99.98	Pounds	45.35	Kilograms
Transport (ocean freighter, residual-fuel-oil powered)	16681.90	Ton-miles	26847.08	Tonne-kilometers
Electricity/heat:				
Electricity (hydropower)	100.26	Kilowatt-hours	100.26	Kilowatt-hours
Natural gas (combusted in industrial equipment)	0.04	Gallons	0.14	Liters
Natural gas (combusted in industrial boiler)	0.01	Gallons	0.03	Liters
Emissions to air:				
Particulates	0.21	Pounds	0.09	Kilograms
Particulates, <10 µm	0.21	Pounds	0.09	Kilograms
Volatile organic compounds	1.00	Pounds	0.45	Kilograms

Adapted from Katers et al. (2012).

percent, respectively. All residue drying was by wood fuel in boilers, over a moisture content range of 74 percent to 6.5 percent (oven-dry basis). Wet residue drying required close to 3 million BTUs per ton.

On Prince of Wales Island, at least 50,000 green tons of residuals are potentially available annually (TSS Consultants 2000). We report that 43,492 bone-dry tons per year are readily available on Prince of Wales Island, with a potential availability of up to 144,592 bone-dry tons per year. The results from this study indicate that at 20-percent substitution of wood pellets, about 44,761 bone-dry tons per year would be required, while at 100-percent substitution, about 283,151 bone-dry tons per year would be needed.

Wood Pellet Production in Southeast Alaska

Wood pellets are manufactured when dry, fine particles are extruded through steel dies using machinery similar to that used for agricultural pellets. Final pellet dimensions are typically about ¼ inch in diameter and 1 inch long. High pressures and temperatures soften lignin and bind the wood particles together to make uniform and consistent pellets. Although no adhesives are required, small amounts of lubricants and water can be added to improve pellet processing and formation. Hot pellets are stored in a hopper and allowed to cool before bagging, usually in small, semi-automated bagging lines. Filled bags of pellets typically weigh 40 lbs.

Life Cycle Assessment Model Development

Our study included both an LCI and LCIA of pellet, heating oil, and cordwood production processes from cradle to grave. Life cycle inventories quantify emissions associated with all activities, from the resource extraction and fuel production through the use of fuels, including the transportation and distribution stages. Emissions released to the production of inputs were included based on their cradle-to-grave activities.

Our study followed the methods set forth in the ISO 14000 series of standards (ISO 2006). The LCA software used in our analysis was SimaPro version 8.03 (PRé Consultants 2014). The LCIA phase establishes links between LCI results and potential environmental impacts and calculates impact indicators such as global warming potential, smog, eutrophication, and acidification (table 10). Environmental impacts are determined using the North American impact method, TRACI (Bare et al. 2011). Each impact indicator is a quantitative measure of one aspect of a potential impact, with indicators weighted equally.

We modelled wood pellet production using wet and dry mill residues from softwood lumber production in the Pacific Northwest and whole-tree chipping. The base model assumes that pellets are first produced in the Seattle, Washington, area, then are shipped by barge from the Port of Seattle to the Port of Ketchikan and other ultimate destinations, then by truck to a distribution center. Once pellets are delivered to each port, they are transported by truck for distribution and customer purchase. Our analysis was based on modelling assumptions for pellets, cordwood, and heating oil, which included specifying moisture content, heating values, and stove efficiencies (table 11).

Transportation flows for cordwood, heating oil, and imported pellets from extraction to combustion were determined, as well as distances transported both regionally (table 12) and locally (table 13). Our model assumed that locally produced pellets would be shipped by barge to Ketchikan (fig. 6), then distributed by the same means as imported pellets to each location in southeast Alaska. Pellets for residential use on Prince of Wales Island, when produced locally, would be transported by road to Hollis or Thorne Bay, Alaska, and loaded onto barges for shipment within southeast Alaska. Pellets shipped to Prince of Wales Island would be shipped by barge to Hollis or Thorne Bay and distributed by truck to retail outlets or households.

It is known that tree growth, harvest, transportation, wood products manufacture, fuel production, and combustion result in carbon dioxide (CO_2) fluxes. This is often evaluated as GWP for a fixed time frame ranging between 20 and 500 years.

