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NARA Uses Woody Biomass to Fuel First US Commercial Flight

The Northwest Advanced Renewables Alliance (NARA), an alliance of public universities, government laboratories and private companies, received a $40 million grant from the USDA National Institute of Food and Agriculture in 2011 to provide technologies, resources and analyses for stakeholders interested in using forest residuals to create bio-based alternatives to petroleum-based products such as jet fuel. Led by Washington State University, NARA undertook a comprehensive approach to building a supply chain for aviation biofuel with the goal of increasing efficiency in everything from forestry operations to conversion processes. Using forest residuals from logging operations as feedstock, the project aimed to create a sustainable industry to produce aviation biofuels and valuable co-products. The project included a broad alliance of private industry and educational institutions from across the Northwest, including the Center for International Trade in Forest Products at the University of Washington.

During the course of the five year project, CINTRAFOR researchers led the effort to conduct a life cycle assessment of the production process for bio-jet fuel produced from woody biomass. They also led the effort to conduct a community impact assessment to evaluate the potential economic impacts of locating a bio-jet fuel production facility in the Pacific Northwest. Typical forest harvest operations in the Pacific Northwest leave behind a considerable volume of unused residual woody biomass in the forest in the form of treetops, branches and unusable logs. Despite the environmental benefits of using these residuals to produce low-carbon energy products, the economic feasibility of extracting residual biomass from the forest is limited due to low market demand and high collection and transportation costs. As a result, most of the residual woody biomass is collected into piles in the forest and burned while the remainder is simply left on the forest floor to decompose. To address the market failure of more fully utilizing woody residues, the NARA project was designed to explore the economic and environmental feasibility of converting residual woody biomass into bio-jet fuel and a suite of co-products. The NARA project took a holistic approach to building a supply chain within the Pacific Northwest region (i.e., WA, OR, ID and MT) with the goal of using forest harvest residuals to produce aviation biofuel and co-products. The primary objectives of the NARA project are empowering rural economies, increasing America's energy security, and reducing aviation's environmental impact. To achieve these goals, NARA looked to improve the efficiency of each stage within the supply chain, from forestry operations to the biomass conversion processes; to create new bio-based products; to provide economic, environmental and social sustainability analyses; to engage and educate stakeholder groups; and to improve the bioenergy literacy of K-12 students, educators, professionals and the general public. One of the most important goals of the project was to produce 1,000 gallons of ASTM-certified bio-jet fuel that could be used to fuel a commercial flight.

The two articles in this edition of the CINTRAFOR News summarize the results of the CINTRAFOR components of the project: the life cycle analysis (LCA) and the community economic impact assessment. In the LCA component of the project, it was critical to be able to show that using bio-jet fuel produced from forest residuals could achieve at least a 60% reduction in the overall global warming potential of biojet fuel relative to fossil-based jet fuel. The 60% reduction in global warming potential was mandated by the Environmental Protection Agency as a condition for bio-based jet fuel to be qualified as a bio-preferred fuel for use in public procurement programs. The results of the LCA showed that the NARA bio-jet fuel produced from forest residuals demonstrated a 72% reduction in global warming potential relative to fossil-based jet fuel. In addition, the community economic impact assessment was conducted to estimate the economic impact, including job creation, that might be generated by the establishment of a bio-jet fuel production facility in western Washington. The results of the impact assessment suggest that a commercial sized bio-jet fuel production plant located in southwestern Washington State could generate approximately $650 million in industrial output while directly creating 173 jobs within the production facility and indirectly leading to the creation of an additional 1,200 jobs within the supply chain.

On November 14, 2016, a total of 1,080 gallons of NARA bio-jet fuel produced from forest residuals from the Pacific Northwest was loaded onto an Alaska jet. The Alaska flight from Seattle-Tacoma International Airport to Ronald Reagan National Airport in Washington DC was fueled by a 20% blend of sustainable aviation biofuel, a first of its kind. Joe Sprague, Alaska Airlines senior vice president of communications and external relations noted that "While the 1,080 gallons of biofuel used on the flight has a minimal impact to Alaska Airlines' overall greenhouse gas emissions, if the airline were able to replace 20 percent of its entire fuel supply at Sea-Tac Airport, it would reduce greenhouse gas emissions by about 142,000 metric tons of CO2. This is equivalent to taking approximately 30,000 passenger vehicles off the road for one year". The Alaska Airlines handout distributed to the passengers on the flight to explain the benefits of using biojet fuel derived from woody biomass is shown on the next page. As one of the project leaders, I think it would be an understatement to say that this project was an unqualified success. *Ivan Eastin*

NARA is led by Washington State University and supported by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30416 from the USDA National Institute of Food and Agriculture.

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http://www.cintrafor.org

In This Issue:

From wood to wings.

Alaska Airlines is using environmentally friendly fuel on a select flight from Seattle to Washington D.C. Your aircraft will be powered by a mixture of traditional petroleum jet fuel and 20 percent sustainable biofuel made from material left over after a timber harvest or forest thinning, such as limbs, tops, stumps, and small diameter logs. This is the first commercial flight to use a fuel blend made from woody plant materials. In June, Alaska conducted a similar biofuel flight but with sustainable corn as the feedstock.

Are these biofuels safe?
Yes. Biofuels are just as safe as the regular fuel we use to power our aircraft. The fuel on your flight meets the same stringent international fuel certification as conventional jet fuel and the Federal Aviation Administration has approved it for use.

Why is Alaska Airlines doing this?
Caring for the environment is important to us. We also have a proud tradition of innovating to make flying safer, more reliable and easier for our customers. Biofuels are the best alternative energy source currently available for aviation. We want to do everything we can to achieve a market for sustainable biofuels as soon as possible.

Why are biofuels so important for aviation?
Biofuels decrease our reliance on petroleum-based fuel, enabling airlines to sustainably reduce our largest impact on the environment and meet the industry's goal of cutting carbon dioxide emissions in half by 2050 compared with 2005 levels. Biofuels also represent a significant, complementary effort to our other green practices, including onboard recycling.

How does it work?
While traditional forest practices leave some of the harvest materials behind to replenish soil nutrients and provide cover, the excess woody biomass usually is piled and burned. To make the fuel used in this flight, excess woody biomass was collected from sustainably managed forests owned by Weyerhaeuser (OR), the Muckleshoot Indian Tribe (WA), and the Confederated Salish Kootenai Tribes (MT), and combined with reject fibers provided by Cosmo Specialty Fibers (WA) to make biofuel.

Woody biomass contains lignocellulose, which is rich in carbohydrates. The carbohydrates are extracted from the wood and converted to biofuel and other biochemical products. The biofuel production is sustainable because the forest residual feedstock does not compete with food production; air pollution is cut by reducing slash pile burning; removal of residuals prepares the forest floor for replanting; and the new industry of woody biomass collection and conversion helps create jobs in rural economies. Also, forest residuals are abundant and can be sustainably supplied from private lands.

