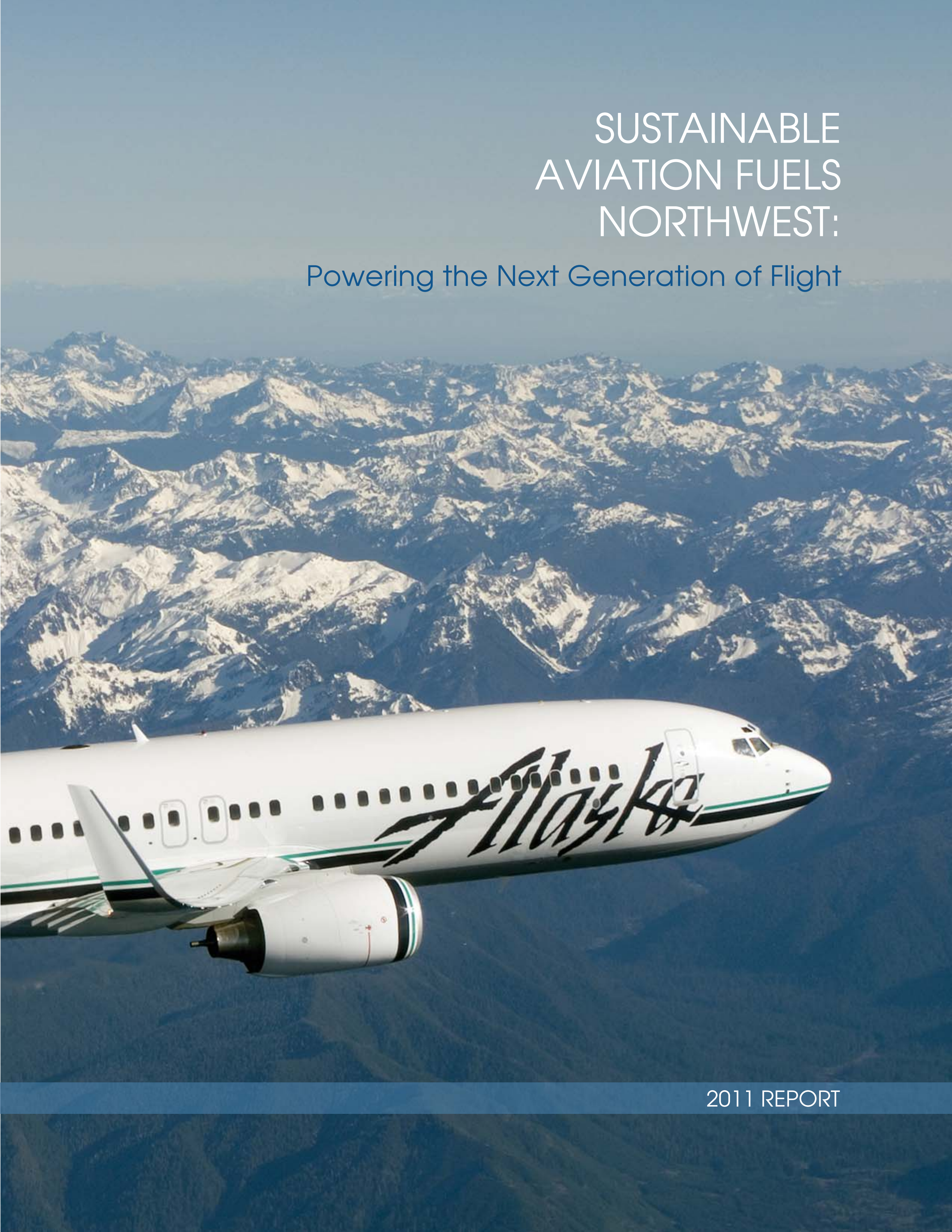
SUSTAINABLE AVIATION FUELS NORTHWEST:

Powering the Next Generation of Flight



2011 REPORT

SUSTAINABLE AVIATION FUELS NORTHWEST SPONSORING ORGANIZATIONS

Alaska Airlines
The Boeing Company
Port of Portland
Port of Seattle
Spokane International Airport
Washington State University

FACILITATOR, PRIMARY RESEARCHER AND REPORT PRODUCERS

Climate Solutions – Ross Macfarlane, Patrick Mazza, Jeannette Allan

STAKEHOLDERS

- ADAGE
- Air Transport Association (ATA)
- AltAir Fuels LLC
- Bioalgene
- BioPure Fuels
- Conservation Northwest
- Core Fuels
- Dennee Consulting
- Great Plains Oil & Exploration, The Camelina Company
- Green Diamond Resource Company
- Houghton Cascade
- Imperium Renewables, Inc.
- MATRIC Research
- Natural Resources Defense Council
- The Nature Conservancy
- Northwest Biodiesel Network
- Oregon Department of Agriculture
- Oregon Environmental Council
- Oregon State University
- Parametrix
- Roundtable on Sustainable Biofuels
- Spokane Industries
- Stoel Rives, LLP
- Sun Grant Initiative - National
- Sun Grant Initiative - Western Region
- United States Department of Agriculture - Rural Development and Agricultural Research Service
- United States Department of Defense, Defense Logistics Agency Energy
- United States Department of Energy
- UOP, Honeywell Company
- Washington Environmental Council
- Washington State Department of Commerce
- Washington State Department of Natural Resources
- Weyerhaeuser
- William D. Ruckelshaus Center
- Wilson Sonsini Goodrich & Rosati

OBSERVERS:

- US Senator Patty Murray
- US Senator Maria Cantwell
- US Representative Jay Inslee
- US Congressman Adam Smith
- Westbrook Associates LLC

TABLE OF CONTENTS






Photo Credits top to bottom:
The Weyerhaeuser Company, NREL, Spokane International Airport, Targeted Growth, Inc., WSU, NREL

OVERVIEW — Taking the Initiative

The year is 2020.

An Alaska Airlines "Next Generation" Boeing 737 powers its engines to more than 25,000 pounds of thrust and rumbles forward until, wheels up, it soars into a Northwest sky.

In the cabin, the 170 men, women and children who are experiencing the everyday miracle of flight settle in for the journey, thinking about their jobs, vacations and loved ones at their destinations across the country.

As the passengers unwind, some open their inflight magazines where they see an article explaining that this plane, like other flights from the major Northwest airports, is partly powered by safe, sustainable fuels refined from plant material grown in the farms, forests, and communities that pass slowly beneath their cabin windows.

The Sustainable Aviation Fuels Northwest (SAFN) effort is focused on turning this vision into reality.

SAFN is the nation's first regional stakeholder effort to explore the opportunities and challenges surrounding the production of sustainable aviation fuels. This report reflects the results of ten months of work and the perspectives of more than forty stakeholders.

The Northwest is a global center of aviation innovation, and aviation is a vital regional economic sector. So the Northwest is a logical place to launch a pioneering effort aimed at identifying safe, sustainable, low-carbon resources to power the next generation of flight.

SAFN is based on a **shared vision** of a future in which regional industries will produce fuels from sustainable regional biomass.

THE BACKGROUND STORY

SAFN was convened by regional leaders in the aviation industry, including **Boeing Commercial Airplanes**, **Alaska Airlines**, the operators of the region's three largest airports — **Port of Seattle**, **Port of Portland** and **Spokane International Airport** — and **Washington State University**, a leader in sustainable fuel research. They retained regional energy nonprofit **Climate Solutions** to facilitate the process and prepare the report.

These leaders recognized that developing sustainable fuels required gathering knowledge and insight from a wide range of stakeholders, including biofuels companies, technology providers, environmental and energy advocates, agriculture and forestry managers, government officials and other experts. A full list of the more than 40 SAFN stakeholders is shown on the cover page.

> No single feedstock or technology pathway is likely to provide sustainable aviation fuel at the scale or speed needed to achieve our goals. Therefore, this report focuses on a portfolio of options. They include different conversion technologies and sources of potentially sustainable biomass, including oilseeds, forest residues, solid waste, and algae.

While the development of alternative jet fuels is a global challenge, SAFN focuses on sustainable biomass grown in the Northwest. This regional approach provides the best opportunity to develop fuels that fit local environmental conditions and spur regional economies. Instead of trying to identify the "best" feedstock for development, the report urges a diverse approach, supporting work on several promising technologies and feedstocks. The report specifically identifies opportunities and challenges for four promising pathways: oilseeds, forest residues, solid wastes, and algae. For each feedstock, SAFN identifies a proposed "flight path" to help overcome key commercial and sustainability challenges and speed fuel production.

Context for Action

A variety of factors drive the need for safe, affordable, and sustainable alternatives to petroleum fuels for aviation. Cost, national security, and climate top the list.

- **Cost:** Airlines are particularly vulnerable to the wild price swings that have characterized global markets for petroleum in recent years, increasing demand for alternative fuels. Supply limitations, rapidly increased demand, and unrest in key petroleum exporting areas may continue to drive up fuel prices.
- **National Security:** With the United States importing ever increasing amounts of petroleum, national security is a key driver for developing home-grown sustainable fuel supplies. The Defense Department has adopted a mission focus on powering its jets with domestically produced alternatives to petroleum fuels.
- **Climate:** Concerns about climate change are driving demands for lower carbon alternatives. Aviation contributes a small, but growing share of carbon dioxide emissions – estimated at two to three percent worldwide. While aviation leaders have made significant strides in reducing fuel use and emissions per passenger mile – designing significantly cleaner planes and increasing efficiency of

operations – industry leaders have identified lower-carbon fuels as a key requirement to meet its climate goals.

Need for Priority Focus on Aviation

The SAFN participants agree that a strong aviation industry is critical for economic, cultural and security reasons. That calls for a priority on developing sustainable aviation fuel supplies. Compared to ground transportation sectors and electricity generation, aviation has fewer fuel alternatives. For at least the next twenty to thirty years, jet airplanes for commercial and military uses will need liquid, high energy-density fuels with the same technical characteristics as petroleum based fuels.

Safety and performance are essential design criteria for aviation fuels. SAFN is only considering "drop-in" fuels that meet rigorous approval standards for safe use in existing planes and fueling infrastructure. First generation biofuels, such as ethanol or biodiesel, will not work. The good news is that drop-in fuels are now available and are being tested and approved for use in both commercial and military aircraft.

> Successful test flights using a variety of biofuel blends have already occurred, involving both commercial and military aircraft. Some of those tests used fuels produced by SAFN participants from biomass grown in the region.

The key international body that ensures that safety and technical standards are met for all fuels, ASTM International, has already approved an alternative fuel specification for one technology and another is expected this year. Based on these efforts, it appears that the technical and safety issues for future approvals are well understood and new processes should find a clearer path to meet this test.

The Need for Sustainable Fuels

From the beginning, the aviation leaders who convened SAFN identified sustainability as a key criteria.

Not all bioenergy is sustainable energy. Production of biofuels without appropriate safeguards can lead to increased carbon emissions, unacceptable competition with food, impacts to water quantity and quality, destruction of critical habitats and other issues. To avoid "reinventing the wheel," SAFN utilized principles established by the Roundtable on Sustainable Biofuels (RSB) to evaluate these issues. The RSB is an international body with a wide range of stakeholders that is developing sustainability standards for biofuels. Given SAFN's focus on the four Northwest states, the focus was narrowed to elements that the RSB and stakeholders agreed were most relevant to determine whether potential biofuel feedstocks and technologies have the potential for sustainable development. These elements included principles addressing greenhouse gas emissions, local food security, conservation, soil, water, air, and technology, inputs and waste management.

SAFN only conducted a screening level evaluation of these sustainability principles, and sustainability will have to be validated in practice. The report does not mandate any particular method for validating sustainability – fuel producers and purchasers may look to third-party certification, compliance with applicable laws and risk evaluations to address these issues.

BUILDING COMPLETE SUPPLY CHAINS WITH DIVERSE FEEDSTOCKS

Instead of trying to identify the "best" source of aviation fuels, SAFN identified the need to create complete supply chains that can draw upon diverse feedstocks.

The Northwest presents a substantial market for jet fuel, with 865 million gallons annually consumed for commercial and military airplane use in the four-state Northwest region, Washington, Oregon, Idaho and Montana. The bulk of demand comes from SAFN stakeholders. By 2030 that demand is projected to grow to more than one billion gallons per year.

Compared to other markets, the aviation industry presents a concentrated market with a relatively small number of "filling stations" – airports – where fuels need to be supplied. Creating a sustainable fuel industry will require an integrated approach along the whole supply chain.

> The SAFN recommendations address sustainable production of biomass, collection and delivery of the feedstocks, crushing and preparation, process technologies for fuels and co-products, and blending and delivery to end-users at airports.

This supply chain approach is consistent with federal recommendations calling for "an outcome-driven, re-engineered system" to meet national goals for advanced biofuels. They include regional supply systems compatible with U.S. transportation and fuel infrastructure, and a strong focus on accelerating drop-in biofuel development.

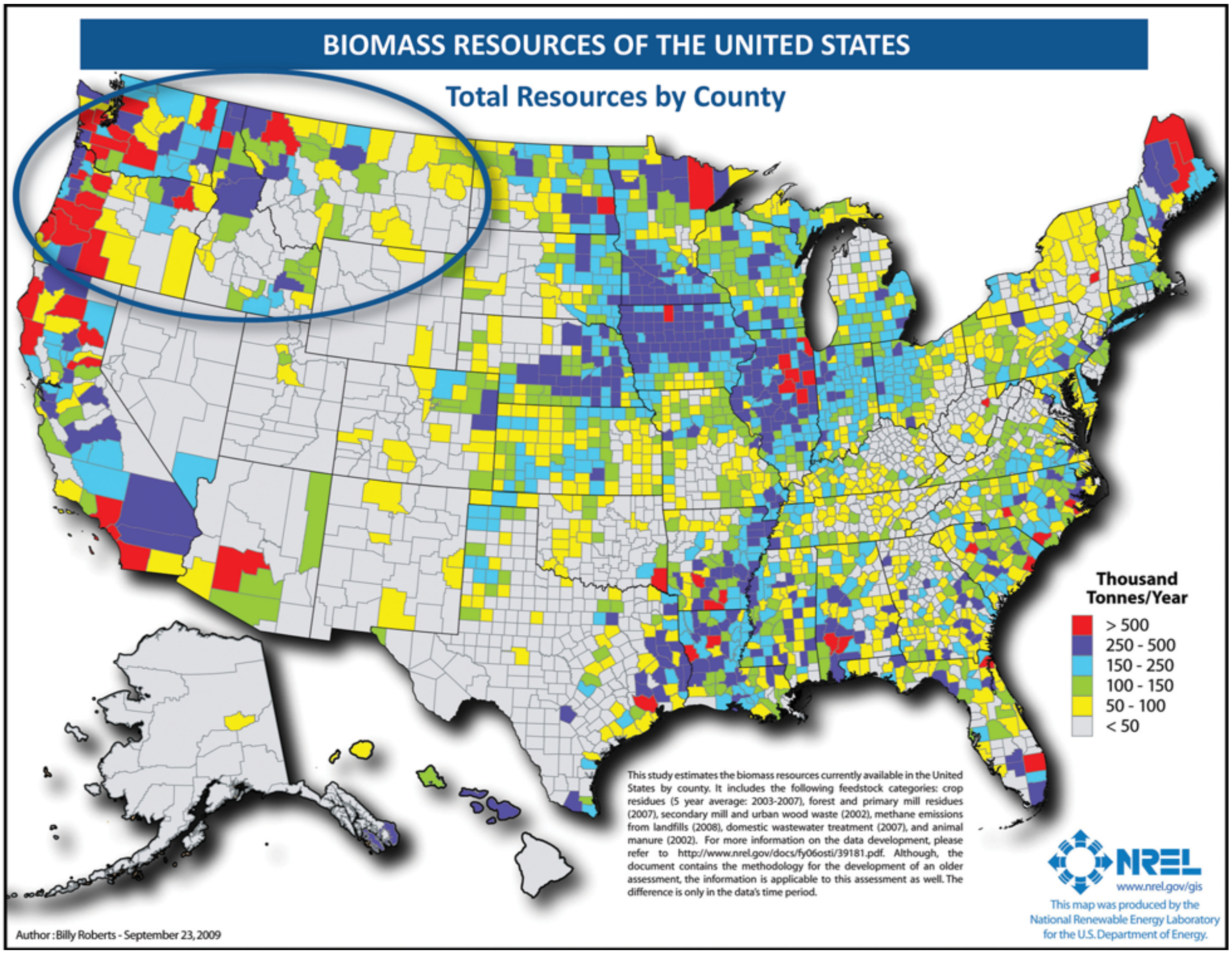
No single feedstock or technology pathway is likely to provide sustainable aviation fuel at the scale or speed needed to achieve our goals. Therefore, this report focuses on a portfolio of options. They include different conversion technologies and sources of potentially sustainable biomass, including oilseeds, forest residues, solid waste, and algae.

This report assesses these technologies and feedstocks, identifies opportunities and challenges, and suggests **"flight paths"** to create sustainable and commercially viable supply chains for biomass-based aviation fuel.

NORTHWEST ASSETS

The Northwest offers significant assets to meet a portion of its jet fuel demands from sustainable regional feedstocks.

The Northwest currently produces virtually none of its own petroleum. Developing a robust sustainable biofuels industry will produce significant jobs and tax revenues and substantially reduce financial outflows from the region. While no specific projections are available for a regional biofuel industry, one national study found that producing 475 million gallons of biofuel in 2009 resulted in 23,000 jobs across the economy, $4.1 billion in added GDP growth, $445 million in federal tax revenues, and $383 million for state and local governments (the fuel quantity used in this study is close to the projected regional demand for aviation, assuming use of a 50 percent biofuel blend).



This map was produced by Billy Roberts on Sep. 23, 2009, National Renewable Energy Laboratory for the U.S. Department of Energy

Feedstock production would likely represent half the direct jobs, boosting employment in rural areas and small communities. Participants in any new industry also can benefit from "first mover" advantage, creating opportunities for regional companies to drive biofuel development throughout the nation and world.

The Northwest agricultural, forest and urban areas have significant potential biomass resources. The region also has tremendous expertise through research universities, government agencies and industries. The Pacific Northwest National Laboratory, for example, is the designated national research center on thermochemical conversion of biomass. Washington State University, one of the SAFN conveners, conducts world-class research on biofuel conversion, forestry and agricultural practices.

Credit left to right: Lynn Ketchum, OSU, The Weyerhaeuser Company, Spokane International Airport, Sapphire Energy

KEY OPPORTUNITIES

SAFN specifically analyzed opportunities and challenges, and developed **"flight paths"** to develop complete supply chains focusing on two primary conversion technologies and four feedstocks.

Conversion Technologies

- **Hydroprocessing** – a technology which has long been used in oil refineries – can be adapted to produce aviation fuels from natural oils. ASTM approval for an aviation fuel using up to a 50 percent biofuel blend is anticipated later this year. This provides a near-term opportunity to create Northwest supply chains for sustainable aviation fuels utilizing oils from oilseed crops such as camelina, as well as algae and biomass. A report chapter covers steps needed to create regional hydroprocessing facilities.
- Technologies are emerging that use heat, chemicals and microorganisms to process **woody biomass** and **cellulose** into fuels and chemicals. This opens the way to using forest and agricultural residue streams, as well as significant portions of municipal and industrial solid waste. One technology has received ASTM approval and others are in cue. A report chapter provides an overview of emerging technologies and ways to site demonstration facilities in the Northwest.

Promising Feedstocks

- **Oilseed crops**, notably camelina, provide an opportunity to derive substantial amounts of sustainable aviation fuels from existing Northwest agricultural land. Camelina can be grown in rotation with dryland wheat, minimizing competition with food production while providing industrial-grade oils and animal feed. But agricultural challenges will need to be overcome to ensure adequate supplies from growers and other supply chain participants. The report's chapter on oilseeds outlines challenges in establishing mass oilseed cultivation including improved agricultural knowledge, better varieties, new product markets, infrastructure and public policies to reduce grower risk.
- Northwest **forest residues** are a potentially significant resource of biomass and create the opportunity to partner with one of the region's strongest traditional industries. Most Northwest forest products have strong markets and so fuels will be derived from materials that have few or no markets now such as residuals, also known as slash. But creation of a new energy demand for forest materials has raised debate on the adequacy of forest protection frameworks. Further dialogue on the sustainability of energy production from forests will be required. Improved technologies to reduce transportation costs are also needed. The forest residuals chapter overviews these challenges and the steps to meet them.

- Municipal and industrial **solid wastes** provide a potentially significant source of biomass. One of the greatest challenges in biomass-based fuels is collecting feedstocks and transporting them to central locations. These systems are already in place for wastes. Despite recycling and composting programs, large streams of organic wastes still go into landfills. Fuel plants capable of processing wastes are in development around the world. Ultimately key decisions on the priority of energy production in waste and recycling are made at the local level. The report's chapter on waste streams looks at regional potentials and calls for local dialogues among policymakers, waste haulers, recycling advocates and other stakeholders to determine the role of energy in waste management plans.
- The Northwest has **algae production** potential through systems adapted to the region's changing seasons. These systems feed algae with sunlight, organic wastes and carbon dioxide. Algae production has already been piloted in the region. Additional field research and pilot projects will be needed to identify the types of algae production that are most suitable for Northwest conditions and to ensure commercial viability. The report's algae chapter lays out steps to build regional algae cultivation.

"Regional Flight Plan"— Key Policy Priorities

SAFN's ultimate goal is to accelerate commercial supply chains in the Northwest for sustainable aviation fuels. As with any new energy industry, policy support will be critical in the early years.

On March 30, 2011, President Obama highlighted the opportunity for domestically-produced, renewable jet fuels. The President directed the Navy, Air Force and other federal agencies to focus efforts on securing advanced fuels that can power military jets, commercial planes and other transportation sectors. He called for breaking ground on four commercial scale refineries within two years.

The Northwest is well positioned to site one or more of these refineries because it has key conditions for success. The region has strong companies, concentrated demand, leading expertise and significant biomass resources. It has also laid the groundwork by engaging key stakeholders in developing consensus flight paths to launch Northwest supply chains for sustainable aviation fuels.

This section highlights our highest priority recommendations for policies that will spur creation of sustainable fuels for aviation. More detailed recommendations are also contained as part of the "flight paths" for specific technologies and feedstocks.

THE TOP RECOMMENDATIONS ARE:

1. Create a strategic focus on sustainable fuels for aviation

SAFN stakeholders urge decision makers to recognize the critical importance of catalyzing the development of safe, sustainable and commercially viable fuels for aviation. Support for aviation biofuels should at a minimum be equal to policies supporting other transport and energy sectors. Ideally, considering aviation's economic, cultural and security importance, sustainable aviation fuels should gain a priority.

2. Promote stable, long-term policy to attract investment

Stable, long-term government policies are needed in order for a sustainable aviation fuels industry to grow and thrive. Well-integrated, consistent policies will help mitigate critical risks for feedstock growers and producers when undertaking a new feedstock or technology. SAFN specifically recommends allowing government agencies, including the military, to enter into long-term contracts for advanced fuels. The stakeholders also urge continuing and expanding key programs under the Farm Bill and other federal programs, and ensuring that aviation fuels and promising feedstocks qualify for incentives detailed in these programs. Specific recommendations include continuing the Biorefinery Assistance Program and excise tax incentives.

3. Ensure support for aviation fuels and promising feedstocks under the Renewable Fuel Standard 2 (RFS2) Program

The RFS2 program provides critical support for advanced biofuels. By qualifying for Renewable Identification Numbers (RINs), producers of low-carbon fuels can earn valuable, market-based credits. SAFN stakeholders urge support for this program and coordinated efforts to ensure that promising technologies and feedstocks used to produce jet fuels qualify for RIN credits.

4. Provide strong state and local backing for this industry sector

Even in today's era of constrained budgets, there are a variety of steps that states and local governments can take to support development of supply chains for aviation fuels. These include support for key infrastructure needed for advanced biofuel refineries, targeted job training, and pilot projects.

5. Target research and development on regional efforts critical to commercializing sustainable aviation fuel projects

SAFN stakeholders support continued investment in targeted research and development that will accelerate advanced biofuels for this sector. In particular, regional research institutions should get priority for coordinated efforts to address key gaps and research needs for this sector. The region has developed strong models for collaborative research involving public universities, U.S. Department of Energy national labs, and other institutions. Future funding should build on these models and specifically target aviation fuels as a critical priority.

6. Incorporate sustainability considerations into efforts to create an advanced biofuels industry

The report highlights the importance of sustainability in creating renewable fuels for the aviation industry. Renewable aviation fuels are being developed to address key issues with existing petroleum fuels, including greenhouse gas emissions, other environmental impacts and energy security. SAFN stakeholders agree that we need to accelerate efforts to find replacements for petroleum fuels, but also emphasize the need to analyze the full lifecycle impacts of potential biomass pathways and technologies. Sustainability should be a crucial consideration as policies are shaped for biofuels generally and more specifically for aviation. This will ensure that policies are crafted to achieve the desired result - reducing greenhouse gas emissions and reducing other impacts - and provide solid measurement and data capability to withstand scrutiny.

CONCLUSION — Working Together

The Northwest can realize a sustainable aviation fuel industry through regional collaboration and policy support.

SAFN has worked to map a flight path to sustainable aviation fuels in the Northwest. Now stakeholders look forward to working with a broader set of regional and national leaders in government, industry and the non-profit sectors to overcome the challenges and create supply chains for sustainable fuels for this critical sector.

As this report demonstrates, aviation is a priority sector with a unique need for sustainable alternatives to petroleum fuels. The Northwest possesses significant institutional assets, leadership vision and natural resources that create an opportunity to build a dynamic new fuels industry. The SAFN process itself provides compelling evidence of the benefits from a unified focus. These recommendations result from the combined expertise and perspectives of a wide range of key stakeholders representing aviation, biofuels, natural resources, public agencies, non-profits and research institutions, all working together.

The payback will be a new regional industry that creates sustainable jobs by drawing on traditional regional economic strengths, including a strong aviation industry and strong farming and forestry sectors. The need is clear. The time to make that future flight a reality is now.

Photo Credit: Frank Young, WSU

Advancing Sustainable Aviation Fuels

INTRODUCING SUSTAINABLE AVIATION FUELS NORTHWEST

Sustainable Aviation Fuels Northwest is the nation's first regional stakeholder initiative aimed at developing safe, sustainable and viable aviation fuels to power the next generation of flight.

As a global center of aviation innovation, it is appropriate that the Northwest is staging this process. The region is home to Boeing Commercial Airplanes, now bringing the world's most efficient commercial jet plane to market – the 787. It is the home of Alaska Airlines, one of the airline industry's fuel efficiency and emissions reductions leaders. It is also home to environmentally innovative metropolitan airports and to leading biofuels research institutions.

Recognizing the importance of sustainability as a factor in alternative fuels breakthroughs, Alaska Airlines and Boeing joined with the region's leading airports, Port of Seattle, Port of Portland and Spokane International Airport, and Washington State University, a center of advanced biofuels research, to create Sustainable Aviation Fuels Northwest (SAFN). SAFN is born of a shared vision – an aviation future using Northwest feedstocks to create jobs in a new sustainable aviation fuels industry. Climate Solutions, a Northwest energy non-profit, was retained to manage a stakeholder process and to research and write this report. The initiative takes place within a network of similar stakeholder processes around the world.

> The SAFN report is based on the insights of more than 40 stakeholder organizations ranging across aviation, biofuels production, environmental advocacy, agriculture, forestry, federal and state government agencies, academic research and technical consultancies.

SAFN's mission focuses on identifying regional opportunities and challenges facing sustainable aviation fuel production in the four Northwest states: Washington, Oregon, Montana, and Idaho.

This report contains the results of the SAFN process. The group has built consensus around the recommendations in this report and actions required to overcome challenges and realize opportunities. SAFN strongly urges coordinated actions by policymakers and industry to develop safe and sustainable fuels for aviation's future.

When SAFN was launched in July 2010, Boeing Commercial Airplanes President and CEO Jim Albaugh said:

> *"The Northwest is a global gateway for people, cultures and commerce, and aviation is a vital contributor to that process. Developing a sustainable aviation fuel supply now is a top priority both to ensure continued economic growth and prosperity at regional levels and to support the broader aim of achieving carbon-neutral growth across the industry by 2020."*

Alaska Air Group Chairman and CEO Bill Ayer agreed, emphasizing that while much has been accomplished, more must be achieved.

Photo Credit: The Boeing Company

> *"By transitioning to a more fuel-efficient fleet and adopting technology to follow more direct flight paths, Alaska Airlines has made significant strides in minimizing the environmental impact of our flying in the communities we serve. Through this initiative, we are joining other key stakeholders in our region to explore the development of alternatives to jet fuel that could further reduce our carbon footprint," Ayer said.*

Since then, from the last half of 2010 through the second quarter of 2011, SAFN conducted five workshops and developed working groups to gather information and provide insights about specific feedstock and technology pathways, sustainability issues, aviation needs and communications.

While sharing best-practices with similar efforts worldwide, SAFN for several reasons has focused on Northwest biofeedstocks that are either purpose-grown for energy or derived from residue. Developing economically and environmentally sustainable fuels for jet travel presents a global challenge. Opportunities and challenges vary considerably from region to region, depending on the climate, soils, economics and social factors of each area. SAFN stakeholders are not seeking to replace our current dependence on petroleum with fuels from a few crops grown in limited regions around the world. This would entail too many economic, environmental and political risk factors and do nothing to address national security concerns related to dependence on foreign sources of energy.

In aviation, safety is always paramount. This report only focuses on "drop-in" fuels, those that can meet the rigorous standards set for aviation fuel.

SAFN has identified key opportunities for the Northwest to supply a wide range of environmentally and economically sustainable aviation-fuel feedstocks. Rather than picking a single feedstock or technology, SAFN recommends a portfolio identified by regional research institutions and stakeholders as having high potential to supply significant amounts of aviation fuel. SAFN also recognizes that options may change, becoming more or less promising, especially as technologies mature.

SAFN specifically analyzed Northwest sustainable aviation fuel opportunities and challenges, and developed "flight paths" to develop complete supply chains focusing on two primary conversion technology fields and four feedstocks.

Conversion Technologies

- **Hydroprocessing** – a technology which has long been used in oil refineries – can be adapted to produce aviation fuels from natural oils. ASTM approval for an aviation fuel using a up to a 50 percent biofuel blend is anticipated later this year. This provides a near-term opportunity to create Northwest supply chains for sustainable aviation fuels utilizing oils from oilseed crops such as camelina, as well as algae and biomass. A report chapter covers steps needed to create regional hydroprocessing facilities.
- **Process technologies for woody biomass and cellulose** are emerging that use heat, chemicals and microorganisms to make materials fuels and chemicals. This opens the way to using forest and agricultural residue streams, as well as significant portions of municipal and industrial solid waste. One technology has received ASTM approval and others are in cue. A report chapter provides an overview of emerging technologies and ways to site demonstration facilities in the Northwest.

Promising Feedstocks

- **Oilseed crops**, notably camelina, provide an opportunity to derive substantial amounts of sustainable aviation fuels from existing Northwest agricultural land. Camelina can be grown in rotation with dryland wheat, minimizing competition with food production while providing industrial-grade oils and animal feed. But agricultural challenges will need to be overcome to ensure adequate supplies from growers and other supply chain participants. The report's chapter on oilseeds outlines challenges in establishing mass oilseed cultivation including improved agricultural knowledge, better varieties, new product markets, infrastructure and public policies to reduce grower risk.
- **Forest residues** are a potentially significant resource of biomass and create the opportunity to partner with one of the region's strongest traditional industries. Most Northwest forest products have strong markets, so fuels will be derived from materials that currently have few or no existing markets such as residuals, also known as slash. But creation of a new energy demand for forest materials has raised debate on the adequacy of forest protection frameworks. Further dialogue on the sustainability of energy production from forests will be required. Improved technologies to reduce transportation costs are also needed. The forest residuals chapter reviews these challenges and the steps to meet them.
- **Municipal and industrial solid wastes** provide a potentially significant source of biomass. One of the greatest challenges in biomass-based fuels is collecting feedstocks and transporting them to central locations. These systems are already in place for wastes. Despite recycling and composting programs, large streams of organic wastes still go into landfills. Fuel plants capable of processing wastes are in development around the world. Ultimately key decisions on the priority of energy production in waste and recycling are made at the local level. The report's chapter on waste streams looks at regional potentials and calls for local dialogues among policymakers, waste haulers, recycling advocates and other stakeholders to determine the role of energy in waste management plans.
- **Algae** cultivation has Northwest production potentials through systems adapted to the region's changing seasons. These systems feed algae with sunlight, organic wastes and carbon dioxide. Algae production has already been piloted in the region. Additional field research and pilot projects will be needed to identify the types of algae production that are most suitable for Northwest conditions and to ensure commercial viability. The report's algae chapter details steps to build regional algae cultivation.

The report addresses additional opportunities, including agricultural residues, wood products, mill residues and hybrid poplar plantations.

The most viable technologies are those that exploit various raw materials in a "hub and spoke" arrangement, one where the initial processing occurs close to the waste stream while further upgrading occurs at the final refinery. This helps overcome transportation and cost challenges.

The basis for these conclusions and the action plans required to realize them are detailed in this report.

AVIATION INDUSTRY COMMITMENTS

Aviation leaders are working with fuel and feedstock producers to create safe and sustainable alternatives to petroleum-based fuels at a commercial scale.

> By actively building a market demand for sustainable fuels, the aviation industry is helping to lay the foundation for a new growth industry. Market demand draws the entrepreneurial initiative, public policy support and financial investment vital to sustainable fuels production.

Global aviation carbon dioxide (CO_2) emissions were estimated at 628 million tons in 2009, equaling slightly more than two percent of human CO_2 emissions.[1] These emissions were projected to grow to three percent by 2050.

The atmospheric effects of other aviation emissions, such as nitrogen oxide and water vapor, are still being evaluated by the scientific community.

In the U.S., by contrast, the greenhouse gas (GHG) footprint of commercial aviation has been shrinking, even as the industry transports far more people and goods. The Environmental Protection Agency's most recent GHG Inventory (currently released in draft form) reports that GHG emissions from commercial aviation in 2009 in the U.S. were 18 percent ***lower*** than in 1990 (down from 136.8 teragrams CO_2 Equivalent in 1990, to 112.5 $TgCO_2eq$ in 2009).[2]

Nevertheless, aviation increasingly is subject to regulatory and public pressures to reduce its GHGs. Beginning on January 1, 2012, the European Union's Emissions Trading System (ETS), is scheduled to initiate a carbon price for flights within, originating from, or going to that continent. This action is subject to legal challenge.[3] The airline industry is the second largest sector in the ETS after power generation.[4] Airlines will pay an estimated 1.4 billion Euros in 2012 for 88 million permits, each representing one metric ton of CO_2, while 175 million permits will be allocated to airlines. Airline carbon payments are expected to increase in the future.[5] New Zealand, meanwhile, already has an emissions trading system. These regulatory actions are important influences on industry action. Stakeholder views vary widely on the appropriateness of these actions.

---

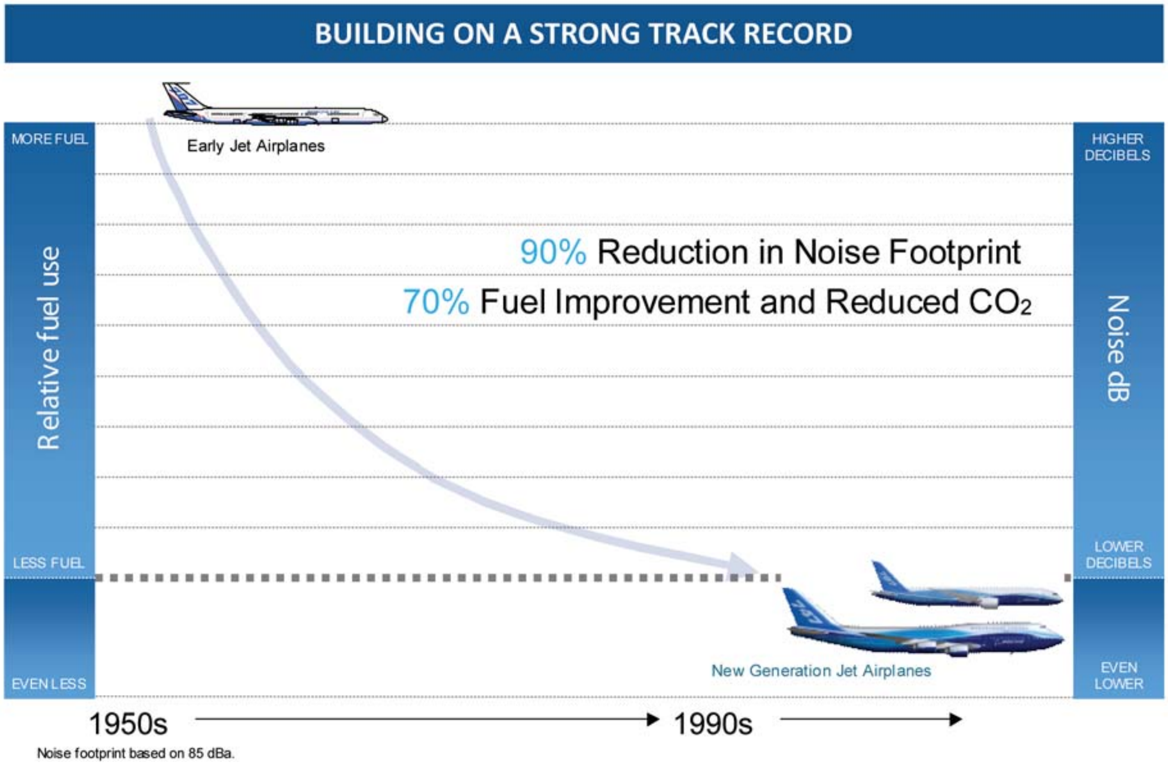
1 "Energy Related Carbon Dioxide Emissions." U.S. Energy Information Administration: International Energy Outlook. 2010. "UNFCC Climate Talks: The right flight path to reduce aviation emissions." A position paper presented by the global aviation industry, ACT, CANSO, IATA, ICCAIA, IBAC, Nov. 2011. Some reports indicate that greenhouse gas emissions from aviation may result in a proportionately larger share of radiative forcing. http://www.gao.gov/products/GAO-09-554.