Table 10—Selected impact indicators, characterization models, and impact categories

Impact indicator	Characterization model	Impact category
Greenhouse gas emissions	Calculate total emissions in the reference unit of CO_2 equivalents for CO_2, methane, and nitrous oxide.	Global warming
Releases to air decreasing or thinning of ozone layer	Calculate the total ozone forming chemicals in the strato-sphere including CFCs, HCFCs, chlorine, and bromine. Ozone depletion values are measured in the reference units of CFC equivalents.	Ozone depletion
Releases to air potentially resulting in acid rain (acidification)	Calculate total hydrogen ion (H+) equivalent for released sulfur oxides, nitrogen oxides, hydrochloric acid, and ammonia. Acidification value of H^+ mole-eq. is used as a reference unit.	Acidification
Releases to air potentially resulting in smog	Calculate total substances that can be photo chemically oxidized. Smog-forming potential of O_3 is used as a reference unit.	Photochemical smog
Releases to air potentially resulting in eutrophication of water bodies	Calculate total substances that contain available nitrogen or phosphorus. Eutrophication potential of N-eq. is used as a reference unit.	Eutrophication
Releases to air potentially resulting in respiratory effects	Calculate total carbon monoxide, nitrogen dioxide, nitrogen oxides, sulfur dioxides, ammonia, particulates <2.5 and <10 µm, and total suspended particulates	Respiratory effects

CO_2 = carbon dioxide; CFC = chlorofluorocarbon; CHFC = hydrochlorofluorocarbon; O_3 = ozone; N = nitrogen.

Table 11—Life Cycle Assessment modeling assumptions

Parameter	Value
Premium wood pellet moisture content	6.5 percent (dry basis)
Cordwood moisture content	14.5 percent (dry basis)
Cordwood higher heating value	8,600[a] BTUs per pound
Pellet higher heating value	8,200 BTUs per pound
Heating oil higher heating value	140,000 BTUs per gallon
Density of heating oil	7.2 pounds per gallon
Cordwood stove efficiency	75 percent
Heating oil stove efficiency	78 percent
Pellet stove efficiency	75 percent
Alaska species mix density	672 kilograms per cubic meter (at 74-percent moisture content)
Carbon content of wood	50 percent

BTU = British thermal unit.

[a] This number was lowered from 8,653 BTUs per pound to an oven-dry moisture higher heating value of 8,600 BTUs per pound. Upon review of the SimaPro model (Pré Consultants B.V. 2014), it was discovered that cordwood was modeled using the lower higher heating value to calculate the fuel moisture content of 14.5 percent. Final use heating value was 7,353 BTUs per pound (Ince 1979).

Table 12—Distances used to model heating oil water transportation

Port location	Type of transport	Distance	
		Miles	*Kilometers*
Distance from port to port:			
Valdez to Washington oil refinery	Ocean freighter	1,439	2,316
Heating oil to Ketchikan	Barge	751	1,209
Ketchikan	Barge		
Distance from Ketchikan, Alaska:			
Wrangell	Barge	103	166
Petersburg	Barge	148	238
Sitka (inside passage)	Barge	331	533
Juneau	Barge	487	784
Hoonah	Barge	465	748
Haines	Barge	561	903
Skagway	Barge	574	924
Prince of Wales Island	Barge	39	63

Table 13—Southeast Alaska ground transportation distances modelled (heating oil and pellets)

Port location	Distance from port to distribution center		Distance from distribution center to residence	
	Miles	*Kilometers*	*Miles*	*Kilometers*
Ketchikan	2.00	3.22	5.00	8.05
Wrangell	0.25	0.40	5.00	8.05
Petersburg	3.00	4.83	5.00	8.05
Sitka (inside passage)	5.00	8.05	5.00	8.05
Juneau	0.50	0.81	5.00	8.05
Hoonah	0.50	0.81	5.00	8.05
Haines	4.00	6.44	5.00	8.05
Skagway	0.25	0.40	5.00	8.05
Prince of Wales Island (Thorne Bay, Alaska)	10.00	19.09	5.00	8.05