How does Alaska Airlines see the future market for biofuels?
Sustainable biofuels cost substantially more than regular jet fuel. The cost of biofuels has to be consistently lowered to a price level that is competitive with fossil fuel. This can be achieved through innovation, cooperation and legislation that stimulates the use of biofuels in aviation. Producing biofuel from woody materials is currently more complex and expensive than similar fuel production from oils, starch, or raw sugar, but technology is narrowing that gap.

Who made the biofuels?
The biofuel on your flight was made by the Nortwest Advanced Renewables Alliance (NARA) and it's partners. NARA, led by Washington State University, is an affiliation of universities, government laboratories and companies working together to build a supply chain that uses forest residuals to make aviation biofuels and other co-products. NARA is supported by the Agriculture and Food Research Initiative Competitive Grant no. 2011-68005-30416 from the USDA National Institute of Food and Agriculture. For more information, visit www.nararenewables.com.

Biofuel powered.

Trade Trends

US total wood exports are projected to reach $8.95 billion dollars in 2016, a 3.3% increase over 2015 (Table 1). Considering the top five exports markets, there was strong growth in exports to China (+21.7%) and Mexico (+4.7%) whereas exports to Canada (-7.4%), the UK (-11.1%) and Japan (-9.9%) were all down substantially. The majority of wood exports from the US (69.3%) were made up of lumber (up 5.8% over 2015), followed by logs (+3.1%) and chips/pellets (-13.3%), Table 2. Washington state remained the largest exporter of wood products (with 15.6% of total US wood exports), followed by Pennsylvania, California and Oregon (Table 3). Taken together, the three west coast states represented 26.6% of total US wood products exports. Softwood lumber exports represented 30.2% of US lumber exports (Table 4). The major markets for US softwood lumber were China (18.9% market share) followed by Mexico (18.7% share), Canada (18.4% share) and Japan (9.6% share). Softwood log exports represented 66.2% of total US log exports (Table 5). The major markets for US softwood logs were China (47.8% market share) followed by Japan (29.8% share) and Canada (13.2% share).

Trade Trends is a new service for our readers where we provide a summary of the most up-to-date trade data. Please let

Table 1. Value of US Total Wood Exports, by Destination, 2010-2016e
Source: Global Trade Atlas

	2010	2011	2012	2013	2014	2015	2016e
World total	***$6,785,568,573***	***$7,593,359,285***	***$7,608,457,938***	***$8,680,347,195***	***$9,463,814,275***	***$8,667,745,103***	***$8,953,780,691***
China	$1,162,660,922	$1,915,350,285	$1,640,263,620	$2,344,302,708	$2,660,090,631	$2,065,769,642	$2,513,628,500
Canada	$2,101,831,525	$2,117,371,307	$2,186,601,990	$2,227,215,045	$2,270,658,571	$2,099,826,393	$1,944,229,257
UK	$212,034,509	$211,649,981	$306,343,200	$431,013,355	$638,043,700	$839,873,139	$746,311,271
Mexico	$481,728,646	$513,768,108	$582,340,481	$604,176,008	$656,015,575	$694,664,582	$727,313,817
Japan	$633,666,682	$734,240,780	$729,583,491	$850,194,163	$813,359,290	$725,718,361	$653,872,243
Vietnam	$156,023,712	$150,000,582	$187,340,989	$210,987,031	$254,832,918	$221,369,361	$215,724,442
Australia	$86,847,808	$111,185,282	$110,239,584	$98,475,532	$112,542,444	$112,362,695	$118,722,424
Korea South	$202,760,908	$206,307,255	$163,788,176	$193,635,537	$191,093,367	$130,714,862	$104,859,462
Italy	$187,857,949	$161,183,822	$112,891,018	$159,852,256	$168,538,224	$152,236,733	$98,558,061
Turkey	$53,722,320	$72,205,420	$100,667,226	$77,981,182	$99,546,013	$124,871,564	$98,448,741
Germany	$148,663,777	$134,603,657	$123,163,320	$105,967,325	$110,242,363	$98,057,422	$97,420,049
Spain	$87,226,118	$72,503,848	$54,564,623	$52,818,038	$71,417,837	$90,516,869	$93,422,460
Dominican Rep.	$54,788,022	$49,095,176	$49,988,580	$67,353,887	$73,181,711	$77,087,625	$76,355,293
Belgium	$52,117,345	$36,427,060	$84,363,933	$79,955,101	$75,463,159	$106,728,540	$62,670,999
Bahamas	$42,116,934	$42,472,599	$51,516,776	$61,329,716	$58,381,731	$54,791,525	$59,394,013
Taiwan	$70,043,062	$73,279,372	$75,531,296	$83,971,127	$85,524,729	$65,421,757	$58,526,304
Hong Kong	$70,625,791	$40,326,210	$38,740,941	$39,592,334	$40,253,009	$36,607,381	$53,973,923
Pakistan	$11,711,235	$17,109,880	$24,722,793	$30,251,207	$37,739,878	$48,560,223	$51,619,517
Indonesia	$50,155,223	$52,973,620	$51,693,309	$50,631,753	$49,003,512	$46,214,245	$50,886,505
France	$33,877,417	$28,658,698	$24,974,316	$28,555,557	$28,611,310	$38,325,739	$43,691,342
Ireland	$17,951,234	$15,229,232	$18,248,274	$19,549,605	$26,396,954	$34,363,333	$42,796,095
India	$16,852,090	$34,234,639	$40,667,161	$45,056,600	$55,440,798	$37,303,777	$27,933,068

Table 2. Value of Total US Wood Exports by Commodity, 2010-2016e.
Source: Global Trade Atlas