2 U.S. EPA. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009." February 2011. (see Table A-109, Total U.S. Greenhouse Gas Emissions from Transportation and Mobile Sources ($TgCO_2Eq$) at pp. A-138 to A-140).

3 ATA, a SAFN stakeholder has challenged the ETS on the grounds that it is contrary to international law. ATA and the global commercial aviation industry advocate for a global sectoral approach for aviation in international negotiations as an alternative to national or regional regulations.

4 Environmental Leader. "Airlines to Be Second Biggest Sector in EU Carbon Market; Energy Firms Want Tough Targets." 7 March 2011.

5 "Airlines to spend estimated €1.4bn on carbon permits in 2012." Guardian, March 8, 2011. Viewed 15 March 2011.



Credit: The Boeing Company

The aviation industry, meanwhile, has adopted its own advanced goals for energy and carbon:[6]

- Develop fuel efficiency improvements, resulting in average annual carbon dioxide (CO_2) efficiency improvement of 1.5 percent per year from 2009 through 2020 on a revenue ton mile basis;
- Cap industry-wide CO_2 emissions from 2020 (carbon-neutral growth), subject to critical aviation infrastructure and technology advances achieved by the industry and government; and,
- Reduce CO_2 emissions by 50 percent by 2050, relative to 2005 levels.[7]

To reduce emissions, the aviation industry is flying airplanes that use less fuel. To the degree possible within the existing air traffic control system, software and procedures that reduce distances, optimize trajectories and lower flying times are also used. Consequently, from the first generation of jet airliners in the 1950s to today's models, aircraft manufacturers through continuous airframe, technology and jet engine improvements have reduced the amount of fuel per passenger-mile by 70 percent, the Boeing Company notes. Since 2004 Alaska Airlines, has reduced the carbon intensity of its operations 23 percent and absolute carbon emissions by 10 percent, crediting much of its fuel-use reduction to more efficient aircraft.[8]

[6] Including Boeing and Alaska Airlines, Air Transport Association, International Air Transport Association and Air Transport Action Group, http://enviro.aero/CNG2020.aspx

[7] "21st Century Aviation - A Commitment to Technology, Energy and Climate Solutions." Air Transport Association. Viewed 25 Jan. 2011

[8] "Improving Our Environmental Footprint: Alaska Air Group 2009 Environment Report." Alaska Air Group, 2009.

SAFETY FIRST

SAFN stakeholders recognize that safety and performance are paramount for any proposed fuel. This report focuses solely on "drop-in" fuels that can meet rigorous safety and technical standards for use in current jet engines. For commercial airlines, approval standards for fuels are established through a process administered by ASTM International. The United States Department of Defense administers approval processes for jet fuel used in military applications.

SAFN is not considering first-generation biofuels such as ethanol, biodiesel or others inappropriate for commercial or military aviation because of their lower energy density and poor performance at high altitudes. While the report considers potential technologies and feedstocks not yet approved for aviation use, SAFN explored only fuels that stakeholders believe can meet these standards. Obtaining approvals for their use in aviation will be on the critical path any new fuels must travel. (The approval processes are detailed below.) Because safety and performance design criteria **must** be met before any fuels are approved for commercial or military aviation, this report goes into less detail on these issues and more on evaluative factors concerning sustainability or commercial viability.

THE NEED TO ADDRESS SUSTAINABILITY

The focus on sustainability is central to the SAFN process.

Over the past decade, first-generation biofuels have experienced a roller coaster ride, both economically and in public perception. Presented as solutions for petroleum and pollution reduction, these fuels have been attacked on a number of fronts. Critics claim these fuels drive up food prices and that feedstock crops increase soil erosion and diminish water quality.[9] Questions emerge about whether first-generation biofuels represent real reductions in fossil energy or carbon emissions.

At the same time, food price pressure on biofuels industry margins caused a wave of bankruptcies. The United Nations Food and Agriculture Organization announced that in December 2010 its global food price index hit a record high of 214.7, a jump of over eight points in a month.[10]

While the debate over first-generation biofuels lies outside the scope of this report, market realities and perception problems facing first-generation biofuels may influence decisions by policymakers and investors. Their support is vital for advanced biofuels development. Sustainability is a key factor, together with commercial scale, economic viability and safety.

---

[9] There has been recent information, however, that puts some of these claims in perspective. See the recent World Bank sponsored report: Baffes & Haniotis, July 2010. Placing the 2006/08 commodity price boom into perspective, WPS5371.

[10] "FAO food price index hits record high in December." *Reuters*. 5 Jan. 2011.

AVIATION INDUSTRY INITIATIVES TO ADDRESS SUSTAINABLE FUELS

Aviation industry players in the U.S., Europe, Latin America, the Middle East, China, and Australasia have signed onto a number of other new sustainable fuel development initiatives. They are:

NATIONAL AND INTERNATIONAL EFFORTS

Air Transport Action Group (ATAG) – ATAG is a global aviation industry coalition that conducts advocacy and research to improve environmental sustainability in aviation, including sustainability standards for new aviation fuels. ATAG represents airports, airlines, manufacturers, air navigation services providers, airline pilot and air traffic controller unions, chambers of commerce, travel and tourism, investment, ground transportation and communications providers.

Commercial Aviation Alternative Fuels Initiative (CAAFI) – Co-founded in 2006, this partnership among the Air Transport Association, the Federal Aviation Administration, Airports Council International-North America and the Aerospace Industries Association explores and promotes the advancement of new sources of both fossil and bio-based fuels through four teams: research and development, certification and qualification, environment and business. Its step-wise approach identifies challenges to the deployment of such fuels and takes them on, either directly or by helping others who share the goal of making commercially viable, environmentally preferred alternative aviation fuels a reality. The CAAFI coalition of more than 300 supporters worldwide includes aviation fuel users, fuel producers, airports, airframe and engine manufacturers, government agencies with remits related to aviation or alternative fuels more generally, NGOs and universities.

International Civil Aviation Organization (ICAO) – The lead United Nations agency dealing with commercial aviation issues, ICAO seeks to develop an international CO_2 standard for aircraft by 2013. It is working to coordinate actions among member states to promote aviation goals for carbon-neutral growth.

Sustainable Aviation Fuel Users Group (SAFUG) – This alliance representing airlines that use approximately 20 percent of global commercial aviation fuel has committed to sustainability standard developments by participating in the RSB's global multi-stakeholder process. (RSB efforts to build a global framework for biofuels sustainability are covered below.) SAFUG standards include:

- Fuel feedstock sources developed in a manner non-competitive with food, minimizing biodiversity impacts without jeopardizing drinking water supplies,
- Total lifecycle greenhouse gas emissions from plant growth, harvesting, processing, and end-use significantly reduced compared to those associated with fuels from fossil sources,
- Outcomes that improve socioeconomic conditions for small-scale farmers in developing nations, that do not require the involuntary displacement of local populations,
- No clearing or conversion of high conservation value areas and native ecosystems.[11]

[11] "Our Commitment to Sustainable Options," Sustainable Aviation Fuel Users Group." Viewed 25 Jan. 2011.

Federal Initiatives — The U.S. Departments of Energy, Agriculture, Commerce, Transportation and Defense as well as the service branches, are deeply engaged in alternative fuel development. Federal initiatives and an aviation industry effort to promote parity for aviation in federal biofuels programs, Farm-to-Fly, are covered in the sections below including one on federal policy.

REGIONAL GLOBAL EFFORTS

Sustainable Aviation Fuel Road Map (SAFRM) – An initiative of the Australasian SAFUG, SAFRM in 2010 was the first comprehensive multi-stakeholder assessment focused on regional supply chain development of sustainable aviation fuels.

China – Leading Chinese aviation and energy entities are working with U.S. partners to establish a domestic sustainable aviation industry. Boeing and the Chinese Academy of Sciences have launched the Joint Research Laboratory for Sustainable Aviation Biofuels, focused on developing algae-based fuel technology.

Plan de Vuelo (Flight Plan) – This formal multi-stakeholder road mapping process in Mexico is led by SAFUG member Aeropuertos y Servicios Auxiliares (ASA), as part of Mexico's Inter-Ministerial Biofuel Development Commission. It guides creation of a Mexican biofuels industry compliant with global sustainability standards such as RSB.

Aliança Brasileira para Biocombustíveis de Aviação (ABRABA) – This Brazilian coalition of academic, government, and commercial parties seeks to create a sustainable aviation fuel supply chain in Brazil.

Sustainable Bioenergy Research Center – This consortium in the United Arab Emirates, hosted by Masdar Institute of Science and Technology, drives technological development in arid land and saltwater-tolerant terrestrial biomass for jet and other fuels.

Sustainable Way for Alternative Fuels and Energy for Aviation – The European Commission's Directorate General for Transport and Energy, in conjunction with an alliance representing commercial biofuel interests and fossil-based alternatives, is investigating the feasibility of alternative aviation fuels.

Aviation Priority

CENTRAL PRIORITY

The creation of a sustainable aviation biofuels industry is a strategic priority and a key SAFN recommendation. SAFN participants agree that commercial and military aviation should receive priority attention in policy development and commercial efforts to create a sustainable biofuels industry. Many public policies, however, often focus on first-generation biofuels and existing biomass-to-electricity generation, failing to recognize and sometimes hindering the development of sustainable aviation fuels.

Several important factors underpin this recommendation, which informs the rest of this report:

- First, aviation is a critical sector of our economy. The SAFN stakeholders agree that we need a strong aviation industry for economic, cultural and security reasons.
- Second, aviation does not have energy alternatives that other sectors can pursue. Compared to ground transportation, heating and electricity generation, the three areas currently developing the largest demands on biomass, aviation has the clearest need for liquid, energy-dense fuels.
- Third, the supply of sustainable biomass feedstocks is limited, both in our region and globally. As demand for alternative energy grows and sensitivity about critical sustainability issues increases, we will be forced to make strategic choices about the best uses for this material.
- Fourth, aviation has some structural advantages that facilitate development of economically viable advanced biofuels including concentrated demand and delivery infrastructure.

KEY DRIVER OF ECONOMIC GROWTH

A strong air transportation network is fundamental to the global, national and regional economy, with direct impact on economic prosperity and national security.

> In the Northwest states, an economically viable alternative aviation fuel industry will mean more jobs in the agriculture, forestry, processing and transportation sectors.

In 2009, 2.2 billion passengers took to the air globally. Commercial aviation worldwide is responsible for 33 million jobs, including 5.5 million directly in the industry. Aviation in the U.S. contributes $731.5 billion to the U.S. economy, more than five percent of gross domestic product, and is responsible for 10.9 million jobs. Air shipments are only five percent by volume of global shipments, but by value represent 35 percent of the total. In the United States, commercial aviation accounts for about 25 percent of the value of all mercantile trade, and about one-third of the value of exports.[12] Aviation links individuals and organizations, enabling human connections in a fashion that the most advanced telecommunications do not.

[12] "When America Flies, It Works: 2010 Economic Report." Air Transport Association of America. 2010; "UNFCC Climate Talks: The right flight path to reduce aviation emissions." A position paper presented by the global aviation industry, ACT, CANSO, IATA, ICCAIA, IBAC, Nov. 2011.

AVIATION AND ENERGY

Credit: Portland International Airport, Spokane International Airport, Port of Seattle

Aviation is a vital component of the Northwest economy. Boeing Commercial Airplanes maintains its headquarters and major production facilities around Puget Sound, with production facilities in the Portland area as well. Aviation industry goals to reduce CO_2 emissions 1.5 percent per year from 2009-2020 will benefit Boeing and other commercial airplane manufacturers, since they will require an estimated $1.3 trillion global aviation industry investment in new economically and environmentally efficient aircraft through 2020.[13]

Northwest airports also are important economic players. For example, direct employment at Seattle-Tacoma International Airport is 89,902 direct jobs, while the Port of Seattle Aviation Division has $13.2 billion in business revenue. Portland International Airport supports nearly 19,000 jobs, totaling income more than $866 million in income annually while generating more than $3.2 billion in business revenues. Spokane International Airport and the adjacent Airport Business Park have a nearly $1 billion economic impact on the Spokane Region, employ more than 3,000 people and form the center of an expanding aerospace industry cluster.[14]

Commercial aviation is an economic lifeline, enabling the “physical Internet” and economic productivity associated with just-in-time supply chains. As stated by the FAA :[15]

> *The speed and reliability of air transportation has enabled industries involved with high-value goods to create efficient, time-sensitive supply chains. The speed provided by air transportation, used in conjunction with modern logistics tools, has made it possible for these industries to reduce inventory requirements and deliver high-value and often perishable goods to end users in ways that would otherwise be impossible. As part of the U.S. transportation infrastructure, the air transport network contributes added efficiency, technological advancement and versatility that enhance the overall quality of life for U.S. residents and the world as a whole. Improvements in the quality of life affect everyone, including the seasoned business traveler, the leisure traveler, the consumer ordering goods online, the patient awaiting an organ donation that might be flown in from across the U.S., and visitors from abroad.*

In short, ensuring a vibrant aviation industry is critical to achieving future clean economic growth. Aviation is a key driver of economic vitality and growth.

---

[13] “UNFCC Climate Talks: The right flight path to reduce aviation emissions.” Air Transport Action Group. A position paper presented by the global aviation industry, Nov. 2010.

[14] Sea-Tac figures from Port of Seattle, Portland International Airport figures from Port of Portland, Spokane International Airport figures from Eastern Washington State University, Report to SIA Board, 2010.

[15] FAA. “The Impact of Civil Aviation on the U.S. Economy.” December 2009: pp. 6-7.

LIMITED OPTIONS

Currently biomass for energy is overwhelmingly directed to biofuels for ground transportation or to create electricity or heat for industrial, residential and other important and commercially viable uses. Nevertheless, these sectors generally have alternatives that do not exist for the aviation industry.

For example, many experts believe that fully electric and hybrid vehicles will play a major role in the future of ground transportation. The recent introduction of cars like the Nissan Leaf and Chevrolet Volt exemplify a major push in this direction. Related developments are occurring in truck and rail transportation, where development of hybrid electric technologies is a major trend. Similarly, renewable alternatives like wind, solar, geothermal, and hydropower for electricity generation are being extensively deployed.

By contrast, plug-in planes are nowhere on the horizon for commercial or military use, nor are planes powered by fuel cells or other fundamentally different sources of energy likely to be feasible and available any time soon.[16] While aircraft manufacturers and defense agencies continue to research and develop new approaches, air travel for the next 30-50 years will be dominated by planes requiring liquid, high-energy density fuels with the same characteristics as current jet fuels. This creates a strategic imperative to produce significant quantities of aviation fuels from available, sustainable biomass.

LIMITED BIOMASS

Bioenergy is not new. We have always used materials from farms and forests for fuel while supplying our food, fiber and animal feed needs. In fact, biomass currently supplies over 50 percent of the renewable energy in the United States.[17] All these uses need to be carefully balanced. In addition to direct human uses, biomass is critical for a wide range of ecosystem and environmental needs. Available biomass estimates vary widely and opportunities are subject to significant regional differences. The quantities that can be sustainably developed for energy are significant but limited. For example, a relatively optimistic assessment with limited sustainability criteria conducted for the United States Departments of Agriculture and Energy in 2005 indicated that biomass could displace only 30 percent of the nation's petroleum needs.[18]

With the focus on sustainability, it is critical that major new demands for bioenergy production not only maintain or improve the productivity of the biomass resource, but accommodate needed human and ecosystem uses. To the extent bioenergy demand is driven by government policies, strategic decisions are required to balance and prioritize biomass demand.

For these reasons, the SAFN participants urge decision makers to give priority to producing aviation fuels from sustainable biomass feedstocks. This does not mean that aviation should be the only energy use; competitive markets and stakeholder support exists for many other uses.

We can and should continue to support a variety of energy uses from sustainably produced biomass; aviation biofuels projects will create co-products such as renewable diesel and chemical feedstocks. SAFN specifically emphasizes the need for public policy makers to strategically focus on creating profitable supply chains to produce sustainable aviation fuel.

---

[16] Such systems may be utilized for supplemental on-board electrical systems but not for the aircraft's engine power source.

[17] US Energy Information Agency. "Renewable Energy Consumption in the Nation's Energy Supply." August 2010.

[18] R. D. Perlack. "Biomass as Feedstock for a Bioenergy and Bioproducts Industry The Technical Feasibility of a Billion-Ton Annual Supply." U.S. Department of Agriculture, U.S Department of Energy, 2005.

Energy Challenges Intensify

ECONOMIC PRESSURES

The past decade has witnessed rising concern over energy. Petroleum prices rose to an all-time record of $147/barrel in 2008, briefly dipped as low as $30/barrel in late 2008, and again in 2011 reached $100/barrel, threatening to dampen global economic recovery. Price volatility is crucial to businesses planning for the future: uncertainty breeds caution and inhibits growth. Petroleum is increasingly concentrated in unstable and unfriendly regions of the world. Given these factors, many forecasters expect oil-price volatility to persist.

> Airlines are particularly susceptible to price spikes and global jet fuel prices have been subject to even greater volatility than other petroleum products in recent years.

Airline profit margins are thin and operating costs are critical considerations. At 2010 consumption rates, every penny per gallon increase in the jet fuel price translates into about $175 million annually for U.S. passenger and cargo airlines. This means that each added dollar per gallon translates to $17.5 billion in operational costs annually.[19]

The rapid spike in petroleum prices during 2007 and 2008 created significant economic losses in the airline industry. The airline industry is highly competitive and subject to sensitive elasticity of consumer demand. This makes it difficult for airlines to pass on increased costs, although capacity reductions in recent years have improved their ability to respond to increased oil prices. While the global recession softened demand and prices, trends in recent months to prices exceeding $100/barrel translate into jet fuel prices above $3.00 per gallon.[20] Airlines use jet fuel, not crude oil, and in recent years, the “crack spread” for jet fuel has risen substantially, meaning jet fuel prices generally rise faster than crude oil prices.

The early 2011 explosion in oil prices driven by Mideast unrest caused the International Air Transport Association (IATA) to reduce its airline industry 2011 profit projection to $8.6 billion, a 46 percent decline in net profits from 2010’s $16 billion. “Profits will be cut in half compared to last year and margins are a pathetic 1.4 percent,” said Giovanni Bisignani, IATA’s Director General and CEO.[21]

While President Obama recently joined every predecessor since Richard Nixon in pledging to reduce our dependency on imported oil[22], the percentage imported has continued to grow, and almost all imports are used in transportation. U.S. oil imports accounted for nearly one-third of total demand in 1973 just before the first oil shock. This has grown to more than 60 percent today[23]. In 2010, the U.S. imported nearly 12 million barrels of oil per day. The cost to import that oil for the year equaled roughly $410 billion (estimated

---

[19] John Heimlich, Chief Economist, Air Transport Association. Personal interview. 7 Feb. 2011.

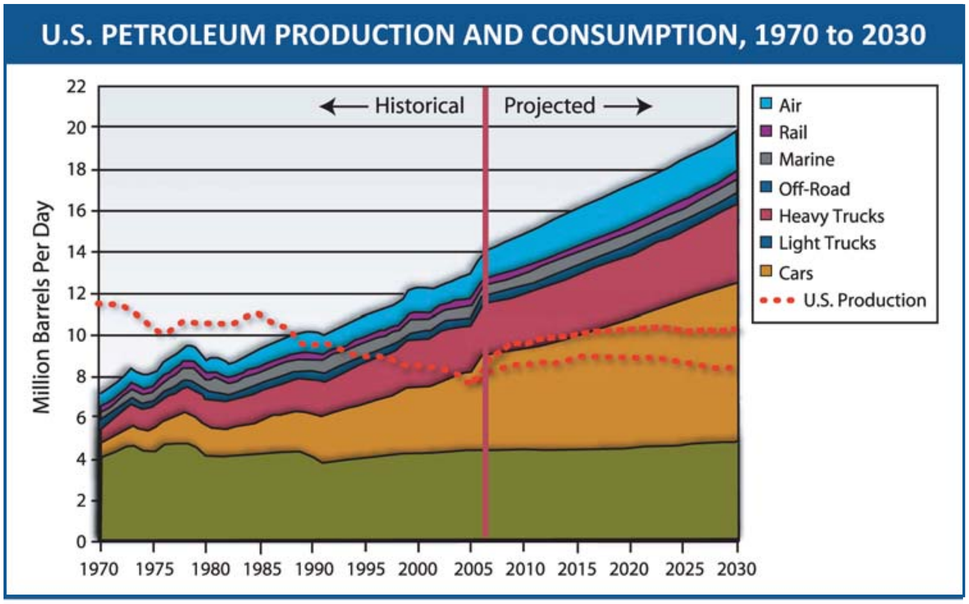
[20] United States of America Energy Information Administration. “Crushing, OK WTI Spot Price FOB.” Independent Statistics and Analysis. 20 Jan. 2011. Viewed 25 Jan. 2011.

[21] International Air Transport Association. “Outlook Downgraded to $8.6 Billion - High Oil Price Cuts Airline Profits by Almost 50%.” 2 March 2011.

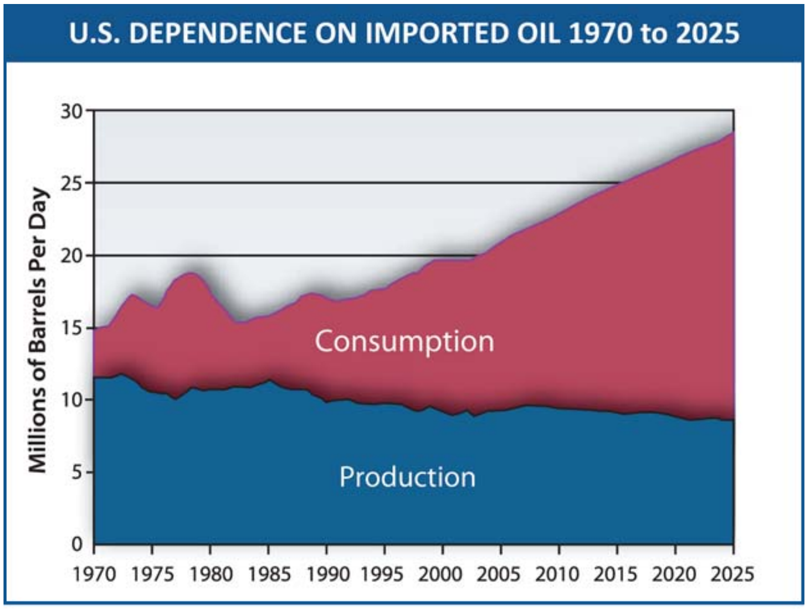
[22] President Obama. “Remarks by the President on America’s Energy Security.” White House Press Office. Washington, D.C., 31 March 2011.

[23] U.S. Energy Information Administration. “U.S. Imports, 1973-2005.” Monthly Energy Review. Viewed 25 Jan.

at an average cost of $75 per barrel). That represented a lion's share of the 2010 U.S. deficit on trade in goods of $506.9 billion, and exceeded the overall current account deficit of $378.4 billion[24]. This places downward pressure on the dollar, which drives up the costs of all imported goods and threatens global financial stability. Import dependency is expected only to increase as domestic production continues a decline that began in the early 1970s. The following charts depict the trends:



Credit: Western Governors Association with data from U.S. Department of Energy



Credit: Western Governors Association with data from U.S. Department of Energy

[24] U.S. Bureau of Economic Analysis, International Economic Accounts. "U.S. International Transactions, 1960-present." Viewed 25 Jan. 2011.

Credit: Green Hornet, U.S. Navy Photo
(Use of released U.S. Navy imagery does not constitute product or organizational endorsement of any kind by the U.S. Navy).

NATIONAL SECURITY CHALLENGES

Even the most casual readers of news headlines recognize the connection between our dependence on imported petroleum and the strategic threats that our armed services face every day. No one is in a better position to recognize their importance than our military leaders.

"The United States Navy and Marine Corps rely far too much on petroleum, a dependency that degrades the strategic position of our country and the tactical performance of our forces," states *The Department of the Navy's Energy Goals*. "The global supply of oil is finite, it is becoming increasingly difficult to find and exploit, and over time cost continues to rise."[25]

An active participant in the SAFN process, the Defense Logistics Agency (DLA), handles fuel purchases for all armed services and a number of federal agencies, and is focused on developing sustainable and competitively priced alternatives to petroleum. In fiscal year 2010, the agency purchased 129 million barrels of fuel for $15.2 billion, and projects 2011 purchases at $16 billion for 125.5 million barrels. Jet fuel constitutes the largest share of the armed services fuel demand, accounting for 73 percent of total purchases.[26]

The U.S. Air Force, the largest consumer in the federal government, using approximately 2.5 billion gallons of aviation fuel per year, "is dedicated to integrating energy management across mission areas and implementing a portfolio of renewable and alternative energy projects that will enhance the Air Force's energy security," notes *Air Force Energy Plan 2010*.

Due to the magnitude of energy consumed by the Air Force alone, "any actions to reduce consumption and procure alternative/renewable sources can significantly impact energy enhancement and national security."[27]

---

[25] "The Department of the Navy's Energy Goals," US Navy. 2009: pg.1.

[26] Serino, Pamela. "Defense Logistics Agency: Sustainable Aviation Fuels Northwest." SAFN 4th Workshop. Sea-Tac International Airport, Seattle, 8 Dec. 2010. Speech.

[27] "Air Force Energy Plan 2010." U.S. Air Force, 2010: pp.3-4.

For this reason, the armed services are actively exploring increased efficiency and alternative fuel use. In fact, the Department of Defense is legally required under Section 526 of the Energy Security and Independence Act of 2007 to limit any alternative fuel purchases to those that demonstrate lower greenhouse gas emissions than conventional petroleum - the types of sustainable, bio-based fuels that are the focus of the SAFN report.

By 2016, the Air Force expects to acquire 50 percent of domestic aviation fuel from alternative blends greener than petroleum. The Navy has a particularly audacious goal to meet 50 percent of its total energy needs from alternative sources by 2020, a requirement for 336 million gallons/year split evenly between aviation fuel and marine diesel.[28]

"This is our own moon to shoot towards," U.S. Navy Director of Operational Energy Chris Tindal said. "We are fast approaching deadlines for 2020."[29]

"All you have to do is read the headlines every day to see why we need to do this," U.S. Navy Secretary Ray Mabus said in late February 2011 as conflict gripped Libya and unrest spread throughout the Middle East. "Just from the situation in Libya, oil prices have gone up more than $7 a barrel."

A $10/barrel increase translates into annual Navy fuel increases exceeding $300 million, Mabus noted. "It's not just availability of fossil fuels and the fact that we're getting them from potentially or actually volatile places on earth, but it's also the price shocks that can come from it."[30]

CLIMATE CHANGE

In January 2011, NASA reported that 2010 tied with 2005 as the warmest year on record, and the 2000s were the hottest decade on record.[31] The aviation leaders who initiated SAFN recognize the concern within the scientific community, which is that human emissions of carbon dioxide and other greenhouse gases are the dominant contributor to climate change. They acknowledge the conclusion made in 2007 by the Intergovernmental Panel on Climate Change (IPCC), the world's most authoritative scientific authority on climate change: "Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations . . . Discernible human influences now extend to other aspects of climate, including ocean warming, continental-average temperatures, temperature extremes and wind patterns."[32]

Throughout this report, lifecycle analysis studies comparing the carbon intensity of petroleum fuels and biofuels employ GHG factors for conventional oil. However, the baseline for the carbon contribution of fuels may be affected by increasing reliance on unconventional fossil fuels such as tar sands, natural gas liquids and heavy oils. All of these sources presently emit more GHGs than conventional sources on a lifecycle basis.[33] This increases the need for low-carbon fuels from non-fossil sources.

---

[28] Tindal, Chris. "Algae and Naval Aviation Fuels," Pacific Rim Summit on Industrial Biotechnology and Bioenergy. Honolulu, HI, 13 Dec. 2011. Speech.
[29] Ibid.
[30] "Mideast Unrest Shows Need For Alternative Fuels: Navy Secretary." Reuters. 22 Feb. 2011. Viewed Feb. 23, 2001.
[31] NASA Research Finds 2010 Tied for Warmest Year on Record." NASA Goddard Institute for Space Studies. 12 Jan. 2011.
[32] Intergovernmental Panel on Climate Change, Climate Change 2007: Working Group I: The Physical Science Basis, Understanding and Attributing Climate Change.
Summary for Policymakers, http://www.ipcc.ch/publications_and_data/ar4/wg1/en/spmsspm-understanding-and.html
[33] The higher carbon intensity for non-conventional fuels serves to make the point that the baseline for aviation fuels is changing. This report does not address or make any recommendations regarding use of these fuels.

Fuel Approval Process

First generation biofuels such as ethanol or biodiesel will not work in commercial jet aircraft, due to factors such as lower energy density and poor performance under extremely low temperatures at altitude. Aviation needs drop-in fuels, defined as alternative fuels that meet the specifications of petroleum jet fuel and that can be used safely and reliably in existing aircraft and fueling infrastructure. Airports and ground operators need to avoid duplicating the extensive fueling infrastructure that exists today with a parallel network of advanced biofuels. For these reasons, this report focuses only on drop-in fuels for turbine engines that can be used in existing aircraft and fueling systems.

> The good news is that drop-in fuels can be produced today with existing technology and are being approved. Several years ago many experts thought it would take decades to develop and certify these fuels, yet the industry made rapid advances.

Developing the technical processes to produce drop-in fuels and acquiring the necessary approval no longer appears to be a critical roadblock. The largest remaining obstacle remains securing the financing necessary to develop commercially useful volumes of alternative fuels.

Test flights using biofuel blends from different feedstocks and conversion technologies already have occurred. Virgin Atlantic was first with a February 2008 test flight, followed by flights by Air New Zealand, Continental Airlines, United Airlines and Japan Airlines. The U.S. Navy staged the first supersonic test with an F-18 flight on Earth Day 2009, while the U.S. Air Force has operated A-10, F-15 and F-22 fighters, and a C-17 cargo plane on bio-derived jet fuels. Three SAFN stakeholders, Imperium, AltAir, and Honeywell/UOP, helped produce fuels used in some of these test flights.

ASTM International (once known as the American Society for Testing and Materials) is the key body which ensures that safety and technical standards are met for all turbine fuels. ASTM has approved for aviation use a fuel blend using Fischer-Tropsch technology. This chemical conversion process employs heat and catalysts to transform cellulose, hemicelluloses and lignin, the basic constituents of plant matter, into liquid fuels. Approval is expected in 2011 for fuels derived from hydroprocessing of plant- and animal-based oils, also known as lipids, using heat, catalysts and hydrogen injection. The approval process for aviation biofuels based on biochemical fermentation of cellulosic material is in preliminary stages. (These technologies are discussed below).

The comprehensive ASTM fuel approval process involves several stages including: identification of a prospective pathway, building a test plan, review and concurrence of the plan within ASTM, executing the test plan, generating and distributing test reports, submitting a ballot application to ASTM, and approval or rejection of the ballot for the new pathway and fuel. The test plan requires involvement, support and resource commitments from airframe and engine manufacturers. The schedule from start to finish is contingent on technical, financial and other factors. In general, applicants should expect a minimum of two years from the submittal of a proposed test plan to final ASTM review and approval.

Credit: Alaska Airlines

U.S. armed services branches have their own certification processes and are working to approve alternative fuels for each engine type. On February 10, 2011, the U.S. Air Force announced the first certification of an aviation biofuel. The Air Force approved a military blend known as JP-8 based on a 50 percent mix of hydroprocessed renewable jet, for use in C-17 Globemaster cargo planes.[34] Joint Base Lewis-McChord, south of Seattle, is a major airlift center with a substantial C-17 fleet.

It is important to note that all efforts to approve biofuels for aviation use to date involve blends with conventional jet fuel; currently the blend is limited to a 50-50 percent mixture. Early aviation biofuels do not include vital components known as aromatics, which are supplied by petroleum. Work has begun to produce a 100 percent bio-based jet fuel with aromatics from a fermentation process. Approval of these completely bio-derived turbine fuels are anticipated in the next five to ten years.

Blend ratios are expected to be low initially due to limits on supply availability. At low blend ratios, the incremental cost of the biofuel content would be diluted and therefore less of a barrier to the economic viability of the finished fuel. For example, if jet fuel is $2/gallon, and biofuel is $3/gallon, then a 10 percent blend would create a 10 cents/gallon impact on the delivered price. This price differential still represents a significant economic challenge to end users – as noted above, each penny increase in jet fuel price per gallon translates into $175 million in increased costs to the industry. If all jet fuel had a 10 percent biofuel component, that would translate into increased costs of $1.75 billion. Though this scenario is unlikely for many years, it illustrates the challenge of implementing new fuels for an industry that is extremely competitive and operates on very tight margins.

[34] U.S. Air Force, "Officials certify first aircraft for biofuel usage." 10 Feb.2011. Viewed 12 Feb. 2001.

Feedstock Supplies

DIVERSE FEEDSTOCKS

From the beginning, SAFN stakeholders recognized that no single feedstock or technology pathway would be likely to provide sustainable aviation fuel in the Northwest at the scale or speed necessary to achieve our goals. Therefore, our efforts are not aimed at identifying the “best” regional feedstock or technology, but rather focus on a portfolio of options. This ensures that the broadest range of bioenergy sources is identified to develop fuels at sufficient scale.

No single feedstock has the capacity alone to replace petroleum fuels. Biomass feedstocks, while potentially abundant, are limited by factors such as land area, water supplies, sustainability concerns and cost. A diversity of feedstocks is needed to maximize regional supply and reduce risks from overreliance on a single feedstock, including weather extremes, pests and pathogens, and economic cycles.

The sections below underscore that the Northwest has a number of promising opportunities. These opportunities will need to be aggregated to reach the scale required by aviation industry goals for energy and emissions reductions. SAFN stakeholders in the biofuels industry and in the research community emphasize the importance of developing biorefineries with technologies that can process multiple feedstock streams.

Assurance of a range of reliable biomass also is crucial to financing and developing biorefineries. For example, an operation capable of processing cellulosic biomass into fuel might base itself on a steady stream of municipal solid waste, and supplement that with residuals from forest operations and farm fields as they become available. A hydroprocessing facility built on a stream of lipids from oilseeds could draw in algal oils as algae cultivation is developed.

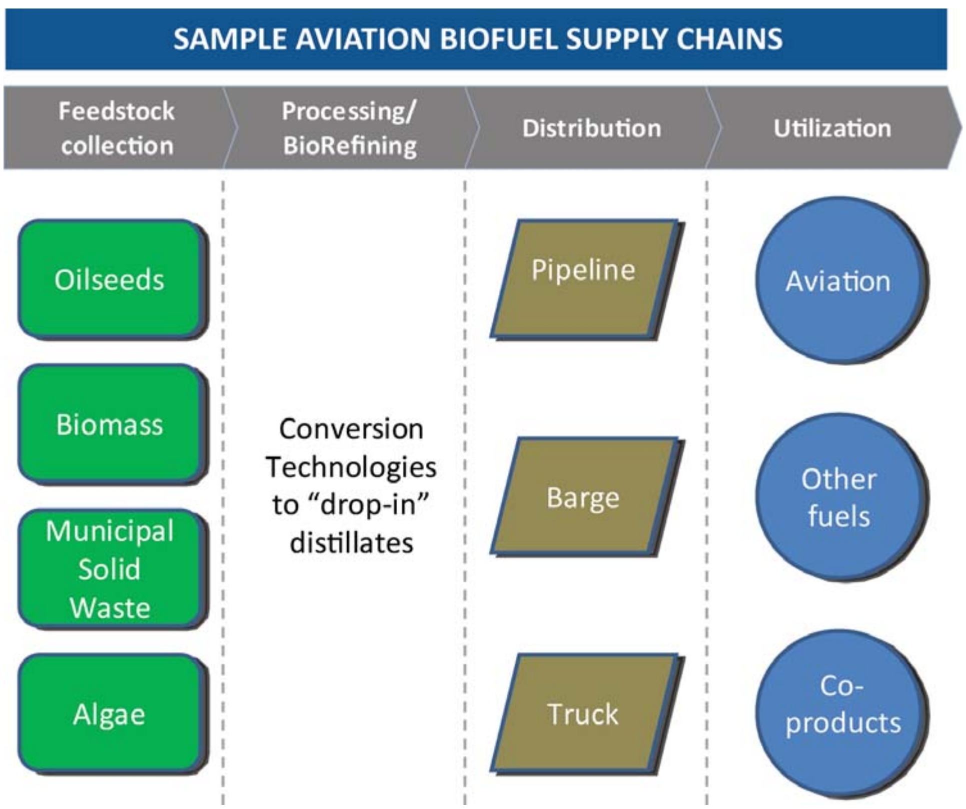
COMPREHENSIVE APPROACH

The SAFN stakeholders believe that the Northwest should focus on developing complete supply chains. Creating an industry to produce sustainable fuels and coproducts will require linking a supply chain from feedstock supply to product delivery. As in any chain, if one link is broken, so is the entire chain. Therefore, a comprehensive approach must address all elements. These include:

- Redirecting existing feedstock supply chains for production of higher value uses,
- Producing, collecting, delivering and storing biofeedstocks in an economically feasible and environmentally sustainable manner,
- Developing and deploying economical technologies to prepare biomass for processing,
- Developing and deploying economical process technologies to convert biomass into fuels and coproducts,
- Developing valuable coproducts such as chemicals and markets for them,
- Developing markets for fuel,
- Blending fuels and delivering them to end-use customers.

New integrated biorefineries will best serve a broad base of renewable fuel customers. The demand for renewable fuels from the aviation industry also may complement marine shipping, railroading and other industrial needs. Developing biorefineries with multiple customers provides a critical demand among essential industries and facilitates commercial scale projects. This reduces production costs and offers a source of potential long-term contracts and project funding.