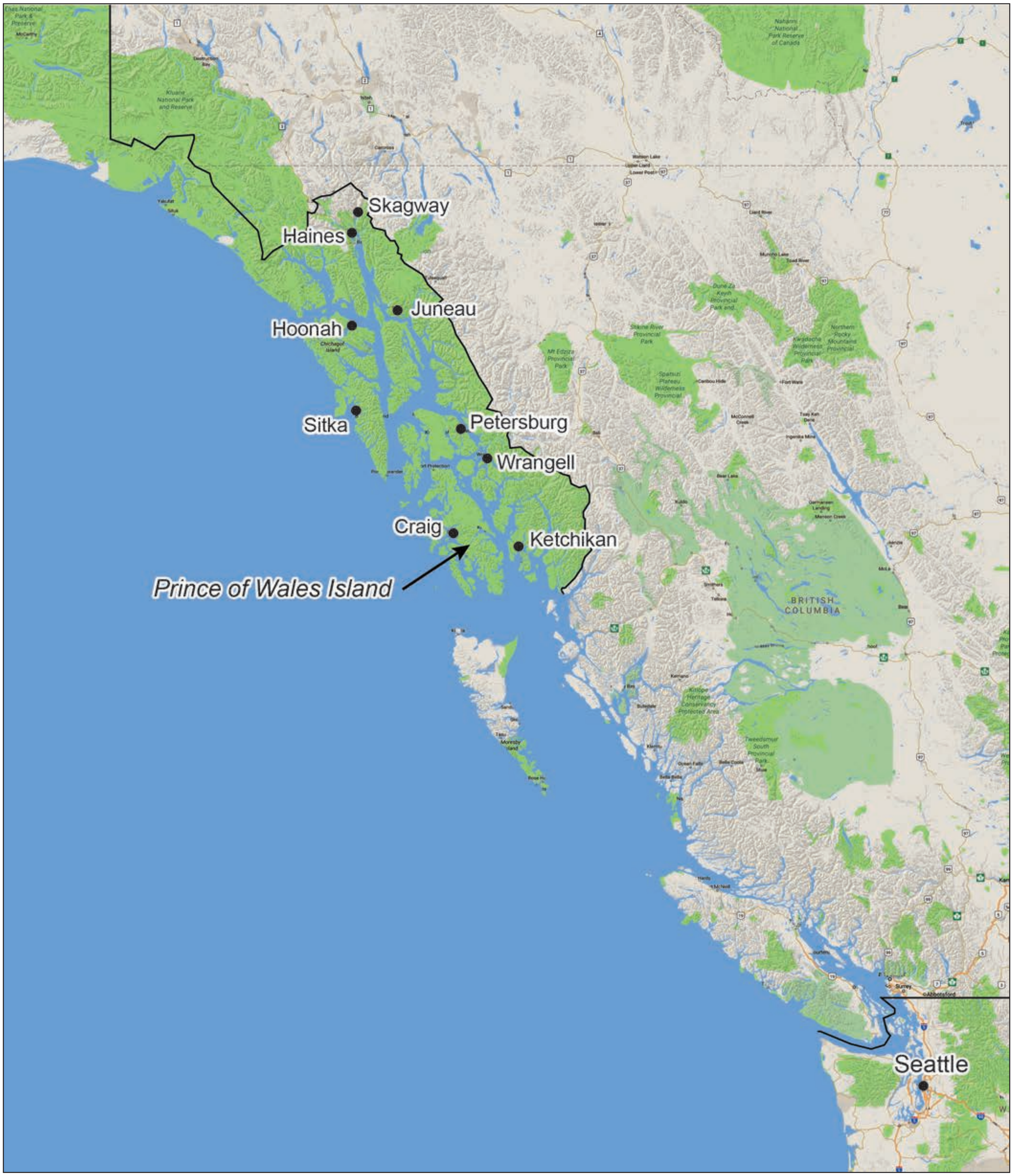

Figure 6—Map of southeast Alaska region.

All calculations in this report for CO_2 absorption during tree growth were based on well-established estimates of 50-percent carbon content for woody feedstocks (Milota et al. 2005).

Net GWP is calculated by subtracting the CO_2 absorbed during tree growth from the total CO_2 emission (fossil- and biomass-based) occurring from cradle to grave. Global warming potential outputs were calculated using the TRACI version 2.1 impact method within SimaPro software. Carbon dioxide absorption was calculated based on standing-tree resources to give a CO_2 equivalent of standing volume or harvested volume. The TRACI impact method was modified to have CO_2 from the combustion of biomass to be considered in the overall GWP.

Scenario 1: current use conditions (cordwood and heating oil)—Scenario 1 (base case) modeled heating oil and cordwood current use (status quo) for home heating in southeast Alaska, but did not consider the use of wood pellets (fig. 7). An estimated 2,473 households in southeast Alaska heat with cordwood (9 percent of total) while an estimated 17,129 households (64 percent of total) heat with heating oil (Brackley et al. 2010).