	2010	2011	2012	2013	2014	2015	2016e
Total	***$6,785,568,573***	***$7,593,359,285***	***$7,608,457,938***	***$8,680,347,195***	***$9,463,814,275***	***$8,667,745,103***	***$8,953,780,691***
Lumber	$2,165,485,033	$2,480,049,110	$2,556,420,960	$3,012,709,159	$3,462,004,183	$3,043,552,959	$3,220,383,386
Logs	$1,873,611,190	$2,230,656,256	$1,986,667,141	$2,432,204,552	$2,515,732,140	$2,029,278,175	$2,092,388,726
Chips/Pellets	$351,212,639	$366,710,200	$525,799,984	$644,079,328	$831,253,768	$1,028,748,736	$891,719,404
Builders' Joinery	$417,081,080	$430,891,936	$432,453,365	$446,645,711	$461,048,132	$412,292,044	$364,466,167
Moulding/Millwork	$243,644,622	$281,961,982	$298,125,688	$298,634,039	$301,324,798	$294,433,943	$307,860,131
Plywood	$351,538,726	$347,237,486	$379,997,078	$398,941,431	$377,642,573	$317,938,455	$304,267,101
Veneer Sheets	$316,571,659	$305,640,394	$304,448,068	$309,607,107	$315,378,145	$304,251,823	$295,763,197
Casks/Barrels	$113,185,542	$109,759,549	$123,609,898	$139,908,266	$184,353,417	$223,274,838	$194,717,986
Fiberboard	$242,570,626	$243,617,289	$261,020,225	$245,326,269	$227,103,639	$202,464,754	$193,232,361
Railway Sleepers	$88,990,579	$130,396,972	$123,820,969	$115,410,467	$142,741,450	$168,779,926	$156,408,357
Particle Board	$150,196,548	$159,082,362	$166,268,133	$183,964,079	$189,407,784	$172,642,234	$153,599,796
Other Wood, Nesoi	$200,212,972	$249,452,891	$194,471,537	$189,415,349	$195,001,454	$173,142,211	$152,070,804
Pallets, Etc	$134,580,684	$137,499,706	$128,860,645	$138,806,811	$131,613,709	$133,070,946	$134,627,876
Wood Marquetry	$28,084,823	$30,137,826	$32,266,227	$30,695,242	$30,058,821	$48,616,956	$90,709,517
Tools/Tool Handles	$49,175,360	$27,436,402	$32,761,101	$29,135,416	$27,390,211	$39,432,764	$44,389,462
Table/Kitchenware	$11,710,919	$13,700,498	$14,374,736	$18,161,709	$21,034,802	$23,400,135	$23,926,638
Wooden Frames	$18,449,824	$20,009,468	$18,562,664	$17,520,874	$18,684,949	$22,686,108	$15,521,835
Wood Charcoal	$9,755,214	$10,867,527	$11,325,025	$14,957,977	$15,606,653	$11,500,195	$12,521,412
Densified Wd Blocks	$4,829,808	$4,258,016	$5,383,089	$4,103,018	$3,198,175	$4,918,671	$9,682,404
Wood Wool	$9,894,964	$10,008,428	$8,276,352	$7,216,845	$7,736,570	$8,576,558	$9,242,957
Split Poles/Stakes	$4,785,761	$3,984,987	$3,545,053	$2,903,546	$5,498,902	$4,742,672	$2,999,740

Trade Tables continued on page 4

Trade Tables continued from page 3

Table 3. Value of Total US Wood Exports, By State, 2010-2016e
Source: Global Trade Atlas

	2010	2011	2012	2013	2014	2015	2016e	Share
Total	***$7,076,308,910***	***$7,914,476,070***	***$7,890,641,014***	***$8,963,166,683***	***$9,744,606,733***	***$8,927,937,190***	***$9,267,198,803***	
WA	$1,302,386,562	$1,716,824,587	$1,427,800,271	$1,918,919,661	$1,800,607,201	$1,314,431,907	$1,441,931,802	15.6%
PA	$350,302,250	$335,470,568	$361,582,608	$427,108,415	$515,637,739	$525,222,895	$608,733,335	6.6%
CA	$353,151,744	$452,662,325	$439,371,483	$507,965,475	$554,662,255	$560,967,360	$551,599,205	6.0%
OR	$493,354,339	$671,406,467	$621,474,094	$659,194,979	$635,920,537	$511,067,880	$468,547,032	5.1%
GA	$222,347,403	$270,894,757	$381,422,742	$403,557,594	$505,888,167	$554,820,094	$429,985,573	4.6%
NC	$365,382,157	$407,873,468	$395,878,371	$414,808,765	$508,820,421	$425,010,573	$402,485,013	4.3%
VA	$251,002,337	$247,933,066	$289,233,202	$343,885,160	$439,923,539	$426,931,184	$400,034,519	4.3%
TX	$186,991,599	$207,141,976	$200,179,691	$206,890,150	$240,557,983	$266,948,126	$366,599,861	4.0%
FL	$293,606,934	$234,765,729	$271,815,789	$324,381,035	$334,522,656	$326,466,879	$345,271,371	3.7%
AL	$219,036,778	$216,415,041	$208,945,258	$282,527,058	$329,362,015	$311,083,827	$333,481,863	3.6%
NY	$325,870,378	$290,836,475	$308,748,908	$381,050,330	$414,207,158	$362,985,018	$318,083,771	3.4%
OH	$242,655,672	$252,858,140	$245,789,359	$251,294,198	$313,900,083	$284,894,731	$305,407,152	3.3%
TN	$174,928,475	$224,458,073	$225,194,317	$240,381,209	$301,521,049	$245,679,718	$262,115,691	2.8%
KY	$116,563,521	$115,911,220	$137,468,478	$170,342,802	$234,899,682	$263,471,399	$246,951,742	2.7%
WI	$184,203,645	$208,833,474	$200,678,297	$209,467,548	$208,290,334	$207,018,173	$223,289,801	2.4%
ME	$221,465,059	$206,045,710	$235,454,925	$278,836,531	$276,605,702	$278,360,867	$199,946,611	2.2%
IN	$160,160,451	$150,116,499	$154,664,285	$169,475,111	$194,299,885	$180,919,300	$196,152,705	2.1%
MI	$147,053,409	$138,288,981	$154,239,403	$159,933,506	$174,960,040	$175,126,128	$175,563,943	1.9%
MO	$102,631,671	$121,384,787	$122,293,170	$128,635,841	$169,687,813	$175,620,011	$171,580,751	1.9%

Table 4. Value of US Softwood Lumber Exports, by Destination, 2010-2016e
Source: Global Trade Atlas