Specific feedstock-technology supply chains are described in more detail in the chapters and appendices focusing on specific technologies and approaches. As previously noted, the solution lies in developing new feedstock supply chains and redirecting existing supply chains to higher and better uses as feedstocks for production of drop-in aviation fuels.



Credit: The Boeing Company

SUPPLY CHAIN FOCUS IS CONSISTENT WITH RECOMMENDATIONS FROM PRESIDENT'S BIOFUELS INTERAGENCY WORKING GROUP

The framework for federal biofuels policy is the Renewable Fuel Standard (RFS) as amended by Congress in 2007 and typically referred to as RFS2. (See accompanying box.) RFS2 includes aviation fuel as potentially eligible to generate Renewable Identification Numbers (RINS), a tracking tool that verifies specific fuel batches qualified to meet RFS2. RINs serve as a substantial economic driver. As of March 2011, RINs were trading at $1.20-$1.30/gallon.

Under the Renewable Fuel Standard, Congress set a goal to blend 100 million gallons/year (mgy) of cellulosic ethanol into the nation's fuel supply by 2010. The Environmental Protection Agency (EPA) in early 2011, however, reported that not a single gallon of cellulosic ethanol was blended in 2010.[35] The long-term goal under the RFS is for 21 billion gallons/year of advanced biofuels to be delivered by 2022. The nation is not on track to reach that goal, according to a report issued in February 2010 by the President's Biofuels Interagency Working Group (BIWG). The BIWG, composed of cabinet-level leaders of the U.S. Department of Agriculture (USDA), the Department of Energy (DOE), and the Environmental Protection Administration (EPA), was assigned to craft strategies to move federal advanced biofuels efforts back on course.

BIWG noted that the challenges include financing new plants in the midst of a credit crunch, and blending biofuels such as ethanol and biodiesel into standard fuel infrastructure and vehicles. Gaps in coordinated supply chain development are also cited:

> *"Hundreds of projects have been funded by federal agencies, but stronger, more robust supply chains would emerge if there were integration of efforts across government agencies," BIWG concluded. "There has been minimal active management to achieve targets across the federal government or private sector. Significant gaps in the biofuels supply chain need to be addressed. Some key policy tools, such as DOE and USDA project loan guarantees and research programs, could be targeted more effectively to support the emerging industry and to deliver outcome-driven results."*[36]

To overcome challenges, BIWG called for "an outcome-driven, re-engineered system." SAFN findings and proposed action steps are highly consistent with the BIWG recommendations noted here:

- Use a regional supply chain systems approach that ensures all fuels produced are compatible with the U.S. transportation fuel infrastructure
  - Manage by a small, centrally-located team(s) accountable to BIWG
  - Establish lead-agency responsibility for each supply chain segment
  - Create a collaborative process for delivery of federal investments.
- Add strong focus on accelerating drop-in biofuels development
  - Streamline strategies that move technology research and development rapidly to pilot-demonstration phase and to full-scale commercial production
  - Comprehensively analyze up-front the elements of feasibility and sustainability for all existing and new technologies to build confidence for creating markets, investments, and credit to sustain long-term biofuels production
  - Develop new technologies and alternative processes to improve economic and conversion efficiencies for biofuels production. Research multiple conversion routes in parallel.

---

[35] Dina Fine Maron. "Much touted cellulosic ethanol is late in making its mandated appearance." *ClimateWire*. 11 Jan. 2011.

[36] President's Biofuels Interagency Working Group, Growing America's Fuel An Innovation Approach to Achieving the President's Biofuels Target, Feb. 2010.

- Support feedstock research and demonstrations to ensure sustainable supply chain development that minimizes transaction costs and creates wealth for farms and rural communities
  - Identify economic, environmental, and social issues for all supply chain segments to build confidence for creating markets, investments, and credit that helps provide long-term sustainable biofuels production supply chains
  - Develop the needed sustainable production and logistic systems that are suited to regional conditions and biofuels refinery specifications
  - Develop superior genetic biofuels feedstocks for perennial grasses, energy cane, biomass sorghum, oilseeds and algae, and woody biomass.[37]

> The Northwest is an ideal proving ground to demonstrate the outcome-driven, supply chain approach called for by the President's Biofuels Interagency Working Group. In a time of limited federal budgets and tighter available spending, federal policymakers must invest public dollars strategically, in a manner most likely to build economically competitive biofuels supply chains.

As the following sections demonstrate, the Northwest has the natural resources and institutional assets required to build complete supply chains focused on sustainable aviation fuel, while also providing products such as drop-in renewable diesel and co-produced chemicals. As with rural electrification, the internet and medical advances from the space program, initial federal investment is essential to make alternative jet fuel a reality. SAFN stakeholders urge federal policymakers to prioritize public investments in this venture.

[37] Ibid.

RENEWABLE FUEL STANDARD

The Renewable Fuel Standard ("RFS") was adopted by the EPA to implement the provisions of the Energy Policy Act of 2005 ("EPAct"), which added section 211(o) to the Clean Air Act ("CAA") Since its inception, the RFS program has mandated an increasing amount of renewable fuel in the U.S. petroleum fuel marketplace. Under RFS1, the fuel marketplace was measured only by gasoline sales, with a goal of producing 7.5 billion gallons of renewable fuel. The typical compliance fuel was ethanol made from corn starch. Market participants were required to utilize Renewable Identification Numbers ("RINs") to track transactions and demonstrate compliance.

A substantial change and expansion to the RFS occurred when Congress passed the Energy Independence and Security Act ("EISA") of 2007. EISA served as the legislative vehicle for RFS2, and greatly expanded the scale and complexity of the program. Regarding scale, during the next eleven years, the annual volume requirements under RFS2 increase from 13 billion to 36 billion, and the program is expanded to include off-road, locomotive and marine fuel. On the issue of complexity, RFS2 mandates obligatory purchase of four types of fuel rather than the single type under the original RFS ("RFS1"). In addition, unlike RFS1, where almost all renewable fuel was treated equally, RFS2 went from a single standard to four standards, while adding greenhouse gas ("GHG") benchmarks as the key factor distinguishing the categories. One of the most ambitious aspects of the program is a substantial expansion of advanced biofuels including a subcategory, cellulosic biofuel.

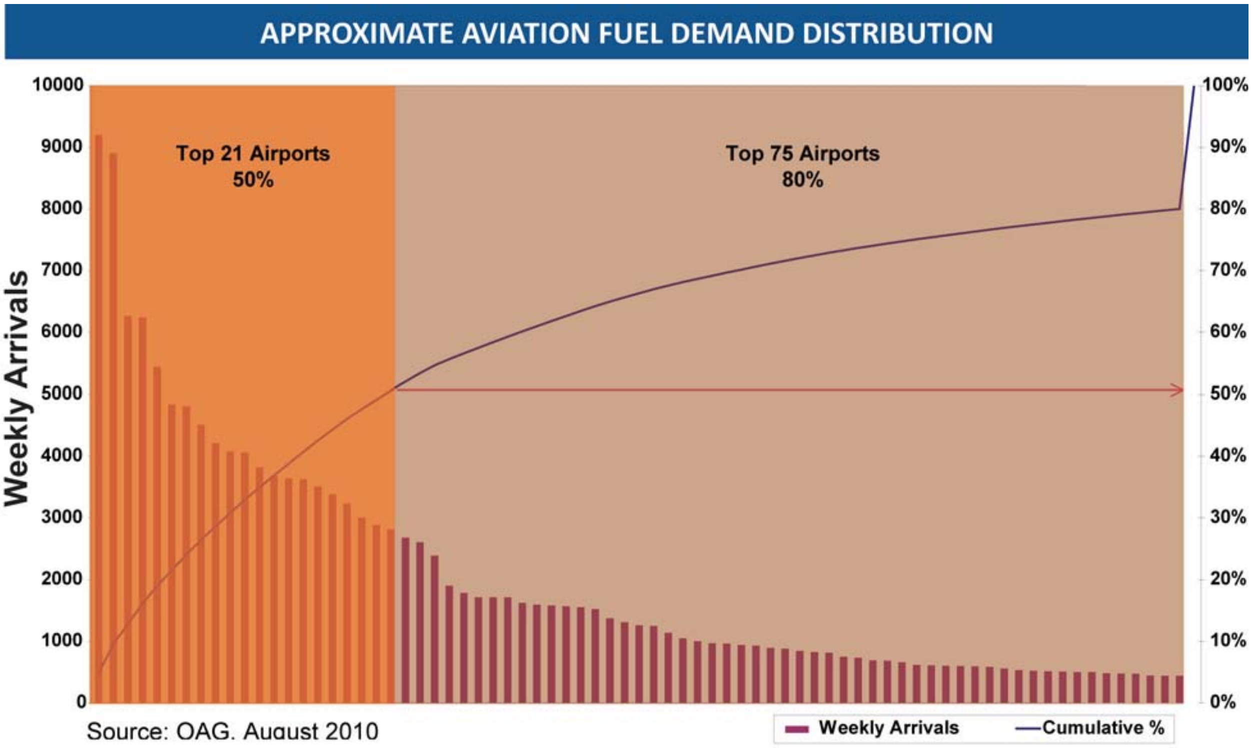
Under RFS2, each year the EPA revisits the state of the renewable fuel industry to determine whether the mandates can realistically be met by production capacity. The EPA then issues a final rule that establishes the applicable requirements for that year. The Final Rule of RFS2 for 2011 severely curtailed cellulosic biofuel from 250 million gallons to six million gallons based on limited industry growth. However, the EPA maintained the overall advanced biofuels projection of 1.35 billion gallons. Since SAFN is focused on drop-in fuels, the category of advanced biofuels is a likely category for the fuels that will be produced. Therefore, the reduction in the cellulosic requirement will not necessarily impact the growth of aviation biofuels. In addition, the RIN market value for advanced biofuels is robust, with trading at $1.20 as of 3/16/11. Under RFS2, the requirement for conventional corn ethanol plateaus at 15 billion gallons in 2015. After 2015, all additional increases in RFS2 are satisfied solely by advanced biofuels which provides a significant long-term policy driver to support advanced aviation biofuels.

Fuel Distribution

The 16 airline members of the Air Transport Association (ATA) and their regional associates account for approximately 90 percent of the passenger and cargo traffic in the United States, and a similar share of the jet fuel used in commercial aviation. As noted previously, a single entity, the Defense Logistics Agency (DLA), handles all fuel purchases for the U.S. military. Aviation provides a more concentrated market for rapid deployment of biofuels than many other sectors. This makes it easier to consider development of long-term supply contracts and to build the infrastructure to supply aviation's needs.

Aviation has a relatively small number of "filling stations" where the renewable fuels will need to be delivered.

Aviation has a relatively small number of "filling stations" where the renewable fuels will need to be delivered. For commercial aviation, the 75 largest airports account for approximately 80 percent of the total traffic – the top 21 airports handle 50 percent of the volume. As discussed below, the fuel delivery and fueling infrastructure within these airports is coordinated and well understood. Compared to the challenges of delivering renewable fuels to passenger vehicles or trucks with millions of customers and hundreds of thousands of delivery points, the aviation industry presents a concentrated market with a relatively small number of customers and filling stations.



Source: OAG, August

CURRENT REGIONAL DEMAND

The Northwest presents a substantial market for jet fuel. For the SAFN process, the Port of Seattle Planning Department assembled the Northwest demand picture from state and federal statistics from 2010 through 2030. Current demand accounts for 743 million gallons annually in the four-state Northwest region, and is projected to reach over one billion gallons in 20 years. The bulk of demand is from SAFN airport stakeholders. In 2009, fuel delivered to planes was:

- Sea-Tac International Airport – 411.1 mgy
- Portland International Airport – 151.6 mgy
- Spokane International Airport – 13.1 mgy

Regional results are shown in the table below:[38]

COMMERCIAL JET FUEL CONSUMPTION PROJECT – 2010 - 2030

Planning Year[1]	Pacific Northwest Four State Area - Summary Report Projected Fuel Consumption (gallons)				Four State Area[2]
	Idaho	Montana	Oregon	Washington	
2010	33,078,060	28,949,640	155,881,140	525,121,920	**743,000,000**
2015	35,804,160	30,638,530	177,072,500	564,318,880	**808,000,000**
2020	38,828,160	32,511,880	194,091,200	601,763,520	**867,000,000**
2025	42,194,520	34,592,230	212,679,700	643,471,360	**933,000,000**
2030	45,990,720	36,902,120	233,513,860	690,049,120	**1,006,000,000**

Compiled by Port of Seattle Aviation Planning Department, January 2011

1. The "Planning Year" reflects a Federal Fiscal Year (FFY) from October through September. Over a long term planning horizon, differences between the FFY and a calendar year will be insignificant.
2. Gallons shown have been rounded to the nearest million and may not add up.

The Defense Logistics Agency-Energy (DLA Energy) reports that military base demands in Washington and Oregon total approximately 99 million gallons of JP8 and JP5 jet fuel through three supply points.[39] Military demand in the region is concentrated at:

- McChord Air Force Base (Tacoma, WA) – 35 mgy JP8 served by pipeline and truck.
- Naval Air Station (Whidbey, WA.) – 25 mgy JP8 served by barge and truck.
- Fairchild Air Force Base (Spokane, WA) – 17 mgy JP8 served by barging to Pasco and delivering the remainder by pipeline.

[38] The Port of Seattle used fuel sales figures from state tax records and Federal Aviation Administration passenger loading figures to generate its data. The U.S. Energy Information Administration reports substantially higher regional consumption totaling 1.1 mgy. http://tonto.eia.doe.gov/state/index.cfm The Port of Seattle considers EIA methodology a gross cut at estimating state consumption from national figures. It uses a proportion of state "sales" to national "sales" and applies it to a national consumption number to get state consumption. In some cases sales figures represent double counting of sales between distributors. Removing them substantially narrows the gap between the two figures.
[39] Pamela Serino, Director, Quality Technical Support Office, Defense Logistics Agency Energy, SAFN 4th Workshop. Seattle-Tacoma International Airport, Seattle, 8 Dec. 2010. Speech.

- Defense Fuels Supply Point Puget Sound (Bremerton, WA) – 5 mgy JP5 (high flash point jet fuel) served by barge.
- Oregon Air National Guard (Portland, OR)- 5 mgy JP8 served by truck (PDX).

There is also a relatively small amount of demand at Idaho and Montana military bases:

- Mountain Home (Mountain Home, ID) – 17 mgy
- Gowen Field (Boise, ID) – 25 mgy
- Malmstrom Air Force Base, (Great Falls, MT) – 0.22 mgy
- MT National Guard Helena (Helena, MT) – 0.4 mgy
- MT National Guard Great Falls (Great Falls, MT) – 4.6 mgy

Current regional military demand for jet fuel totals approximately 127 million gallons per year.[40] The total estimated Northwest civilian and military jet fuel demand amounts to 865 mgy, with the military portion amounting to approximately 14 percent.

DLA Energy emphasizes that the diesel co-products that would be produced at advanced biofuel refineries are very important to their efforts to meet the Navy's goals for energy independence and carbon reduction. For example, 20.7 mgy of marine diesel are delivered every year through DFSP Puget Sound for use in Navy vessels. The DLA Energy is hoping to sign off-take agreements with advanced biofuel producers that will help meet their needs for regional alternative supplies of both jet fuel and marine diesel. Agreements for both jet fuel and marine diesel will be critical building blocks for any efforts to make the region a home port for the Navy's demonstration project to sail a "Great Green Fleet" by 2016.[41]

EXISTING FUEL DISTRIBUTION SYSTEM

Transporting finished fuels to airports most likely will be efficiently achieved through the existing fuel delivery infrastructure, although new delivery infrastructure (pipelines, barges, rail, truck) could be developed to support processing and blending of fuels at refineries that are not currently delivering fuel to the region's airports.

Fuel distribution, blending and logistics will be determining factors in the economic feasibility of production facilities. Current fuel production is situated primarily at Washington's five oil refineries, including four major plants in the North Puget Sound and one in Tacoma. Unlike other areas of the country, which are connected to transportation fuel pipelines that can accommodate supply disruptions, western Washington and Oregon fossil fuel markets are "shut-in" and disconnected to other markets. This isolation constrains supply/demand market dynamics and contributes to the relatively high prices of transportation fuels in the Northwest.

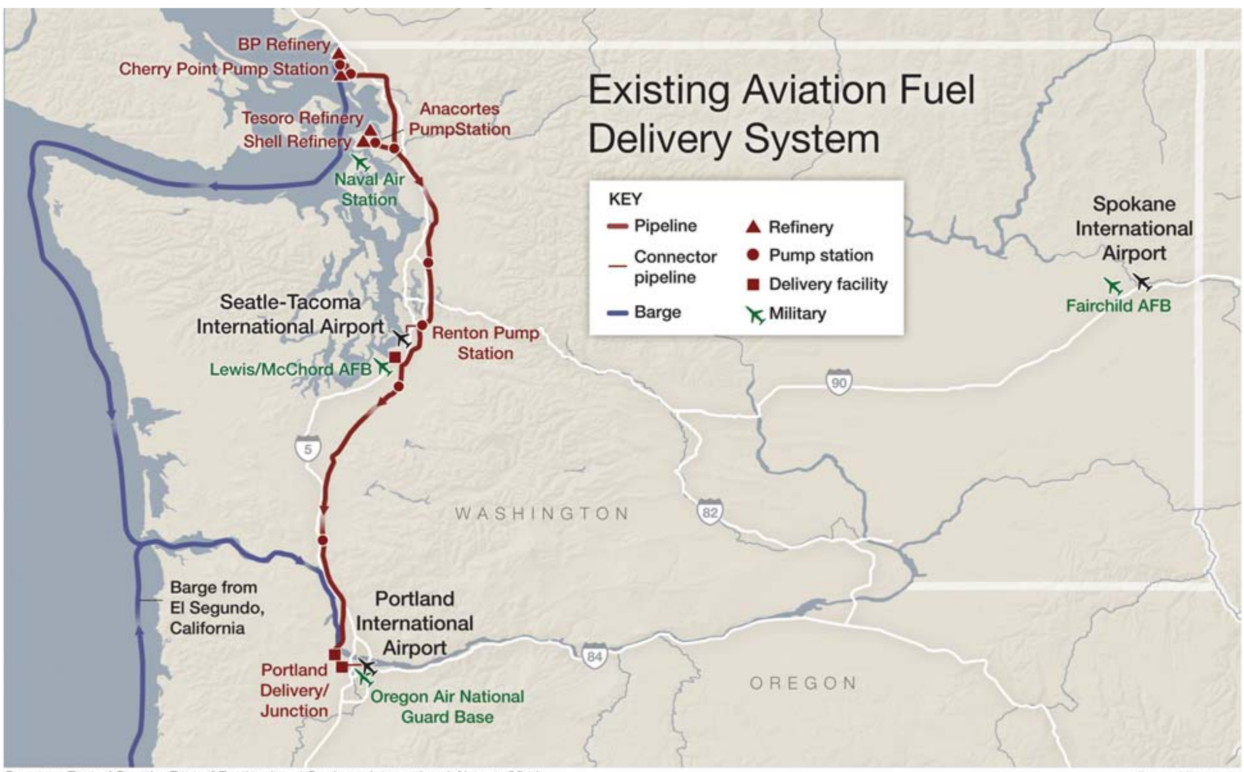
Most refined petroleum products are shipped by pipeline, primarily to Seattle and Tacoma markets and on to Portland via the Cascade Pipeline, which runs from the northwest corner of Washington to Eugene, Oregon. Washington's five refineries rely on this pipeline to transport their products to population centers. The pipeline delivers multiple fuel products in series. A pipeline intermix that acts

[40] Northwest base usage figures from Pamela Serino, Defense Logistic Agency Energy, 13 April 2011.
[41] Navy Secretary Mabus announced the "Great Green Fleet" effort in a speech on 14 October 2010. The Navy's vision is for a carrier strike force that is fueled by low-carbon fuels, including nuclear powered carrier, and biofuel based marine diesel and aviation fuels for the support ships and planes.

as a buffer between fuel grades is returned to refineries for reprocessing into the specific grades. Because biofuels have not been delivered by pipeline, operators will have to be assured new drop-in fuels pose no contamination risk.

Because the current pipeline capacity is fully used, a significant portion of the North Sound refineries' product is shipped by barge as well. Refiners prefer to deliver gasoline by pipeline because it is lighter, which means a larger quantity can be delivered. Barging is the preferred delivery mode for heavier distillates such as jet and diesel. From the refineries, products move to storage facilities such as airport tank farms and to fuel terminals where additives and biofuels are blended.

Northwest airports receive fuel by pipeline, barge and truck. Seattle-Tacoma International Airport obtains its full supply from the pipeline which runs south from refineries around Anacortes, Washington. Portland International Airport, also served from Anacortes, receives 50 percent of its fuel from the pipeline and the other half by barge. Spokane International Airport is supplied by fuel trucked from depots in North Spokane and Tacoma, Washington.[42]



Sources: Port of Seattle, Port of Portland and Spokane International Airport; 2011 Port of Portland

[42] Personal communications with the Port of Seattle, Port of Portland and Spokane International Airport.

Supplying aviation biofuels to airports will require blending alternative fuels with petroleum fuel at least initially, since a 50 percent biofuel mixture will likely be the highest allowed in the early years due to the limitations of initial safety and performance approvals. These blending facilities may be sited at various existing fuel terminals, refineries and storage tanks with their substantial infrastructure and skilled personnel. Fuel terminals are strategically located in the Northwest near airports and military bases. Airports would receive blended jet fuel through the same transportation channels from which they receive standard jet fuels. Blending facilities might also be sited at airports. These facilities, however, could face challenges of constrained land footprints, public resistance and permitting hurdles, and would require new functions and skills.

Ensuring Sustainability

KEY ISSUE

At SAFN's inception, the stakeholders recognized the need to evaluate and demonstrate the long-term sustainability of all biofuel production. Not all bioenergy is sustainable. Inappropriate production of biofuels can lead to impacts such as unacceptable competition with food production, land use changes that result in increased releases of carbon dioxide into the atmosphere, excessive water use, and destruction of critical habitats and other environmental resources.

The aviation leaders who convened SAFN agreed that sustainability is a key criteria – along with commercial viability and scale – central to any consideration of potential fuels and feedstocks (As noted already, safety is a threshold consideration that must be met before any potential fuel is used). As a result, the SAFN process is focused on advanced biofuels that appear likely to meet sustainability criteria. Throughout the report, internationally recognized criteria were utilized as a framework for measuring the sustainability of biofuel production.

It is also important to measure the sustainability of biofuels against petroleum-based fuels. The goal should be to move towards sustainable and economically practicable alternatives, recognizing challenges in the current supply chain.

Building a sustainable aviation fuels industry in our region will require public support for the use of natural resources and public investment to jumpstart a new industry. This entails building public good will. Sustainable biofuels must be produced transparently with reliable, cost-effective verification to maintain public confidence and achieve the environmental improvements that are central to these efforts.

SETTING STANDARDS

There are many definitions of sustainability. A classic comes from the *Report of the Brundtland Commission*, sponsored by the United Nations:

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[43]

Sustainability encompasses environmental, social and economic factors that relate to the ability to maintain practices over an extended period.

[43] The Report of the Brundtland Commission, "Our Common Future." Oxford University Press, 1987.

Based on assessments by SAFN participants who are working on these issues throughout the world, the Roundtable on Sustainable Biofuels (RSB) is a widely recognized international effort devoted to setting global biofuels sustainability standards. Other sustainability standards are being developed in the United States and globally for biomass energy and for forest and agriculture practices.[44]

The RSB criteria and tools result from an international process involving biofuel producers, feedstock growers, consumers, government agencies and NGOs representing energy, environmental, human rights and others with concerns relevant to sustainability issues. RSB seeks to increase the collaboration among the existing certification systems, and take advantage of common elements. It meshes existing voluntary and regulatory programs into a common verification system.[45] RSB is developing systems to compare its protocol with other certification standards for fuels and feedstocks. For example, a producer certified to a forestry standard may potentially meet RSB standards with minimal additional effort.

SAFN did not want to "reinvent the wheel" by developing its own sustainability criteria. Therefore, this report identified the RSB principles as an evaluative screening tool for sustainability issues. SAFN does not regard RSB as the exclusive tool for validating the sustainability of biofuels, and some SAFN stakeholders have differing views on the appropriateness of different approaches for validation and certification, including the content and appropriateness of the RSB standards. Not all SAFN stakeholders agree on all the RSB principles, nor on whether they should be used to measure the sustainability of aviation fuel production in the United States. But stakeholders agree it is appropriate to use the RSB principles for the limited purpose of establishing a general framework to identify and evaluate key sustainability issues relating to specific feedstock paths and conversion technologies. RSB representatives have been active in SAFN and have helped with this screening evaluation. At the same time biofuel producers and customers should be aware of the need for transparent approaches to validate that sustainability goals are met in fuel production.

RSB focuses on 12 principles that guide its evaluation of the environmental, social and other impacts of biofuel production. Given that SAFN's focus is on biofuels that can be developed in the four Northwest states, we worked with RSB representatives to identify the principles most appropriate for the screening level in this report.[46] The 12 RSB principles are shown in a sidebar, with those identified as most relevant for this report in bold and the other principles in italics. All RSB principles should be evaluated by proponents of particular projects, although in many cases the italicized principles may likely be satisfied by a risk management analysis or by showing compliance with applicable federal, state and local laws. The most relevant sustainability principles are evaluated in the discussion of each feedstock.

[44] In the U.S., the Council on Sustainable Biomass Production is developing a standard for agricultural crops and purpose-grown forestry crops. Other, more long-standing international certification programs are already in place for forest management, including those of the Forest Stewardship Council (FSC), the Programme for Endorsement of Forest Certification (PEFC) and the Better Sugarcane Initiative. The U.S.-based Sustainable Forestry Initiative (SFI) and American Tree Farm program are endorsed by PEFC. There are also a variety of standards for agricultural lands, including the USDA NRCS conservation programs.

[45] One stakeholder noted that any voluntary, private sector standard would need to demonstrate that it meets the requirements of OMB Circular A-119 if it is to be used by US federal agencies, and under the Standards Development Organization Advancement Act of 2004 (15 U.S.C. §4301 et seq.) for antitrust relief. OMB Circular A-119 establishes the principles voluntary, private sector standards must meet if federal agencies wish to use them.

[46] Roundtable on Sustainable Biofuels. "RSB Guidance on Principles & Criteria for Sustainable Biofuel Production." 2010.

RSB Principles

RSB has identified the following twelve principles for evaluating the sustainability of biofuel operations. The principles that have been identified as most relevant for the screening evaluation in this report are shown in bold, the other principles are shown in italics.

Principle 1: *Legality -- Biofuel operations shall follow all applicable laws and regulations.*

Principle 2: *Planning, Monitoring and Continuous Improvement-- Sustainable biofuel operations shall be planned, implemented, and continuously improved through an open, transparent, and consultative impact assessment and management process and an economic viability analysis.*

Principle 3: Greenhouse Gas Emissions – Biofuels shall contribute to climate change mitigation by significantly reducing lifecycle GHG emissions as compared to fossil fuels.

Principle 4: *Human and Labor Rights -- Biofuel operations shall not violate human rights or labor rights, and shall promote decent work and the well-being of workers.*

Principle 5: *Rural and Social Development -- In regions of poverty, biofuel operations shall contribute to the social and economic development of local, rural and indigenous people and communities.*

Principle 6: Local Food Security – Biofuel operations shall ensure the human right to adequate food and improve food security in food insecure regions.[47]

Principle 7: Conservation – Biofuel operations shall avoid negative impacts on biodiversity, ecosystems, and other conservation values.

Principle 8: Soil – Biofuel operations shall implement practices that seek to reverse soil degradation and/or maintain soil health.

Principle 9: Water – Biofuel operations shall maintain or enhance the quality and quantity of surface and ground water resources, and respect prior formal or customary water rights.

Principle 10: Air – Air pollution from biofuel operations shall be minimized along the supply chain.

Principle 11: Use of Technology, Inputs, and Management of Waste – The use of technologies in biofuel operations shall seek to maximize production efficiency and social and environmental performance, and minimize the risk of damages to the environment and people.

Principle 12: Land Rights -- Biofuel operations shall respect land rights and land use rights.

[47] This principle is primarily aimed at developing nations. The Northwest is not regarded as a food insecure region. Nevertheless, we have included this principle in the screening evaluations because of the extensive concern about food-fuel conflicts.

VALIDATING SUSTAINABILITY

The SAFN stakeholders agree that sustainability is a critical issue. They also agree that development of biofuels should address sustainability to ensure public acceptance. In practice this will require both a clear and transparent evaluation of how these principles apply to a given producer and verification and documentation of how they are met in practice.

While SAFN stakeholders agree that sustainability is a critical issue, SAFN does not recommend that biofuel or feedstock providers use any particular method of validation; that is beyond the scope of the stakeholder exercise. Approaches and best practices to validate sustainability are evolving and may be affected by policy and political processes. Certification, compliance with applicable laws and regulations, and risk analyses all provide potential methods to show that sustainability concerns are addressed in the actual harvesting and production of biofeedstocks and fuels. A variety of certification approaches have been developed for biofuels, including one from RSB which recently launched a certification facility. There are also certification approaches for feedstocks in specific resource areas that may be suitable to validating sustainability. Future mechanisms may emerge in the US or other countries, in some instances sustainability can be verified by showing compliance with applicable laws or by analyzing key risks.

The screening evaluation in this report does not attempt to address all the questions surrounding whether particular feedstocks or technologies may be used to supply aviation fuel in a manner that meets sustainability criteria. More specific information will be required to validate that sustainability concerns are being met in the actual production of fuels. Our goal is to show that the potential biofuel sources evaluated in this report can be developed with strong sustainability principles while identifying some key issues that need to be resolved – not to sign-off on their production or use.

Overview

ECONOMIC CHALLENGES AND OPPORTUNITIES

Other than a modest amount of oil production in Montana, the Northwest produces none of its own petroleum fuels. In 2008, which saw all-time peaks in oil prices, Oregon, Washington and Idaho cumulatively shipped $28.5 billion out of the region for fossil fuel imports.[48] That equaled six percent of personal income in those states.[49] Oil prices have escalated in recent months, exceeding $100/barrel. Jet fuel prices have climbed even faster. Both oil and jet fuel prices have fluctuated widely over the last several years. Development of a stable supply of viable alternative aviation biofuels could introduce competition into the market, mitigating price increases and the volatility of jet fuel prices. Both effects have significant economic benefits to industry and the region.

Development of a substantial sustainable biofuels industry would reduce outflows of income, producing positive ripple effects in state economies. A study on the U.S. biodiesel industry measured direct and indirect economic impacts of producing 475 million gallons of biodiesel in 2009. The results indicate that nearly 23,000 jobs across the economy, $4.1 billion in added GDP growth, $445 million in federal tax revenues, and $383 million to state and local governments were created.[50] Results are outlined in the chart below. These are national figures and no specific projections are available for a regional biofuels industry of similar scale. They do provide a reasonable approximation for the potential economic and job creation impacts for meeting regional demand with regional sources. A 50 percent share of the region's aggregated commercial and military jet fuel demand represents over 400 million gallons per year.

2009 U.S. BIODIESEL INDUSTRY ECONOMIC IMPACTS

		IMPACT		
INDUSTRY	Spending (Mil 2009 $)	GDP (Mil 2009 $)	Earnings (Mil 2009 $)	Employment (Jobs)
Annual Operations				
Feedstocks (soybean oil and other fats)	$1,106.2	$2,306.8	$818.0	19,686
Industrial chemicals	$129.8	$234.5	$93.1	1,743
Electric, natural gas, water	$35.6	$52.8	$22.8	410
Maintenance and repair	$14.3	$20.5	$13.6	342
Business Services	$25.9	$39.8	$26.2	541
Transportation	$2.1	$3.5	$1.8	42
Earnings paid to households	$14.4	$13.1	$6.8	172
Subtotal	**$1,328.3**	**$2,670.9**	**$982.3**	**22,935**
Plus value of biodiesel output				
Biodiesel		$1,434.5	$14.4	
Co-products (glycerin)		$12.8		
Total Impact		**$4,118.3**	**$996.7**	**22,935**

Credit: John Urbanchuk

[48] Sightline Institute. "Spending on Imported Fossil Fuels." 2008.
[49] U.S. Department of Commerce Bureau of Economic Analysis, State Annual Personal Income, Total 2008 -$476B, OR - $139B, WA - $287.B, ID, $50B. Viewed 24 Jan. 2011.
[50] John Urbanchuk. "Economic Impact of Eliminating the Biodiesel Tax Credit." LECG LLC, 3 Dec.2009: pg. 7.

A study from Bio Economic Research Associates, supported by the Biotechnology Industry Organization, finds large national economic benefits from producing 21 billion gallons of advanced biofuels annually by 2022, as mandated by Renewable Fuel Standard 2.[51] The study also estimated cumulative industry investment of $122 billion from 2009-22 and cumulative savings on oil imports of $350 billion between 2010-22.

U.S. ECONOMIC BENEFITS FROM PRODUCING 21 BILLION GALLONS OF ADVANCED BIOFUELS

	Direct Industry	Overall Economy
Employment	190,000	807,000
Economic Impact	$37 billion	$148.7 Billion

Credit: Bio Economic Research Associates

Feedstock production represents nearly half the direct jobs total in the BERA study. This makes an important point for the Northwest. A large share of the economic benefits of developing a sustainable aviation fuels industry would accrue to rural agricultural and forestry communities, where unemployment rates were high even before the current downturn and could use the boost. Building the industry would link and fortify major Northwest economic sectors ranging from forestry and agriculture to aviation.

NORTHWEST ASSETS

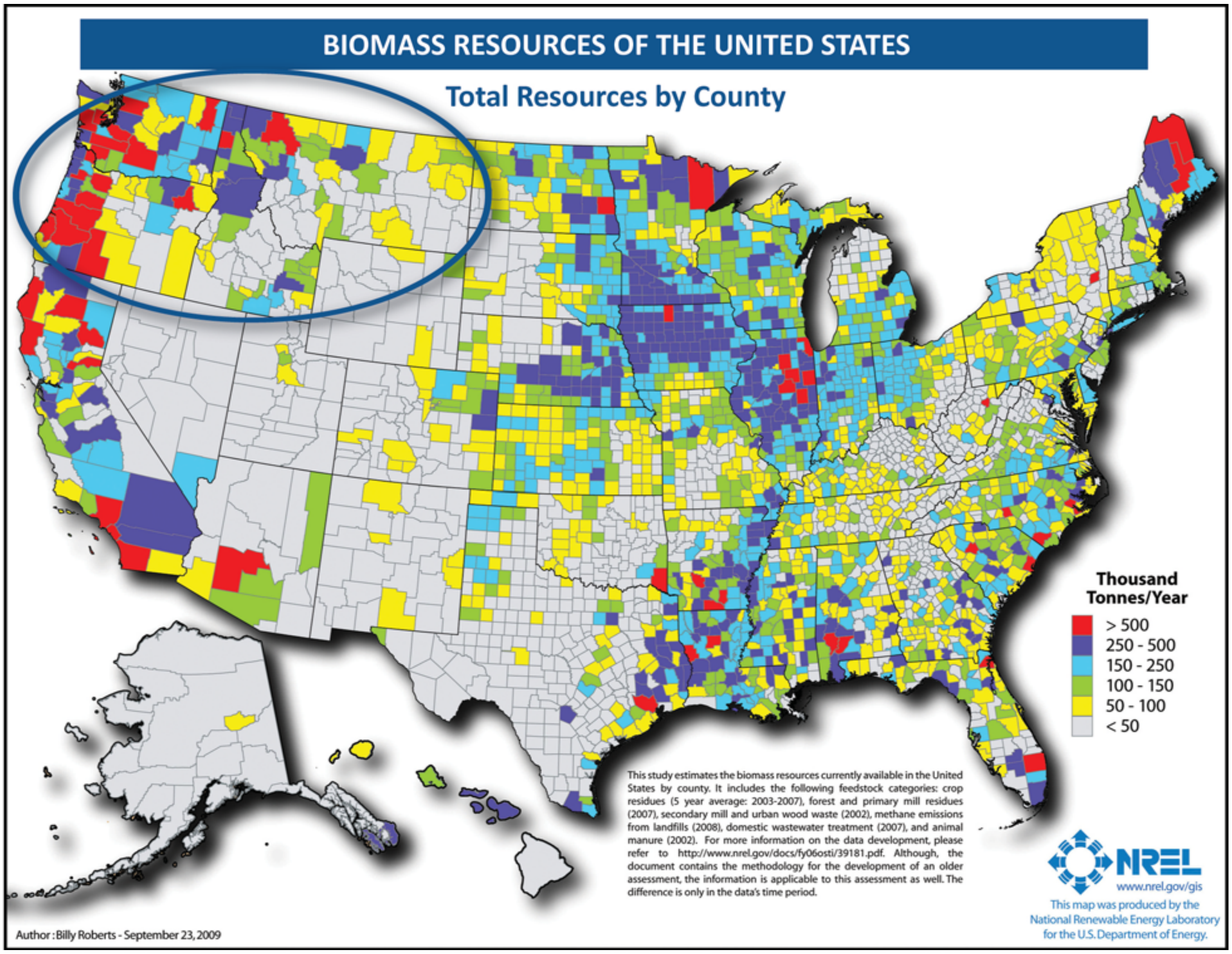
The Pacific Northwest possesses a rich array of assets on which to construct a sustainable aviation fuels industry.

> The Northwest is one of the nation's major biomass production regions. Significant forestry and agricultural sectors provide diverse feedstocks from varying climates and geographies, avoiding risks of overreliance on one or two sources.

The overall size of the region's biomass resources is shown in the adjacent map from the National Renewable Energy Laboratory.[52] At the same time, while the Northwest has great resources, biophysical constraints to the region's productivity must be addressed in developing strategies.[53] Fuel markets will not replace profitable food, feed and fiber markets, but must find niches within current markets.

The region's coastal states are national leaders in finding alternatives to municipal solid waste landfills. This provides fertile ground for developing waste-to-fuels programs that assure highest and best use.