The carbon impact of residential heating in southeast Alaska is 204,357 tons CO_2 eq. (table 14), with heating oil contributing 98 percent of this. Our analysis found that trees sequestered 30,075 tons of CO_2 during growth, while cordwood

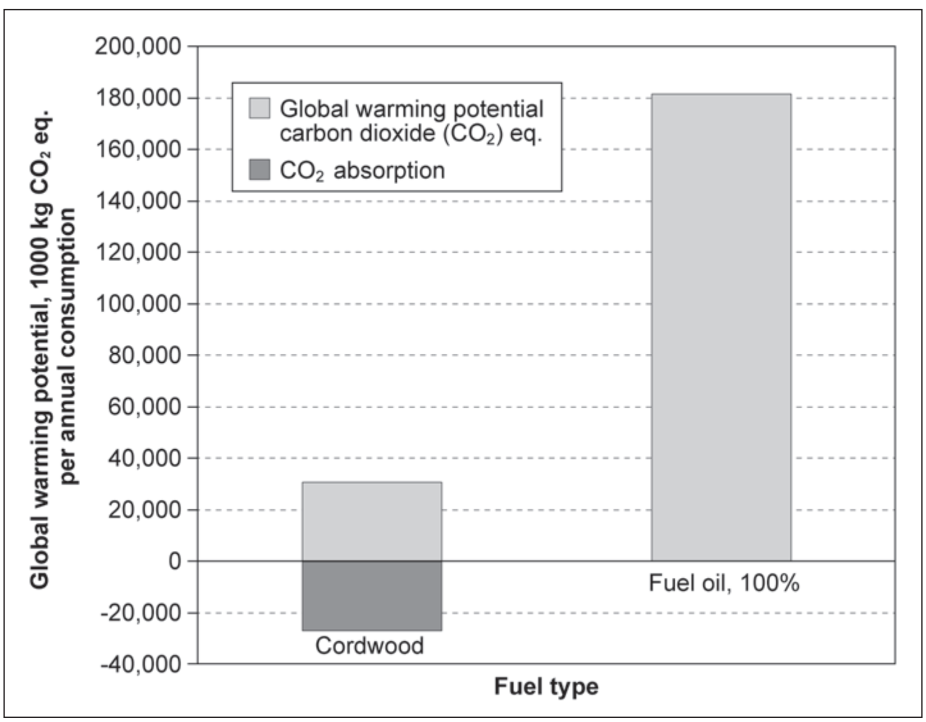

Figure 7—Scenario 1: total global warming potential, carbon dioxide absorption, and net global warming potential for cordwood and heating oil in southeast Alaska.

Table 14—Total global warming potential, carbon dioxide absorption, and net global warming potential for the five scenarios evaluated

Scenario	Fuel and level of use	Total global warming potential	Carbon dioxide absorption	Net global warming potential	Reduction from Scenario 1
		- - - - - *CO_2 equivalent (metric tons)* - - - -			*Percent*
1	Cordwood	30,852	- 27,284	3,568	
	Heating oil, (100 percent)	181,939	-177	181,822	
	Total for southeast Alaska	212,791	-27,401	185,390	
2	Cordwood	30,852	- 27,284	3,568	
	Heating oil (80 percent)	145,551	- 93	145,458	
	Imported pellets (20 percent)	62,668	- 45,203	17,465	
	Total for southeast Alaska	239,071	-72,580	166,491	10.2
3	Cordwood	30,852	- 27,284	3,568	
	Heating oil (60 percent)	109,163	-70	109,093	
	Imported pellets (40 percent)	125,337	- 90,554	34,783	
	Total for southeast Alaska	265,352	-117,908	147,444	20.5
4	Cordwood	30,852	- 27,284	3,568	
	Imported pellets (100 percent)	313,342	-226,014	87,328	
	Total for southeast Alaska	344,194	-253,298	90,896	51.0
5	Cordwood	30,852	- 27,284	3,568	
	Heating oil (80 percent)	145,551	- 93	145,458	
	Local pellets (20 percent)	56,827	- 46,481	10,346	
	Total for southeast Alaska	233,230	-73,858	159,372	14.0

combustion released 34,008 tons CO_2 eq., resulting in a net GWP of 2 percent. For Scenario 1, net GWP for cordwood was 3,933 tons CO_2 eq., while for heating oil the net GWP exceeded the total GWP for cordwood at 200,424 tons CO_2 eq. (table 14). Unit process inputs and outputs for cordwood were modelled for collection (table 15) and for combustion (table 16).