	2010	2011	2012	2013	2014	2015	2016e
Total Lumber	***$2,165,485,033***	***$2,480,049,110***	***$2,556,420,960***	***$3,012,709,159***	***$3,462,004,183***	***$3,043,552,959***	***$3,220,383,386***
HW Lumber ttl	*$1,322,010,118*	*$1,443,468,767*	*$1,593,369,005*	*$1,858,639,452*	*$2,335,897,156*	*$2,059,664,097*	*$2,248,202,801*
SW Lumber ttl	*$843,474,915*	*$1,036,580,343*	*$963,051,955*	*$1,154,069,707*	*$1,126,107,027*	*$983,888,862*	*$972,180,585*
China	$100,556,884	$246,214,829	$140,419,748	$222,021,146	$203,679,501	$157,472,033	$192,084,386
Mexico	$112,184,869	$127,118,094	$152,210,907	$162,729,063	$169,753,612	$173,262,781	$181,146,238
Canada	$188,639,971	$183,433,646	$202,828,432	$219,721,746	$212,556,891	$178,835,984	$177,137,042
Japan	$136,023,091	$156,368,019	$146,200,007	$178,654,256	$129,118,852	$114,073,147	$95,445,002
Dominican Rep.	$37,514,399	$31,159,257	$31,990,139	$43,627,134	$44,990,410	$51,163,641	$51,163,642
Pakistan	$5,340,794	$10,308,584	$12,150,132	$17,198,512	$22,947,757	$30,971,573	$32,287,865
Jamaica	$18,782,060	$21,183,967	$19,915,943	$27,492,264	$25,478,906	$21,384,502	$22,688,957
Taiwan	$31,194,287	$36,967,858	$33,001,704	$45,121,120	$46,736,841	$29,186,542	$19,067,568
Bahamas	$7,818,211	$6,442,592	$10,642,362	$13,766,330	$16,523,055	$16,274,152	$18,477,672
Haiti	$22,633,952	$19,942,633	$11,226,690	$16,850,720	$12,761,359	$14,716,297	$17,138,599
Indonesia	$13,384,273	$16,174,910	$14,699,016	$18,088,598	$14,953,518	$8,811,933	$12,660,985
SW Lumber Ratio	**38.95%**	**41.80%**	**37.67%**	**38.31%**	**32.53%**	**32.33%**	**30.19%**

Table 5. Value of US Softwood Log Exports, by Destination, 2010-2016e.
Source: Global Trade Atlas

	2010	2011	2012	2013	2014	2015	2016e
Total Logs	***$1,873,611,190***	***$2,230,656,256***	***$1,986,667,141***	***$2,432,204,552***	***$2,515,732,140***	***$2,029,278,175***	***$2,092,388,726***
HW Logs ttl	*$769,898,246*	*$689,513,884*	*$678,937,603*	*$671,065,077*	*$801,182,912*	*$771,296,647*	*$706,810,132*
SW Logs ttl	*$1,103,712,944*	*$1,541,142,372*	*$1,307,729,538*	*$1,761,139,475*	*$1,714,549,228*	*$1,257,981,528*	*$1,385,578,594*
China	$414,823,625	$824,049,827	$568,160,969	$858,010,392	$865,741,721	$521,973,638	$613,788,801
Japan	$296,479,827	$336,992,180	$350,100,171	$454,755,151	$424,129,319	$360,837,289	$391,400,207
Canada	$182,421,320	$180,536,472	$188,803,530	$209,925,317	$187,845,232	$202,682,925	$161,457,218
S. Korea	$146,073,830	$147,180,385	$109,255,692	$127,038,662	$100,042,746	$55,505,482	$47,534,895
Italy	$3,692,415	$1,891,350	$4,145,491	$28,642,031	$34,625,096	$52,521,318	$13,907,645
India	$1,784,022	$4,738,670	$11,624,920	$23,520,148	$27,979,523	$11,448,518	$9,030,591
Pakistan	$890,478	$209,319	$922,839	$1,966,669	$2,471,277	$3,127,982	$6,378,894
Vietnam	$3,846,927	$2,853,609	$3,477,813	$5,656,022	$6,409,710	$4,463,624	$5,745,130
Bangladesh	$307,031	$14,127	$647,580	$438,964	$751,525	$1,087,111	$4,500,966
Mexico	$2,824,526	$3,946,327	$7,428,901	$3,217,269	$3,606,711	$5,161,001	$2,160,911
SW Log Ratio	**58.91%**	**69.09%**	**65.83%**	**72.41%**	**68.15%**	**61.99%**	**66.22%**

Life Cycle Assessment Based Environmental Impact of NARA Bio-jet Fuel

Indroneil Ganguly, Francesca Pierobon, Cindy Chen and Ivan Eastin, University of Washington

The Life Cycle Assessment (LCA) method was used to estimate the overall environmental impact associated with producing bio-jet fuel from recovered residual woody biomass, as well as any net reduction in emissions to the atmosphere achieved by displacing fossil fuel-based bio-jet fuel. LCA is an internationally recognized methodology to assess the environmental impacts of a product or activity over its entire life cycle. A comprehensive LCA of forest residue based aviation fuel was performed using a 'cradle-to-grave' approach where 'cradle' is defined as forest residues collected into slash piles in the forest and 'grave' is defined as the combustion of the jet fuel during flight in an aircraft. Utilizing a 'Woods-to-Wake' (WoTW) LCA approach, which is comparable to a Well-to-Wake (WTW) LCA for petroleum based aviation fuel, the environmental implications of feedstock recovery, production, and utilization of residual woody biomass based bio-jet fuel were assessed. A comparative assessment of the LCAs for petroleum based jet fuel and bio-jet fuel from woody biomass was then conducted to assess the overall environmental impact of substituting bio-jet fuel for fossil-based jet fuel.

System boundary

Identifying a system boundary is key to understanding the overall scope of the assessment as is identifying the processes that are included as part of the entire life cycle system and the assumptions specific to the system being assessed. The product system is woody biomass based bio-jet fuel whose function is to fuel an aircraft during flight. The functional unit of the system is 1 GJ of energy produced by fuel combustion. The study is based on a production facility which is scaled to produce 112,980 tons of IPK (bio jet fuel) using 700,000 bone dry metric tons of screened woody biomass. The overall system boundary for developing the LCA of the bio-jet-fuel consists of the following components: (i) feedstock collection and delivery to the conversion facility, (ii) calculating the carbon credit for the avoided carbon emissions derived from not burning the slash pile in the forest, (iii) conversion of the biomass to isoparaffinic jet fuel, and (iv) combustion of the bio-jet fuel in the jet engine. These individual components of the LCA process are explained in the following sections. A mass allocation between logs and the residual woody biomass (tops and branches) is used to identify the upstream environmental burdens associated with the piled woody biomass at harvest landing. In addition, two non-energy wood based co-products, activated carbon and lignosulphonate, are also produced during the production process. Another mass allocation was performed to allocate the environmental burdens associated with the bio-jet fuel, and the two co-products produced during the manufacturing process. The additional activities undertaken for value addition of the co-products are outside the bio-jet fuel system boundary and therefor are not considered.

Feedstock

Woody slash piles (a.k.a. harvest residues) at forest landings are generated during harvest operations, with a significant portion of the residual biomass being scattered around the forest floor during the harvest and skidding operations. Based on empirical time-motion studies, it is estimated that approximately 65% of the residual biomass is accumulated into slash piles located at the primary forest landings (Perez-Garcia et al. 2012) while the remaining 35% remains scattered across the forest floor. After factoring in the loss of biomass during the in-woods collection and grinding processes, it is estimated that only 58.5% of the total harvest residuals generated during the timber harvest operation will be delivered to the pre-treatment facility for conversion into biofuel.