[51] "U.S. Economic Impact of Advanced Biofuels Production: Perspectives to 2030." Bio Economic Research Associates. Feb. 2009: pp.1-2.
[52] "Biomass Resources of the United States." National Renewable Energy Laboratory, 23 Sep. 2009.
[53] "A USDA regional roadmap to meeting the biofuels goals of the Renewable Fuels Standard by 2022." USDA Biofuels Strategic Production Report. 23 June 2010.



This map was produced by Billy Roberts on Sep. 23, 2009, National Renewable Energy Laboratory for the U.S. Department of Energy

Northwest universities are building strong efforts in biofeedstocks and process technologies:

- WSU researches oilseeds, algae and pyrolysis. Washington State University has further invested in the Bioproducts Science Engineering Laboratory in Richland, jointly operated with Pacific Northwest National Laboratory. In addition to advanced laboratories the BSEL building houses a high bay where full biofuels concepts can be tested. The combined WSU/PNNL group is strong in both thermochemical and biochemical technologies to process biomass. (These are detailed in the lignocellulosic technologies section below.)
- WSU and the University of Washington are both investigating production pathways for biojet from woody biomass. The UW also conducts lifecycle analysis and the impact of forestry practices on soil and wood productivity.
- Oregon State University houses the regional Sun Grant Initiative, a federally-funded national network of land grant colleges working together on bioenergy and bioproducts.

- The University of Idaho is one of the nation's original biodiesel research centers, while Montana State University is advancing camelina oilseed crops.

Federal agencies are engaged in advanced bioenergy research in the Northwest:

- Pacific Northwest National Laboratory is a national center for thermochemical biomass processing research.
- Idaho National Laboratory is a national center for research and development in biomass collection and delivery.
- The Northwest Regional USDA Biomass Research Center is one of five national networks of Agricultural Research Service and Forest Service research facilities focused on the genetic development and sustainable production of biomass and other dedicated feedstocks. The Northwest Regional Center is comprised of 12 research locations with leadership provided at Pullman and Corvallis. ARS research focuses on the incorporation of oilseed crops into existing cereal-based production systems, and Forest Service research is centered on woody biomass short-rotations and wood from conventional forest operations. Significant consideration is given to the sustainable use of forest woody and crop straw postharvest residues.

State and local governments are leaders in biofuels policy, with renewable fuel standards enacted in Oregon, Washington and Montana, and substantial use in public fleets. Bioenergy is cited as a major opportunity in state economic development strategies. For example, the Washington State Clean Energy Leadership Council recently identified advanced bioenergy (and specifically sustainable aviation fuels) as one of the state's top three opportunities for leadership in clean technology.[54]

NORTHWEST PROSPECTS

The SAFN process was launched to explore opportunities and challenges in producing sustainable aviation fuel from Northwest feedstocks. Though fuel is a global market, regional supply chains shape much of the on-the-ground reality, as current Northwest dependence on fossil oils from Alaska and Alberta underscores. Thus, the focus here is to build new regional supply chains and redirect existing supply chains that rely on Northwest biofeedstocks grown for energy or derived from residue streams.

This does not imply that the region will not import bio-feedstocks from elsewhere or export processed fuels. In fact, some developers of oilseed fuel chains, discussed below, expect imports of some bio-feedstocks will be necessary, at least initially, to build a regional production facility that can provide a market to establish Northwest oilseed crops. But the ultimate goal envisioned by SAFN stakeholders is to generate as much sustainable aviation fuel regionally as possible. Besides supporting the regional economy, this will shorten transportation distances between fuel production and delivery, thus reducing overall carbon emissions.

One advantage of the Pacific Northwest relative to other regions of the U.S. is a low demand for wood chip and wood pellet exports to the EU and other rapidly growing carbon neutral renewable energy production centers. The South, East Coast and upper Midwest are exporting millions of bone-dry tons of woody

[54] Recommendations and Report of Clean Energy Leadership Council. January 2011.

biomass, increasing the cost of these feedstocks to domestic energy producers. In the broader Northwest region, by contrast, only British Columbia and Alberta, due to the abundance of trees killed by mountain pine beetles, are major exporters of wood biomass for electricity.

The crucial limiting factor is the availability of feedstocks on a consistent basis at an economically sustainable price. To explore potential regional feedstocks, SAFN applied the following criteria:

- **Sustainability** – Fuel products will supply genuine GHG reductions verifiable by analysis of the full product lifecycle. Fuel production impacts on natural resources including water, soils and wildlife will not violate the sustainability criteria used for screening purposes in this report.
- **Scalability** – The feedstock can potentially supply a significant portion of regional jet fuel demands. The threshold for significance is 25 million gallons/year (mgy) of production. This is based on a rule of thumb for biorefinery size to meet economies of scale. While many industry participants regard 50 mgy as ideal, the cost curve typically begins to level off around 25 mgy. Smaller biorefineries might be better matched to local feedstock supplies in some cases.[55]
- **Timeframe** – The feedstock has the potential to supply significant quantities of product economically in a 20-year time frame. This is based on a standard organizational planning horizon.
- **Competitiveness** – The feedstock does not have other markets of significantly higher value. Fuel markets for the feedstock will not be outcompeted by other product markets such as food and building.

Given the limited scope, budget and tight schedule challenging this project, the SAFN report relies on stakeholder input and substantial analyses of regional biofuel potential already completed by regional research institutions. SAFN based its selections of the most promising feedstock-technology pathways on input from stakeholders and regional studies that thoroughly assessed Northwest potentials across multiple feedstocks and technologies.

Among the studies were:

- Pacific Northwest National Laboratory study, *Biofuels in Oregon and Washington: A Business Case Analysis of Opportunities and Challenges*; [56]
- The Western Governors Association's *Strategic Assessment of Bioenergy Development in the West: Biomass Resource Assessment and Supply for the WGA Region*;[57]
- A Washington State University report mandated by the Legislature; *Biofuel Economics and Policy for Washington State*;[58]

---

[55] C. Larry Mason et al, "Wood to Energy in Washington: Imperatives, Opportunities and Obstacles to Progress – Report to the Washington State Legislature." School of Forest Resources, University of Washington, Seattle. June 2009. See chart pg. 88.
[56] Dennis Stiles et al. "Biofuels in Oregon and Washington: A Business Case Analysis of Opportunities and Challenge." Pacific Northwest National Laboratory, Feb. 2008.
[57] Western Governors Association, Strategic Assessment of Bioenergy Development in the West: Biomass Resource Assessment and Supply for the WGA Region, Kansas State University and U.S. Forest Service, 1 Sep. 2008
[58] Jonathan Yoder. "Biofuel Economics and Policy for Washington, School of Economic Sciences." Washington State University, Feb. 2010.

- A University of Washington School of Forestry assessment also mandated by the State Legislature which synthesized wood energy opportunities, challenges and actions, *Wood to Energy in Washington: Imperatives, Opportunities and Obstacles to Progress*;[59]
- A USDA study; *A USDA regional roadmap to meeting the biofuels goals of the Renewable Fuels Standard by 2020*;[60] and
- A study by the Washington State Department of Ecology and Washington State University regarded as the most detailed biomass survey by any state, *Biomass Inventory and Bioenergy Assessment: An Evaluation of Organic Material Resources for Bioenergy Production in Washington State*.[61]

Although not all of these studies were peer reviewed, we used the best available information on regional biomass potential and relied on the SAFN stakeholders and research institutions to identify relevant information. We accessed biomass studies from the USDA and other Northwest states cited in relevant chapters. For technology assessments we consulted stakeholders and other experts and surveyed literature cited in relevant chapters.

While SAFN relied heavily on existing literature, we did not limit our work to its conclusions. Instead, we drew important contributions from stakeholders. For example, while algae is not cited as a major Northwest prospect in the above reports, algal biofuels stakeholders made a compelling case for developing distributed and diverse production systems in which the region can potentially compete.

In identifying the most promising regional feedstocks for detailed evaluation, SAFN relied on stakeholder input and available literature to identify four major categories: oilseeds; woody biomass from forest waste streams; municipal and industrial solid waste; and algae. SAFN considered a number of other feedstocks including hybrid poplars, sugar beets, and agricultural residues. Although these feedstocks were not selected for detailed evaluation through the stakeholder process, they may present important opportunities. Since the development of advanced biofuels is in its early stages, new advances in technology, agronomy, or other factors may make other feedstocks more competitive. SAFN's selection of feedstock pathways was based on stakeholder input and the best information we could find, but is not intended to be exclusive or preclude further evaluation.

[59] C. Larry Mason.
[60] "A USDA regional roadmap to meeting the biofuels goals of the Renewable Fuels Standard by 2022." USDA. 2010.
[61] Craig Frear et al. "Biomass Inventory and Bioenergy Assessment: An Evaluation of Organic Material Resources for Bioenergy Production in Washington State." Washington Department of Ecology, Washington State University, Aug. 2006

Technologies: Hydroprocessing

BASICS

The long established oil refinery technology of hydroprocessing has now been demonstrated for jet fuel production from lipids, which are natural oils produced from crops and animals. A Northwest regional hydroprocessing facility could become the center of a supply chain that first employs oilseed crops such as camelina and canola, along with animal fats, and then incorporates algal oils as algae cultivation matures.

Using catalysts and heat, hydroprocessing removes oxygen, adds hydrogen and rearranges carbon molecules to create a drop-in petroleum substitute that requires no engine modifications in a 50 percent blend. Hydroprocessing produces renewable diesel, and can produce 50-70 percent jet fuel with an additional cracking step.[62] The remaining product would be mostly renewable diesel, with fractions as propane and Naphtha, a feedstock for plastics and chemicals. Hydroprocessing by the UOP/Eni Ecofining™ process produces Honeywell Green Diesel™ from biological feedstocks, and in the UOP Renewable Jet Process™ can produce hydrocarbons in the jet fuel range.[63]

Honeywell UOP hydroprocessing technology has provided fuel for successful test flights by Air New Zealand, Continental, Japan Airlines, KLM, TAM Interjet, the U.S. Navy, and the U.S. Air Force (USAF A-10C, US Navy Green Hornet, USAF C17, USAF F15 III Strike Eagle and US Navy RCB-X). In support of these test flights, Honeywell UOP used a tolling facility to produce Honeywell Green Jet Fuel™ that was blended with commercial and military aviation jet fuel in a 50-50 blend for the flights. In 2011, ASTM approval for the use of renewable jet fuel derived from hydroprocessing is moving into the final stages. The Department of Defense is separately completing approvals for fuels produced by this technology for military jets. These developments position hydroprocessing technology as likely the most immediate opportunity to develop a Northwest sustainable aviation fuel supply chain.

ECONOMICS

Extensive economic analysis has been conducted by SAFN stakeholders, including Targeted Growth, Imperium Renewables, the Camelina Company, and Honeywell UOP, but data and results vary. What these parties have been willing to reveal indicates that the one-time capital expenditure for a 100 million gallon/year hydroprocessing facility and supporting functions including feed oil purification and hydrogen production is approximately $250 million.

> A Northwest regional hydroprocessing facility could become the center of a supply chain that first employs oilseed crops such as camelina and canola, along with animal fats, and then incorporates algal oils as algae cultivation matures.

As with other feedstocks, a critical challenge is improving the market economics for sustainable aviation fuel so that it can compete with renewable diesel markets. Petroleum diesel currently tends to draw higher prices than jet fuel, and hydroprocessed renewable jet fuel from any vegetable oil source requires additional processing beyond renewable diesel. Conversion is less efficient and more hydrogen is required.

---

[62] Review of the potential for biofuels in aviation, *E4tech*, Aug. 2009
[63] Honeywell UOP, stakeholder input.

Natural bio-oils have carbon chain lengths that are in the diesel range, 16-18 carbon atoms in the hydrocarbon. Converting these molecules to the jet fuel range of 10-12 carbon atoms results in a loss of yield. More light hydrocarbons like LPG and Naphtha are produced in the renewable jet than renewable diesel process. Additional process steps needed to cleave the hydrocarbons into jet range could amount to as much as 30-40 percent higher cost of production for renewable jet compared to renewable diesel. Various factors, such as site specific costs of hydrogen and utilities, as well as market prices of byproducts like renewable diesel, LPG and Naphtha also have an impact on the net cost of production of renewable jet and its differential over the renewable diesel.[64]

This production cost differential should be considered in any policy or market premium structure to provide parity to the green fuel producer for renewable jet production with renewable diesel production. A combination of policies, incentives, subsidies and green jet fuel premiums are likely needed to address this differential.

Current incentives and subsidy structure for bio-based diesel (for instance RIN credits and the $1.00 federal tax credit for blenders) are aimed at putting renewable diesel and biodiesel on par with petroleum based diesel. The basis for this support is primarily the cost of the feedstock, the bio-oil, in comparison with petroleum crude oil. The smaller scale of production of renewable fuels compared to petroleum based fuels produced in standard refineries also plays a supporting role. For reasons discussed above, renewable jet needs a further extension to this support to level the playing field.

In the big picture, to achieve ultimate parity with petroleum based transport fuels, both diesel and jet are going to depend critically on the ability of the feed oil costs to drop to a point where fuel production based on the cost of the bio-oil would find parity in the market without special incentives. Long term pricing for petroleum will obviously play a major role. In the short term however, as the supply chain of second generation feedstocks gains traction, adoption and use of renewable fuels will need the support that is external to market driven pricing, as discussed above.

Additional regional factors may come into play for local markets. Policy-driven renewable diesel markets in California and British Columbia provide higher premiums in West Coast markets. Current biofuel policy incentives such as state and federal RFS mandates provide significant market incentives for biofuels. If the aviation market is unable to compete with similar policy initiatives, the policy supports for ground transportation markets will work against aviation. State and provincial jurisdictions should explore policies that pay incentives for aviation biofuels on a par with those in the ground transportation arena.

ADDITIONAL CHALLENGES

Feedstock supplies – A 100 million gallon/year capacity hydroprocessing plant is considered the minimum economically justified scale by SAFN biofuels industry and technology stakeholders. This scale will require more oils than the Northwest can supply from regional oilseed crops in the near future. It will take a number of years to obtain widespread acceptance from farmers, develop co-product markets, establish adequate crushing capacity and build substantial production. The challenges and requirements of establishing oilseed crops are detailed in a chapter below. At the same time, it will be virtually impossible to grow these crops at scale without clear demand and established processing facilities.

[64] Ibid.

So to "prime the pump," any hydroprocessing facility located in the Northwest may have to be supplied with oils coming from outside the region to begin production at economical levels. SAFN stakeholders engaged in hydroprocessing development proposals, including Targeted Growth and Imperium Renewables, envision production that begins by using soy and canola oil, as well as animal tallows. SAFN stakeholder experts consider the use of food grade oils and tallows in early years as the only way that this industry can scale. "There is no way to do this without using at least some portion of food grade oil in the beginning," says Imperium CEO John Plaza.[65] This could be viewed as a contradiction with aviation industry goals to avoid competition with food markets, yet illustrates the practical steps needed to ultimately reach those goals. A roadmap to phasing out these feedstocks with regionally produced feedstocks will help to develop a sustainable supply chain. Actions are covered in the oilseeds chapter below.

The Northwest has a small amount of tallow and grease production that could provide minor supplements to aviation biofuels production but which most likely will go to local plants serving ground transportation markets, such as Seattle's General Biodiesel. Washington, the region's only tallow source, produces 65 million pounds annually, enough to produce 8.7 million gallons of biodiesel. Yellow grease across the region amounts to 23 million pounds, sufficient to generate 3.1 million gallons of biodiesel.[66]

One issue is whether a new hydroprocessing plant could compete for oils with the region's substantial biodiesel production capacity, which can operate at lower costs. John Plaza of Imperium, which represents most of that capacity, responds that the market strongly prefers the renewable diesel drop-in fuel that hydroprocessing produces, as opposed to biodiesel or methyl ester. "If any production facility produced renewable diesel, the market would certainly prefer that product and we believe that product could be sold at a premium to biodiesel."

Siting – A hydroprocessing facility will require transportation infrastructure to bring in feedstocks and ship products, and utility infrastructure to serve the plant. Hydrogen supplies are expected to be supplied by on-site hydrogen generation. Hydroprocessing facilities envisioned for current fuel industry locations nonetheless will have to undergo regulatory review. All energy facilities require extensive permitting from state and federal governments. SAFN obtained differing views from stakeholders on whether a hydroprocessing plant would most likely be sited at an existing oil refinery or as a stand-alone unit. While we could draw no firm conclusion, active efforts are underway to develop both options in the Northwest. The question will be settled by practical results.

SUSTAINABILITY SCREENING

(The following section addresses hydroprocessing infrastructure. Feedstock sustainability is addressed in the oilseeds chapter.)

Greenhouse Gas Emissions – Lifecycle analysis conducted by Michigan Technological University indicates that renewable jet and diesel produced from hydroprocessing reduce greenhouse gas emissions 80-85 percent. The study is based on the use of camelina. For feedstock aspects see oilseeds section below.[67]

---

[65] John Plaza, personal communication.

[66] Western Governors Association.

[67] David Shonnard and Koers, Kenneth, "Life Cycle Assessment of Camelina-Derived Transportation Fuels: Comparison of Biodiesel, Green Diesel and Green Jet." Michigan Technological University. 21 May 2009.

Local Food Security – Not applicable

Conservation – A land use planning process for plant siting should identify potential impacts on critical species and ecosystems. Siting should take place in areas of lowest risk. Buffer zones should be created between plants and sensitive areas and/or watercourses.

Soil – Soil effects should be minimized in development and chemical releases to soils should be prevented. Applicable laws and regulations must be followed.

Water – Water quality should be maintained both on the surface and in ground water tables. Applicable laws and regulations must be followed.

Air – Air pollutants should be minimized. Applicable laws and regulations must be followed.

Use of Technology, Inputs, and Management of Waste – Applicable laws and regulations must be followed, as should manufacturers' recommendations for materials usage.

ACTION "FLIGHT PATH"

Key recommendation – Support development of regional hydroprocessing facilities producing biojet and other coproducts

Provide long-term purchase contracts:

- SAFN stakeholders engaged in the fuel industry consistently cited contracts in the 15-20 year range as critical to gaining private financing.
- Contracts should include provisions addressing sustainability.
- Contracts may need to include a premium price, at least for the early years, though a customer premium should not be viewed as the exclusive means to support new facilities.

Key Actors:

- ***Department of Defense, Defense Logistics Agency-Energy – DLA-E***, fuel buyer for the military, should provide contracts for a period as long as the law allows, currently five years with opportunity for single-year renewal for the next five.
- ***Airlines*** – Provide multi-year contracts involving several airlines in order to avoid competitive risks.
- ***The Boeing Company*** – Provide leadership on fuels development through technical and strategic expertise; utilize biofuels in own operations as feasible.
- ***Northwest state governments*** – Provide long-term fuel purchase contacts and incentives.

Build partnerships to drive development of the facility:

- Draw together the biofuels and petrochemical industries to explore potential sites.
- Gain support from federal agencies in the form of loan guarantees and direct capital support in order to reduce financing and product costs.
- Gain economic development support from state governments including infrastructure and workforce development.

Key Actors:

- ***Local petrochemical refineries*** – Explore options for siting and prospective partnerships with the biofuels industry.
- ***Biofuels industry*** – Explore options for siting and prospective partnerships with the petrochemical industry.
- ***USDA Rural Development*** – Provide loan guarantees and capital support.
- ***U.S. Department of Energy Office of Biomass Research*** – Provide loan guarantees and capital support.
- ***Northwest state governments*** – Work with developers to assess infrastructure and workforce needs and direct state resources to meeting needs.

Technologies: Lignocellulosic Biomass Processing

BASICS

Lignocellulosic biomass is composed of three materials – cellulose, hemicellulose and lignin. The latter two bind and protect the cellulose. Technologies must break down the material in order to process biomass into bioenergy and bioproducts. These technologies have long been available but the fundamental challenge is to make the processes economical. The two major biomass processing technologies employed are separation of biomass into chemical components, which are then separately converted to fuels and products (example: biomass to sugar to fuel) and conversion of whole biomass to fuels or chemicals through thermal and chemical routes. They are extensively detailed in other literature, so this section will provide only a brief summary. A sidebar briefly notes a range of technology developers, illustrating the diverse processes under development.[68]

Separation into Chemical Components – Separation of biomass into components is typically used where those components, such as sugars, are desired for further conversion into fuels or chemicals. One of the primary processes converts sugars into alcohols such as ethanol, butanol or methanol. First, sugars must be released from biomass, known as saccharification. This begins with a pretreatment stage to begin breaking down lignocellulosic structure and converting the hemicellulose and part of the cellulose to sugars. A variety of processes are available using acid, alkaline or oxidative chemicals, and microorganisms. Heat is applied at this stage. One widely used process, dilute acid hydrolysis, employs diluted sulphuric acid at temperatures above 160°C. Options include hot water and steam pretreatments, as well as rapid exposure to steam, ammonia and CO_2.

In the next step, cellulose is transformed into sugars by processing it with acids or enzymes. The enzymatic process requires less heat and energy than the acid process, and produces fewer chemicals that block fermentation. So investment and research efforts have tended to favor enzymatic hydrolysis.

Finally, the main route for conversion of sugars is through biological means using fermentation. Sugars are fermented to alcohols that become the basis of fuels and chemicals, using yeasts or microbes such as Zymomonas mobilis. Development of economical microorganisms and enzymes is vital. Some emerging

[68] For detailed discussions of technologies see "Review of the potential for biofuels in aviation," *E4tech*.

processes combine saccharification and fermentation into single processes. However, there are conversion processes that transform sugars into platform chemicals via purely chemical means that do not involve fermentation organisms.

The pretreatment and subsequent conversion to fuels or chemicals will also yield the lignin fraction of the starting biomass. This lignin may be used for energy or converted into higher value products, such as plasticizers to replace bisphenol A. Utilization of the lignin for value-added products creates more favorable economics for the production of bio-aviation fuels and would provide diversification of markets to sustain and secure the job creation associated with the production of bio-aviation fuels.

Conversion of Whole Biomass – This process uses high temperatures and/or chemicals to break down all three components of biomass. One thermochemical option is gasification, which produces syngas, a combination predominantly composed of carbon monoxide and hydrogen. Once known as "town gas," it was generated from coal by what is now the rusting structure at the center of Seattle's Gasworks Park. Challenges for biomass processing are economical purification of gas and a need for economic improvements in catalyst performance. Syngas is transformed into fuels through two major modalities:

- **Catalytic** – A combination of heat and catalysts rebuild molecules into longer chains required for fuels. The Fisher-Tropsch (FT) process provides a prominent example, as it was developed by the Germans in the 1920s and used to a limited extent in World War II, and by the South Africans for the last 20-plus years to make jet fuel. Today a number of companies seek to commercialize FT for biomass-based fuels but capital costs present a challenge. Other catalytic technologies are in development.
- **Biological** – Syngas is fed to microbes that ferment into alcohols and acetic acid, which can then be upgraded to other fuels and chemicals.

A variation of this technology is the hydrolysate concept where the pretreated material is fermented directly into platform molecules ready for further upgrading into, for instance, jet fuels by catalysis. This process harvests the enzyme producing capability of a consortium of microbes to produce platform molecules without the addition of external enzymes or acids. Another major advantage is that the yield of jet fuel, or other potential fuels produced, is far higher than for concepts based only on fermentable sugars because lignin content can be employed as well as cellulose.

Another thermochemical option is pyrolysis which places biomass under high temperatures in an oxygen-starved environment, yielding a mix of syngas as well as bio-oil and biochar. Fast pyrolysis yields a higher proportion of bio-oil, while slow pyrolysis produces a greater percentage of biochar. Pyrolysis oils are corrosive and lose stability if stored over periods of months, so processing is a challenge. The Bioproducts, Engineering and Science Laboratory jointly operated by WSU and Pacific Northwest National Laboratory have upgraded bio-oils to drop-in substitutes for petroleum diesel and gasoline using catalysts and have made progress on the stability challenges of pyrolysis oils.

In addition to gasification and pyrolysis, it is possible to use solvent-based systems to dissolve biomass, although these systems are less popular and still in the research phase.

SELECTED EMERGING TECHNOLOGY COMPANIES

A wide range of companies is pursuing interesting technologies that may be suitable for producing aviation fuels in the Northwest region. Some of the most interesting technologies and companies are listed below:

Amyris employs sugars to produce chemicals and fuel using fermentation with engineered yeast strains. Amyris has a pilot plant at Emeryville, California.[69]

BlueFire uses a proprietary acid hydrolysis process. Its planned plant at Fulton, Mississippi is intended to convert municipal solid waste (MSW), forestry residues and other woody biomass to ethanol. Another plant planned for at Lancaster, California is projected to produce 3.9 mgy of ethanol from MSW.[70]

Choren's process gasifies biomass, separates chemical raw materials and uses the Fischer-Tropsch process to synthesize gas to a green diesel fuel. It opened a 3.9 mgy plant in Germany in 2008. Company owners include Daimler and Volkswagen.[71]

Cobalt processes cellulosic biomass such as forestry wastes to make butanol through fermentation. Cellulose and hemicellulose are hydrolyzed and processed cellulose and organisms are fed to a fermenter/reactor on a continuous basis. Integrating sugar extraction from cellulose and hemicellulose results in shorter time periods in a reactor and less need for equipment. Continuous bioreactor design (as opposed to batch reactors) claims to reduce energy and equipment requirements.[72]

Clean-Vantage, a new company based in Richland, Washington, with background technology out of Denmark, works on their patent protected *BioChemCatTM* process. The company uses wet oxidation pretreatment technology, an environmentally friendly process where no chemicals are added. Fermentation is done by a consortium of bacteria without adding enzymes, and where a high yield of platform molecules are produced and recovered during the fermentation process. Catalysis is used to upgrade the intermediate products into the desired product. The overall process is a full concept with all parts of the biomass and process water recirculated after nutrient removal. The process allows wide variations in feedstock composition. For an "nth" plant, one developed after the first few are operating, a final fuel price of $2.33 has been calculated with a raw material price of $60 per metric ton.

Coskata gasifies biomass to create syngas, and then applies proprietary organisms to ferment them into ethanol. A Madison, Pennsylvania, demonstration plant plans to produce ethanol from municipal solid waste. It will employ gasification with fermentation using proprietary organisms claimed to reduce need for costly enzymatic pretreatment.[73]

[69] http://www.amyrisbiotech.com/
[70] http://www.bluefireethanol.com/
[71] http://www.choren.com/en/
[72] http://www.cobalttech.com/
[73] http://www.coskata.com/

Dynamotive Energy Systems Corporation uses pyrolysis technology (soft and hard woods), cellulosic biomass, and plant and agricultural residues to produce 60-75 percent bio-oil, 10-20 percent syngas, and 15-20 percent biochar. Woods are reduced to a moisture content of less than 10 percent and 1-2 mm diameter particles, and then fed into a pyrolysis reactor that operates at 450-500°C. Biochar is then removed from the output stream and syngas is recycled to process the heat. The remaining product stream is cooled to create a liquid bio-oil. A plant, co-located with a wood flooring company in West Lorne, Ontario, processes 100 tons a day of wood waste into bio-oil.[74]

Enerkem gasifies biomass and processes syngas into ethanol. A commercial pilot plant in Westbury, Quebec, constructed from October 2007-December 2008, began start-up operations by January 2009. A plant at Edmonton, Alberta is planned to process 100,000 metric tons MSW annually to produce chemicals and 9.5 mgy of ethanol. Ground was broken on the C$76 million plant in Sept. 2010. A planned $250 million plant at Pontotoc, Mississippi will supply nearly 20 mgy of ethanol using waste from municipalities, farms and forests. The goal is to produce 1.3 million gallons/year from creosoted utility poles and other waste. The company claims one metric ton of waste will produce 95 gallons ethanol.[75]

Ensyn employs a range of biofeedstocks to make syngas, biochar and bio-oil that can replace #2 or #6 heating fuel, natural gas or coal in a boiler and chemicals. Biomass is fed into a pyrolysis reaction vessel where it is rapidly heated to 500°C in a vortex of sand in an oxygen-starved environment. Materials are rapidly cooled, producing a pourable liquid bio-oil, which can further processed to become green gasoline, diesel or jet.[76]

Envergent Technologies, a Joint Venture between Ensyn Corporation (listed above) and Honeywell International Inc.'s UOP LLC, employs fast pyrolysis technology to process a range of lignocellulosic biomass feedstocks. It makes pyrolysis oil that can replace #2 or #6 heating fuel, natural gas or coal for producing heat or that can be used in a stationary diesel engine to produce electricity. Biomass is fed into a pyrolysis reaction vessel where it is rapidly heated to 500°C by contact with hot sand in the absence of oxygen. Materials are rapidly cooled, producing a pourable liquid biofuel, called pyrolysis oil. UOP, in conjunction with the joint venture partner Ensyn (through Envergent Technologies), is working on upgrading pyrolysis oil into transport fuels -- green gasoline, diesel and jet.[77]

Fulcrum Bioenergy uses InEnTech plasma gasification technology to gasify the cellulosic portion of MSW. The resulting syngas is processed through a proprietary catalyst into ethanol. Construction is underway at the company's Sierra BioFuels plant 20 miles east of Reno, Nevada. It will annually use 90,000 tons of MSW left after recycling to produce 9.5 mgy of ethanol. The company claims a 75 percent lifecycle GHG reduction, and production of 95 gallons of ethanol from one metric ton of waste. Plant cost is placed at $120 million.[78]

[74] http://www.dynamotive.com/
[75] http://www.enerkem.com/en/home.html
[76] http://www.ensyn.com/
[77] http://www.envergenttech.com/files/envergent-press-20110310.pdf
[78] http://www.fulcrum-bioenergy.com/

Gevo employs fermentable sugars from grain crops, sugar crops and cellulosic biomass to produce butanol and other alcohols that can be made into gasoline, diesel and jet fuel, as well as chemicals for plastic and fiber production, and animal feeds. Gevo targets processes that use existing ethanol production technology, and recently purchased an existing Minnesota ethanol plant for conversion. The harvest, milling, fermentation and solids extraction steps are the same as ethanol production. Differences from standard ethanol production are the type of organism and the addition of enzymes, catalysts and nutrients to the bioreactor/fermentor. The liquid phase from fermentation is distilled. Gevo is involved with an ASTM task force that is establishing the specification for ATJ (Alcohol to Jet) Fuel derived from renewable biomass sugar. Gevo is starting with commercially available starch but is evaluating cellulosic providers from woody and agricultural waste feedstocks to create a commercially available cellulosic jet fuel.[79]

Lanzatech can use any biomass source gasified into carbon monoxide and hydrogen. It can also use flue gas captured from industrial processes after carbon monoxide gas is scrubbed and cooled. The gas is sent to a bioreactor containing proprietary microbes which create liquid biofuel. Product recovery isolates high octane fuel or other material. Lanzatech, piloting its technology co-located with a metals plant in New Zealand, has successfully isolated 2, 3-Butanediol from fermentation products. These can be converted to intermediaries like butenes, butadiene and methyl ethyl ketone.[80]

LS9 employs sugar cane and cellulosic biomass to make UltraClean™ products that are claimed to be essentially indistinguishable from gasoline, diesel, and jet fuel. A fermentor/reactor combines several steps, including addition of a sugar/cellulose source and proprietary organisms. LS9 claims its fuels have higher energetic content than ethanol or butanol. The company bought a complex in Florida and expects to complete retrofitting and startup in 2011.[81]

Mercurius Biofuels, a Ferndale, Washington company, is developing acid hydrolysis and upgrading cellulosic biomass to produce non-aromatic hydrocarbon liquid fuels and chemicals. Acid hydrolysis produces an acid intermediary, char and chemicals. The intermediary is “built” into larger carbon chain molecules using catalysts. Hydrogen is used to “polish” and deoxygenate the feed. Unused hydrocarbons are recycled. Fuel produced by this process must be blended with aromatics to maintain engine sealing. The process is capable of producing jet fuel. A biochar coproduct is also generated.

Pacific Ethanol is developing a cellulosic ethanol plant in Boardman, Washington, that makes use of BioGasol technology, which was developed and demonstrated in Denmark by Birgitte Ahring, who is presently the Director and Battelle Distinguished Professor at Washington State University’s Center for Bioproducts and Bioenergy in Richland, Washington. Pacific Ethanol, the largest West Coast-based marketer and producer of ethanol, was awarded a matching grant of $24.32 million to build the cellulosic ethanol demonstration plant. The plant will employ a technology to produce ethanol from wheat straw, wood chips and corn stover. It will be co-located at the site of Pacific Ethanol’s existing corn-based ethanol facility in Boardman, Oregon.[82]

[79] http://www.gevo.com/
[80] http://www.lanzatech.co.nz/
[81] http://www.ls9.com/
[82] http://www.pacificethanol.net/

Range Fuels has built a commercial-scale cellulosic biofuels plant in Soperton, Georgia using forestry materials, and plans to experiment with perennial grasses. Biomass is gasified and syngas is then processed through a proprietary catalyst, yielding mixed alcohols. These are separated and processed into a variety of low-carbon biofuels including cellulosic ethanol and methanol. The company announced its first production of methanol in August 2010 and then promptly closed down the facility.[83]

Rentech uses inputs of biomass, municipal solid waste and coal. Power is generated with syngas, then conditioned and cleaned up gas is fed into the Fischer-Tropsch process to make jet fuel, diesel, and chemicals. Rentech is developing a gasification process that can use biomass, municipal solid waste and coal. Gas is fed into the Fischer-Tropsch. CO_2 produced during gasification is then "ready" for capture. The initial use would be injection into oil wells to enhance petroleum recovery.[84]

S4 Energy Solutions, a joint venture of Waste Management (WM) and InEnTech of Bend, Oregon, plans a plasma gasification facility at WM's Columbia Ridge landfill in Arlington, Oregon. This is expected to begin operation by the second quarter of 2011. The facility complements on-site landfill gas electrical generation. Plans are to use plasma gasification technology developed by InEnTech. It includes two chambers to produce syngas: the first heats to 1,500° F; the second to 10,000-20,000° F. The syngas is initially intended to produce electrical energy, but WM has expressed an interest in exploring liquid fuel production for aviation and other markets.[85]

Solena Group, based in Washington, D.C., announced in 2010 that it would form a partnership with British Airways in the first European commercial plant to produce jet fuel from MSW, as well as agricultural and industrial waste. The plant, projected to cost $300 million and located in East London, will convert nearly 500,000 metric tons of biomass annually into 16 mgy biojet, eight mgy bionaptha, and 40 megawatts of electricity; 50 percent of which will be shipped externally to the grid. Fisher-Tropsch technology is planned. Solena is working toward similar European plants in Hamburg, Germany; Copenhagen, Denmark; Dublin, Ireland; and Paris, France. Plans to build other plants around the world include Sydney, Australia; Newark, New Jersey; and Houston, Texas. Solena is considering a plant in Gilroy, California to produce fuel from agricultural, forestry, and municipal waste.[86]

Terrabon's MixAlco process converts biomass into organic chemicals and alcohols through anaerobic digestion followed by thermal conversion. Terrabon has demonstrated drop-in synthetic gasoline based on hydrogenation of ketone to isopropanol, then gasoline. A demonstration plant in Bryan, Texas, processes MSW, sewage sludge, forest residues and other wood waste. The company recently reported that a test run produced 70 gallons of green gasoline per ton of cellulosic biomass. Waste Management and Valero Energy are its investors.[87]

[83] http://www.rangefuels.com/
[84] http://www.rentechinc.com/
[85] Personal communication with Susan Robinson, Waste Management Director of Public Sector Services http://www.s4energysolutions.com/technology/index.html
[86] http://www.solenafuels.com/
[87] http://www.terrabon.com/

Zeachem broke ground in 2010 for the first advanced biorefinery in the Pacific Northwest. Zeachem's 250,000 gallon/year pilot plant in Boardman, Oregon will employ hybrid poplar as well as farm and forest residues to produce ethanol. The process mixes gasification and fermentation of biomass to acetic acid with no CO_2 byproduct, unlike traditional ethanol fermentation, so Zeachem claims a 50 percent greater efficiency. Acetic acid is converted to an ester and hydrogen is added to make ethanol. Gasified lignin provides the hydrogen. Zeachem has bench-tested a process to convert ethanol to jet fuel.[88]

ECONOMICS

Cost barriers – Biofuels from lignocellulosic matter are not new. For example, for many years Georgia-Pacific operated an acid hydrolysis facility to make ethanol from pulping liquors produced at its Bellingham, Washington, plant. The challenge today is to operate biorefinery networks that produce economically competitive fuels. As noted in the "Building Supply Chains" section above, the U.S. is not on track to meet goals for advanced biofuels, and did not blend a single drop of cellulosic ethanol into the national fuel supply in 2010 when the original goal was 100 mgy. This illustrates the challenges.

"High production and initial construction costs for untested technologies and processes on a large scale increase investment risk and affect the willingness of investors to underwrite projects," writes the USDA Economic Research Service. "Estimated production and capital costs for next-generation biofuel production are significantly higher than for first-generation biofuels. These costs are expected to decline as companies step up production."[89]

An assessment of biomass energy opportunities by the University of Washington's School of Forest Resources conducted for the Washington State Legislature says, "Continued research investment to develop superior conversion technologies for liquid fuel production from Washington biomass resource will help to identify advancements that provide maximum energy yields at least costs. Investment in a pilot project towards development of a commercial integrated biorefinery is highly recommended as an important next step."[90]

Cost studies – A number of cost studies have been done for cellulosic ethanol that can offer a proxy for drop-in fuels. Estimates vary widely but indicate that biofuel costs will remain high for the initial years and will require policy support to begin production.

Studies show that gasification technologies face high upfront costs. For sugar-based conversion processes, economical pretreatment of biomass is a particular challenge being addressed by researchers seeking to produce lower-cost enzymes or more effective thermal treatments. Whether pretreatment can meet the challenge is "the million dollar question," says Brian Duff, chief engineer for the U.S. Department of Energy (USDOE) Office of Biomass Research. Another key aspect of sugar-based conversion technologies uses the lignin component for energy, fuel or higher value products.