Scenario 2: Cordwood status quo, heating oil (80 percent), imported pellets (20 percent)—

In Scenario 2, residential cordwood use remained constant, while 20 percent of household energy from heating oil was substituted with the equivalent energy in wood pellets. The pellet production for Scenario 2 originated from a hypothetical

Table 15—Unit process inputs and outputs for modelling cordwood collection in southeast Alaska

Products	Value	Unit	Value	Unit
Cordwood for residential heating in southeast Alaska[a]	1.00	Tons	907.18	Kilograms
Materials:				
Cordwood harvested in southeast Alaska	74.85	Cubic feet	2.12	Cubic meters
Gasoline, combusted in equipment[b]	0.08	Gallons	0.31	Liters
Lubricants	0.0107	Pounds	0.0049	Kilograms

[a] Density of southeast Alaska cordwood = 428 kg/m^3. Based on oven-dry specific gravity for Sitka spruce (25 percent of total), western hemlock (50 percent of total), and red alder (25 percent of total) (USDA FS 2010).

[b] National average for chainsawing operations used for thinning operations (Johnson et al. 2005, Oneil et al. 2009).

Table 16—Unit process inputs/outputs for cordwood combustion in wood burning stoves in southeast Alaska

Products	Value	Unit
Heat from cordwood (average Alaska stove)/	1.00	Megajoules
Materials/fuels:		
Heat from cordwood (EPA-certified catalytic heaters)	0.219	Megajoules
Heat from cordwood (EPA-certified non-catalytic heaters)	0.206	Megajoules
Heat from cordwood (uncertified conventional heaters)	0.575	Megajoules

pellet plant located in the vicinity of Seattle, Washington. Twenty percent of the energy market of heating oil represented 275 billion BTUs for southeast Alaska, the equivalent of 22,414 tons of wood at 6.5 percent moisture content, and an assumed stove efficiency of 75 percent. This scenario allocated 3,426 out of 14,129 households currently heating with heating oil. Table 14 shows the total GWP, CO_2 absorption, and net GWP for Scenario 2.

Carbon released from woody biomass combustion is considered to be neutral because it is removed from the atmosphere by trees during growth) (Beauchemin and Tampier 2008). The total GWP for southeast Alaska under this scenario was 183,524 tons CO_2 eq. a 10.2-percent decrease versus the base case (table 14).

Scenario 3: Cordwood, heating oil (60 percent), imported pellets (40 percent)—This scenario doubles the use of pellets (from 20 to 40 percent), thereby doubling the GWP impact for pellets (fig. 8). However, under Scenario 3, the net southeast

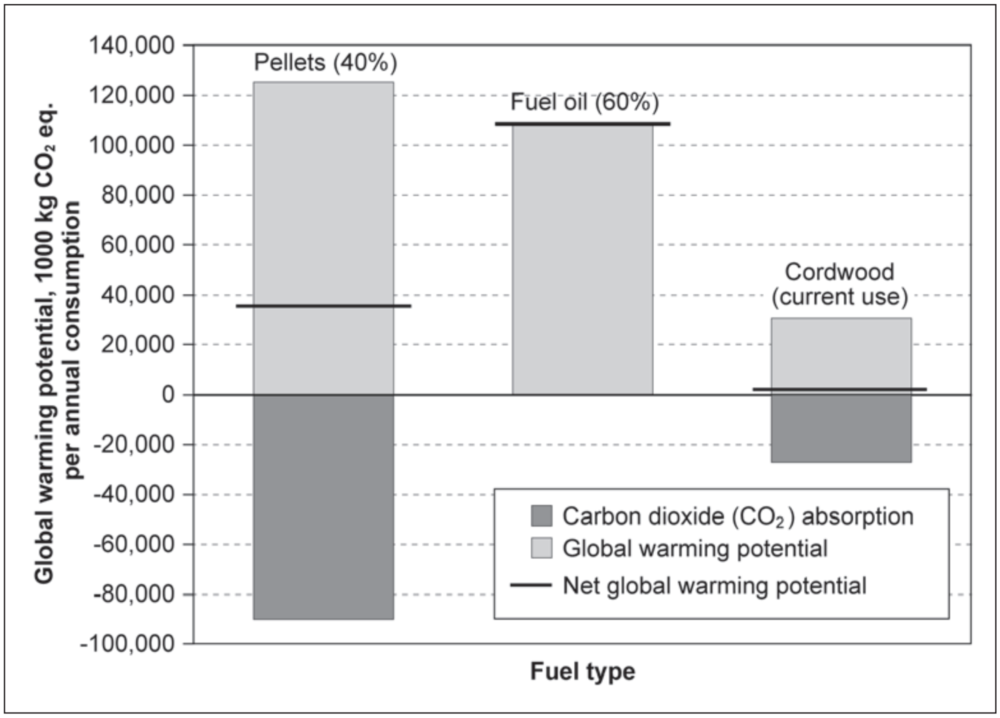

Figure 8—Scenario 3: total global warming potential, carbon dioxide absorption, and net global warming potential for cordwood, 60-percent heating oil, and 40-percent imported pellet use in southeast Alaska.