This study assumes that the collection of residual biomass from the harvest landings will be used as the feedstock for bio-conversion into bio jet fuel. The biorefinery conversion facility is estimated to consume 700,000 bone dry metric tons of screened woody biomass annually. Assuming a 9% reject rate, the total feedstock demand is estimated to be 770,000 bone dry metric tons of unscreened residual woody feedstock per year delivered to the gate of the screening facility. Geographic location, regional forest type and topographic characteristics can influence the environmental impacts associated with collecting and transporting woody residues from the forest landing to the biomass processing facility. This paper focuses on the production of woody biomass in the Western Washington region. A mass allocation approach is used to account for the upstream burdens associated with the feedstock (including the harvesting, forwarding and skidding operations).

Avoided Slash Pile Burn Credit Framework

The feedstock used for producing bio-jet fuel is residual harvest slash left over from commercial timber harvest operations. Recovering harvest residues to produce bio-jet fuel results in avoided emissions attributed to the reduced amount of slash pile burning that occurs in the forest. Existing slash treatment options include burning of the slash pile or collecting, chipping and selling it as hog-fuel or pulpwood. Based on the WA biomass calculator ("Washington State Biomass Calculator. Available at: Http://wabiomass.cfr.washington.edu," n.d.), given the existing demand for residual biomass, a conservative estimate of the amount of biomass consumed in non-burn alternatives (excluding the biomass scattered on the forest floor) ranges from between 20 - 40%, depending on the location of the slash piles. Given the low demand for hog-fuel and pulpwood in the region, this would suggest that between 60 and 80% of the biomass in the slash pile is disposed of by pile burning. Based on ISO 14044 guidelines (ISO 2006b), the avoided environmental impacts of slash pile burning attributed to collecting the biomass for bio-jet fuel production can be incorporated in the LCA as a credit. In this paper we considered a 50% and a 100% slash pile burn scenario for the avoided emission credit, to evaluate the beneficial environmental impacts of not burning the slash piles in the forest.

Biomass Conversion and Biofuel Refinery

The scenario considered in this analysis assumes an integrated biomass conversion facility, where the biomass storage, extraction of sugar from the woody biomass and the conversion of the sugar into bio-jet-fuel, are all undertaken at the same location. The conversion process uses a mild bisulfite pre-treatment of the biomass feedstock to liberate the C6 sugars and break down the lignocellulosic material. This slurry is then mixed with a cellulase enzyme and hydrolyzed to produce a fully saccharified sugar stream. The fermentable sugars are then converted to isobutanol (iBuOH) using a proprietary bio-catalytic fermentation and oligomerization process to produce bio-jet fuel (iso-paraffinic kerosene, IPK). Therefore, in this study the overall process for converting residual woody biomass to aviation biofuel is separated into four different sub-processes; (i) pre-treatment of the residual woody biomass, (ii) enzymatic hydrolysis, (iii) fermentation

LCA Bio-jet fuel continued on page 6

LCA Bio-jet fuel continued from page 5

and oligomerization of the hydrolysate to produce iso-paraffinic kerosene (IPK), and (iv) boiler, wastewater treatment and other utilities.

IPK combustion

The model assumes that 6.818 kg of bone dry clean woody biomass produces 1kg of IPK. In the analysis we assumed a calorific value of 43.1 MJ kg-1 for the petroleum based jet fuel and 43.2 MJ kg-1 for the bio-jet fuel (Johnston 2013). Combustion emissions were estimated using the Ecoinvent database for intercontinental air freight since primary data for IPK combustion are not available (Ecoinvent 2013).

Location of the bio-refinery

The location of the bio-refinery plays a significant role in the overall LCA analysis. There were a number of factors used in the analysis that are location specific, while others are specific to the region. The annual feedstock demand for the facility is scaled at 700,000 bone dry metric tons of screened woody biomass to produce 112,980 tons of IPK per year. The overall impact of the feedstock collection, in-woods processing and transportation to the bio-refinery is heavily dependent on the location of the facility (e.g., road transportation distance from forest landing to bioprocessing facility). The LCI data associated with the local electricity grid, the cost of diesel fuel, baseline jet fuel prices, etc., are region specific (e.g., for electricity we used the 'Electricity, at eGrid, NWPP', which is recommended for the PNW). For the analysis presented in this paper, we used a hypothetical location in Grays Harbor county in Western Washington. This site was selected based on its proximity to a reliable and sustainable supply of feedstock to supply the bioconversion facility, the availability of the necessary support infrastructure and a site suitable for building a bioconversion facility of the proposed scale.

Evaluation methods and model assumptions

This study followed the ISO 14040 and 14044 standard (ISO 2006a; ISO 2006b) for the overall LCA framework. The environmental impacts were assessed using TRACI 2.1 (Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts) (Bare 2011). The following impact categories were included in the LCA analysis: global warming, smog, acidification, eutrophication, carcinogenics, non carcinogenics, respiratory effects and ecotoxicity. The life cycle inventory analysis and impact assessments were conducted using SimaPro 8. As per the IPCC Fifth Assessment Report, this paper reports the 100 year impact for the global warming potential for both the bio-based jet fuel and the fossil-based jet fuel (IPCC 2013).

Comparative Assessment Framework

The overall environmental impact associated with the production of bio-jet fuel was then compared against the emissions associated with the production of petroleum-based jet fuel. For the comparative analysis, it is critical to use comparable system boundaries for both of the jet fuel production processes under consideration. A simplified diagram of the system boundaries associated with the production and utilization of woody biomass based bio-jet fuel (Panel A) and petroleum based jet fuel (Panel B) is shown in Figure 1. For this analysis, the LCA emissions associated with 1 GJ of energy produced using bio-jet fuel (iso-paraffinic kerosene, IPK) were compared with those emitted using fossil-based jet fuel (kerosene). The results for the global warming potential were also compared against the baseline for the life cycle GHG emissions from fossil-based jet fuel sold or distributed in the United States, as specified by the