[88] http://www.zeachem.com/
[89] William T. Coyle. "Next-Generation Biofuels: Near-Term Challenges and Implications for Agriculture." USDA Economic Research Service, May 2010: pg.10
[90] C. Larry Mason et al. "Wood to Energy in Washington: Imperatives, Opportunities and Obstacles to Progress." School of Forest Resources, Report to the Washington State Legislature, June 2009: pg. 145.

A recent study led by researchers from Iowa State University, ConocoPhillips and the National Renewable Energy Laboratory (NREL) created seven scenarios to assess costs for cellulosic ethanol production from pioneer plants and "nth" plants. Pioneer plants are the first few to employ a new process. Nth plants are those that are built after several pioneer plants are operating, so have lower risk and start-up cost. The study is based on corn stover delivered at $75/BDT (bone dry ton) and a 2,000 metric ton/day capacity, with a 10 percent return on investment. For pioneer plants, producing a unit of energy equal to the same amount of gasoline (gasoline gallon equivalent – GGE), costs ranged from $2-$12/gallon.[91] Energy return on investment, the amount greater than energy devoted to production, showed pyrolysis with hydrogen purchase with the highest returns at 77.1 percent. The lowest was dilute acid processing with 44.4 percent. Nth plant results are shown below.

CAPITAL COST ESTIMATES FOR CELLULOSIC ETHANOL PLANTS

Process	Total capital investment	Cost Gallon Gasoline Equivalent	Energy Return on Investment
Dilute acid	$380M	$5.00	44.1
Gasification high temp.	$610M	$4.50	52.5
Gasification low temp	$500M	$5.00	42.1
Pyrolysis hydrogen production	$280M	$3.00	76.7
Pyrolysis purchased hydrogen	$200M	$2.00	77.1

Credit: data from Anex et al

[91] Robert P. Anex et al. "Techno-economic comparison of biomass-to-transportation fuels via pyrolysis, gasification, and biochemical pathways." Fuel 89. 2010: pp. 529-535.

Purdue University provides the following cellulosic ethanol cost estimates:[92] Ethanol energy density is 75,700 Btu/gallon, 56 percent of jet at 135,000 Btu/gallon.[93] The gge – gasoline gallon equivalent – figure in the graphs below reflect differing energy densities.

BIOCHEMICAL PRODUCTION COSTS

Plant Size (MGPY)	Capital Costs: $ Million	Capital per annualized gallon	Capital charge ($/gal.)	Operating costs ($/gal)	Total Cost ($/gal.)	Total Cost ($/gge)	Cost Year
25	$136	$5.44	$0.73	$0.77	$1.50	$2.25	1999[b]
45	$183	$4.07	$0.54	$0.94	$1.48	$2.22	2007[c]
50	$338	$6.76	$0.61	$1.31	$1.92	$2.88	2009[d]
69.3	$220	$3.17	$0.43	$0.90	$1.33	$2.00	2007[f]
100	$349	$3.49	$0.47	$1.30	$1.77	$2.65	2009[g]
150	$756	$5.04	$0.67	$0.50	$1.17	$1.76	2005[h]

Note: In some cases, the orignal source calculated $/gge (gallon gasoline equivalent) and in others $/g ethanol.

Source: Compiled by Tyner, Brechbill, and Perkis, Purdue University, August 2010, from listed sources.
Notes: MGPY = Million gallons per year. "Capital costs" per annual gallon are included in order to compare capital expenses for plants of various sizes. The "Capital charge" per gallon is estimated using an annual payment calculated at a 12% interest rate for a plant with a life of 20 years. The "Total Cost" per annual gallon equals the sum of the capital charge (per gallon) and operating costs (per gallon).

a. Prices published as $ per gallon of ethanol (volumetric basis) were multiplied by 1.5 in order to convert to $ per gallon of gasoline energy-equivalent basis.
b. McAloon, A., F. Taylor, W. Yee, K. Ibsen, and R. Wooley, *Determining the cost of producing ethanol from corn starch and lignocellulosic feedstocks,* NREL/TP-580-28893, National Renewable Energy Laboratory, (Golden, CO), October 2000.
c. Tao and Aden (2009)
d. Rismiller and Tyner (2009).
e. $1.33 per gallon is the minimum ethanol selling price.
f. Foust et al (2009).
g. NAS, *Liquid Transportation Fuels from Coal to Biomass* (2009).
h. Wright and Brown (2007).

Credit: Wally E. Tyner, Purdue University and NREL

[92] Personal communication, Wallace E. Tyner, Purdue University.
[93] Oak Ridge National Laboratory, http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_04_06.html

THERMOCHEMICAL PRODUCTION COSTS

Plant Size (MGPY)	Capital Costs: $ Million	Capital per annualized gallon	Capital charge ($/gal.)	Operating costs ($/gal)	Total Cost ($/gal.)	Total Cost ($/gge)	Cost Year
45	241	$5.36	$0.72	$0.60	$1.32	$1.98	2007[b]
45	488	$10.84	$1.45	$1.70	$3.15	$3.15	2009[c]
61.8	210	$3.40	$0.45	$0.77	$1.22	$1.83	2007[e]
67	636	$9.49	$1.27	$1.78	$3.05	$3.05	2008[f]
150	854	$5.69	$0.76	$0.44	$1.20	$1.80	2007[g]

Note: In some cases, the orignal source calculated $/gge (gallon gasoline equivalent) and in others $/g ethanol.

Source: Compiled by Tyner, Brechbill, and Perkis, Purdue University, August 2010, from listed sources.
Notes: MGPY = Million gallons per year. "Capital costs" per annual gallon are included in order to compare capital expenses for plants of various sizes. The "Capital charge" per gallon is estimated using an annual payment calculated at a 12% interest rate for a plant with a life of 20 years. The "Total Cost" per annual gallon equals the sum of the capital charge (per gallon) and operating costs (per gallon).
a. Prices published as $ per gallon of ethanol (volumetric basis) were multiplied by 1.5 in order to convert to $ per gallon of gasoline energy-equivalent basis.
b. Tao and Aden (2009).
c. Rismiller and Tyner (2009).
d. $1.22 per gallon is the minimum ethanol selling price.
e. Foust et al, Cellulose (2009).
f. NAS, *Liquid Transportation Fuels from Coal to Biomass* (2009).
g. Wright and Brown (2007).

Credit: Wally E. Tyner, Purdue University and NREL

Coproducts – Biomass processes produce not only liquid fuels but gases to drive electricity generation, and a wide array of valuable chemical products. Among them are products that can be produced from lignin macromolecules. These include carbon fibers, polymer modifier, resins, adhesives and binders, as well as aromatic chemicals like BTX chemicals, lignin fragments, low molecular weight byproducts and fermentation products.

A screening by the U.S. Department of Energy looked at chemicals that can be produced from fermentation processes. The study identified 12 chemicals that are building blocks for many products. They are 1,4 diacids (succinic, fumaric and malic), 2,5 furan dicarboxylic acid, 3 hydroxy propionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, xylitol/arabinitol.[94] Thermochemical processes employing catalytic conversion have fewer economical co-product options, because they convert most of the biomass to fuel building blocks. Other chemical opportunities from thermochemical conversion of biomass are hydrogen and methanol.[95]

[94] T. Werpy & G. Peterson. "Top Value Added Chemicals from Biomass Volume I - Results of Screening for Potential Candidates from Sugars and Synthesis Gas." U.S. Department of Energy, Energy Efficiency and Renewable Energy, Aug. 2004.
[95] J.J. Bozell et al. "Top Value-Added Chemicals from Biomass Volume II - Results of Screening for Potential Candidates from Biorefinery Lignin." U.S. Department of Energy, Energy Efficiency and Renewable Energy, Oct. 2007.

Pyrolysis products include synthesis chemical feedstocks, food flavorings and adhesives, as well as biochar. With potential to sequester carbon in soils for hundreds or thousands of years, while improving soil quality, biochar is drawing much interest as a potential high-value coproduct. It could, prospectively, reduce full fuel carbon lifecycles to zero or even absorb more carbon than the lifecycle emits.

ADDITIONAL CHALLENGES

Feedstock certainty – Supplying sufficient volumes of sustainably produced feedstocks to biorefineries represents a critical challenge. The economical delivery range for bulky biomass is generally considered no more than 50 miles or one hour. Therefore one option may include smaller, regionally scaled conversion facilities that produce more energy-dense biomass components, such as sugar, or fuel intermediates. These components and intermediates can then be economically shipped to a large scale refinery for final conversion. Biorefineries capable of processing diverse feedstocks can also use an array of regional feedstocks. For example, biorefineries might have a steady stream of municipal solid waste as their basic supply, and supplement supplies of forest and seasonal farm residues as they become available. In addition, densification or drying of biomass may extend the cost-effective transport range. At the same time, as with any bio-based process, feedstock quality must be controlled to match plant requirements, so trade-offs are to be expected.

Mike Pruett of Green Diamond, a SAFN forest lands management stakeholder, notes, "I have been talking to various companies interested in developing a biofuels business on our landscape over the last two years. We have listened carefully to what they needed in order to make an investment into a production infrastructure necessary for a biofuels market to blossom.

"The three primary components these developers and their financial backers are looking for are as follows: 1) Certainty in fuel supply for volume, price and timeframe; 2) Concentrated fuel supply potential within feasible transportation distance of conversion facility (approximately 50 miles); 3) Conversion facility located in an area with transportation advantages. I cannot stress how important item #1 is. . . These developers want annual commitments for specific volumes of material at certain prices for 10-plus year periods or more so they can proforma their business and attract financing."[96]

The UW wood energy assessment says, "A rule of thumb for investor confidence in the financing and development of bioenergy projects is that fuel availability should be two to three times the minimum value to sustain operations."[97]

Feedstock information – In another place the UW assessment notes that forest resource estimates have been based on "sparse" and "outdated" information. "Consequently, estimates of potentially available woody biomass are coarse resolution of insufficient quality to support detailed analysis of bioenergy project planning."[98]

[96] Personal communication, Mike Pruett, Green Diamond.
[97] C. Larry Mason, pg. 89.
[98] C. Larry Mason, pg. 135.

Better data on available feedstocks is needed. An Oak Ridge National Laboratory (ORNL) assessment conducted in 1999 found that Northwest states generate these amounts of waste biomass deliverable at various price points each year:[99]

FOREST RESIDUE FEEDSTOCK QUANTITIES				
	<$20/dry ton	<$30/dry ton	<$40/dry ton	<$50/dry ton
Idaho	204,265	2,572,162	4,117,282	7,165,782
Montana	69,060	1,421,766	2,159,358	3,983,058
Oregon	192,532	3,341,220	4,126,075	9,809,975
Washington	297,432	3,979,387	5,938,641	9,920,241

Credit: Oak Ridge National Laboratory (ORNL)

In 2011, updated state and national resource figures are expected when USDA and USDOE release a new version of the 2005 “billion-ton study” aimed at assessing U.S. biomass capacities.[100] This study and the original use limited sustainability screens, meaning their results may be overly optimistic. Part of the push for new data comes from states such as Washington which are finding more materials than the ORNL study.

In 2005, Washington State University and the Washington Department of Ecology released what is widely regarded as the best state study of biomass energy potentials. The Washington study looked at a wider range of sources. An updated version found 16.9 million dry tons available annually, with over 30 percent concentrated in King, Pierce, Snohomish and Yakima counties.[101] Of the total, 85 percent is lignocellulosic material.

“This shows the significance of doing a more specific state inventory instead of relying on a nationwide report that struggles to identify the uniqueness of each state,” the Washington researchers wrote.[102]

David Sjoding of the Washington State University Energy Extension Program, who works extensively on state biomass activities, said a further inventory revision is in the works.

By adding new information on categories such as biosolids, the study will show that the state generates at least 20 million dry tons of residues each year, Sjoding says.[103]

---

[99] Marie E. Walsh. “Biomass Feedstock Availability in the United States: 1999 State Level Analysis.” Oak Ridge National Laboratory, Jan. 2000. The study also assessed energy crops and at 1999 stage of development found potential only in Montana adding 2,778,386 dry tons annually to the <$50 column.

[100] R.D. Perlack.

[101] Craig Frear. “Bioenergy Inventory and Bioenergy Assessment for Washington State.” Presentation to Harvesting Clean Energy Conference, Spokane, Washington, 27-28 Feb. 2006;
Craig Frear et al. “Biomass Inventory and Bioenergy Assessment: An Evaluation of Organic Material Resources for Bioenergy Production in Washington State.” Washington State University, Washington Department of Ecology, Dec. 2005.

[102] Ibid.

[103] Personal communication, David Sjoding, Washington State University.

Siting – Cellulosic biofuels plants will require significant transportation infrastructure both to bring in what are typically bulky feedstocks, and to ship products. Utility infrastructure will also be needed to supply energy, water and waste disposal needs. The impact of air and water emissions from these plants and other facilities must also be evaluated. All energy facilities require extensive permitting from state and federal governments.

SUSTAINABILITY SCREENING

Greenhouse Gas Emissions – GHG profiles will vary widely by feedstock and technology. Developers have financial incentives to meet a threshold for 50 percent GHG reductions from a 2005 baseline in order to gain valuable Renewable Identification Number (RIN) credits for cellulosic biofuels, under the Renewable Fuel Standard (RFS). While aviation fuel supplies are not part of RFS, renewable aviation fuels that meet GHG standards can nonetheless receive RINs. GHGs will vary by technology and feedstocks. It is beyond the capacity of the SAFN initiative to provide detailed estimates on the numerous potential combinations involved. Feedstock-technology pathways will have to be analyzed based on specific proposals.

Local Food Security – not applicable. For feedstocks, see sections below.

Conservation – A land use planning process for plant siting should identify potential impacts on critical species and ecosystems. Siting should take place in areas of lowest risk. Buffer zones should be created between plants and sensitive areas and/or watercourses.

Soil – Soil effects should be minimized in development, and chemical releases to soils should be prevented. Applicable laws and regulations must be followed.

Water – Water quality should be maintained both on the surface and in ground water tables. Applicable laws and regulations must be followed.

Air – Air pollutants should be minimized. Applicable laws and regulations must be followed. Thermochemical operations are expected to have greater challenges than biochemical operations.

Use of Technology, Inputs, and Management of Waste – Applicable laws and regulations must be followed, as should manufacturers' recommendations for materials usage. Where microorganisms are employed, escape into the environment must be prevented. Potential hazards related to the use of genetically modified organisms must be disclosed, in consultation with the Biosafety Clearinghouse established under the Cartagena Protocol on Biosafety. Monitoring for releases and emergency plans to address releases must be implemented.

ACTION "FLIGHT PATH"

Key Recommendation: Build up existing research and development efforts at Northwest institutions

- Public universities should seek federal funding to build up existing efforts such as WSU's Center for Bioproducts and Bioenergy, the University of Washington's work on biomass pretreatment and lifecycle analysis, and the Sun Grant Initiative based at Oregon State University (OSU).
- Public universities and USDOE national labs should build up their existing collaborations such as the Bioproducts, Science and Engineering Laboratory operated by WSU and Pacific Northwest National Laboratory.

- Public universities and national labs should work with each other, the industry, and state and federal government agencies to build research consortia. Federal agencies should fund biomass technology R&D connected to accessing Northwest feedstocks through the regional USDA Biomass Research Center and Agriculture and Food Research Initiative.

Key Actors:

- ***Public universities*** – Build up internal programs and collaborations
- ***USDA Agricultural Research Service*** – Stage research and pilot projects
- ***USDA Forest Service Research & Development*** – Stage research and pilot projects
- ***State natural resources, environmental and energy agencies*** – Work with public universities and federal agencies on research efforts
- ***USDA NIFA Sustainable Bioenergy Challenge Grant*** – Fund regional technology development efforts
- ***USDA NIFA/USDOE Biomass Research and Development Initiative*** – Fund regional technology development efforts
- ***US DOE EERE Office of Biomass*** – Fund regional technology efforts
- ***Local fuel and allied product manufactures*** – Partner in research with public agencies and universities

Key Recommendation: Build a demonstration project aimed at proving the feasibility of a commercial biorefinery

- Build a consortium involving regional public universities, industry, DOD and state governments to explore development of a demonstration biorefinery.
- Upgrade biomass assessments by states, the Western Governors Association and the federal government to identify prospective biorefinery sites in areas with diverse feedstock supplies. Model a reliable supply chain built on multiple feedstocks.
- Build early markets with long-term contracts to supply fuel to commercial aviation and U.S. military branches in order to draw private financing to the project. Issue a Request For Information seeking proposals for bioprocessing technology developments that could generate products from Northwest feedstocks to supply Northwest military facilities.
- Seek federal funding from agencies including USDA Bioenergy Program for Advanced Biofuels, USDA Biorefinery Assistance Program, DOE/USDA Biomass Research and Development Initiative, and DOE EERE Office of Biomass.
- Urge the USDA Biorefinery Assistance Program to increase funding for loan guarantees and increase coverage from the current 80 percent to 90 percent, and specify that “rural” targeting of the program means 75 percent or more of consumables are derived from rural purchases (in order to allow co-location at urban refinery sites).

- Urge federal agencies to identify priority technology investments and create a coherent strategy that links bench, pilot, demonstration and commercial development, thus eliminating the financial "valley of death."
- Contracts and funding should specify performance-based sustainability criteria.

Key Players:

- ***Public universities*** – Build on research efforts to create biorefinery development partnerships with other institutions.
- ***State natural resources, environmental and energy agencies*** – Assess infrastructure and workforce needs, as well as available state physical and financial resources.
- ***Federal funding agencies*** including USDA Bioenergy Program for Advanced Biofuels, USDA Biorefinery Assistance Program DOE/USDA Biomass Research and Development Initiative, DOE EERE Office of Biomass – Provide loan guarantees and capital support for biorefinery development.
- ***Western Governors Association*** – Supply information on biomass availability and potential locations based on WGA research.
- ***Industries including biofuels, wood products and petrochemicals*** – Explore biorefinery development opportunities and partnerships with public agencies and universities.
- ***Forest landowners, including family forest owners, and Indian tribes in the region*** – Explore opportunities to supply feedstocks and plant sites.
- ***Customers including airlines and U.S. Department of Defense, Defense Logistics Agency-Energy*** – Provide agreements to purchase fuels.
- ***Local communities*** – Offer prospective plant sites. Work with public and private partners on siting.
- ***Environmental groups*** – Work in biorefinery development partnerships to assist in development of appropriate sustainability criteria.

"Hat in camelina field"
Credit: The Camelina Company

Feedstocks: Oilseeds

BASICS

SAFN identifies oilseed crops as a strong near-term opportunity to build a sustainable aviation fuel supply chain because of the dynamics of fuel approval covered in chapters above. One federal agency estimate projects a potential for 180 million gallons of oilseed based biofuels production in the Northwest by 2022.[104] The primary challenge is economic, creating incentives and markets to provide economically attractive returns for farmers.

Lipids, natural oils derived from oilseeds, tallow, or algae, are high energy density feedstocks easily converted to petroleum fuel substitutes. As this is written, a biofuel from lipids for jet fuel produced with hydroprocessing technology is nearing ASTM approval. (Jet fuel produced from biomass processed through Fisher-Tropsch technology is also approved. While there are no current proposals to build FT plants in the Northwest, there are at least two active efforts to develop hydroprocessing plants.)

> This chapter deals with the requirements to more broadly establish oilseed crops in Northwest states to feed a hydroprocessing supply chain. It primarily focuses on a promising Northwest oilseed opportunity now being used in biojet test flights, Camelina sativa.

Cultivated in Eastern Europe for over 2,000 years, this ancient crop has had little research or development attention until recently, when it was identified as a stress-tolerant, adaptable, short-season annual oilseed producing industrial-grade oil and meal for livestock feed. Camelina has significant potential as well as significant need for improvement in terms of variety development, better agronomic practices, and supportive production inputs and policy to place it on a level playing field with existing crop alternatives.

Oilseeds are well established in the prairies of the U.S. and Canadian Midwest. But higher temperatures and stresses in the Northwest have posed obstacles to mass oilseed cultivation in the region. Camelina is attractive because, compared to other oilseeds, it possesses high frost tolerance as a seedling, lower impacts of high temperatures on seed yield during flowering, and broad adaptation to seeding in fall, winter or spring. These attributes, plus the fact food markets do not compete for camelina's industrial-grade oil, have made it an attractive crop candidate for aviation fuel and garnered both public and private sector investment.

Some SAFN stakeholders have singled out other brassica oilseed crops closely related to camelina as alternatives, including canola, rapeseed and mustard. These crops already have a global commercial research effort behind them and are highly improved for many growing regions. Oilseeds such as canola have some history in the Northwest. A summary of their potential can be found in a sidebar within this chapter. These and other potentially adapted oilseeds could represent a profitable economic option for farmers in regions with favorable temperature and moisture profiles. Researchers and farmers together must explore the options.

Camelina currently produces a seed with 29-42 percent oil content that can be grown in rotation with dryland wheat. The oil is not approved for food use by the U.S. Food and Drug Administration, and has

[104] "A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022." USDA, 23 June 2010.

unusual properties with both high n-3 fatty acids as well as presence of vegetable-based cholesterol. Genetic selection and breeding new varieties would be necessary to improve the oil to match the expectations for quality of a modern food ingredient. In contrast, camelina oil's properties for industrial uses – such as a biofuel feedstock – are sufficient in current varieties.

In the Northwest, camelina is typically cultivated as a summer annual crop grown in rotation with dryland winter wheat.[105] Wheat, in the drier portions of the region, is produced in rotation with fallow – a season with no planted crop – to accumulate soil moisture, mineralize soil nutrients, and break up pest/disease cycles. An appropriate inclusion of camelina in wheat rotations could improve agricultural sustainability. Using tillage to control weeds during the fallow period leaves little surface residue. Uncovered soils are subject to wind erosion and increased loss of moisture to evaporation. Over the past several decades, a "chem" fallow year has become widespread with the advent of low-cost broad spectrum herbicides and no-tillage practices. An alternative long studied has been the concept of a managed "green" fallow that uses available moisture, provides cover to reduce erosion, fixes carbon and retains mobile soil nutrients. The presence of a living crop plant will improve the biological, and hence, chemical and physical properties of the soil. But farmers need an economic incentive to plant cover crops. Markets for sustainable aviation fuel from oilseed crops could provide such an incentive.

An oilseed rotation uses moisture that would otherwise be lost to evaporation. While fallowing is useful in stabilizing wheat yield, only about one-third of precipitation that falls during fallow is ultimately available to the subsequent wheat crop.[106] Camelina shifts water and nutrient loss from fallow to plant uptake/transpiration. Oilseeds also diversify wheat monocultures, breaking up pest and disease cycles and thus reducing pesticide use. For example, Montana farmers are facing challenges from the stem wheat sawfly. A camelina rotation can disrupt their breeding cycles.

Camelina is attractive because it matures in 85-100 days, is tolerant of freezing conditions as a young seedling, and uses existing farm equipment. The main inputs for camelina are fertilizers and herbicides. Camelina responds to fertilizer applications, but economic and environmental guidelines are in development. At least three years of data on responses to nitrogen fertilization in the four Northwest states have been collected by university and USDA scientists. Fertilization decisions are made by the growers themselves based on the economics of balancing fertilizer costs and diminishing returns of using more than required by the crop. Among results, presented for illustrative purposes, are Montana field trials showing yield response for up to 50 pounds/acre nitrogen and 60 pounds/acre phosphorus. Grant Jackson of Montana State University reports that camelina requires 80 pounds/acre of available nitrate in the top three feet of soil when the crop is following summer fallow.[107] Camelina aggressively takes up residual nitrogen from previous fertilizer nitrogen applications or decomposing organic matter.

In addition to camelina, a number of other oilseed crops have been developed that are detailed in the table below.[108]

---

[105] Researchers and some farmers have also used fall planting, but most find these crops less consistent in yield while weed control is sometimes more difficult.

[106] Schillinger et al. "Dryland cropping systems in the Western United States." PNW Tillage Handbook Series No. 28.

[107] Unpublished results. http://ag.montana.edu/wtarc/documents/CamelinaFertSummaryTab42and43.pdf

[108] Retrieved on March 18, 2011 from the archives of the NewCROP Resource Online Program at Purdue University.

OILSEED CROPS WITH NORTHWEST GROWING POTENTIAL

	Camelina	Canola	Rapeseed	White or Yellow Mustard	Brown or Oriental mustard	Black mustard	Crambe
Scientific name	*Camelina sativa*	*Brassica rapa, campestris, and napus*	*Brassica rapa, campestris, and napus*	*Brassica alba*	*Brassica juncea*	*Brassica nigra*	*Crambe abyssinica*
Seed yield	600-2,500*	1,500 – 4,000	1,500-3,000	1,000-1,500	1,000-1,500	1,000-1,800	1,000-2,500
Seed oil content	32-42%	40-44%	40-42%	30%	38%	32%	30-32%
Oil production per acre	50-135	80-150	80-140	40-60	50-75	45-75	40-100
Northwest growing history	Studied since 1980's with commercial interest in last five years	Widely commercial-ized for last twenty years	Commercial-ized since 1970's	Limited production and study	Limited production and study	Very limited study	Limited since the 1990's
Agronomic development level	Limited. Only recently have breeding programs and regionally adapted varieties and cropping systems been explored	Well developed with competitive cultivars available for each region. Both spring and winter seeded	Developed, but not as widely as canola (food grade) for the variety and diversity of cultivars available	Limited, but traditional varieties grown as condiment	Limited, but traditional varieties grown as condiment	Very limited	Somewhat developed with some active breeding programs and some on-going commercial production
Typical cropping system	A fallow substitute in wheat rotations	In rotation with wheat as spring or winter seeded, depending upon region	In rotation with wheat as spring or winter seeded, depending upon region	In rotation with wheat and other cereal crops	In rotation with wheat and other cereal crops	In rotation with wheat and other cereal crops	In rotation with wheat and other cereal crops
Agronomic Promise	Relative drought and stress tolerance, adaptation over wide region with spring and winter seeded types	The most widely grown and supported temperate brassica oilseed, with increasing stress tolerance in new varieties. Susceptible to heat and drought	The crop from which canola (the food grade oil and low glucosinolate meal variant) was bred was developed in	Less stress tolerant than well adapted new canola/rapeseed cultivars.	Less stress tolerant than well adapted new canola/rapeseed cultivars. Shattering can be problem	Some evidence of greater stress tolerance than other mustard types	Yield potential but also disease susceptibility in the more humid regions of Northwest. Also, shattering can be problem. Good tolerance of many insect pests

*see table on camelina/brassica yields from various Northwest regions.

Photo Credit: WSU

	Camelina	Canola	Rapeseed	White or Yellow Mustard	Brown or Oriental mustard	Black mustard	Crambe
Competing markets	Oil not approved by FDA for food uses	Food grade oil	High-erucic acid oil for slip agents and other industrial uses	Food market as a condiment	Food market as a condiment	n/a	High-erucic acid oil for slip agents and other industrial uses
Coproduct potential	Meal only with limited approvals due to glucosinolates	Meal widely used and 34% protein	Meal high in glucosinolates has limits on inclusion in rations	Table mustard and mustard products	Table mustard and mustard products	n/a	30% protein meal with limited use in rations due to glucosinolates
Federal support	Limited	Yes	Yes	Yes	Yes	Yes	Yes

	Cuphea	Meadowfoam	Safflower	Sunflower
	Cuphea spp.(many)	*Limnanthes* spp.	*Carthamus tinctorius*	*Helianthus annus*
Seed yield, lbs/acre	350-1,000 in research trials.	Up to 1,750 with 750-1,500 expected in western OR	Up to 2,000-2,500 with much of Northwest in 1,000-1,500 range	Up to 3,000 with much of Northwest in 1,500-2,000 range
Seed oil content, %	25%	24-30%	32-52% with 40% typical in Northwest	40-48% with 42% expected in Northwest
Expected Northwest oil production, gallons/acre	16-20	25-50	50-80	80-110
Northwest growing history	Research in Northwest since 1980's.	Research since 1960's in Willamette Valley	Since 1970's, commercially in eastern part of region (MT)	Since 1970's but limited commercial production
Agronomic development level	Very limited. Needs further domestication for commercial production and mechanization.	Limited. Native to CA Sierra foothills, Willamette Valley been site of most development. Several cultivars produced.	Developed and commercial cultivars and production in eastern part of region	Advanced with competitive cultivar development and commercial production in Great Plains
Typical cropping system	Unknown	Valuable in rotation with grass seed crops in Willamette Valley conditions.	Grown in rotation with cereal grains. In drier regions, reduces potential of following wheat crop.	Grown in rotation with cereal grains. In drier regions, reduces potential of following wheat crop.

	Cuphea	Meadowfoam	Safflower	Sunflower
	Cuphea spp.(many)	*Limnanthes* spp.	*Carthamus tinctorius*	*Helianthus annus*
Agronomic Promise	Need further breeding and domestication to prevent shattering and other undesirable traits. Valuable property is unique oil of medium chain lengths (C8,10,12).	Limited adaptation and yield potential. Value is in unique oil properties high in long chained fatty acids (>C18).	Drought and temperature tolerant, deep tap root mines nutrients and water. Many cultivars disease susceptible without dry conditions.	Drought and temperature tolerant (less so than safflower, however), deep tap root mines nutrients and water
Competing markets	Tropical medium chain length oils and meal.	Unique industrial uses.	Food grade oil, feed meal	Food grade oil, feed meal
Co-product potential	Unique medical and industrial uses.	Oil and meal derivatives and high value products.	Meal accepted in most feed markets, ~20-24% protein with hulls included.	Meal accepted in most feed markets, ~28% protein with hulls included.
Federal support	No	No	Yes	Yes

RESOURCE POTENTIAL AND ECONOMICS

WSU scientists estimate that 100 percent adoption of oilseed rotation on dryland wheat acreage in the four Northwest states would theoretically produce 233 million gallons of raw oil from oilseeds at current yields.[109] Of course, actual adoption rates will be lower. A USDA roadmap projects 180 million gallons of oilseeds-based biofuels production in the Northwest by 2022.[110] As noted below, significant yield improvements are important to making camelina an economically viable and scalable source of jet fuel. The capacity, of course, is directly proportional to the yields from land under cultivation.

POTENTIAL CAMELINA/BRASSICA OIL PRODUCTION IN DRY LAND CROPPING REGIONS OF THE PNW

Region	Acres	Years in Rotation	Current Yields /Acre	Ann. Production
Inland PNW low rainfall	3.8M	1 in 3 = 1.27M	600 lbs.	762M lbs.
Inland PNW intermediate	2.4M	1 in 3 = 0.8M	1300 lbs.	1040M lbs.
Inland PNW high rainfall	2.0M	1 in 3 = 0.67M	2000 lbs.	1340M lbs.
Intermountain region	2.0M	1 in 3 = 0.67M	1300 lbs.	870M lbs.
Montana*	8.8M	1 in 3 = 2.93M	700 lbs.	2053M lbs.
			TOTAL:	6065 M lbs. ~ 233 M gallons**

*** Dry land acres not planted to hay or pasture, or currently enrolled in CRP**

**** Gallons based on 36% oil content; 80% pressing efficiency (cold), 7.5 lbs. oil/gallon**

Credit: Scot Hulbert, Washington State University

The primary challenge to establishing significant Northwest oilseed production is to create markets that provide economically attractive returns for farmers. Sustainable Oils reports paying $0.145 per pound of camelina seed over the 2010 season to meet contracts with the Department of Defense for test flight fuel. While recent canola prices have ranged in the 24 cents/pound area, this is in a commodity market framework. Scott Johnson with Sustainable Oils notes that camelina is being developed through forward contracts with a price guarantee, reducing risks in a way that allows farmers to take lower returns.

Current crop commodity prices are at or near historic highs. Net return for wheat production is currently around $150/acre in Montana and around $200/acre in Washington, Oregon and Idaho.[111] Net return from oilseed production must either provide competitive returns, or provide farmers with other benefits. For example, substituting a crop for fallow generates returns that would not otherwise have been made, while reducing herbicide and equipment use costs associated with fallow. Camelina industry stakeholders

[109] Scot Hulbert, Washington State University.

[110] "A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022." USDA, 23 June 2010.

[111] Data on costs of wheat production in the Basin/Range (WA, ID, OR, western MT) and Northern Great Plains (eastern MT) were retrieved on May 5, 2011 from "Recent Costs and Returns, United States and ERS Farm Resource Regions, New Format and Regions." USDA ERS Commodity Costs and Returns.

also maintain that the opportunity to break up pest and disease cycles noted above will draw farmers to oilseed cultivation.

The camelina market is attracting early adopter farmers who want to gain crop-growing experience. One example is Richard Barber of central Montana, who has planted camelina for three rotations. In 2010, he made a profit for the first time, but not enough to compete against other options such as peas and lentils. Barber provides these figures, underscoring the vital role of yield in meeting economic challenges:

- Per/acre expenses…………..$94.85
- Per/acre gross…………….......$144.00 @ 993 lbs/acre (three years average 700 lbs/acre)
- Per/acre net…………….........$49.15
- Competitive per/acre net…$150.00

  @ $0.145 requires 1,700/lbs./acre

  @ 993/lbs/acre, requires $0.25/pound.[112]

Yield improvements on this order are well within reach, Integration of DNA markers with conventional plant breeding has enormous potential to improve oil content and seed yield. This is not a genetically modified organism approach, but instead a selection approach that identifies high-potential strains.

The Sun Grant Initiative has supported three years of trials, including plots at Corvallis and Pendleton, Oregon; Lind, Washington and Moscow, Idaho. Montana State University Research Center personnel have conducted camelina trials for seven years. Targeted Growth reports that tests under nursery conditions tripled yields from 1,000 to 3,000 pounds/acre. Great Plains - The Camelina Company reports similar yield improvements in its field and university trials, as well as yields over 2,000 pounds/acre by multiple commercial growers. SAFN stakeholders engaged in camelina development consider rapid yield improvements quite feasible.

An overall Northwest average yield of 1,500 pounds/acre is not unreasonable and backed by over 150 site years of data collected mostly within the last five years. USDA-ARS in cooperation with Agricultural Experiment Stations reports the data in the table below:

NORTHWEST OILSEED YIELD - POUNDS PER ACRE[113]

	Spring Canola	Spring Rapeseed	Spring Camelina
Washington	1,725	1,348	1,953
Oregon	1,094	829	1,636
Idaho	2,211	2,002	1,551
Montana	1,255	NA	1,600

Credit: USDA-Agricultural Research Service

[112] Richard Barber comments to Farm-to-Fly Initiative meeting, Everett, Washington, 28 Oct. 2010.
[113] Compiled from Agricultural Experiment Station and USDA-ARS replicated field plot data summarized by Brenton Sharratt (WA, ID, OR) and Andy Lenssen (MT). All data collected between 2001-2010.

SAFN's biofuels industry stakeholders believe it would be difficult to produce fuel for wholesale prices of $2-$3/gallon at crop prices in the range of $0.145-$0.25/pound. This suggests that yield improvements and improved agronomic knowledge will be vital to lowering costs. At the same time, a trend for higher petroleum prices is pushing overall fuel prices higher, and camelina industry stakeholders believe that their model of forward contracting will prevent camelina prices from moving fully in tandem with petroleum. So cost profiles could converge.

SAFN worked with Targeted Growth, Sustainable Oils and Honeywell UOP to obtain cost estimates for producing fuel from camelina, based on the partnered companies' extensive analysis work. Figures are based on an idealized scenario in which local crushing capacity has been built and animal meal markets have been fully developed. The following results were obtained:

- Based on Sustainable Oils $0. 145/pound offering price
- Add $0.04/pound freight
- Add $0.04/pound crushing
- Total $0.225/pound
- Deduct $0.10/pound for meal sales on 60 percent of weight
- Net cost of raw vegetable oil $0.165/pound
- Typical cold press yield, 29 percent oil
- At 7.6 pounds/gallon = raw oil at $4.40/gallon
- Hydroprocessing cost = $1.10/gallon of feed oil where majority of product is renewable jet fuel (Actual cost may be $1.10 +/-20 percent depending on on-site cost and availability of hydrogen, feed and product storage, etc.).
- Final fuel price depends on market value of coproducts including Naphtha, renewable diesel and LPG.

Coproducts – A critical strategy to make camelina economically viable involves improving markets for coproducts. Animal feed from meal is a primary opportunity. Seventy percent of oilseed volume by weight is meal (depending upon the oilseed processing technology). A screw-pressed camelina meal contains nearly 40 percent protein and 6-10 percent oil with 2.5-4 percent omega-3 fatty acid, providing potential high-value feed that transmits the heart-healthy fatty acid substance to eggs and meat. A 10 percent camelina portion is approved by the Food and Drug Administration for broiler and laying chickens and feedlot cattle. Approval for dairy cows and aquaculture would dramatically expand the market for the meal.

The high proportion of glucosinolates left in the meal using current camelina varieties, however, may limit feed intake and ability to gain FDA approval for greater proportions of camelina meal. Under some conditions, these substances can influence metabolism, and cause thyroid problems interfering with animal growth, performance and reproduction. Expanding the allowed camelina meal portion of animal feeds will require development of low glucosinolate plant cultivars.

Dry meal has also been found to have some desirability as a soil amendment and could also work as a natural pesticide to control soil diseases, weeds and other pests. Fractionation could produce potentially

valuable co-products including glucosinolates, omega-3 fatty acid oil, lecithin, enzymes, gums and mucilages that bind soils. Meal can also be made into composite fuel pellets. Meal peroxidase activity in combination with low cost hydrogen peroxide can be used to eradicate manure odors and for environmental remediation of toxic aromatic compounds such as creosote and dichlorophenol.

ADDITIONAL CHALLENGES

Agronomics – Camelina is a relatively new crop in North America, so growers and researchers have not optimized management or varieties. Many questions remain about how best to produce camelina economically and sustainably. These questions revolve around optimal planting rates and dates, tillage systems, weed control, harvest methods, and best varieties for different climates. Researchers identify broadleaf weed management in established camelina as one of the greatest limitations for long-term sustainable camelina production systems. Another limitation is the residual activity of some wheat herbicides on camelina, which can prevent successful stand establishment for up to three years. These weed management challenges require additional research. For example, investigations are now underway regarding camelina varieties that would be resistant to herbicides.