Alaska GWP was lowered by 20.5 percent relative to scenario 1 (table 14). When wood pellets made up 40 percent of the heating-oil energy use, total GWP for pellets was slightly above that for heating oil (120,332 tons CO_2 eq. for heating oil and 138,160 tons CO_2 eq. for pellets). Similarly to the results from scenarios 1 and 2, under scenario 3 the number of households using wood is driving the differences in GWP, not the emissions from pellet transportation. Because energy and resources are consumed to make energy, there are primary fuels and resources consumed during extraction, production, and transportation.

Scenario 4: Cordwood, imported pellets (100 percent)—
In scenario 4, cordwood use remained constant and heating oil was not used at all (i.e., 100 percent of this energy demand was met by imported wood pellets) (fig. 9). This scenario produces a net carbon benefit by reducing net GWP in southeast Alaska by 51 percent from the base case (Scenario 1) (table 14). Given the existing forest resource economy and resource availability for pellet production in southeast Alaska, Scenario 4 is only possible using imported wood pellets. As such, Scenario 4 would still require a significant amount of fossil-fuel energy to transport

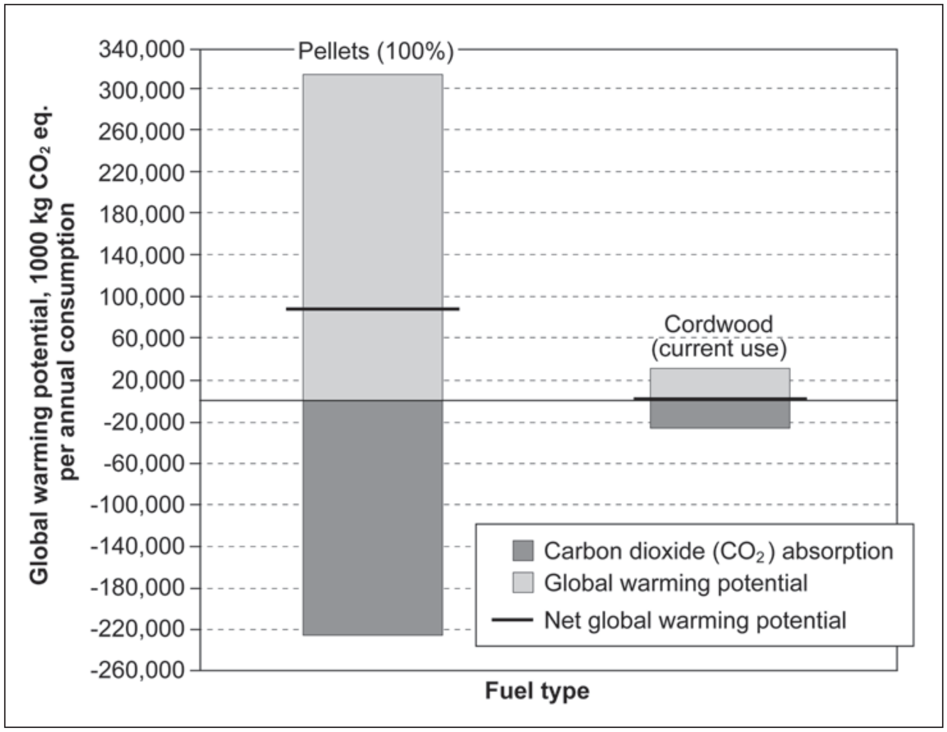

Figure 9—Scenario 4: total global warming potential, carbon dioxide absorption, and net global warming potential for cordwood and 100-percent imported pellet use in southeast Alaska.

pellets to each port and distribution center in southeast Alaska. Total primary fossil-fuel energy consumption decreased 38 percent from the base case (Scenario 1), while total primary fuels only decreased by 16 percent, with 23 percent of the total energy coming from biomass used to process the pellets.