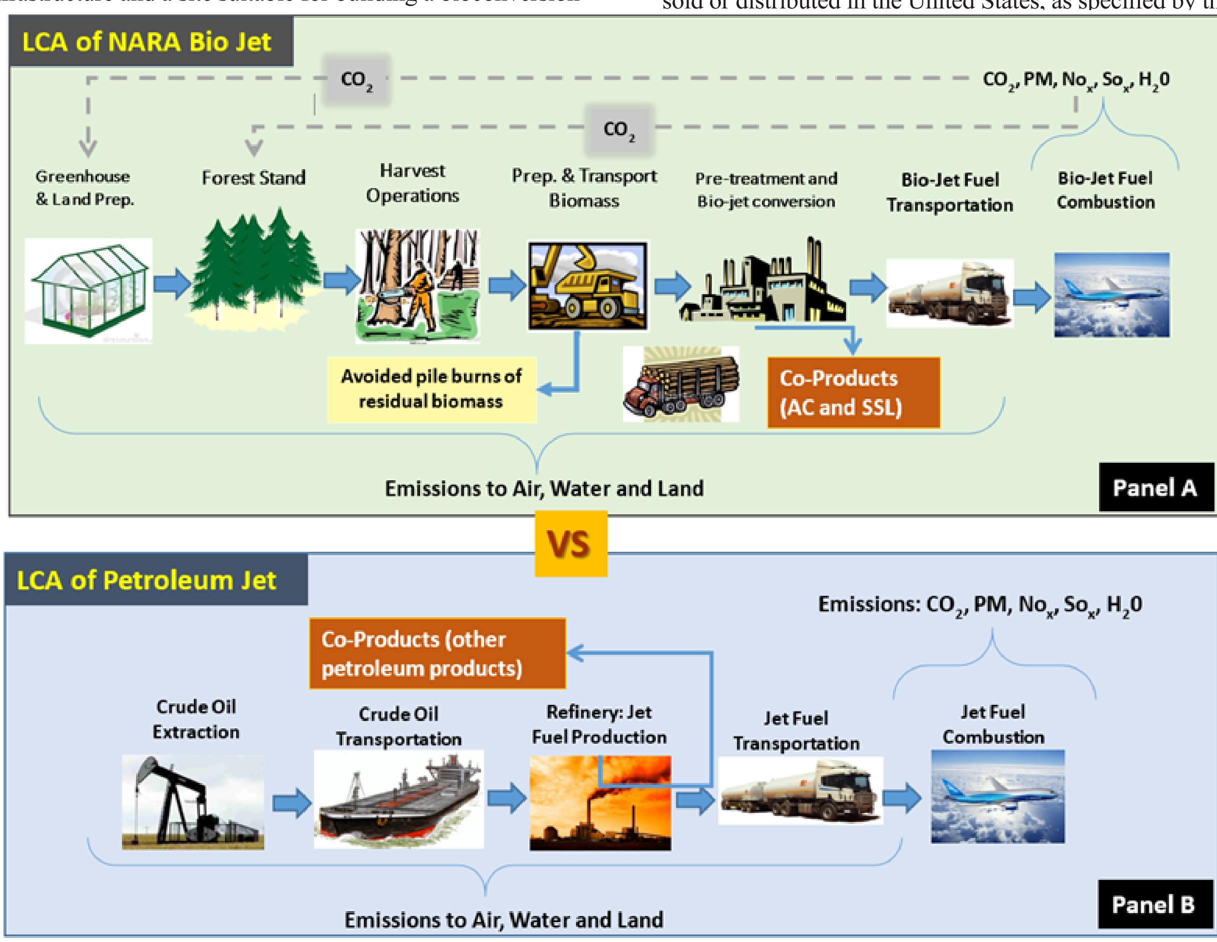

Figure 1: Comparable system boundaries for the production of bio-jet fuel and fossil-based jet fuel

LCA Bio-jet fuel continued on page 7

LCA Bio-jet fuel continued from page 6

Energy Independence and Security Act of 2007 (EPA 2007).

Results

The results presented here correspond to two of the most environmentally conservative and realistic scenarios developed by the NARA researchers. The 'cradle to grave' comparative analysis of fossil-based jet fuel and bio-jet fuel reveals that a more than 70% reduction in the global warming potential, as a result of the reduction in greenhouse gases (GHGs) into the atmosphere, can be achieved by substituting petroleum-based jet fuel by 100% residual woody biomass-based jet fuel, for both of the scenarios, Figure 2. The key environmental benefits associated with residual biomass based bio-jet fuel are the avoided emissions attributed to not burning the residual slash piles (which is indicated by the net negative 'respiratory effects' LCA impact category). The residual woody biomass based bio-jet fuel also showed a substantial reduction in the 'carcinogenics' (110% to 96%), 'non carcinogenics' (37%), 'smog' (5% to 27%) and 'ecotoxicity' (81%) LCA impact categories. Generally, eutrophication is one of the most important areas of concern for biofuels due to the high use of chemicals and enzymes during the conversion process, fertilizers during feedstock production, and waste water management and disposal within the bioconversion facility. In this respect, it is also worth noting the eutrophication impact of the bio-jet fuel is comparable (in the 50% avoided burn case), if not better (in the 100% avoided burn case) relative to fossil-based jet fuel.

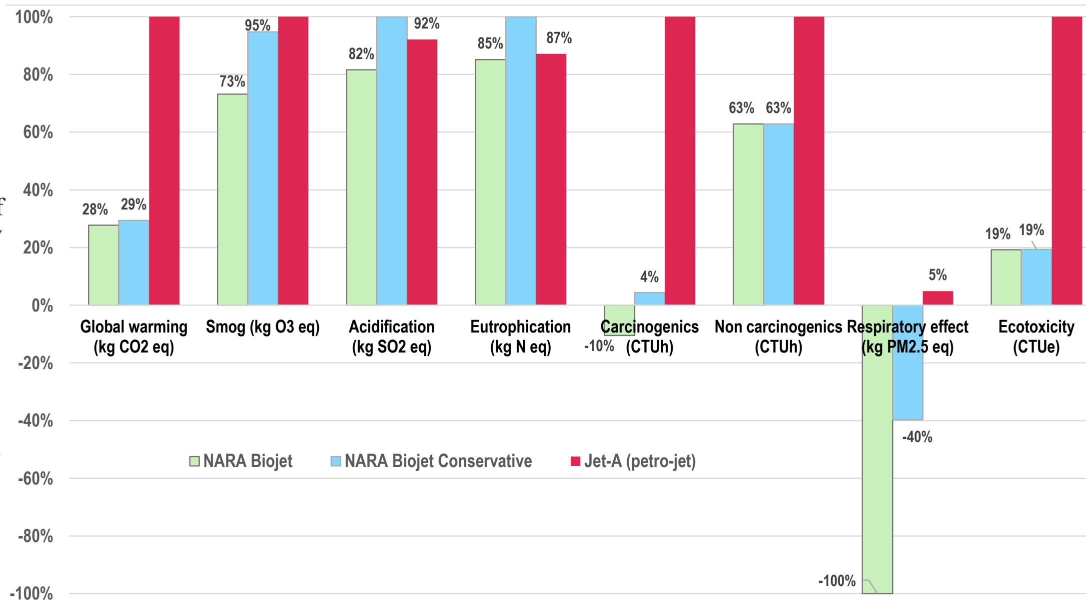

Figure 2. Comparative environmental assessment of fossil-based Jet-A vs NARA bio-jet IPK.