Food-Fuel Interactions – One uncertainty is the effect of an oilseed rotation on production of the wheat crop that follows it in a given field. While camelina uses moisture that would otherwise evaporate, it also draws down soil moisture. Fields are allowed time after the camelina crop to rebuild moisture, but if that coincides with a low rainfall period, a recharge deficit could reduce wheat productivity. At the same time, oilseed crops can recycle soil nutrients, making their fertilizing effect more available to subsequent crops. In any event, farmers relying primarily on wheat returns are unlikely to add an oilseed rotation if they perceive it will decrease overall profitability.

"The biggest disadvantage of camelina or any other crop in place of a fallow year is lack of moisture in the fall to get the winter wheat growing before winter sets in," Montana farmer Richard Barber notes. "There can be a reduction in the winter wheat crop several bushels per acre. To overcome the yield loss the camelina crop must be profitable enough to compensate for a possible reduction in winter wheat yield the following year."[114]

The central issue is the allocation of resources among food, feed, fiber, fuel and ecological functionality. While integrating camelina into a wheat-fallow rotation could decrease the amount of wheat produced, it also is likely to increase the system's total productivity. High protein feed from the oilseed meal will offset some meal that is imported from Canada and the Midwest into the Northwest.

Even if diversifying wheat-fallow systems by adding camelina reduces overall food calories, it would make production of those calories more sustainable by conserving soils. The EPA lifecycle study described above is a venue to sort out these questions, since by law it must account for impacts to crop displacement in other areas. An indirect land-use change that displaces winter wheat production elsewhere "is not necessarily a show stopper, just something that needs to be accounted for," SAFN stakeholder Natural Resources Defense Council states.

[114] Richard Barber comments.

Infrastructure – Camelina seed is stable and can be harvested, shipped and stored in the same systems used for wheat. Adequate oilseed crushing facilities are needed and must have enough year-round use to allow for adequate returns on capital investment. Seed will likely be stored and crushed not more than a few months before the oil can be shipped and refined. The Northwest has several small-scale crushers. For example, Willamette Biomass at Rickreal, Oregon, 15 miles west of Salem has been operating since January 2008, and is involved in the camelina market. Its capacity is 120 tons/day. Larger 500-ton/day facilities could provide economies of scale.

"Policies that encourage construction of a large scale hexane crusher, more than any other single event, would drive dramatic increases in Northwest production of camelina and other oilseed crops," says Tom Todaro of Targeted Growth, whose Sustainable Oil subsidiary is contracting regional camelina production.

Typically, the capacity of the oilseed facility is also indicative of the technology used to separate oil and meal. Smaller crushers, processing less than 200 tons/day, typically use mechanical screw presses which at best leave 5-8 percent residual oil in the meal. Larger processors typically use solvent extraction, where oil removal is nearly complete, leaving less than one percent oil in the meal. The relative oil and meal yield and their market values are a necessary part of the supply chain for oilseeds. Proportions will be shaped by crop, oil, and meal economics. Theoretical Northwest production volumes of 6,065 million pounds shown above would require nearly 9,000 tons per day of total crush capacity.

Biorefineries used for biofuel conversion may require the oil to be equal to the oilseed industry food supply chain standard of being "refined and bleached." These additional processing steps would be required after the crude oil is obtained, and may be beyond the capability of smaller oilseed processors.

Refining steps include 1) degumming (commonly with hot water or steam plus some acidic materials), by continuous centrifugation, 2) neutralization with an alkaline solution, and 3) drying to remove traces of water from oil. Bleaching can then be done by adsorption of any color producing substances remaining in the oil (such as chlorophyll, carotene, etc.) through use of an adsorbent material, such as clay.

Farm policy – Camelina is not currently eligible for federal risk management programs including federal crop insurance and price guarantees, creating risks most farmers are unwilling to assume. For example, hail can destroy a crop depending upon timing, and in key growing regions such as Montana this is a significant threat. Other risks include drought, frost, pests, and disease to name a few. One obstacle is the difficulty to assemble actuarial data on yield and production risk before significant crop production has occurred, a classic "chicken-and-egg" problem. Great Plains – The Camelina Company is working with the USDA to remedy this situation. A proposal for camelina crop insurance was provided to the USDA in early 2011.

Climate – Future climate is uncertain and is being affected by changes such as declining mountain snowpack. Many Northwest projections show lower precipitation in summer and higher in winter.[115] The effects on oilseed crops "could swing in different directions, depending on temperatures," WSU scientist Bill Pan says. "If it is warmer and wetter during winter, we could conceivably get more winter soil storage due to less runoff and more infiltration leading to potentially higher yield potentials. If we end up with most of that excess winter water running off, then we will have more severe droughts and lower (oilseed) yields."

[115] Philip W. Mote & Salathé, Eric P. "Future Climate in the Pacific Northwest," Climatic Change. 2010: 102: 29–50.

John King of Great Plains – The Camelina Company, says, “These climate changes will have an impact on all crop production in the Pacific Northwest, and could favor production of moisture-efficient, short-season crops such as camelina. In dry conditions, the moisture efficiency is needed. In wetter conditions, growing seasons could be shorter due to late spring availability of fields, making the short-season nature of camelina valuable.”

Changing precipitation patterns could force alterations in crop rotations. Wheat planting times might move from August to October/November, and the need for longer fallows to recharge soil water might impinge on rotations with camelina. At the same time, reduced rainfall could increase the area where wheat cannot be grown annually because fallow between crops is needed. The increased fallow region could increase the demand for an oilseed crop. Precipitation forecasts vary widely and are highly uncertain, making conclusions about climate impacts on future oilseed production uncertain.

SUSTAINABILITY SCREENING

Greenhouse Gas Emissions – Renewable jet and diesel produced from camelina via hydroprocessing reduces greenhouse gas emissions 80-85 percent relative to equivalent petroleum fuels, according to a Michigan Technological University lifecycle analysis. The study includes agricultural impacts such as nitrogen fertilizer use, but not direct or indirect land use change. Opening up new croplands leads to significant greenhouse gas releases. However, camelina cropping is expected to occur in rotation on existing farm lands during periods when the land would otherwise be fallow.

U.S. Environmental Protection Agency Region 10 is now including land use impacts in lifecycle analysis of canola, camelina and mustard. This will help to determine whether the latter two meet Renewable Fuel Standard 2 (RFS2) requirements for at least 50 percent greenhouse gas reduction required under law. This determination will be needed to obtain Renewable Identification Numbers (RINs), which are critical to the market value. SAFN stakeholders identified this as a vital step to commercialize biofuels from these feedstocks. While aviation is not covered under RFS2, aviation fuels that meet RFS2 standards qualify for RINs.

Local Food Security – See above discussion on food-fuel interactions

Conservation – Oilseed crops may be planted in Conservation Reserve Program lands. On lands deemed arable and suitable for cultivation by Natural Resources Conservation Service classification, suitable cultivation with current conservation cropping practices might occur. Areas critical to biodiversity should be avoided, and riparian buffers maintained.

Soil – Intensifying cropping systems by replacing some fallow with oilseed crops could reduce soil erosion in wheat/fallow rotations in the Northwest. Fertilizer and probably herbicides will be used, but the fallow that would be replaced requires considerable inputs for weed control and seed zone moisture management. These inputs include herbicides and tillage. More frequent cropping should improve the soil quality over a wheat fallow system by adding organic matter.

Water – Oilseed rotations capture water that would otherwise evaporate. It is unlikely that oilseeds would be grown on significant irrigated acreage because of the very high value of food and feed crops that can be grown on irrigated land. Runoff from oilseed fields is highly unlikely to be greater than runoff from fallow fields.

Air – Reduced soil erosion improves local air quality. Wherever the amount of land in conventional wheat fallow rotations is reduced, the amount of soil particulates in the air diminishes.

Use of Technology, Inputs, and Management of Waste – Oilseed crops have similar inputs to spring wheat but less than winter wheat. Some herbicide use is expected but replaces fallow inputs, wither herbicides or extensive tillage using tractor diesel. Grower experience so far has seen little need for fungicides or insecticides.

ACTION "FLIGHT PATH"

Key Recommendation – Improve oilseed crop economics by funding research that improves yields, develops coproducts and validates sustainability

- Fund research on oilseeds at land grant universities and Agricultural Research Service.
- Develop and demonstrate best practices for crop production.
- Research genetic, environmental, and agronomic factors to optimize production across a diversity of Northwest climatic zones.
- Develop improved plant cultivars through conventional and molecular breeding techniques.
- Build practical knowledge on optimization of rotations and production systems.
- Build knowledge on interactions among camelina, wheat, pulse and other rotational crops.
- Develop and gain approval for post-emergent herbicides that can be used with camelina, possibly using current registrations among other crucifers as a guide.
- Develop low glucosinolate cultivars to reduce barriers to a Food and Drug Administration approval for camelina feed use for dairy cattle and aquaculture, and in higher proportions for dairy and feedlot cattle, broiler and laying chickens.
- Support development of coproducts including glucosinolates, biopesticides, enzymes, gums and mucilages.
- Educate growers, industry members and a future work force, including those from underrepresented groups, on best practices for profitable and sustainable oilseed production.

Key Actors:

- ***Northwest land grant colleges*** – Build proposals and collaborative research efforts. Engage growers through Extension Service.
- ***USDA*** – Fund research by land grant universities and the Agricultural Research Service Northwest Regional USDA Biomass Research Center, through the National Institute for Food and Agriculture, to support Agriculture and Food Research Initiative – Sustainable Biomass Research program.

Help validate sustainability of Northwest oilseed crops:

- Complete GHG lifecycle analysis, including direct and indirect land use impacts, in order to gain valuable Renewable Identification Number credits.

- Do lifecycle analysis on water, air and soil impacts of producing oilseed crops.
- Employ mechanistic modeling to evaluate these sustainability criteria.
- Benchmark existing state and federal agricultural regulations to determine how they match with emerging biofuels sustainability protocols.
- Educate growers and agricultural industry players on values of certification under sustainability protocols, such as potential credits for low-carbon aviation fuel under regulatory regimes.

Key Actors:

- ***U.S. Environmental Protection Administration*** – Complete lifecycle analysis of camelina for inclusion in Renewable Fuel Standard 2.
- ***USDA Biomass Research Centers*** – Biophysical/economic modeling, long-term agro-ecological research networks, and carbon flux and greenhouse gas reduction network.
- ***State universities and land-grant colleges*** – Bring resources to bear on lifecycle analysis and grower outreach.
- ***Roundtable on Sustainable Biofuels*** – Benchmark certification standards against current crop practices and regulations. Educate growers on the value of certification.
- ***Wheat grower organizations*** – Work with Extension and other engaged parties to educate growers on oilseed growing opportunities.

Key Recommendation: Reduce grower risks in establishing a new crop and improve incentives by providing tools available to other crops

Implement administrative actions:

- Add camelina to the list of crops specifically eligible for marketing loans and loan deficiency payment programs administered by the Commodity Credit Corporation (canola is already listed). This will allow farmers to plant crops as collateral and sell when market conditions are favorable.
- Create a PNW pilot program to provide crop insurance against production and revenue losses for camelina in advance of actuarial data.
- Specify that oilseed acreage will not be deducted from acres eligible for wheat commodity program supports.
- Evaluate the potential for shifting a portion of Conservation Reserve Program (CRP) acreage into dedicated bioenergy cropping when contracts with farmers expire.
- Approve crop insurance program for camelina.

- Ensure continued support of the Biomass Crop Assistance Program (BCAP) established under the 2008 Farm Bill for camelina, or develop NW regional version of BCAP specific to camelina production. [116]

Key Actors:

- ***USDA Farm Service Agency*** – Build crop support programs for camelina including crop insurance and credit.
- ***USDA Rural Development*** – Provide grants, loans and loan guarantees to projects that build oilseed market infrastructure.
- ***USDA Risk Management Agency*** – Build risk management profiles for camelina and other oilseeds.
- ***USDA Natural Resources Conservation Service*** – Identify areas where oilseed production can fit into lands where CRP contracts are expiring.

Key Recommendation: State governments should support crushing facilities

- Identify appropriate scale and locations for oilseed crushing facilities.
- Provide support for oilseed crushing facilities in terms of tax incentives and capital support, with support conditioned on performance-based sustainability criteria.
- Identify whether seasonal use of crushing facilities can support an adequate return on capital investment.

[116] It should be noted that one stakeholder expressed significant concerns with BCAP. Though the program could help support aviation biofuel production, it currently lacks the kind of environmental safeguards that are discussed in this report. In addition, the stakeholder believes that its administration by USDA is not currently well-designed to promote the advanced biofuels Congress adopted it to stimulate. Furthermore, the stakeholder is concerned that most BCAP funding has been directed to collection and delivery subsidies for which USDA has performed no environmental effects analysis.

“Woody biomass pile”
Credit: The Weyerhaeuser Company

Feedstocks: Forest Residuals

BASICS

This section discusses the potential to create fuels from waste materials from the region’s largest source of biomass, the forest industry. Aviation fuels could be produced from materials that do not have higher value in standard commercial markets and pose disposal challenges. This discussion focuses on forest residuals, otherwise known as logging slash. Another related source of forest biomass – thinnings from fire hazard reductions – was discussed but we did not reach stakeholder consensus. Some background information on forest thinnings is presented in Appendix 2.

The production of fuels and chemicals from forest residuals employs the conversion technologies already described for lignocellulosic biomass. Developing these conversion technologies will potentially allow production of fuels from forest, farms and urban waste streams as well as other potential feedstocks, such as mill residuals, hybrid poplars, and agricultural field residues.

It is important to note, however, that some of the liveliest discussions among SAFN stakeholders centered on the sustainability of forest biomass use for energy and fuel production and the appropriate approaches to validate sustainability in practice. This is one area where consensus proved most challenging. Proponents developing supply chains for aviation and other fuels from forests should be aware of the wide range of stakeholder views over proposals to increase use of forest biomass for energy.

Forest residuals constitute mainly tree limbs, tops, small or broken logs, and other wood that remains after merchantable timber is harvested. The residuals are typically left piled up at landings, where yarding operations prepare logs for loading by cutting them up and shaving off branches. Slash also includes foliage, bark and rotten logs, and represents around 20-30 percent of above-ground biomass cut in a typical Northwest logging operation.[117] Residuals are typically left on site to decompose or are burned.

Another potential residuals stream emerges at mills in material remaining from processing saw logs. But 95 percent of that material is currently used to generate electricity and heat for plant operations, and to provide raw material for pulp and paper operations.[118] SAFN forest industry stakeholders confirmed that liquid fuel markets will need to pay competitive prices for this raw material. Further analysis would be needed to understand whether this would translate into competitive costs for biofuels. At this point, most industry stakeholders believe that liquid fuels are likely to have difficulties competing for sawmill residuals. However, one forest industry stakeholder observed that changes in the regional pulp and paper industry could prospectively open the way for fuels as the highest and best use for these residuals in specific geographical areas. Sawmill residuals should be evaluated as a potential feedstock for supply chains addressing forest residues, and may provide some supplemental materials to biofuels plants.

---

[117] C. Larry Mason . “Wood to Energy in Washington: Imperatives, Opportunities, and Obstacles to Progress.” University of Washington , Seattle, WA. June 2009: pg. 66.
[118] Yoder, pg. 57.

OTHER FEEDSTOCKS

While SAFN has focused on four primary feedstocks that were identified as most promising in the stakeholder process, there is an array of other materials that may become important for fuel production. The list is by no means exclusive. Other feedstocks with the greatest amount of stakeholder interest and support include:

AGRICULTURAL FIELD RESIDUES

Straw left from harvesting cereal and grass seed crops represents a potentially large regional feedstock for advanced biofuel production through lignocellulosic technologies. The quantity of straw available for removal from a field is highly sensitive to the amount that must be left to ensure long-term sustainable crop production.

A study by USDA scientists finds 6.5 million metric tons annually available in Idaho, Oregon and Montana after sufficient straw is left on the soil to maintain carbon and nutrients. The study employed county-based criteria set by the Natural Resources Conservation Service. Average residue was 4,480 kilograms/hectare. However, the researchers note that the material is distributed at a fairly low density "and in many locations will require small- or local-scale technology to enable economical conversion of the feedstock to energy."[119]

WSU researchers found that it may cost farmers $13.48/acre to replace nitrogen, potassium, phosphorus and sulfur removed with one ton of wheat straw.[120] But biochemical conversion processes can create a high-value soil amendment that allows for carbon and nutrients to be returned to the soil. Thermal processes produce ash, which can be used as a soil amendment to recycle nutrients and carbon to soils where crop residues have been removed.

PERENNIAL GRASSES

While high yields for perennial grasses such as switchgrass and arundo donax have been observed on USDA Agricultural Research Service test plots in the Columbia Basin, some experts believe that high yield cultivation may require irrigation in the region. Where irrigation is needed, food crops would likely provide higher value uses for the land and water. Arundo donax has a reputation as an invasive species, although some developers believe these challenges can be overcome. One intriguing possibility is giant miscanthus. A study reported in *Science* finds that western Oregon and Washington, uniquely in the continental western U.S., could grow the crop.[121] Yields upwards of 17.8 tons/acre were projected in the modeling study, "mostly due to the availability of rainfall," researcher Chris Somerville says. The team did not model irrigated production. The study concluded: "We are doubtful that irrigation of energy crops would be economically or environmentally feasible, except possibly during the establishment phase while the roots are short."[122] The sterile hybrid for giant miscanthus is less likely to have invasiveness issues.

HYBRID POPLAR

The Northwest currently grows approximately 100,000 acres of hybrid poplar from southern Oregon to British Columbia.[123] Plantations can reach high yields in eight years. Green Wood

[119] Gary M. Banewetz et al. "Assessment of straw biomass feedstock resources in the Pacific Northwest." Biomass & Bioenergy, 32 2008: pp. 629– 634.
[120] Dave Huggins. "Harvesting Wheat Straw: Trade-offs among Bio-energy, Soil Quality, and Nutrient Removal." USDA-ARS, Pullman, WA. 2008.
[121] Chris Somerville et al. "Feedstocks for Lignocellulosic Biofuels, *Science*." 13 Aug. 2010: Vol. 329, pp. 790-792.
[122] Personal communication, Chris Somerville.
[123] Jon D. Johnson and Gorden Ekuan. Hybrid Poplar Research Program. Washington State University. Viewed 22 March 2011.

Resources operates a 17,000-acre plantation on irrigated farm lands near Boardman, Oregon. Zeachem is constructing a 250,000 gallon/year pilot ethanol biorefinery in Boardman, Oregon.[124] Zeachem intends to use poplar as its primary feedstock. Zeachem ultimately hopes to construct a number of 25 million gallon/year plants that rely on poplar.

Currently, poplar has highly competitive markets as a raw material for pulp and paper, fiber board, cabinetry and trimmings. At an estimated $58/ton cost for farming and harvesting, poplar is a high-cost feedstock for fuels. Residuals from these uses can be used for energy production, including advanced fuels. The few existing poplar plantations large enough to supply residuals can provide up to 50 percent of the required feedstock for a moderate sized biorefinery, according to Jake Eaton with Green Wood.

Eaton adds, "Alternatively, there are opportunities to grow dedicated poplar energy plantations to produce feedstock for liquid fuel biorefineries. Our analysis shows that purpose-grown feedstock can be competitive with forest thinning and slash removals, and can provide a sustainable feedstock that is of higher quality than existing forest residuals."[125] Green Wood estimates that the region has 600,000-1.2 million acres appropriate for cultivation that would not compete for food and feed crops.

Forest seed orchards and tree genetics programs are very advanced in the Northwest representing an immediate opportunity via tree breeding programs to significantly increase biomass yields per acre. The lignin content of poplars poses challenges. Biochemical technologies must separate lignin in order to process sugars from the remainder of the tree. A team at WSU led by Dr. Norman Lewis is developing low-lignin poplar varieties that might be more appropriate for energy production. These varieties are genetically modified and will require careful attention to public and regulatory concerns before any commercial production. Other scientists at WSU lead by Dr. Birgitte Ahring have developed technology converting lignin into hydrolysates, jet fuel precursors.

Poplar may have promising long-term potential for sustainable energy use, particularly with development of new varieties. "While the best use of this material will probably still be found in the structural materials or pulping market, production of hybrid poplars as a source of biomass for biofuels warrants careful study and continued support of research that could improve the productivity and overall economics of producing biofuels," the Pacific Northwest National Laboratory concludes.[126]

SUGAR BEETS

The Northwest has grown significant quantities of sugar beets in the past for food markets. Washington once grew 4 - 7 percent of U.S. production, while Idaho produced 14 percent as of 2008. While beets could feed ethanol plants, WSU researchers have concluded that this is unlikely due to competition from more valuable crops on irrigated lands, high production costs and transportation disadvantages. Even if beet production increased, these researchers believe that food markets might still outcompete fuel demands.[127]

---

[124] C. Larry Mason, pg. 69.
[125] Personal Communication, Jake Eaton, 2011.
[126] Stiles, pg. 58.
[127] Yoder, pp. 46-47.

RESOURCE POTENTIAL AND ECONOMICS

Assessment – A wide range of studies have been done on the extent of biomass that can be sustainably collected from Northwest forests, but stakeholders do not agree on the use of any single report. Pacific Northwest National Laboratory's (PNNL) business case assessment of regional biofuels potentials quotes a 2001 WSU Energy Program study as "the most comprehensive region-wide analysis of realistically available harvest residue. . ."[128] The study has limited sustainability filters that include harvests of material on slopes with an angle of no more than 35 degrees, on lands located 500 feet or less from a road. With those limitations in mind, the results of the study provide a first-order approximation of the potentials.

The WSU study shows 1,522,496 bone dry tons economically deliverable to Northwest central plant locations at $80/bone dry ton and under.[129] The results are shown in the table below. Based on lab test data from WSU's Bioproducts Science and Engineering Laboratory, we used a figure of 72 biojet gallons/bone dry ton biomass.[130] That would translate into nearly 1.1 billion gallons of biojet production annually from forest residuals.

It is important to note that stakeholders have a wide range of views regarding the amount of forest biomass that can be sustainably and economically collected for fuel. We did not reach consensus on these issues and recommend more analysis as this pathway is developed. Ultimately, any actual production will be conditioned on meeting sustainability and commercial criteria.

ANNUAL FOREST RESIDUALS AVAILABLE AT UP TO $80/BONE DRY TON

LOCATION	TONNAGE
Aberdeen, WA	299,400
Springfield, OR	295,161
Roseburg, OR	286,514
Sandpoint, ID	284,091
Tacoma, WA	178,489
Everett, WA	101,750
Port Angeles, WA	77,091

Credit: Washington State University Energy Program

ADDITIONAL CHALLENGES

Assessing Sustainability of Forest Biomass

Several Northwest states have adopted and updated forest practices rules with extensive input from industry and the public in response to concerns about sustainability of forest harvests and specific issues including protection of endangered fish and bird species, critical habitats, and other issues. These rules result in substantial biomass being left at a logging site.

[130] Personal Communication, Birgitte Ahring, WSU Bioproducts Science and Engineering Laboratory.

SAFN stakeholders have a wide range of views regarding the adequacy of current forest practices rules to address sustainability concerns regarding energy production from forest ecosystems, or whether updates to those rules or additional protections (such as third party certification) will be needed. Some stakeholders believe that current Northwest state rules are among the most protective for forest habitats and are sufficient to address current and future energy uses; others believe that these rules need to be updated to address added demands created by markets for electrical generation and liquid fuels. Stakeholders similarly hold a wide range of views regarding the applicability or adequacy of existing certification regimes for the forest practice industry, including the Forest Stewardship Council and Sustainable Forest Initiative.

One potential tool to inform future discussions involves comparing international sustainability protocols, such as those developed by the Roundtable on Sustainable Biofuels (RSB), against existing forest practices rules. This "benchmarking" could potentially be used to compare sector-specific certification methods offered by groups such as the Forest Stewardship Council and Sustainable Forest Initiative, and biofuel certification approaches from the RSB or others. Benchmarking can be used to analyze how far rules and certification go in enabling producers to meet biofuels production targets and sustainability standards, and to identify further actions to help address concerns.

SAFN stakeholders emphasized that clear standards and streamlined approaches to validate sustainability are needed to keep costs manageable. Generally, forest biomass available for energy markets will have lower economic value than other wood products. Since most sustainability concerns involve the overall management of forest lands, these stakeholders emphasized that it is important to integrate efforts to validate sustainability of energy production from forest lands in tandem with other uses. Stand-alone approaches that require separate certification or analysis for biofuel production and impose costly new requirements are unlikely to be cost-effective for forest landowners and biofuel producers. "Given the low economic value of biofuel feedstocks and their status as co-products or waste, I believe that producers will hesitate to take on new sustainability standards," notes George Weyerhaeuser of Houghton Cascade.

Another issue that provoked considerable discussion was the separate regulatory requirements that apply to federal forest lands. Under current law, for example, biomass from federal forest lands is not eligible for Renewable Fuel Standard 2 credits for advanced biofuels. This poses an economic obstacle to development of advanced biofuels from federal forest feedstocks. Views vary widely regarding the appropriateness of this exclusion and the importance of federal lands. Because of the uncertainties in relying on federal forest biomass, Green Diamond's Mike Pruett expects it will represent 10 percent or less of feedstocks entering a forest-based biofuels plant. More work will be needed to the extent that future proposals for aviation fuels envision using significant quantities of biomass from federal lands.

Logistics – Collection and delivery of diffuse, bulky forest biomass with typical moisture content of 50 percent represents a major economic challenge in deriving energy from forest biomass. A delivery radius around a biorefinery of one hour, representing a 50-mile distance, has been identified as the practical limit for the economical transportation of forest residues –unless on-site densification technologies can be cost-effectively deployed. Idaho National Lab researchers conclude that typical delivery costs to a biorefinery within a 50-mile radius would be $20.50/bdt for residuals.[131] The breakdown is shown in the following tables:

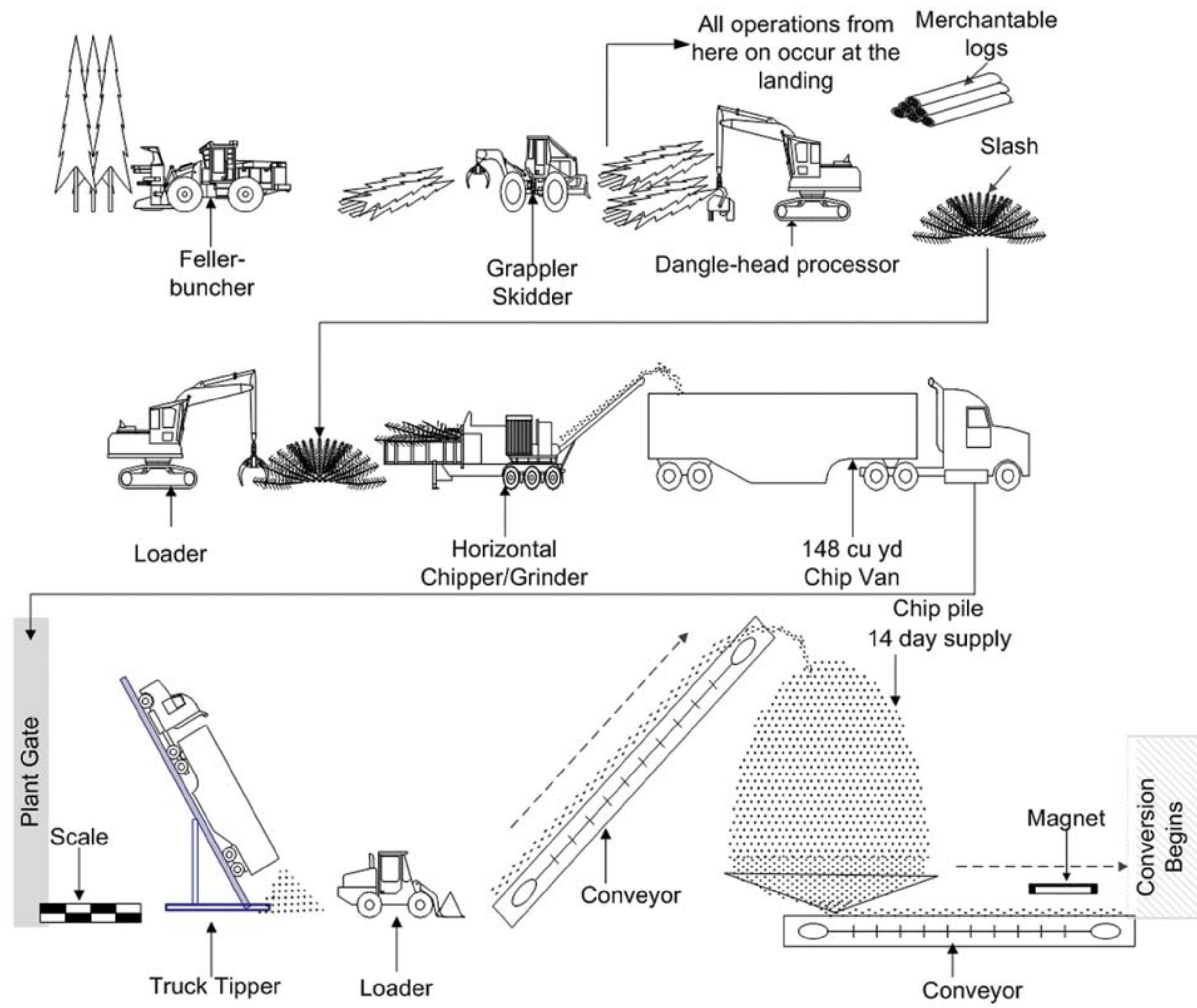
[131] D. Brad Blackwelder and Erin Wilkerson. "Technical Memorandum, Supply System Costs of Slash, Forest Thinnings, and Commercial Energy Wood Crops." Idaho National Laboratory. Oak Ridge National Laboratory, Sept. 2008, TM2008-008-0 (INL/MIS-09-15228).

FIELD OPERATING COSTS							
Slash Harvest, Collection, and Transportation Costs in $/Bone dry tons							
Feller-buncher	Skidder	Processor	Loader	Chipper	120 cu yd Chip Van	Total 2005 $	Total 2007 $
n/a	n/a	n/a	$1.40	$4.77	$10.25	$16.42	$17.75

PLANT OPERATING COSTS						
Receiving and Storage Costs in 2007 $/Bone dry tons						
Scale	Truck Tipper	Conveyor/ Reclaimer	Storage	Magnet	Subtotal	Stump-to-Reactor Cost
n/a	$0.65	$1.32	$0.50	$0.07	$2.75	$17.75=$2.75=$20.50

Credit: Idaho National Laboratory

TYPICAL BIOMASS COLLECTION OPERATION



Credit: Idaho National Laboratory

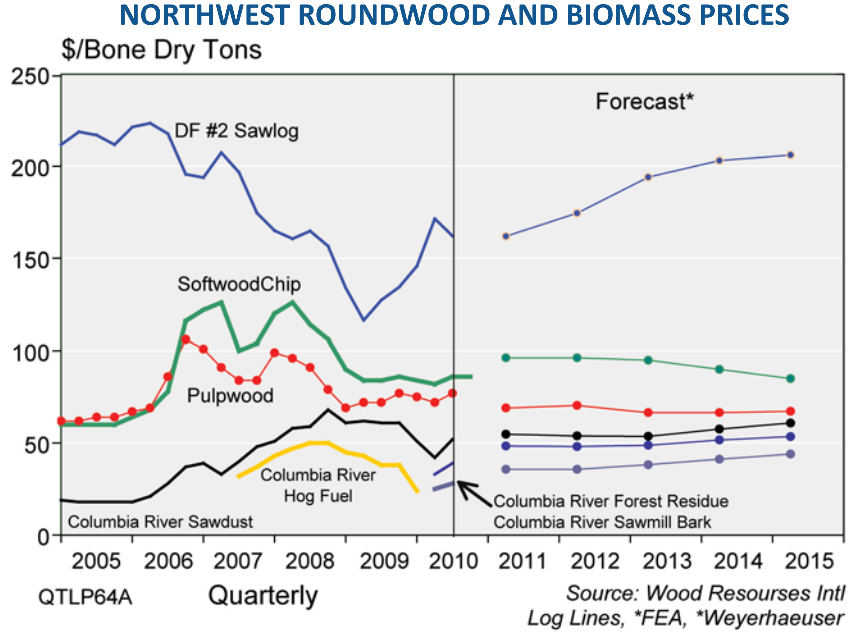
Densification – Current biomass delivery is preceded by chipping on site, as the accompanying graphic depicts. Densification and compaction of biomass is viewed as key to improving economics and expanding delivery ranges. Among technologies under development are:

- **Compaction baling** – Forest Concepts of Auburn, Washington, in 2008 prototyped a baler purpose-designed for woody biomass from forests and farm fields. In development since 2002, the technology addresses problems standard baling systems have in handling low-density biomass.[132]
- **Mobile pelletizers** – Burnaby, British Columbia-based IMG Pellet systems offers a mobile pellet plant transportable in a 20-foot container and powered by its own diesel engine.
- **Mobile pyrolysis** – Container-based units capable of pyrolyzing biomass at logging sites is envisioned as a means to reduce it to transportable liquid form.

"Portable densification and pretreatment technologies are emerging that may hold promise. However, none has been commercially deployed," the UW wood energy assessment states. "The most technically mature alternatives appear to be baling systems and mobile pelletizers. . . ."[133]

Competition with materials markets – Forest products have many well developed markets including building materials, pulp and paper production, and established energy uses for process steam and co-generation of electricity at forest products facilities. These markets typically command higher prices, which markets for liquid biofuels may not be likely to meet, SAFN stakeholders from the forest sector emphasized. The accompanying graph, Northwest Roundwood and Biomass Prices, illustrates this. Prices paid for wood products plant boiler hog fuel are substantially below those of competing uses. Based on stakeholder input and published studies, SAFN concludes that liquid fuels would come from residues with little or no current market value. A different analysis would be needed for projects that propose to use whole mature trees.

NORTHWEST ROUNDWOOD AND BIOMASS PRICES



[132] http://www.forestconcepts.com/index.php?page=11002. Viewed 3 Feb. 2011.
[133] C. Larry Mason, pg. 86.

The UW School of Forestry wood energy assessment, meanwhile, cautions that policies which favor electrical power generation from biomass could "jeopardize the future" of the pulp and paper industry "by creating distorted competition for raw materials." They cite state renewable energy standards and regional carbon market designs that promote electrical energy generation from biomass but do not cover biofuels. It remains unanswered whether "the pulp and paper industry should regard renewable energy as an opportunity or a threat."[134] On the other hand, some stakeholders in that industry indicate that changing economic conditions in the pulp and paper industry may favor greater energy uses of residuals.

Competition with power markets – Liquid fuel markets for forest residuals have a clear competitor in biomass energy generation for electricity. A number of new biopower plants have been proposed for the Northwest. An indication of the impact on forest biomass comes in an assessment from UW's Olympic Natural Resources Center (ONRC). ONRC found 126 megawatts of Olympic Peninsula biopower production proposed at the time of the study that would require 184 thousand bone dry tons annually.[135] Many proposed biopower plants in the region have encountered significant resistance from some environmental and community groups.[136]

In its wood energy assessment, the UW School of Forestry sent a strong statement to the Washington Legislature that biofuels should take priority. "An important finding of this investigation has been that biomass resources are finite and when renewable energy alternatives from potential resources are compared in the context of the three imperatives (climate change mitigation, energy independence and sustainability, liquid fuels emerge as the overarching priority."[137]

"Liquid fuels from wood (and other cellulosic feedstocks) pose the most difficult economic and technical challenges but could in our view deliver the most needed benefits for Washington," the UW wood energy assessment continued. "Biomass is the only resource from which renewable liquid transportation fuels can be made . . . since the greatest gains derive from the most difficult courses of action, clear commitment from state authorities is essential if biomass energy benefits are to be accessed, coordinated and optimized."[138]

SUSTAINABILITY SCREENING

Greenhouse Gases –Available information suggests that using forest residuals for fuel generates lower net emissions than burning them as slash piles or allowing slow decomposition. The Stockholm Environment Institute (SEI) conducted an analysis for the Olympic Region Clean Air Agency regarding emissions from forest slash and residue collection. This study found that displacing fossil fuel use by gathering forest residues at roadside, and converting them to ethanol, reduced net CO_2 equivalent emissions two to three fold,

[134] C. Larry Mason, pg. 85.
[135] John Calhoun et al. "Wood to Energy in Washington: A Second Supply Level Analysis for the Olympic Peninsula." Olympic National Resource Center, University of Washington. Harvesting Clean Energy Presentation, 8 Feb. 2008.
[136] For example, six environmental groups this January sought to block a proposed biopower installation at Nippon Paper Industries in Port Angeles, Washington, by appealing a shoreline development permit. They included No Biomass Burn, Port Townsend Air Watchers, World Temperate Rainforest Network, Olympic Environmental Council, Olympic Forest Coalition and the Washington state chapter of the Sierra Club. Local opposition has also been encountered relating to proposed plants in Port Townsend and Shelton, Washington.
[137] C. Larry Mason, pg. 135.
[138] C. Larry Mason, pg. 109.

compared to leaving them onsite to burn or decompose.[139] The study accounts for transport and processing emissions. SEI examined 15 uses for residuals, none of which were drop-in fuels. The following table shows the results for the most similar uses:[140]

FATE OF BIOMASS	CO_2 EQUIVALENT/Bone Dry Tons
Decomposition	1.6
Combustion	1.8
Ethanol - biochemical	0.53
Ethanol - thermochemical	0.87

Credit: Stockholm Environmental Institute

Some SAFN stakeholders have asked for peer-review of this analysis, and believe further research will be needed to accurately reflect greenhouse gas reductions from forest residue use in fuel production.

Local Food Security – Not relevant

Conservation – If collection of residues does *not* drive economics in a way that increases logging operations, and if biomass removal is *not* greater than what would take place already in operations, then use of this material for fuel would *not* cause new conservation impacts. However, impacts to wildlife and ecosystems will need to be evaluated. This is especially true if fuel economics cause substantial changes in logging and biomass removal. Some available studies are summarized in an appendix.