Scenario 5: Cordwood, heating oil (80 percent), local pellets (20 percent)—Scenario 5 is the only Scenario that considered pellet production in southeast Alaska. Here, we assumed that pellets would be produced on Prince of Wales Island near the lumber mill in the vicinity of Klawock, Alaska. The primary distinction between Scenarios 5 and 2 is the need in Scenario 5 for pellet transportation from Seattle, Washington, to Ketchikan, Alaska. The removal of this transportation component, combined with the use of only wet mill residues, lowered the GWP under Scenario 5 from 183,528 tons of CO_2 eq. per year to 175,678 tons. Thus, a reduction of 14 percent in GWP was realized by replacing only 20 percent of the heating oil use with local pellet production (table 14). Locally produced pellets reduced GWP only 4 percent compared to imported pellets under the same usage level (i.e., equivalent to 20 percent of the heating oil use) (fig. 10).

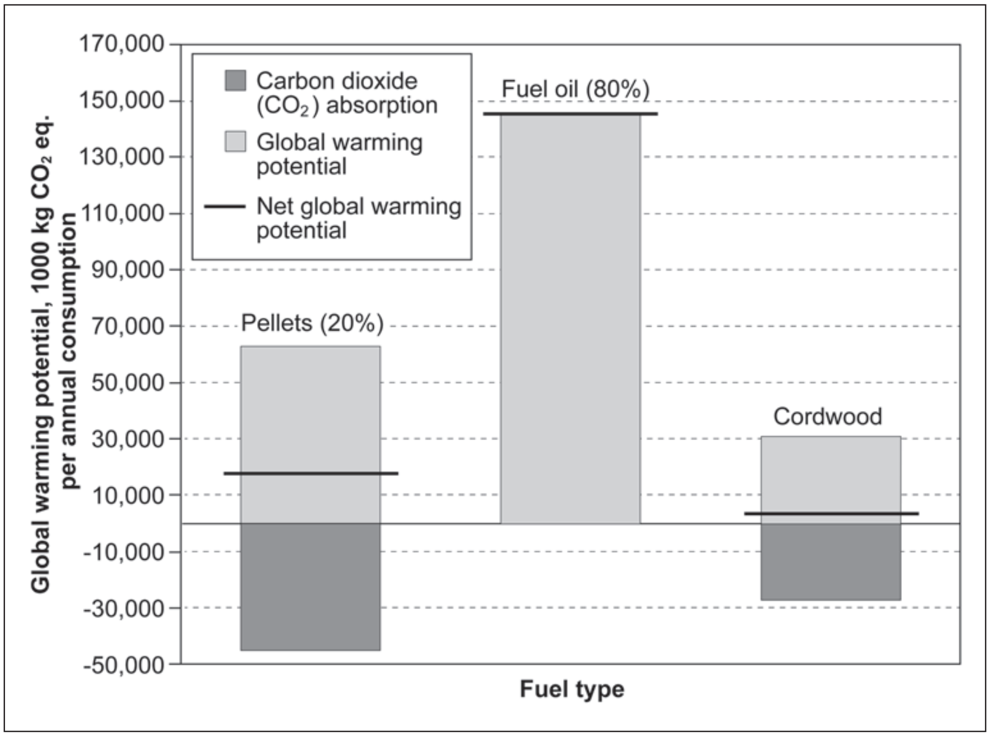

Figure 10—Scenario 5: total global warming potential, carbon dioxide absorption, and net global warming potential for cordwood, 80-percent heating oil, and 20-percent local pellet use in southeast Alaska.

Results and Discussion

The infrastructure needed to establish pellet markets in southeast Alaska will likely be the largest hurdle in establishing a self-sustaining pellet industry within the region. In this context, infrastructure needs would include harvesting equipment, transportation and trucking equipment, wood products mills, and wood drying facilities at a minimum. Outside of Prince of Wales Island, there is a reduced log supply, and there are few mills producing residuals. In addition, there are few commercial dry kilns in southeast Alaska, or secondary manufacturing facilities, meaning that all pellet feedstock residues would need to be dried (requiring additional energy inputs).

There are also other practical barriers. Rainy weather conditions in southeast Alaska make it difficult to maintain low pellet moisture contents unless they are stored in closed containers or bagged. Further, bulk handling systems are often difficult to use, especially for smaller producers just entering this industry. As an alternative, interest is growing in producing larger “wood energy bricks” (typically up to 4 inches maximum dimension) instead of pellets. These “bricks” have the dual advantage of being able to replace firewood in conventional stoves while having greater weather resistance than pellets. At least one firm on Prince of Wales Island is actively producing wood energy "bricks."