Highlights

- The WoTW/WTW comparative analysis of residual biomass-based and fossil-based jet fuel reveals that a more than 70% reduction in global warming potential (GWP) can be achieved by substituting 100% petroleum-based jet fuel with 100% residual woody biomass-based bio-jet fuel. This result is significantly better than the US Environmental Protection Agency mandated 60% GWP reduction that is required in order for bio-jet fuel to qualify as a bio-preferred fuel for public procurement programs.
- Another important environmental benefit associated with producing residual biomass-based bio-jet fuel is the avoided slash pile burns which improves local air quality and reduces the local health impacts caused by the harmful pollutants generated from burning slash piles in the forest.
- Using residual woody biomass based bio-jet fuel also contributed to a substantial reduction in the 'carcinogenics', 'non carcinogenics', 'smog' and ecotoxicity LCA impact categories. These positive local environmental benefits make residual woody biomass a much more environmentally appealing feedstock for energy production than fossil fuel-based alternatives.

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Economic Impact Analysis of a NARA Woody Biomass Jet Fuel Refinery

by Daisuke Sasatani and Ivan Eastin

Background

One of the objectives of the NARA project was to pioneer the development of environmentally sustainable wood-based jet fuel to contribute to the economic development of rural timber-dependent communities, and to quantitatively estimate the economic impacts associated with the development of a hypothetical woody biomass jet-fuel refinery that could be sited in the Pacific Northwest. It was estimated that a potential bio-refinery would process 770,000 BDT (bone dry tons) of unscreened residual woody feedstock annually. Following a comprehensive review of potential sites, the NARA management team selected Longview WA as the best site to locate the bio-refinery because of the ready availability of biomass around that location.

This study employed a regional input-output analysis (I/O) based on a theoretical woody biomass jet-fuel refinery designed by the NARA techno-economic assessment team (TEA) using economic transaction data. The NARA base case production process uses a mild bisulfite pretreatment of softwood chips derived from forest residuals to produce isoparaffinic kerosene (IPK), the biomass jet-fuel. The conversion process produces two co-products, lignosulfonate and activated carbon, from the portions of the feedstock not converted to IPK (primarily the lignin). The market price of the feedstock was estimated to be $62.60 per BDT delivered at the gate of the refinery. The production process used in the NARA conversion process is designed to produce 35.7 million gallons of IPK, 196,000 dry tons of lignosulfonates and 66,000 dry tons of activated carbon annually. The market prices for these products, based on current market prices, were $2.56/gallon for IPK, of renewable identification numbers (RINs) is $1.54 per cellulosic RIN ($2.464 per gallon of IPK), $200/dry ton for the lignosulfonate and $1,500/dry ton for the activated carbon. The total annual revenue of the refinery was estimated to be $318.1 million. On the cost side, the refinery purchases $215.8 million of various inputs and services from its suppliers. In addition, $102.4 million is value-added, including $15.9 million for employee compensation, $41.0 million of taxes. The total profit for the woody biomass jet-fuel refinery is estimated to be $45.4 million.

Methodology

The total economic impact was calculated by aggregating the direct, indirect and induced economic impacts that are accrued within western Washington and Oregon as a result of all of the economic activities associated with the bio-refinery. In the I/O analytical framework, direct impacts are the economic activities directly attributed to the biofuel refinery: the sale of biofuel and co-products. The direct effects create additional economic activity within the region, which is also captured within the I/O modeling framework. These indirect effects generated by the refinery are the business-to-business transactions that occur as firms engaged in economic transactions with the refinery in turn increase their purchases from other regional businesses. For example, the sale of wood chips to the refinery and the sale of spare parts and fuel for the wood chipper are considered to be indirect impacts. As the direct and indirect effects create new jobs, households will increase their spending on local goods and services. This increased economic activity is the induced effect. On the other hand, payments for inputs purchased from other regions, tax payments to government, and dividends distributed to stockholders residing in other regions are referred to as economic leakages and are not part of the economic impacts.

In order to understand the regional economic activities, there are two different measures that can be used, the ‘gross output’ approach and the ‘value added’ approach. The gross output is the total value of increased sales including the costs of intermediate goods consumed during production (e.g., materials and services). The value added contribution equals the difference between the gross output and the cost of its intermediate inputs, including employee compensation, proprietor income, other types of property taxes and taxes on production. We present the regional economic activities generated by the biofuel refinery using both of these approaches.

Table 1. Annual economic Impacts of a woody biomass jet-fuel refinery located in Longview, WA

	Direct	Indirect	Induced by Employees	Induced by Proprietors	Total
Gross Output ($MM)	$318	$258	$81	$37	$657-$694
Value Added ($MM)	$57-$102	$127	$47	$22	$230-$297
Jobs	173	1171	561	260	1,905 - 2,166

Results

Operation

Based on these estimates and assumptions, an I/O economic analysis of the potential refinery was performed. The economic impacts of the annual operation of the plant are shown in Table 1. With regard to direct effects, the revenue expected to be generated by the refinery is estimated at $318 million (i.e., gross output) of which $57-$102 million would go to employees, stockholders and government (i.e., value added), with 173 full time employees projected. For indirect effects, suppliers of goods and services to the biofuel plant and other companies along the supply chain are expected to generate $257.9 million in sales (i.e., gross output) and create an additional 1,171 jobs. The newly hired employees of biofuel plant and its suppliers would spend approximately $80.9 million within the region (i.e., induced gross output), which would lead to the creation of an additional 561 new jobs. Furthermore, stockholders of the plant would receive up to $37.3 million in dividends although it is uncertain how much of these dividends would remain in the region. In conclusion, the total annual economic impacts of a potential biomass jet-fuel refinery located in Longview is between $656.9 and $694.2 million in industrial gross output, and approximately one-third of these economic impacts are considered to be value added. The establishment of the refinery is expected to create a total of between 1,905-2,166 jobs in the region.

Regional Industrial Sector Benefit

Table 2 shows the sectors that are expected to experience more than $10 million in gross output. The forestry sector, including commercial logging companies, will benefit by $47.6 million, largely through wages paid to forestry workers employed to collect and process harvest residuals to supply the biofuel refinery. The utilities sector ($42.8 million), the construction and maintenance sectors ($34.7 million), and the chemical products sector ($25.9 million) are each expected to generate substantial economic benefits within the region. The truck transportation sector will generate $16.9 million, largely through hauling contracts to supply woody biomass to the plant. It is expected that the facility will require 161 truckloads of woody biomass every day when operating at full capacity. In addition, it is expected that the refinery will consume 48 truckloads of hog fuel supplied from nearby wood processing facilities, which would increase their revenue by $14.3 million.