Soil – Stakeholders have wide and varying views regarding whether slash removal operations are likely to create significant impacts on soils, including soil compaction from equipment operations, nutrient removal, and increased erosion. "The potential environmental outcomes of woody biomass removal are complex and interrelated," says a report by the Oregon State Forester surveying what is known about the effects of forest biomass removal on forest ecosystems. "Effects may be positive, negative or a mix of both," the report says.[141]

Some available studies are reported in Appendix 2.

---

[139] Carrie Lee et al. "Greenhouse gas and air pollutant emissions of alternatives for woody biomass residues." Stockholm Environment Institute for Olympic Region Clean Air Agency, November 2010: pp. 36, 76, 78 – figures reflect carbon dioxide, nitrous oxide, methane. The study does not address the issue of global warming forcing potential of biomass carbon immediately released into the air via fuels use as opposed to slower release via decomposition. But in response to critique of the report, SEI noted "the widely accepted scientific and economic understanding is that climate damages rise more than linearly with CO_2 concentration in the atmosphere. As a result, a ton of CO_2 emitted 20 years from now may in fact produce greater marginal damage than the same ton of CO_2 emitted today . . ." SEI Response to Review and Critique of ORCAA Report, 1 April 2011.

[140] Ibid, pg. 13.

[141] "Environmental Effects of Forest Biomass Removal," Oregon Department of Forestry, Office of State Forester. 1 Dec. 2008.

Water – If biomass removal is increased as a result of fuel demand, the effects in terms of runoff and stream sedimentation must be evaluated. The effects of increased traffic on logging road erosion must also be evaluated.

Air – Net emissions of fine particulate matter (PM 2.5) from burning forest residuals in slash piles is approximately 17 pounds per bone dry ton, compared with very minimal impacts from conversion to biofuels.[142] There are growing concerns in the medical community and regulatory agencies about smaller particles. This suggests that properly managed operations to create fuel from forest residues and minimizing burning of residuals may have positive impacts on air quality.

Use of Technology, Inputs, and Management of Waste – Field operations to densify biomass must meet environmental regulations.

ACTION FLIGHT PATH

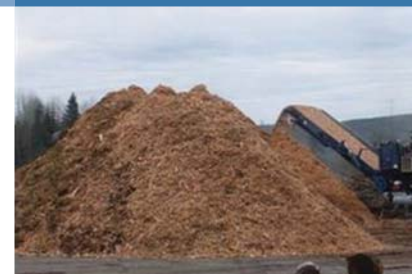
Key Recommendation: Facilitate discussions and analysis regarding the sustainability framework for use of forest biomass to create liquid fuels

- Stakeholder processes involving forest conservation advocates, forest scientists, the forest industry and bioenergy developers should help develop clarity on the impact of bioenergy demand on forest practices, and agreement on the adequacy or need for improvements in current forest practices rules.
- Explore opportunities to benchmark Roundtable on Sustainable Biofuels (RSB) standards against state forest practices rules and existing forest products certification regimes, including standards from the Forest Stewardship Council, Sustainable Forestry Initiative, and the American Tree Farm system. This benchmarking could help participants understand the verification systems potentially available to substantiate claims about the environmental attributes of potential fuel supplies and issues to be determined in establishing a viable certification system. RSB should engage forest industry landowners, environmental groups and other experts in a post-SAFN dialogue to determine what value an additional certification system could add, if any, in the Northwest.

Key Actors:

- ***Aviation industry*** – Explore legal/regulatory and certification systems to determine issues in validating sustainability of renewable fuels.
- ***Forest industry*** – Explore opportunities to direct forest residuals to fuel production. Bring forest industry perspectives to stakeholder discussions.
- ***Biofuels industry*** – Explore forest residuals use in fuels production. Bring industry perspective to stakeholder discussions.
- ***Forest landowners including family forest owners and Indian Tribes*** – Explore opportunities to supply biomass to fuels operations. Bring landowner perspectives to stakeholder discussions on sustainability frameworks.
- ***Universities*** – Provide research basis to inform stakeholder discussions on sustainability frameworks.

[142] Carrie Lee, pg. 16.



- ***Regional and national environmental groups*** – Bring environmental perspectives to stakeholder discussions.
- ***State forest practices boards and natural resources agencies*** – Bring state perspective to stakeholder discussions.
- ***Certification organizations*** – Inform regional dialogues with national and international experience. Explore needs for regional certification system.
- ***U.S. Forest Service and Bureau of Land Management*** – Bring federal forest management agency perspectives to stakeholder discussions.

Key Recommendation: Policies must balance use of limited biomass resources

- State energy planning efforts should take into account the urgent priorities for renewable liquid fuels including economics, energy supply and climate, and build integrated strategies.
- State standards and incentives for liquid fuels should at least parallel those for renewable electricity and should incorporate performance-based sustainability criteria.
- State and regional efforts to cap carbon, including the Western Climate Initiative should promote low-carbon fuels in the electrical and transportation sectors, making sure both are addressed.[143]

Key Actors:

- ***State governors and legislatures*** – Set policy priorities for use of biomass in energy. Make sure standards and incentives are balanced.
- ***State natural resources, environmental and energy agencies*** – Assess the effects of energy plans, standards and policies on biomass energy and recommend pathways for highest and best use.
- ***Western Governors Association*** – Assess state policies to determine if they are balanced and offering proper incentives to transportation.
- ***Western Climate Initiative*** – Address both transportation and electricity in carbon reduction plans and make sure policies are balanced.
- ***Environmental groups*** – Work with public agencies to make sure sustainability is taken into account with use of biomass, and that biomass is prioritized to best uses.

Key Recommendation: Fund technology and workforce development to overcome logistical challenges

- Federal and state funding agencies should provide greater R&D support for efforts to improve biomass collection, processing, delivery and storage at universities, at the Idaho National Laboratory, and at designated USDOE research centers in this area.
- Federal and state workforce development agencies should assess the need for skilled wood industry workers and mount training efforts for “green jobs” in forest bioenergy.

[143] Note that federal law may preempt state and regional efforts to regulate commercial aviation through carbon pricing or caps.

Key Actors:

- ***State workforce development agencies*** – Assess workforce needs and develop programs to meet them.
- ***Community colleges*** – Assess workforce needs and provide training.
- ***Wood industry unions*** – Work with state agencies and community colleges to make sure adequate training programs are put in place.
- ***U.S. Department of Labor*** – Assess workforce needs and develop programs to meet them.
- ***Research institutions*** – Build R&D for biomass collection, processing, delivery and storage.

“Waste at dumpsite”
Credit: Spokane International Airport

Feedstocks: Solid Waste

BASICS

Large waste streams emerge from municipalities and industry. Most go to landfills, even with Northwest leadership advocating to reduce, reuse and recycle materials. The organic portion of solid waste collected by municipalities represents the largest energy opportunity. It includes paper, packaging, yard waste, food waste, construction and demolition debris, and land-clearing debris. Industries such as food processing and pulp and paper also generate large organic waste streams that they handle themselves. (The relation between potential energy uses and recycling/composting programs is discussed below in the policy section.)

Post-consumer plastics also are viewed by some as a potential fuel source, available in landfills and auto wrecking yards. Since plastics are overwhelmingly made from fossil fuels, fuels derived from them would represent a fossil carbon emission, and are not within the scope of this report.

> Systems for hauling and delivering wastes are already in place providing opportunities for co-locating fuels plants at central sites set up for collection, transportation or disposal of wastes.

One of the greatest challenges in developing renewable fuels involves collecting, transporting and storing the large streams of bulky material required. Systems for hauling and delivering wastes are already in place providing opportunities for co-locating fuels plants at central sites set up for collection, transportation or disposal of wastes. As the larger Northwest cities currently transport most of their wastes by rail to landfills east of the mountains, a diversion to local fuels facilities eliminates transportation fuel use and emissions, diminishing competition for rail lines increasingly congested with shipments to and from the ports.

For municipalities and industries, creating a fuel market slows the rate at which landfill space is used. Eighty-five percent of disposal is concentrated at nine landfills, and only a few landfills have permitted capacity beyond this decade. In Washington, for example, 81 percent of permitted-capacity is at Roosevelt Landfill in Klickitat County.[144] Disposal costs are increasing. For example, tipping fees at King County, Washington, transfer stations are $102.50/ton for mixed waste, $82.50/ton for green waste and are expected to keep rising.[145] The LRI Landfill in Pierce County charges $127.73/ton.[146] A waste-based aviation fuel plant being developed in East London by Solena Group will be supported by tipping fees roughly equivalent to the above.

RESOURCE POTENTIAL AND ECONOMICS

Capacity – SAFN did not inventory all Northwest solid waste streams, but accessed reports to validate that a large potential opportunity exists for aviation fuel production.

Studies by WSU and the Washington Department of Ecology, widely regarded as the most comprehensive state-based studies of their kind, finds annual organic municipal solid waste collection in Washington amounts to:

[146] Stiles, pg. 66.
[145] http://your.kingcounty.gov/solidwaste/facilities/disposal-fees.asp
[146] http://www.lrilandfill.com/location_detail.asp?fac_id=2

- 4,141,453 tons total
- 905,408 tons diverted to recycling
- 1,048,518 diverted to composting or energy uses
- 2,187,527 tons landfilled

The study also found another 139,148 tons of food processing waste and 144,375 tons of food packaging waste generated annually.[147] Other industrial waste streams are also large. For example, the pulp and paper industry in 2001 used private landfills for 250,000 tons of organic waste in Oregon, and 300,000 tons in Washington.[148] (Other potential streams including materials currently composted are discussed in the Policy section below.)

Pacific Northwest National Laboratory (PNNL) finds that 1.9 million tons each is sent to the two largest facilities, Roosevelt in Klickitat County, Washington and Columbia Ridge, close to Arlington, Oregon.[149]

PNNL concludes, “It seems that production of liquid transportation fuels would be a higher value use for a significant fraction of the diverted biomass handled by municipalities in Oregon and Washington, perhaps as much as three million tons per year.”[150]

Based on a figure of 72 gallons biojet/ biomass ton from lab scale tests at the Bioproducts Science and Engineering Laboratory, that three million tons would yield 216 million gallons/year of biojet.[151]

Biological processing of wastes by technologies from companies such as Terrabon only can handle the organic portion. Plasma gasification technology like that being installed by S4 Technologies at Columbia Ridge, can process the plastics portion as well. Approximately nine percent of Oregon MSW consists of non-recyclable plastics.[152]

Cost studies – Available studies look at ethanol production. Because ethanol has only 56 percent of the energy density of jet fuel, costs for jet fuel are likely to be significantly higher. These results are presented to provide an initial sense of costs.

A University of Washington MSW-to-fuels study concluded that conversion of the cellulosic portion of MSW to ethanol is economically viable. The study found a dilute acid hydrolysis process to be an effective pre-treatment for the lignocellulosic portion of MSW. The product is readily fermentable with yeast. A production case using brewers yeast found total project investment to be an estimated $168.8 million, yielding 105.6 gallons/ton of ethanol at a minimum selling price of $1.49/gallon. A production case using the organism Zymomonas mobilis to ferment materials found total project investment of $163.3 million, ethanol yield of 115.8 gallons/ton and a minimum selling price of $1.36/gallon. Mixed paper and yard waste cases were also studied with ethanol gallon costs range from $2.15-$2.92. Researchers concluded that these materials currently have better uses respectively in replacing virgin pulp and composting.[153]

[147] “Washington state biomass inventory by category.” Washington Department of Ecology, Solid Waste in Washington State, 19th Annual Status Report, December 2010. Publication #10-07-031.
[148] Stiles, p. 65-67.
[149] Stiles, p. 66.
[150] Stiles p. 66.
[151] Biojet production ratio from personal communication, Birgitte Ahring, Bioproducts Science Engineering Laboratory.
[152] Table A2. Oregon Statewide Waste Composition 2009, pg. 1.
[153] Azra Vajzovic et al. “Converting Washington Lignocellulosic Urban Waste to Ethanol.” College of Forest Resources and Mechanical Engineering, University of Washington, Seattle, WA.

PNNL studied a process in which MSW is processed to refuse derived fuel (RDF) with shredder-and-screening technology, and then gasified and catalytically converted to ethanol. PNNL found that 9.65 million annual tons of MSW would produce 27 mgy of ethanol along with 9 mgy of propanol and high alcohols. This translates into 28 gallons/dry ton of ethanol; and nine gallons/ton propanol and high alcohols. Capital investment is $449 million to process 2,000 pounds/day of RDF. Selling price is $1.85 gallon (2008 dollars, 10% rate of return).[154]

Coproducts – Coproduct opportunities that could improve feedstock economics include chemicals such as ketones, isopropanol and naptha. If pyrolysis of the lignocellulosic fraction and plastics is employed, biochar and syngas can be produced along with bio-oils. Slag from plasma arc gasification can be used to make rock wool, roof tiles, insulation, landscaping blocks, and road aggregate material.

Competition – Expanded recycling could draw additional organics into traditional markets such as paper and packaging. Waste-to-energy combustion facilities might be expanded, drawing combustible streams including construction and demolition waste. At the same time, biofuels plants will likely generate energy from fuels co-products that could provide electrical surplus to the grid.

With the development of liquid fuel technologies, waste haulers may want to prioritize fuel use for their own fleets. However, Waste Management (WM) Federal Public Affairs Director Susan Robinson affirmed the company's interest in exploring commercial markets for jet and other fuels. WM is a major hauler in the Puget Sound and Portland metropolitan areas and has invested in fuels companies including Enerkem and Terrabon, and is a partner in S4, which is siting a plasma gasification plant at Columbia Ridge that could feed electrical generation and liquid fuels production.

OTHER CHALLENGES

Technology – MSW is composed of many diverse waste streams that present challenges in processing to liquid fuels. Organic and inorganic components are mixed. In addition, a diversity of materials and toxic elements present obstacles to biochemical processing. Gas contaminants can create problems for downstream processing. High ash content of organic components poses challenges. MSW contains large objects that need to be reduced for processing. If gasification technology followed by Fischer-Tropsch processing into fuels is employed, economies of scale would require location at only the largest regional landfills.[155] Smaller scales could be developed if the final products were alcohols. Biological processes, such as those being developed by Micromidas, convert waste streams into bio-plastics. These types of technologies may be deployed to produce fuel.

Policy – A major policy challenge in fuels based on MSW is assurance that a fuel demand will not divert waste streams that might have higher and better uses in recycling and composting. Performance in the existing waste-to-energy (WTE) combustion arena provides some perspective. A national survey of 98 communities with WTE facilities found that the average recycling rate was 33 percent, compared to the U.S. average municipal recycling rate of 28 percent. Fifty-seven of the communities beat the national average. WTE does not discourage recycling growth, the survey shows. For example Spokane, a

[154] SB Jones et al. "Municipal Solid Waste (MSW) to Liquid Fuels Synthesis." Volume 2: A Techno-economic Evaluation of the Production of Mixed Alcohols, Pacific Northwest National Laboratory, PNNL-18482, April 2009.
[155] C. Valkenburg. "Municipal Solid Waste (MSW) to Liquid Fuels Synthesis," Volume 1: Availability of Feedstock and Technology, Pacific Northwest National Laboratory, PNNL-18144, Dec. 2008: pp. 3.1, 3.5.
[156] Jonathan V. L. Kiser. "Recycling and Waste-to-Energy: The Ongoing Compatibility Success." MSW Management. May-June 2003.

community with WTE combustion, demonstrated similar growth in recycling rates, moving from a relatively high rate of 31 percent when its plant opened in 1991 to 41 percent 10 years later.[156]

During the SAFN process the question arose as to whether materials currently diverted to recycling and composting should instead move into energy production. Opinions varied and no conclusion was drawn.

One stakeholder, for example, commented, “Preserving recycling for recycling’s sake makes little sense if a more economically valuable purpose with (at least) equal benefits to the environment is available (e.g. MSW to energy production).” Another stakeholder said that energy plans “must insure that recycling and composting goals are not undermined” and the return of nutrients to the soil through composted materials should not be reduced.

Yet another stakeholder said, “All green waste should be considered as feedstocks. Compost is not the highest and best use for green waste. Even standard anaerobic digestion is better than composting – an excellent soil amendment is produced and energy is recovered as well. The use of green urban waste as feedstock for making jet fuel from biochemical processes would yield liquid fuel and soil amendments – a higher and better use than compost or anaerobic digestion, which produces compost and power.”

Some SAFN stakeholders suggested that policy makers consider a major redefinition of recycling to include energy recovery. That would place the force of public recycling goals behind energy development, but would require a significant change to existing waste management priorities. Washington’s Beyond Waste plan sets a goal for zero waste and includes biofuels as one destination for materials.[157]

In a practical sense, the use of waste streams is an issue for solid waste management plans created by local jurisdictions such as Seattle, King County, Pierce County and Portland Metro. SAFN polled major Northwest municipalities including King County and Portland Metro and found no explicit goals for liquid fuel production in solid waste plans. King County is just beginning a dialogue on WTE for electricity. Any new use of MSW for energy will require a public dialogue to convince policymakers and interested citizens that energy will be an environmentally beneficial use of waste streams. Communities must agree on priorities for limited MSW biomass. The case made through this report that liquid fuels should take priority over electrical generation, because fewer clean options are available for the former, should be part of local debates.

An improved knowledge base is needed to identify the highest and best uses of waste streams. Lifecycle analysis should be conducted to determine the best outcomes in terms of energy balance and carbon emissions. These should consider the benefits of improving soil carbon from compost applications, as well as reducing atmospheric carbon by reducing fossil fuel use.

SAFN identified a federal policy issue surrounding qualification for waste-derived fuels to meet the Renewable Fuel Standard. These can gain valuable Renewable Identification Numbers through two methods – obtaining yard and food waste separately from municipal solid waste collection systems, or using a standard test to determine the organic component of MSW separated from recycling streams. One biofuels industry stakeholder exploring the use of waste streams said that various rulings by EPA remain confusing, and appear to set up materials segregation requirements that are difficult to meet.

[157] “Beyond Waste: Washington State’s Waste Reduction Plan.” Washington State Department of Ecology.

"From my perspective the rules are not clear or practically viable so we need to get them corrected," the stakeholder stated.

Siting – Another local policy action to facilitate liquid fuels production is identification of potential plant sites. Co-location at existing waste stream management facilities such as landfills is logical. Any new facility will have prospective water and air impacts that must be assessed, as well as new transportation and utility demands. Facilitating siting will help draw fuels companies and private investment to the table.

SUSTAINABILITY SCREENING

Greenhouse Gas Emissions – A University of California lifecycle analysis modelled MSW-based production at 1.2 billion gallons/year of ethanol and found an 81 percent GHG reduction compared to equivalent gasoline emissions.[158] However, landfill gas recovery for energy that exceeds 75 per cent would produce even lower GHG emissions, the study suggests. Landfill site studies have shown gas recovery ranges of 10-90 percent. The University of California study does not take into account reduced emissions resulting from less shipments of urban waste by rail or truck to rural landfills. In any event, a societal decision on priorities is required, parallel to the balance between biopower and biofuels from forest materials. More options exist for clean electricity than renewable fuels, so there is some reason to assign a priority for MSW energy uses.

Local Food Security – No conflict with food supplies.

Conservation – For siting fuels plants, a land use planning process should identify potential impacts on critical species and ecosystems. Siting should take place in areas of lowest risk. Buffer zones should be created between plants and sensitive areas and/or watercourses.

Soil – In siting plants, water quality should be maintained both on the surface and in ground water tables. Applicable laws and regulations must be followed. Reduced landfilling potentially reduces threat of leakage into soils.

Air – Biofuels plants must comply with air pollution laws and regulations. Based on experience permitting WTE facilities, significant community concerns arise relating to potential emissions of toxics from plastics and other elements of the waste stream.

Use of Technology, Inputs, and Waste Management – Applicable laws and regulations must be followed, as should manufacturers' recommendations for materials usage. Monitoring for releases and emergency plans must be implemented.

ACTION "FLIGHT PATH"

Key Recommendation: Spur a public dialogue in the region's major jurisdictions leading to explicit goals for sustainable aviation fuel production in solid waste management plans

- Draw together local policymakers, waste haulers, fuels companies and recycling advocates in local dialogues on the role of energy production in solid waste management plans.

[158] Mikhail Chester and Elliott Martin. "Cellulosic Ethanol from Municipal Solid Waste: A Case Study of the Economic, Energy, and Greenhouse Gas Impacts in California." Environ. Sci. Technol 2009, 43 (14) pp. 5183-5189.

- Set a numerical target and timeline for production of liquid fuels based on emerging technologies.
- Set a priority for MSW biomass to be used for liquid jet fuels before grid electricity.
- Coordinate with efforts to develop a regional pilot biorefinery called for in the “flight path” for lignocellulosic technologies above.

Key Actors:

- ***Local elected officials and solid waste agencies*** – Explore aviation options in solid waste plans.
- ***Waste haulers*** – Work with local jurisdictions to explore aviation fuel options. Explore aviation fuel production at facilities managed by haulers.
- ***Conventional fuels and biofuels companies*** – Examine opportunities to produce aviation fuels from wastes. Work with local jurisdictions and waste haulers to site plants.
- ***Recycling/composting advocates*** – Develop positions on energy use of wastes, with criteria for prioritizing energy in relation to recycling and composting. Join local dialogues on these topics.

Key Recommendation: Improve knowledge base and ensure clarity regarding use of wastes for fuels

- Develop lifecycle analysis based on regional conditions that provides a base for determining the highest and best uses for various waste streams.
- Make sure there is a clear national definition of wastes as an approved biomass supply source for renewable fuel standards such as RFS2.
- Improve knowledge of waste streams available from industry.

Key Actors:

- ***Public university researchers*** – Conduct research and studies.
- ***State environmental agencies*** – Conduct research and studies.
- ***U.S. Environmental Protection Agency*** – Clarify definitions for waste-based fuels under RFS2. Conduct studies to identify the best uses for waste streams.

"Algae in petri dishes"
Credit: Targeted Growth, Inc.

Feedstocks: Algae

BASICS

Algae can grow in a variety of environments and in complex or single-cell forms. The latter, microalgae, is the primary focus of advanced biofuels research. High-yield strains can be selected from over 100,000 known species, which grow in a range of climates as well as fresh water, salt water and wastewater. An International Energy Agency (IEA) report projects potential per-acre yields approximately 20 times greater than soybeans, primary source of today's biodiesel.[159] Oil content of commercially relevant species ranges from 10 percent to over 50 percent, a similar portion to oilseeds. The remainder is biomass. For fuels production from oils, hydroprocessing technology is the destination. The biomass component is a potential feedstock for lignocellulosic technologies -- those concerning lignose and cellulose, the essential compound in the cell walls of woody tissue.

Algae can grow directly in sunlight or in a closed processing system using organic matter. These are known respectively as photosynthetic or heterotrophic systems. Algae are cultivated in open ponds or closed bioreactor systems, or a combination. Mass cultivation in the Northwest is likely to be in open ponds due to the costs of closed systems. Some crops mature in as little as three days. Algae presence in water is typically very dilute. Harvesting requires dewatering to concentrate the algae. Oil must be extracted from algae cells. Algae can be harvested daily or weekly, and can be selectively bred or genetically modified to optimize outputs. Because of its land efficiency and ability to use waste, saline and brackish water, algae does not compete with human food crops for arable land or water, while producing food and/or feed coproducts as well.[160]

> Washington State University scientists are putting forth the concept of algae production fed by the abundant sunlight of long Northwest summer days and diverse supplies of organic matter from regional agriculture and forestry.

Algae provide the environmental advantage of capturing and recycling greenhouse gases. Algae require 1.8 tons of CO_2 to yield one ton of algal biomass, as well as nitrogen, phosphorus and potassium nutrients.[161] Energy is also required for growth, dewatering and processing. The sustainability screening below discusses this.

Distributed production – A prime requirement for successful commercialization of algae supply chains is a year-round production system. For this reason, much attention has been focused on photosynthetic production in Southwest locations with abundant, year-round sunshine. However, Washington State University scientists are putting forth the concept of "mixotrophic" production that leverages the abundant sunlight of long Northwest summer days along with diverse supplies of organic matter from regional agriculture and forestry. Use of forest and farm residues to provide organic nutrients could avoid reliance on food-based sugars that might pose food-fuel competition issues. Photosynthetic and

[159] Al Darzins, Pienkos, Philip Les Edye. "Current Status and Potential for Algal Biofuels Production: A Report to IEA Bioenergy Task 39." National Renewable Energy Laboratory and Bioindustry Partners, Report T39-T2, 6 Aug. 2010: pg.iv.
[160] An overview of algae potentials and sustainability issues is offered by the Natural Resources Defense Council and Terrapin Bright Green in the report, Cultivating Green Energy: The Prospect of Algal Biofuels, Oct. 2009.
[161] Rene W. Wijffels and Barbosa, Maria J. "An Outlook on Microalgal Biofuels." *Science*, Vol. 39, 13 Aug. 2010: pp. 796-9.

heterotrophic systems would work in coordination. With this mix, "This region is as competitive as any other region," WSU scientist Shulin Chen says. "The combination between the two types of process is important for the Northwest." Research to identify appropriate Northwest algae species is underway at WSU.

Northwest resources provide the basis for distributed algae production at various scales across the region, leveraging presently available resources and infrastructure. Recycling CO_2, process energy and nutrients from existing facilities improves energy and carbon balance, as well as economics. Among prospective sites are:

- **Power stations and cement plants** – These are the country's largest point-source emitters of CO_2. Algae grow fast on CO_2 and waste heat generated by these operations. Bioalgene has cultivated open-pond algae using unscrubbed flue gases at Portland General Electric's Boardman, Oregon coal-fired power plant.
- **Municipal wastewater plants** – Organic wastes and existing pools could be used to produce fuel feedstock, while biogas could provide process heat. Growing algae adds a value stream by cleaning waste water of nutrients and heavy metals. Spokane International Airport and Bioalgene are actively planning to produce algae on airport land, supplied with CO_2 from the adjacent Spokane Regional Solid Waste System incinerator, and using organic nutrients from Spokane's wastewater system.
- **Food processing and pulp/paper plants** – These operations generate organic residues that often present a disposal problem, waste heat, and CO_2 from on-site boilers. All these can drive algae production. Algae AquaCulture Technologies of Whitefish, Montana is piloting such a system at F.H. Stoltze Land and Lumber Co. in nearby Columbia Falls to produce organic fertilizer. The system could be adopted to produce vehicle fuels if a competitive market emerges.
- **Dairy biodigesters** – Processing dairy manures in biodigesters yields heat, biogas, nutrients and CO_2. Combined with other farm residues, this could provide year-round production. After lipid extraction algal biomass could be fed back into the biodigester, and algae paste could provide high-protein feed for herds or organic fertilizer.
- **Geothermal resources** – Heat provided from geothermal wells could drive algae cultivation.

RESOURCE POTENTIAL AND ECONOMICS

Capacity – Though around 5,000 dry tons of algal biomass are produced worldwide each year for high value food products, much higher amounts will be required for energy.[162] Algae production for energy is in its early research stages, so it is difficult to estimate Northwest production potentials. Bioalgene, a SAFN stakeholder, and other algae stakeholders submitted estimates that Portland General Electric's Boardman, Oregon, coal plant's annual CO_2 emissions of five million tons could be used to generate 100-200 million gallons/year of algal biofuels. The TransAlta Centralia, Washington, plant with 10 million tons of CO_2 could supply 100-400 mgy.

At the same time, both these plants are facing regulatory processes that project their closure. In early March an agreement to close one of Centralia's two units by 2020 was announced. Trans Alta is exploring replacement with natural gas generation.[163] Portland General Electric has looked at biomass

[162] Wijffels.
[163] "Agreement reached to stop burning coal at Centralia power plant." Seattle Times, 5 Mar. 2011.

options. CO_2 from these sources could also feed algae production. A comprehensive evaluation of other regional sources of CO_2, heat and nutrients has not been done, so evaluating Northwest potentials requires further research.

Cost studies – An update for International Energy Agency of a 1996 techno-economic analysis from the National Renewable Energy Laboratory (NREL) finds oil production costs ranging from $2.84-$22/gallon in an open pond raceway system. The highest figure is based on productivity generated at NREL's Roswell, New Mexico test site in the 1990s, while lower costs derive from scenarios for higher lipid yields. Closed bioreactor systems show triple the costs over pond systems. At the time of the update, soybean oil was running $3.41/gallon and petroleum diesel $2/gallon.[164] A report to the United Kingdom Committee on Climate Change by E4tech cites a European Algal Biomass Association finding that current algal biofuel costs run 10-30 times conventional biofuel costs.[165]

Coproducts – Algae contains proteins, carbohydrates and nutritional substances, all of which can yield valuable coproducts. The protein content of algae paste could balance a Northwest animal feed protein deficit and augment supplies for livestock, poultry and fish. Other potentials are biopolymers to produce plastics and nutriceuticals such as Omega 3 fatty acids. An evaluation of algae prospects published recently in *Science* states, "Economically feasible production of microalgae for biofuels will only be achieved if combined with production of bulk chemicals, food, and feed ingredients."[166]

OTHER CHALLENGES

Research and Development – Most expert evaluations agree that mass production of algal oils will require overcoming a number of basic science and technology challenges. The National Algal Biofuels Technology Roadmap notes that ". . . many years of applied science and engineering will likely be needed to achieve affordable, scalable and sustainable algal-based fuels."[167]

Notes the International Energy Agency, "…past research and development funding in this field has been inadequate to facilitate the development of a robust algal biofuels industry. Realizing the strategic potential of algal feedstocks will require breakthroughs, not only in algal mass culture and downstream processing technologies, but also in the fundamental biology related to algal physiology and the regulation of algal biochemical pathways."[168]

Several commercial parties are actively making the move from bench to field-testing scale. Solazyme, Sapphire and Solix are among the most visible. The Defense Logistics Agency has already purchased 72,000 gallons of converted algae-based biojet fuel from Solazyme, which has just filed an initial public offering. Sapphire, with federal grant backing, is building 300 acres of production ponds in New Mexico.

Much of the technology is known and is ready to move out of lab and small-scale testing to field scale. But pilot or full commercial scale production at CO_2-producing sites, including power plants, has not been built. Developing the value chain requires integration of biology, mechanical and chemical engineering, as well as animal and food sciences for high outputs of varied high value products. Technology challenges include:

164 Darzins, pp. 67-8.
165 Review of the potential for biofuels in aviation, E4tech, Aug.2009: pg. 75.
166 Wijffels
167 National Algal Fuels Technology Roadmap, U.S. Department of Energy, May 2010: pg. iii.
168 Darzins, pg.ii.

- Optimizing lipid content, quality and extraction methods.
- Culturing algae to high densities, harvest quickly and cheaply.
- Eliminating contamination of culture by bacteria and other algae species.
- Developing inexpensive drying approaches or processes that can use wet biomass for downstream conversion or transport.

The key action identified by SAFN stakeholders to overcome these challenges is funding and implementing field pilot projects that build knowledge and experience in the following areas:

- Life science R&D in algae growth efficiency, cellular oil concentration and yield, nutrient utilization and reduced predation from bacteria and other algae species.
- Engineering development of thermal/environmental controls, CO_2 injection, harvesting, dewatering, water use efficiency and recovery, oil extraction and separation technology.

Siting – Mass algae production for energy is a new venture for which regulatory clarity will be required. The lack of clear understandings and policies will hinder development. For example, it is vital to clarify whether algae ponds will be regulated for industry or agriculture. The former will set a significantly higher bar. It also must be determined whether algae will be regulated as a new category or as an existing form of aquaculture. Permits for water use and discharges into and from projects will be required at federal and state levels. In addition, use of non-native or genetically modified species that pose a potential impact on biodiversity might have to pass Endangered Species Act muster. If algae strains are genetically modified, federal regulation will take place through the National Institutes of Health, Environmental Protection Agency and USDA. Overall, development of algae cultivation facilities could require environmental impact statements.

Regional perception – As noted above, the Northwest is not viewed as a prime algae production region due to climate, so R&D resources and commercial investments focus on the Southwest. This hinders development of Northwest systems and poses a risk for algae development generally. There is evidence of a technology bias favoring phototrophic over heterotrophic production modes. This does not imply that Southwest development is not highly promising, but diversifying production to areas farther north reduces pressures on any one region.

SUSTAINABILITY SCREENING

Greenhouse Gas Emissions – A number of lifecycle analyses have yielded widely varying results. This is attributed to many production scenarios, along with many data gaps due to limited real-world experience. In several scenarios, energy and fertilizer usage tip GHG emissions higher than equivalent petroleum products.[169] An Oregon State University lifecycle analysis of algal biodiesel found GHG emissions for a 24 kilogram batch reduced net CO_2 emissions by 20.9 kilograms, compared to petroleum diesel when de-watering is done by filter press. Use of algal biomass co-products for animal feed and ethanol production is vital to achieve this positive balance.

[169] Andres Clarens et al. "Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks," Environmental Science and Technology, 2010: 44 (5), pp. 1813–1819; Laurent Lardon, "Life-Cycle Assessment of Biodiesel Production from Microalgae." Environmental Science and Technology. 2009: 43 (17), pp. 6475–81;

[170] Kyle Saunder & Murthy, Ganti S., "Life cycle analysis of algae biodiesel." Intl. J. Life Cycle Assess, 2010 15: pp. 704-14.

But a centrifuge array would use nearly twice the energy and result in emissions of 135.71 kilograms over the petroleum equivalent.[170]

A study from the MIT PARTNER project finds that algal biojet fuel could produce up to 2.2 times the greenhouse emissions of conventional jet fuel, or as little as 0.16 as much. Results are highly dependent on algae productivity and lipid content, as well as energy used in de-watering and drying. Replacing natural gas with biogas produced from algal biomass has a significant impact, as does using that biogas to replace grid electricity.[171]

The Environmental Protection Agency has determined that renewable diesel produced from algal oils will reduce GHGs at least 50 percent once commercial production is reached. This is the threshold set for renewable diesel qualified to meet the Renewable Fuel Standard under the 2007 Energy Independence and Security Act.[172]

Local Food Security – Algae production is not expected to be sited on current agricultural lands, so it poses no competition with food supplies, and promises to be significantly more land efficient in terms of oil production per acre than oilseed crops. Algae co-products could improve food and feed availability.

Conservation – Algae cultivation, particularly in open ponds, could leave a significant footprint. Siting of algae production facilities on sensitive lands could pose threats to biodiversity and ecosystems. Specific project proposals must be examined for impacts. Use of genetically modified species and non-native species must be vetted by appropriate regulatory authorities.

Soil – Non-GMO algae are typically an all-natural crop, completely biodegradable. If chemicals are added in algae production, they could leak salts into soils, posing contamination threats. Siting of algae production facilities will require soil impacts analysis.

Water – In general, systems that use brackish, saline and waste water are preferred to avoid competition with fresh water supplies. Algae has the advantage of cleaning water by extracting nutrients and pollutants. Algae production systems must be analyzed individually. One modeling study found it will take 530,000 gallons to fill a 20-centimeter deep open pond covering one hectare, or nearly 2.5 acres. Evaporation in desert areas can exceed 13,000 gallons/day. If cultures double daily, this will require moving and recycling 260,000 gallons/day. Water injected into the process may require removing chemicals and microorganisms that could hinder algae growth. Once through the process, treatment to remove salts, fertilizers, chemicals and algae cells will likely be needed. Enclosed bioreactors hold water, but this can be cancelled through spraying and cooling towers to control temperature.[173] For all systems, impacts on surface waters and groundwater must be understood.

Air – Air emissions represent a limited concern.

Use of Technology, Inputs, and Management of Waste – Chemical solvents such as hexane or methanol can be used to extract algal oils, but university researchers and SAFN participant companies are exploring more natural alternatives that are less costly and have fewer potential impacts. These

---

[171] Russell W. Stratton; Wong, Hsin Min; Hileman, James I. "Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels." MIT Partner Project 28 report, June 2010: Version 1.2, pp. 95-6.

[172] U.S. Environmental Protection Agency, Office of Transportation and Air Quality, "Regulatory Announcement: EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels." Feb. 2010.

[173] National Algal Fuels Technology Roadmap.

include harvesting and extraction methods that avoid complete drying of farmed algae, potentially sidestepping a large portion of energy requirements for processing. Use of toxic chemicals to extract oils from biomass must be controlled to avoid releases and injuries. Escape of microorganisms into the environment must be prevented. Potential hazards related to the use of Genetically Modified Organisms (GMOs) must be disclosed, in consultation with the Biosafety Clearing-house established under the Cartagena Protocol on Biosafety. Monitoring for releases and emergency plans to address releases must be implemented.

ACTION "FLIGHT PATH"

Key Recommendation: Stage algae production field pilots in a variety of settings to build basic knowledge and experience

Identify and inventory resources to build the groundwork for a distributed algae production model:

- Map existing regional industrial facilities, including power, cement, food processing and wood products which bring together sufficient supplies of CO_2, process energy, nutrients, land, water and transportation facilities.
- Work with the regional dairy industry to establish biodigesters that provide value streams to benefit algae production.
- Inventory public physical resources that could be brought to bear on pilot programs, including public lands, wastewater treatment facilities and geothermal sites.

Key Actors:

- ***State government energy, economic development and natural resource agencies*** – Conduct mapping and inventories.
- ***Western Governors Association*** – Support mapping and inventory work by states.
- ***State and land grant universities and extension services*** – Work on mapping and inventory projects. Work with dairy industry to develop biodigesters.
- ***Federal agencies*** – Identify land and facility resources that could support algae production.
- ***Industry and trade groups, biofuels developers*** – Explore opportunities in dairy, wood products, food processing, power, cement and other industries with prospective resources.
- ***Local governments*** – Explore opportunities in waste water treatment plants.

Build the case for funding algae pilot projects appropriate to conditions in northern regions.

- Bring together regional public, private and nonprofit stakeholders in energy and related fields to advocate for pilot programs that test distributed models that mesh phototrophic and heterotrophic systems.
- Develop the case for diverse, regionalized production chains that avoid overconcentrating development in any one region.