Although many locations in the continental United States have a well-established network of roads and wood products facilities, this is not the case in southeast Alaska. Here, there is only one medium-size sawmill (on Prince of Wales Island). Further, most markets can be served only by barge or air owing to the isolated nature of island communities and the lack of a road system to connects them. All these challenges point to the reality that many of southeast Alaska's goods (including wood fuel) are often more economically shipped in from outside locations than produced locally.

Comparing GWP per energy unit for complete substitution of heating oil in southeast Alaska with wood pellets, a reduction in net GWP of 14.0 percent could be achieved if pellets were to be produced locally and a 10.2-percent reduction in net GWP would be seen if the same level of imported pellets were used (table 14).

Substitution levels at 20-percent heating oil resulted in the greatest reduction in both GWP and energy use when compared to the current scenario of 100-percent heating oil and no pellets. The cradle-to-grave fuel production and use impacts at the 20-percent substitution level produced only modest differences in GWP between locally and imported pellets because of the remaining high use of heating oil.

When considering differences in individual fuel production and use, our main interest was in the overall impact on southeast Alaska as a whole, based on different levels of pellet use and total energy use. Energy reductions can be associated with less transportation of both heating oil and pellets, and less energy required for pellet production. As noted previously, locally produced pellets use only wet mill feedstocks, which are dried once they are processed into pellet furnish. Because the imported pellets used feedstocks from dried mill residues, a portion of the upstream embodied energy was allocated for drying. The shipping distances for heating oil (assumed to originate in Alaska) were nearly double that of imported wood pellets in our analysis. Because Prince of Wales Island and Skagway had the fewest households using heating oil, transportation scored highest in almost all of the impact categories. We found that for both pellets and heating oil fuel, unless fuel consumption is substantial, transportation will be the main GWP contributor. The GWP was highest for combined extraction, production, and use for every location except Prince of Wales Island and Skagway. Similarly to the scenario of 20-percent pellet use, the extraction, production, and use stages showed higher impact contributions in all nine impact categories for southeast Alaska's largest communities (Juneau, Sitka, and Ketchikan). In most locations the difference in GWP between extraction, production, use and transportation was significant (accounting for up to 96 percent of total impact). However for smaller communities such as Wrangell and Skagway, this was not the case (accounting for 5 percent or less of total impact).

When we considered the GWP of residential heating fuels, total household fuel usage played a much greater role in GWP than did transportation. For example, for households using either heating oil or imported pellets, Juneau had the highest numbers, with 8,414 and 1,683 households heating with heating oil and pellets, respectively. Prince of Wales Island, with the lowest population of any location in our model, had only 108 households heating with heating oil and 22 households heating with pellets.

Summary

Wood pellet use for residential heating in southeast Alaska was evaluated using modelling techniques as a cradle-to-grave LCA. This analysis allowed comparing of the GWP of imported wood pellets, locally produced pellets, locally produced cordwood, and heating oil. Substitution of heating oil with pellets was assessed at the 20-, 40-, and 100-percent levels. Cordwood use remained the same for all comparisons (i.e., the status quo). Global warming potential (kg CO_2 eq.) was lower for all substitution scenarios versus the current case that assumed 100-percent heating oil plus cordwood use.

Several assumptions were made in this study owing to the lack of actual pellet production data in southeast Alaska and Washington State. The results do strongly indicate the environmental advantage of increase use of wood-based biofuels in southeast Alaska for residential heating. Environmental benefits can be further enhanced when fuel is produced locally to alleviate the transportation burdens associated with importing goods to southeast Alaska. Although we focused primarily on carbon impacts, there are several other environmental impacts that could be reported when investigating fuel substitutions, such as smog, respiratory effects, and ozone depletion.

Forest resource use is a continually evolving issue in southeast Alaska, and estimating future timber harvest and the availability of material suitable for energy use in southeast Alaska has large uncertainties. The Tongass National Forest transition to young growth is underway, and, over the next few decades, this resource, and its ability to generate wood-energy feedstocks in the form of harvesting residues, small-diameter timber, and sawmill residues, will have a major impact on the region’s ability to locally produce forest products.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	25.4	Millimeters (mm)
Feet (ft)	0.3048	Meters (m)
Miles (mi)	1.609	Kilometers (km)
Pounds (lb)	0.4536	Kilograms (kg)
Tons (ton)	0.907	Tonnes
Degrees Fahrenheit (°F)	56(°F – 32)	Degrees Celsius (°C)
British thermal units (BTU)	0.00106	Megajoules (MJ)
Pounds per square inch (psi)	0.006895	Megapascals (MPa)

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