Feedstock Collection

Feedstock collection activities to supply the biomass for the refinery will provide a strong boost to rural economic development. Using the assumptions regarding the potential plant mentioned previously, the feedstock supply to the facility in Longview was estimated on a

Table 2. Annual regional economic impacts generated by a woody biomass jet-fuel facility, by industry ($millions)

	Sector	Indirect	Induced by Employees	Induced by Proprietors	Total ($millions)
	Total	$257.9	$80.9	$37.3	$694.2
1	Forestry	$47.5	$0.0	$0.0	$47.6
2	Utilities	$41.1	$1.2	$0.5	$42.8
3	Construction & Maintenance	$33.0	$1.2	$0.5	$34.7
4	Chemical Products	$25.4	$0.3	$0.1	$25.9
5	Truck Transportation	$15.9	$0.7	$0.3	$16.9
6	Retail	$5.0	$6.8	$3.2	$15.0
7	Wood Products (Sawmills)	$14.0	$0.1	$0.1	$14.3
8	Wholesale Trade	$8.2	$4.1	$1.9	$14.2
9	Residential Rentals	$0.0	$9.5	$4.4	$13.9
10	Insurance Carriers	$8.9	$3.3	$1.6	$13.8
11	Real Estate	$2.4	$5.4	$2.4	$10.2

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Economic Impact continued from page 8

county basis, Figure 1 (where the circle shows the location of Longview). Based on a variety of factors including available supply, transportation distance and biomass pricing, our supply analysis suggests that the facility would receive 154,040 BDT of woody biomass from Cowlitz County annually, followed by Lewis County (135,632 BDT), Clatsop County (117,459 BDT) and Pacific County (111,715 BDT). In total, 15 counties in southwestern Washington and northwestern Oregon are expected to benefit from the refinery. The economic impacts of feedstock collection within each county are summarized in Table 3. As a result, businesses in Cowlitz County WA would likely receive $19.1 million of additional revenue annually, Lewis County WA ($11.1 million), Clatsop County OR ($9.0 million), Columbia County OR ($7.8 million) and Pacific County WA ($8.2 million). The logging sector in these counties is expected to receive $40.2 million in revenue and provide employment for an additional 330 workers. The truck transportation sector is projected to receive $12.8 million and provide employment for an additional 84 workers. In addition, because of the economic ripple effects, other local business in the region, such as gas stations, restaurants, hospitals, hardware stores, real estate agencies, etc. are expected to receive $23.3 million and be able to hire an additional 216 workers. In total, the collection of forest residues for a biofuel refinery is expected to provide $76.3 million in gross output, while creating 630 new jobs, the vast majority of which would be in rural, timber-dependent communities.

Table 3. Economic contribution from feedstock collection, by county, ($millions and (number of jobs created))

	Feedstock (BDT)	Total	Logging	Truck	Others
Cowlitz WA	154,040	$19.1 (139)	$8.2 (55)	$4.2 (28)	$6.7 (57)
Lewis WA	135,632	$11.1 (95)	$6.3 (51)	$1.3 (8)	$3.5 (35)
Clatsop OR	117,459	$9.0 (72)	$5.4 (39)	$1.0 (7)	$2.7 (27)
Pacific WA	111,715	$7.8 (69)	$4.8 (45)	$1.1 (8)	$1.8 (16)
Columbia OR	64,092	$8.2 (67)	$3.5 (27)	$2.5 (16)	$2.1 (25)
Wahkiakum WA	50,853	$4.4 (45)	$2.7 (31)	$0.4 (3)	$1.3 (11)
Clark WA	50,076	$3.9 (30)	$2.4 (19)	$0.4 (2)	$1.1 (9)
Washington OR	40,728	$3.4 (31)	$1.8 (18)	$0.5 (3)	$1.2 (10)
Tillamook OR	35,748	$2.5 (26)	$1.5 (17)	$0.4 (3)	$0.6 (6)
Thurston WA	26,592	$2.2 (17)	$1.1 (8)	$0.3 (2)	$0.8 (7)
Clackamas OR	24,962	$2.0 (17)	$1.0 (9)	$0.3 (2)	$0.7 (7)
Grays Harbor WA	15,385	$1.1 (10)	$0.6 (6)	$0.2 (1)	$0.4 (3)
Skamania WA	13,760	$0.9 (7)	$0.6 (5)	$0.1 (1)	$0.2 (2)
Others	5,018	$0.6 (4)	$0.2 (1)	$0.2 (1)	$0.3 (2)
Total	**846,059**	**$76.3 (630)**	**$40.2 (330)**	**$12.8 (84)**	**$23.3 (216)**

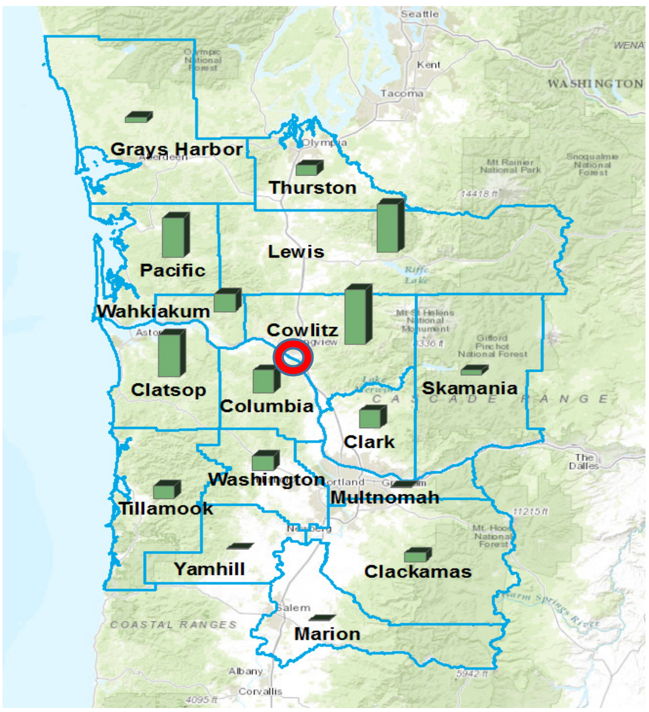

Figure 1. Regional feedstock supply for the hypothetical woody biomass jet-fuel refinery located in Longview WA

Construction of the Plant

In addition, building the refinery will require $1.04 billion in capital investment. Its construction should generate substantial short-term economic benefits to the local economy. It is expected that businesses in Cowlitz County WA could receive up to $797 million in annual revenues and see the creation of up to 3,951 annual jobs during the construction of the biofuel refinery. However, many of these economic impacts would dissipate soon after the construction of the facility is completed.

Conclusions

The results of an economic analysis show that the operation of a biomass jet-fuel refinery will bring substantial economic impacts. If the refinery were to be located in Longview, the total economic impact would be around $700 million in gross output that could create about 2,000 new jobs in the region. The economic ripple effects of forest residue collection could create 630 jobs in rural timber-dependent communities located in southwestern Washington and northwestern Oregon. Establishing an innovative wood-based biomass jet-fuel refinery in this region would provide a huge boost for the environment and be beneficial to rural economies.

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