- Develop plans and scenarios for distributed production models that build on resource inventories, with detailed capacity and economic projections.
- Present results from resource inventories to federal and venture funders.

Key Actors:

- ***State governors and lead agencies in energy, economic development and natural resources*** – Build the case and bring it before federal policymakers and investors.
- ***Northwest Congressional Delegation*** – Carry advocacy for regional algae pilots into legislation and communication with executive agencies.
- ***Land grant and state universities*** – Help build plans and scenarios.
- ***Industry stakeholders*** – Industries with prospects to branch into algae production, along with potential fuel buyers - particularly the aviation industry- advocate for regional pilot projects to gain support from federal policymakers and investors.

Build partnerships to draw funding for field pilot projects:

- Draw together public-private partnerships to design pilot projects using existing regional resources, informed by inventories, plans and scenarios.
- Work to draw funding from federal programs including:
  - USDA Bioenergy Program for Advanced Biofuels
  - USDA Regional Biomass Research Centers
  - USDA NIFA Plant Feedstock Genomics for Bioenergy program
  - DOE Biomass Research and Development Initiative
  - DOE Advanced Research Projects Agency – Energy
  - DOD Advanced Research Projects Agency and service research agencies
  - National Science Foundation.

Key Actors:

- ***State and land grant universities*** – Build consortia with each other and with industry to design project proposals and seek funds.
- ***Industry stakeholders*** – Existing industries with prospective algae production resources work with emerging biofuels companies and university researchers to design and implement proposals.
- ***State energy, economic development and natural resources agencies*** – Bring information resources and support to the table for pilot project proposals.
- ***Federal funding agencies*** – Support Northwest pilot projects.

Key Recommendation: Validate algae sustainability and build clear regulatory roadmaps for algae production.

Specify sustainability metrics and industry standards, and employ data emerging from pilot projects to refine lifecycle analysis studies:

- Quantify greenhouse gas emissions and overall energy balances.
- Quantify water and land use requirements.
- Quantify local air emissions and water discharge impacts.

Key Players

- ***State and land grant universities*** – Contribute to lifecycle analysis.
- ***Algal Biomass Organization and industry*** – Develop sustainability standards and metrics. Contribute resources and data to lifecycle analysis.

Create regulatory clarity for siting and permitting algae cultivation and processing facilities

- Bring together interagency task forces at federal and state levels to:
  - Inventory all regulations that might come into play, and assess the appropriate level of regulation needed for algae aquaculture ponds, for non-native species, and for GMO and non-GMO species.
  - Develop regulatory roadmaps that clarify agency roles and responsibilities and lay out clear steps needed for permitting.
  - Resolve uncertainties around coal power plant futures, to determine whether those sites will remain viable for algae cultivation (as they would be if the plants are converted to alternate fuels).

Key Players:

- ***Federal agencies*** – All relevant agencies including Environmental Protection Agency, USDA, Department of Energy, Fish and Wildlife Service, National Institutes of Health form federal task force.
- ***State agencies*** – All relevant agencies in the areas of environmental and land use regulation, natural resources and energy form state task forces.
- ***Western Governors Association*** – WGA works to harmonize regulations among western states.
- ***Algal Biomass Organization and industry*** – Work with state and federal task forces and WGA to clarify regulatory issues and establish clear roadmaps.

Priority Action Steps

SAFN's ultimate goal is to accelerate development of commercial supply chains for sustainable aviation fuels in the Northwest and to unite stakeholders to mobilize support for critical efforts. As with any new energy supply, policy support will be critical in the early years.

On March 30, 2011, President Obama highlighted the opportunity for domestically-produced, renewable jet fuels. The President directed the Navy, Air Force, U.S. Department of Agriculture and U.S. Department of Energy to focus efforts on securing advanced fuels that could power military jets, commercial planes and other transportation sectors. He called for breaking ground on four commercial scale refineries within two years.[174]

The Northwest is well positioned as a site for these refineries because it possesses key conditions for success. The region has strong companies, concentrated demand, leading expertise and significant biomass resources. It also has laid the groundwork by engaging key stakeholders to develop consensus "flight paths" to launch supply chains for sustainable aviation fuels.

This section highlights our highest priority recommendations for policies that will spur creation of sustainable fuels for aviation. More detailed recommendations are also contained as part of the "flight paths" for specific technologies and feedstocks.

The top recommendations are:

1. **Create a strategic focus on sustainable fuels for aviation**
2. **Promote stable, long-term policy to attract investment**
3. **Ensure support for aviation fuels and promising feedstocks under the Renewable Fuel Standard 2 (RFS2) Program**
4. **Provide strong state and local backing for this industry sector**
5. **Target research and development efforts on regional initiatives critical to commercializing sustainable aviation fuel projects**
6. **Incorporate sustainability considerations into efforts to create an advanced biofuels industry**

These recommendations are discussed in more detail below.

1. Create a Strategic Focus on Sustainable Aviation Biofuels

SAFN stakeholders urge decision makers to recognize the critical importance of catalyzing the development of safe, sustainable and commercially viable fuels for aviation. Support for aviation biofuels should at a minimum be equal to policies supporting other transport and energy sectors. Because of aviation's importance and unique needs, SAFN stakeholders believe that priority attention is merited. Because aviation does not have renewable alternatives to high-energy dense liquid fuels, there is a strong case for this priority. Consistent programs and strategic focus are essential. For example, SAFN supports the work of the Farm-to-Fly Initiative, a joint policy effort among the U.S. Department of Agriculture, Boeing and the Air Transport Association. This type of initiative should be continued and replicated to ensure that relevant agencies are focusing on effective strategies to promote development of renewable aviation fuels. In addition, the USDA, the USDOE and other agencies can begin to reflect this priority in their own investment decisions prior to congressional action.

[174] President Obama. "Blueprint for a Secure Energy Future." The White House Press Office, Washington, D.C., 30 March 2011.

Specific examples of actions that SAFN stakeholders advocate for include:

- Urge agencies to place a high priority on technology investments for aviation fuels. Technology investments should address the entire supply chain for aviation fuels and link bench, pilot, demonstration and commercial development, thus addressing the financial "valley of death." For example, aviation fuels and promising technologies should receive priority attention in decisions under the USDA's Biomass Research and Development Initiative.
- Urge state energy planning efforts to recognize the urgent priority for renewable aviation fuels and develop integrated strategies to assure that biofuels opportunities will not be precluded by biomass demands from other uses such as electrical power generation facilities.
- Urge that state standards and incentives for renewable electricity be balanced with similar standards and incentives for liquid fuels.
- Work to ensure coverage of aviation fuels under existing programs, such as the expedited extension of crop insurance to new feedstocks.

2. Foster adequate and stable policy to attract investment

Stable, long-term government policies are needed for a sustainable aviation fuels industry to grow and thrive. Well-integrated, consistent policies will help mitigate critical risks for feedstock growers and producers when undertaking a new feedstock or technology. Dependable, coordinated policies are critical to provide access to capital and feedstocks. The SAFN stakeholders therefore encourage key federal agencies and Congress to support collaborative efforts to coordinate federal policies. We commend and support the efforts of the President's Biofuels Interagency Working Group, the Farm-to-Fly effort, and similar initiatives, and encourage future cooperation.

Long-term contracting for federal agencies, including the Defense Department, would provide necessary support for the development of advanced biofuels. Some SAFN stakeholders have indicated that 15 years is the minimum term needed to attract investment. Many projects can take more than a decade from conception to market viability, and long-term contracts to purchase products can be a powerful tool to drive investments.

Other priority recommendations include:

- 2012 Farm Bill: Incorporate aviation biofuels into existing program provisions, and advocate for preserving programs under Title IX and other key areas that support biofuels development. In particular, the Biorefinery Assistance Program (section 9003 of the Farm Bill) provides important support for supply chain development that should be available to promising projects supporting aviation fuels. The SAFN stakeholders recommend that Congress reauthorize this program and fund promising projects.
- Price collar legislation: A price collar mechanism would be an effective tool to help reduce risks in growing and production of new feedstocks.
- Continued or modified tax incentives that support aviation biofuels: Tax credits and other incentives can reduce risks and increase the likelihood for investment in all parts of the aviation biofuels supply chain. The stakeholders support appropriate incentives for sustainable advanced biofuels. While

there is a variety of views about how to best structure incentives, it is agreed that that aviation biofuels should have parity with other sectors, and should provide short-term assistance with the expectation that the industry will be self-sustaining after it is more established.

- Coordinate and harmonize definitions for biofuels and biomass across different programs to the extent possible.

3. Ensure support for aviation fuels and promising feedstocks under the Renewable Fuel Standard 2 (RFS2) Program

The Renewable Fuel Standard 2 program (RFS2) was originally established by the EPA in 2005 as the first renewable fuel mandate in the United States. In 2007 it was expanded under the Energy and Independence Security Act (EISA) with the goal of promoting renewable fuels that provide real reductions in greenhouse gas emissions. The program sets a goal to increase the volume of renewable fuels in the transportation industry from nine billion in 2008 to 36 billion gallons by 2022. To accomplish this, the EPA must show that the new fuel has significantly lower lifecycle emissions of GHGs than petroleum fuels. This in turn requires the EPA to review new fuels and set volume requirements for each one.

Renewable Identification Numbers (RINs) essentially act as the currency for the RFS program. Producers and distributors, as well as renewable fuel exporters, can earn credits for qualifying fuels under the program. To earn a RIN value is a multi-step, detailed process.

Aviation fuels can qualify for RINs under RFS2, but are not subject to the mandatory volume requirements that apply to fuels for ground transportation. Timely approval for promising feedstocks and technologies will be critical to ensuring that the industry is commercially viable. Approved pathways exist for fuels from algae, solid waste and cellulosic materials; EPA is currently in the process of reviewing an approval for hydroprocessed fuels from camelina.

The stakeholders therefore recommend establishing a working group of legal and industry experts to clarify whether existing pathways encompass target feedstocks and conversion technologies for aviation fuels and to evaluate the petition process relating to aviation fuels to the extent new pathways must be established. It would also evaluate the petition process relating to aviation fuels to the extent that new pathways need to be approved. Where needed, interested parties could work together to file petitions with the EPA to establish fuel pathways for promising Northwest feedstocks.

4. Provide strong state and local backing for this critical industry sector

Despite current budget challenges, state and local governments can take steps to aid commercialization of biofuels in the Northwest by prioritizing infrastructure improvements, promoting workforce development and supporting pilot scale projects. Examples include the following:

- Help with key infrastructure needs such as highway access, pipelines, and water facilities. The Northwest has existing infrastructure that can be used to incorporate aviation biofuels. Maintaining and improving this infrastructure and assisting with specific site needs will foster development and investment.
- Workforce development agencies and programs should identify needs for skilled workers in advanced biofuels and promote training as appropriate.

- Pilot programs provide data points that help reduce risk for larger scale commercial investment. A current example of this type of state support is Washington HB 1422, which was recently passed by both houses of the legislature. This bill establishes a demonstration project for aviation fuels resulting from forest residues that will be administered by the Washington State Department of Natural Resources and creates a foundation for stakeholder efforts to explore opportunities and overcome barriers for this feedstock.

5. Target research and development efforts on regional efforts critical to commercializing sustainable aviation fuel projects

SAFN stakeholders support continued investment in targeted research and development that will accelerate advanced biofuels for this sector.

- Public universities should receive priority attention for available federal funding to build up existing efforts such as Washington State University's biofuels research, the University of Washington's work on biomass pretreatment and lifecycle analysis, and the Sun Grant Initiative based at Oregon State University (OSU), WSU, and the University of Hawaii. Together, these institutions represent the western U.S. in the nationwide network of the Sun Grant Initiative. The lessons learned in the SAFN process and follow-on work can be taken across the country via this already existing network.
- Public universities and USDOE national labs should emphasize existing collaborations such as the Bioproducts, Science and Engineering Laboratory operated by WSU and Pacific Northwest National Laboratory.
- Public universities and national labs should work with each other, the industry, and state and federal government agencies to build research consortia to address key issues identified for this industry.
- Federal agencies should focus available funding on research and development connected to technologies that will allow cost effective conversion of Northwest feedstocks into sustainable aviation fuels and co-products.

6. Incorporate sustainability considerations into efforts to create an advanced biofuels industry

SAFN stakeholders agree on the need to accelerate efforts to find replacements for petroleum fuels, but also recognize the importance of analyzing the full lifecycle impacts of potential biomass pathways and technologies. Sustainability should be a crucial consideration as policies are shaped to support development of advanced biofuels. This will ensure that policies are crafted to achieve the desired results: reducing greenhouse gas emissions, improving energy security, and reducing other impacts. It will also help provide biofuel producers, consumers and policy makers with the measurement tools and data that will help respond to appropriate scrutiny.

To the greatest extent possible, aviation leaders urge policy makers and fuel industry leaders to strive for consistent standards. Aviation is a global industry in which the products and services cross borders constantly, often many times a day. Ideally, global sustainability criteria will reflect and integrate with voluntary standards, sector-specific certification approaches, and national, regional and local government laws. For example, a biofuel producer using crops from Montana farmers should be able to sell its product to airlines operating on multiple continents by meeting one set of standards.

All SAFN participants agree that integrated standards and better knowledge should enable rather than obstruct cost-effective implementation of truly sustainable sources of bioenergy. A number of groups, including the Bioenergy Research Consortia sponsored by Boeing and housed at École Polytechnique Fédérale de Lausanne (EFPL) in Lausanne, Switzerland, are analyzing ways to better integrate and benchmark different sustainability standards. EPFL is launching a project to compare Northwest laws against international sustainability standards to facilitate reporting and verification for parties interested in showing that their products are sustainable.

SAFN does not advocate that biofuel producers or consumers use any particular standard for sustainability or any specific method to verify and validate compliance. It does recommend that sustainability be a key consideration in policies and actions to accelerate supply chains for aviation fuels.

Conclusion

Many of our greatest industries, such as aerospace, computers, pharmaceuticals and automobiles, have drawn vital early support and investment from government. For example, U.S. postal contracts in the 1920s were a vital bridge to help grow Boeing and other aviation leaders from their infancy into major cornerstones of our regional and global economies. Military and space program purchases in the 1960s and 1970s made computers and the internet a feature of everyday life. Building a sustainable aviation fuels industry is no exception. The industry will require early public support and coordinated strategies to build it into an economic competitor.

SAFN stakeholders do not advocate permanent subsidies, but recognize that focused public investments and policy support will be needed to place this new industry on an economically competitive basis. Strategically targeted public investments in sustainable aviation fuels will ultimately provide payback through increased tax revenues and leadership in an emerging global industry, while offsetting the outflow of capital to pay for imported petroleum.

As this report demonstrates, aviation is a priority sector with a unique need for sustainable alternatives to petroleum fuels. The Northwest possesses significant institutional assets, leadership vision and natural resources that create an opportunity to build a dynamic new fuels industry. The SAFN process itself provides compelling evidence of the benefits from a unified focus. These recommendations result from the combined expertise and perspectives of a wide range of key stakeholders representing aviation, biofuels, natural resources, public agencies, non-profits and research institutions, all working together.

SAFN stakeholders have identified a set of actions to create a sustainable aviation fuels industry in the Northwest. Many parties will be needed at the table to implement them including federal, state and local governments, industry associations, universities and industries including aviation, fuels, agriculture and forestry. The effort will require substantial public investment and policy support, along with business entrepreneurship and innovation, and the full deployment of scientific and technology R&D assets. These elements will need to be coordinated to accelerate development of comprehensive supply chains. This translates into the need for widespread regional collaboration and a unified regional voice advocating for appropriate policies and public support.

SAFN has mapped a "flight path" to sustainable aviation fuels in the Northwest. Now stakeholders and a broader set of regional and national interests must join to forward it at all levels. The payback will be a new regional industry that strengthens traditional economic sectors from farming and forestry to aerospace, creates new companies and jobs, and places the long-term future of aviation on an environmentally sound basis. The SAFN stakeholders look forward to working with legislators, agency leaders and others to make safe, sustainable jet fuels a reality in our region. The time to start is now.

Appendix 1:
Glossary

Aerospace Industries Association (AIA): represents the nation's leading manufacturers and suppliers of civil, military, and business aircraft, helicopters, unmanned aircraft systems, space systems, aircraft engines, missiles, materiel and related components, equipment, services and information technology.

Air Force Energy Plan 2010: it serves as the operational framework for all military and civilian Air Force personnel in communicating the Air Force energy goals, objectives and metrics.

American Society for Testing and Materials (ASTM): develops international standards for materials, products, systems and services used in construction, manufacturing and transportation.

Airports Council International – North America (ACI—NA): represents local, regional and state governing bodies that own and operate commercial airports in the United States and Canada.

Air Transport Association (ATA): founded in 1936, ATA is the nation's oldest and largest airline trade association, including among its members the nation's commercial airlines.

Bio Economic Research Associates (BERA): is a private research and advisory firm working at the intersection of emerging biological knowledge and the economy.

Bioenergy Program for Advanced Biofuels (BPAB): authorized under section 9005 of the 2008 Farm Bill, the Bioenergy Program for Advanced Biofuels re-titles, renews, and extends the program formerly known as the Bioenergy Program. This program provides incentive payments to ethanol and biodiesel producers on an incremental basis to increase production. Biofuel producers entering into a contract with USDA are reimbursed based on quantity, duration and on net nonrenewable energy content.

Biofuel: a wide range of fuels derived from biomass, delivered in solid, liquid or gaseous forms. Biofuels are gaining increased public and scientific attention, driven by factors such as oil price spikes, the need for increased energy security, and concern over greenhouse gas emissions from fossil fuels.

Biofuels Interagency Working Group (BIWG): co-chaired by USDA, DOE, and EPA, and with input from many others, BIWG is missioned to develop a comprehensive approach for accelerating the investment in and production of U.S. biofuels and reducing dependence on fossil fuels.

Biojet term for jet fuel derived from biomass feedstocks.

Biomass: organic matter, particularly plant matter that can be converted to fuel and is therefore regarded as a potential energy source.

Biomass Crop Assistance Program (BCAP): a federal program that provides financial assistance to owners and operators of agricultural and non-industrial private forestland who wish to establish, produce, and deliver biomass feedstocks.

Biorefinery Assistance Program (BAP): a federal program that provides guaranteed loans for the development and construction of commercial-scale biorefineries or for the retrofitting of existing facilities using eligible technology for the development of advanced biofuels.

Biotechnology Industry Organization (BIO): world's largest biotechnology organization, providing advocacy, business development and communications services for more than 1,100 members worldwide.

Bone Dry Ton (BDT): is defined as biomass having zero percent moisture content. Wood heated in an oven at a constant temperature of 100°C (212°F) or above until its weight stabilizes is considered bone dry or oven dry.

Carbon-neutral: describes operations that add no net carbon emissions to the atmosphere.

Climate Solutions: a Northwest research and advocacy group working to accelerate practical and profitable solutions to global warming by galvanizing leadership, growing investment and bridging divides.

Coarse Woody Material (CWM): consists of snags, fallen logs, wind blown trees and large branches. Through decomposition, coarse woody debris returns to the soil the nutrients it gathered and the carbon photosynthetically captured in live trees. The rate of decomposition varies according to temperature, moisture, oxygen and carbon dioxide levels and decomposer organisms involved. The size of material affects the kinds of roles it can play in the ecosystem, with larger material generally having greater influence over longer periods of time

Commercial Aviation Alternative Fuel Initiative (CAAFI): a coalition representing leading stakeholders in the field of aviation that focuses the efforts of commercial aviation to engage alternative fuels through building relationships, sharing and collecting data, identifying resources, and directing research, development and deployment of alternative jet fuels

Commodity Credit Corporation (CCC): a government corporation created in 1933 to "stabilize, support, and protect farm income and prices". The CCC is authorized to buy, sell, lend, make payments and engage in other activities for the purpose of increasing production, stabilizing prices, assuring adequate supplies, and facilitating the efficient marketing of agricultural commodities.

Defense Logistics Agency (DLA): is the Department of Defense's largest logistics combat support agency, providing worldwide logistics support including energy supplies to the military services as well as several civilian agencies and foreign countries.

Energy Information Administration (EIA): federal agency that collects, analyzes, and energy information.

European Algal Biomass Association (EABA): Fosters synergies among scientists, industrialists and decision makers in order to promote the development of research, technology and industrial capacities in the field of algae.

Environmental Protection Agency (EPA): is an agency with lead authority for environmental protection, including assessments of biofuel.

Environmental and Social Impact Assessment (ESIA): an assessment of the possible positive or negative impact that a proposed project may have on the environment, based on the natural, social and economic aspects.

European Union Emissions Trading System (EU ETS): as the first and largest international scheme for the trading of greenhouse gas emission allowances, the EU ETS covers some 11,000 power stations and industrial plants in 30 countries, and in 2012 the aviation industry.

European Commission's Directorate-General for Transport and Energy (ECDGTE): is responsible for developing and implementing European policies in the energy and transportation sectors..

Farm-to-Fly: a collaborative effort to promote development of renewable fuels for aviation resulting from a Working Together Resolution signed on July 21, 2010, by USDA Secretary Vilsack, Boeing and the Air Transport Association.

First Generation Biofuels (See Generational Biofuels)

Fischer-Tropsch process: is a set of chemical reactions that convert a mixture of carbon monoxide and hydrogen derived from coal, natural gas, or biomass into liquid petroleum substitutes...

Federal Aviation Administration (FAA): the U.S. Department of Transportation agency that inspects and rates civilian aircraft and pilots, enforces the rules of air safety, and installs and maintains air-navigation and traffic-control facilities.

Generational Biofuels:
First Generation: fuels from agricultural crops such as sugars, corn, rapeseed and palm oil.
Second Generation: fuels from sources that typically do not compete in food markets, such as woody biomass or inedible residues.
Third Generation: often used to describe fuels based on algae

Greenhouse Gas (GHG): trace atmospheric gases that absorb and reflect infrared radiation emerging from solar heating of the Earth. The natural greenhouse effect that results is vital for life on Earth. Humans have added to natural GHGs by burning fossil fuels, emitting fossil carbon into the atmosphere. The major human-caused GHG is carbon dioxide, atmospheric concentrations of which have increased by roughly one-third in the past 250 years. Methane and nitrous oxide are also significant GHGs that emerge from human activities.

Idaho National Laboratory (INL): is a USDOE federal laboratory with missions in nuclear and energy research, science and national defense, national center for R&D on biomass collection, delivery and storage.

International Air Transport Association (IATA): is an international trade body, created over 60 years ago by a group of airlines. Today, IATA represents some 230 airlines comprising 93 percent of scheduled international air traffic, and the airline industry in general.

International Energy Agency (IEA): is an intergovernmental organization which acts as energy policy advisor to 28 member countries in their effort to ensure reliable, affordable and clean energy for their citizens.

Ladder Fuel: those that provide vertical continuity between understory or midstory surface fuels and canopy fuels, consisting of vine or liana fuels, draped foliage fuels, and hanging broken branches.

MGY: One million gallons per year.

Municipal Solid Waste (MSW): commonly known as trash or garbage, is a waste type consisting of everyday items we consume and discard.

National Renewable Energy Lab (NREL): is a USDOE federal laboratory, based in Golden, Colorado, dedicated to the research, development, commercialization and deployment of renewable energy and energy efficiency technologies.

National Resources Defense Council (NRDC): an environmental action group with1.3 million members and online activists, and a staff of more than 350 lawyers, scientists and other professionals working on issues including biofuels, transportation and climate policy.

Oak Ridge National Laboratory (ORNL): is a USDA federal laboratory and the national center for biomass supply assessments, based in Oak Ridge, Tennessee.

Olympic National Resources Center (ONRC): the University of Washington Center is located on the Olympic Peninsula in Forks, Washington, provides scientific information to address critical issues and solve problems concerning forestry and marine sciences in the region.

Olympic Region Clean Air Agency (ORCAA): a local government agency charged with regulatory and enforcement authority for air quality issues in Clallam, Grays Harbor, Jefferson, Mason, Pacific, and Thurston counties, one of seven such regional air pollution control agencies in Washington State.

Pacific Northwest National Laboratory (PNNL): is a USDOE federal laboratory and national center for research on thermochemical biomass processing based in Richland, Washington.

Plasma Arc Gasification a waste disposal technology that gasifies biomass through arcs created by high voltage electrical currents.

Refuse Derived Fuel (RDF): a fuel produced by shredding and dehydrating solid waste (MSW) and consists largely of combustible components such as plastics and biodegradable.

Renewable Identification Numbers (RIN): batch numbers mandated by the Environmental Protection Agency to validate that renewable fuels meet standards set for meeting the Renewable Fuel Standard, which adds value to the batch.

Roundtable on Sustainable Biofuels (RSB): an international initiative coordinated by the Energy Center at EPFL in Lausanne that brings together farmers, companies, non-governmental organizations, experts, governments, and inter-governmental agencies to set certification standards for the sustainability of biofuels production and processing.

Second Generation Biofuels (See Generational Biofuels)

Stockholm Environment Institute (SEI): an independent international research institute engaged in environment and development issues at local, national, regional and global policy levels for more than 20 years.

Sustainable: capable of being maintained at a steady level without exhausting natural resources or causing severe ecological damage.

Sustainability: meet present needs without compromising the ability of future generations to meet their needs.

Sustainable Aviation Fuels Northwest (SAFN): stakeholder process to explore opportunities and challenges in producing aviation fuel from sustainable biomass generated in the four Northwest states.

Sustainable Aviation Fuel Users Group (SAFUG): an aviation industry group formed in September 2008 to accelerate the development and commercialization of sustainable aviation biofuels.

Sustainable Way for Alternative Fuels and Energy for Aviation (SWAFEA): is a study for the European Commission's Directorate General for Transport and Energy to investigate the feasibility and the impact of the use of alternative fuels in aviation.

United States Department of Agriculture (USDA): is the United States federal cabinet-level department working to support agriculture, including promoting agricultural energy production including biofuels.

United States Department of Energy (USDOE): is the United States federal cabinet-level department with lead responsibility in energy research and development including biofuels.

Third Generation Biofuels (See Generational Biofuels)

Waste to Energy (WTE): the process of creating energy in the form of electricity or heat from the incineration of waste source.

Waste Management (WM): waste hauling company serving a number of major jurisdictions in the Northwest.

Western Governors Association (WGA): an independent, non-profit organization that joins Western state governors in work on common issues, has set major renewable energy goals and researched biomass availability.

Appendix 2:
Forest Materials – Technical Information and Background Reports

Forest Thinnings

This section describes forest thinnings as a potential source of biomass for sustainable aviation fuels. This discussion was moved to an appendix to reflect the significant controversy relating to thinning practices. Some stakeholders believe that this is an important source of sustainable biomass. Others believe that some practices may have limited applicability to Northwest forests, especially in wetter forests on the west side of the Cascades. Stakeholders also disagree regarding the available science on where and how thinning should occur, including its effectiveness in preventing catastrophic wildfires. Since we do not have consensus on these issues, we are noting some of the key research as a resource for subsequent work.

Thinnings emerge from forest operations intended to reduce dense overgrowth in the forest understory. Thinnings are done for different reasons on "intensively managed" lands (typically on the West side of the Cascades and generally privately owned), and "extensively managed" lands, often East of the Cascades and typically managed by federal or state agencies.

A range of studies address whether thinnings constitute a net reducer of GHG emissions. This may depend on the specific type of forest, the long term plan for timber harvest, and the fate of products derived from the forests.

An Oregon State University study modeled carbon storage in east Cascades ponderosa pine forests, west Cascades western hemlock–Douglas-fir forests, and Coast Range western hemlock–Sitka spruce forests. The study found that thinning to reduce fire dangers required removal of more biological carbon than would be released in fires. Most carbon remains on site, even in a fire. For example, 169 years would be required to re-accumulate carbon taken from a Coast Range forest thinning operation. If materials are used to make cellulosic ethanol, OSU researchers calculated that the carbon payback time would be 339 years.[1]

The OSU scientists therefore suggest that, "…. forest management plans aimed solely at ameliorating increases in atmospheric CO_2 should forgo fuel reduction treatments in these ecosystems, with the possible exception of some east Cascades ponderosa pine stands with uncharacteristic levels of understory fuel accumulation. Balancing a demand for maximal landscape (carbon) storage with the demand for reduced wildfire severity will likely require treatments to be applied strategically throughout the landscape rather than indiscriminately treating all stands."[2]

Another study from University of Washington scientists has shown significant greenhouse gas reductions for restoration thinnings conducted in eastside forests that are fire and disease prone and fuel laden.[3] They compared managed to unmanaged Eastern Washington forests. Based on climate change

---

[1] Mitchell, Stephen R., Mark E. Harmon, and Kari E. B. O'Connell. "Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems." Ecological Applications. Vol. 19: pp. 643–655. [doi:10.1890/08-0501.1]; Oregon State University, "Forest fire prevention efforts will lessen carbon sequestration," 7 July 2009.

[2] Ibid.

[3] O'Neil, Lippke, Mason. "Discussion Paper (DP8): Eastside Climate Change, Forest Health, Fire and Carbon Accounting, Future of Washington Forest and Forest Industry Study," July 2007.

projections of 1.7 percent burn rate per year, the study found that only an estimated 40 metric tons of carbon would remain on an acre of forest in 2101while approximately 70 metric tons would have burned into the atmosphere. By contrast, an acre in a forest managed through thinning would account for 90 metric tons of carbon, of which 30 tons would be in the form of word products derived from the forest.

"While this is a coarse approximation of potential carbon impacts from fire under expected climate change scenarios, it does highlight how unmanaged forests are likely to become a source of carbon emissions rather than a sink," the UW scientists say. "This analysis also illustrates the hazard associated with slow adoption of restoration activities designed to reduce fire risk on these forests.

A bill introduced by Oregon Sen. Ron Wyden in December 2009 reflects a possible approach that has support from some forest advocates and the forest industry on the thinnings issues (one SAFN stakeholder noted, however, that some forest advocates oppose this bill). The Oregon Eastside Forests Restoration, Old Growth Protection and Jobs Act would set the stage for thinning on six national forests, while prohibiting logging trees larger than 21 inches in diameter. The bill would allocate $50 million to ramp up the effort, and set up a science advisory committee to guide it. The bill has been reintroduced in the 2011 Congressional session.[4]

Another collaborative example focuses on specific watersheds, assembling stakeholders from local communities, federal agencies, industry and environmental groups. The Collaborative Forest Landscape Restoration Program for the Lakeview Federal Stewardship Unit on the Fremont and Winema national forests along the Oregon-Nevada border vets plans for restoration logging operations. The decade-long thinning operation intended to reduce severe wildfire threats produces a mix of saw logs and biomass. The latter is for 24-megawatt power at the Collins Company Fremont Sawmill.

The U.S. Forest Service worked to design the plan with the Lakeview Stewardship Group which includes The Wilderness Society, The Nature Conservancy, Defenders of Wildlife, Collins Companies, Concerned Friends of the Fremont/Winema, Lake County Chamber of Commerce, Lake County Resources Initiative, Lakeview High School, Oregon Department of Economic &Community Development, Oregon Wild, Sustainable Northwest and local government. The group released a plan in 2005 and updated it in 2010.[5]

Impacts of Biomass Removal

A Forest Guild assessment states, "Interest in extracting woody biomass for energy has increased because of rising fossil fuel costs, concerns about carbon emissions from fossil fuels, and risks from catastrophic wildfires. Previously developed forest practices guidelines did not anticipate the increased removal of biomass and offer no specific guidance on the amount of removal that is safe. In general, wood that would have been left on-site under traditional harvest conditions is removed in a biomass harvest, which can mean reduction of dead wood. Guidelines should make clear and specific recommendations to retain standing dead trees, existing coarse woody material (CWM), harvest generated CWM, fine woody material, and the forest floor and litter layer."[6]

---

[4] Oregon Eastside Forests Restoration, Old Growth Protection and Jobs Act. Viewed 4 Feb. 2011.
[5] Collaborative Forest Landscape Restoration Program, Proposal, Lakeview Federal Stewardship Unit, Fremont and Winema national forests, 13 May 2010.
[6] Alexander M. Evans and Perschel, Robert T. "An Assessment of Biomass Harvesting Guidelines," Forest Guild, Jan. 2005.

“The potential environmental outcomes of woody biomass removal are complex and interrelated,” says a 2008 report by the Oregon State Forester mandated by the Oregon State Legislature surveying what is known about the effects of forest biomass removal on forest ecosystems. It states, “effects may be positive, negative or a mix of both.” [7] The major concerns are effects on forest soils, water and wildlife.

The Oregon State Forester report found, “tremendous knowledge gaps in how different animal species will respond.” Large carnivores have wide ranges so only limited impacts are expected. Ungulate foraging is benefited but the animals need dense thickets for protection, so a forest mosaic is probably best. Small mammals may suffer negative impacts but recover quickly. Bird effects vary by species – opening dense second growth forests tends to increase diversity.

“In general, opening up dense stands over time increases understory plant biomass and biodiversity, and habitat diversity for wildlife . . .,” observed the report from the Oregon State Forester. “Biomass removal prescriptions that retain untreated refugia stands and create a mosaic of different forest structures across the landscape will likely retain greater wildlife species diversity than large, homogenous stands given the same treatment.” [8] One SAFN stakeholder noted their view that this conclusion was likely limited to westside forests.

The National Council for Air and Stream Improvement has conducted a meta-analysis on impacts of biomass harvesting on biodiversity in U.S. forests (in review) and examined 66 studies that cover a multitude of impacts, including specific taxa response (e.g., from invertebrate responses to thinning) to the general effect of different treatments (e.g., woody biomass removal, thinning, SRWC, intercropping). The NCASI meta-analysis indicates that multiple studies have concluded that thinning often has a positive impact on species diversity because it increases structural complexity of forest stands.[9]

In terms of soil impacts from forest residue removal and thinnings, studies from a long-term research site at Fall River, Washington were supplied to SAFN.

“Practices such as vegetation control, tillage, and fertilization can potentially increase site productivity and ameliorate negative impacts on productivity caused by soil compaction or nutrient removal,” say scientists reporting on a multi-year study at the Fall River site in coastal Southwest Washington. The effect of biomass removal on soil nutrients is a research focus there. Nitrogen stored below ground is 10 times the amount in above-ground vegetation, so tree harvest reduced nitrogen is 3-6 percent.[10]

The Oregon State Forester cites a long-term Rocky Mountains field study indicating that coarse woody debris “does not appear to make a significant contribution to N (nitrogen) and P (phosphorus) cycling in

---

[7] Oregon Department of Forestry, Office of State Forester “Environmental Effects of Forest Biomass Removal,” 1 Dec. 2008.

[8] Oregon State Forester, pp. 2-5.

[9] See Janowiak, M.K. and C.R. Webster. “Promoting ecological sustainability in woody biomass harvesting.” *Journal of Forestry.* 2010: 108: pp. 16-23; or National Council for Air and Stream Improvement, Inc. (NCASI). IN PRESS. *Relationships between intensive biomass production and biodiversity in U.S. forests – a literature review*. Technical Bulletin or Special Report No. XXX. Research Triangle Park, N.C.: National Council for Air and Stream Improvement, Inc.

[10] Adrian Ares et al. “The Fall River Long-Term Site Productivity Study in Washington State: Site Characteristics, Methods, and Biomass and Carbon and Nitrogen Stores Before and After Harvest.” USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-691, Jan. 2007.

these forests and may actually compete with vegetation for limiting nutrients."[11] The theory is that bacteria breaking down the wood consume available phosphorus.

The U.S. Forest Service North American Long-Term Soil Productivity Experiment found that removing all surface organic matter prior to planting, beyond what would be economically and operationally feasible, had no impact on total biomass production after 10 years across the studied geographies (five from the Sierra Nevadas and seven from the Southeastern Coastal Plain). [12] The study further found that removing surface organic matter also had no impact on carbon or nitrogen levels in the upper soil profiles. These studies found that post-harvest carbon increased at all depths across all studies (regardless of whether or not surface organic matter had been removed). The authors conclude that "soil inputs following disturbance depend less on decomposition of surface residues and more on the decay of fine roots that remained from the previously harvested stand."[13]

---

[11] Oregon Department of Forestry, pg. 44.

[12] Powers, Robert F., Felipe G. Sanchez, D. Andrew Scott, and Deborah Page-Dumroese."The North American Long-Term Soil Productivity Experiment: Coast-to-Coast Findings from the First Decade." US Department of Agriculture Forest Service Proceedings RMRS-P-34. 2004.

[13] Powers et al, 2004.

Appendix 3:
SUSTAINABLE AVIATION FUELS NORTHWEST CORE TEAM

SPONSORING ORGANIZATIONS STEERING COMMITTEE REPRESENTATIVES

Alaska Airlines - Megan Lawrence, Jacqueline Drumheller
The Boeing Company - Amy Bann, Mike Hurd, Darrin Morgan
Port of Portland - Phil Ralston, Renee Dowlin
Port of Seattle - Elizabeth Leavitt, Michael Lufkin
Spokane International Airport - Todd Woodard
Washington State University - John Gardner, Marcia Garrett

CLIMATE SOLUTIONS

Ross Macfarlane - Facilitator
Patrick Mazza – Lead Researcher/Writer
Jeannette Allan – Project Coordinator

STAKEHOLDERS

ADAGE - Al Wolfson
Air Transport Association - Tim Pohle, Steve Barker
AltAir Fuels LLC - Tom Todaro, Margarett McCormick, Laurie Sheahan
Bioalgene - Stan Barnes, Dale Gluck
BioPure Fuels - Bill Wason, Barry Code
Conservation Northwest - Mitch Friedman
Core Fuels - Bill Quigg, Bob Kommer
Dennee Consulting - Tammy Dennee
Great Plains Oil & Exploration, The Camelina Company - John King
Green Diamond Resource Company - Michael Pruett
Houghton Cascade - George H. Weyerhaeuser Jr.
Imperium Renewables, Inc. - John Plaza, Todd Ellis
MATRIC Research - Keith Pauley
Natural Resources Defense Council - Debbie Hammel
The Nature Conservancy - Molly W. Ingraham
Northwest Biodiesel Network - Erica Chung, Ray Brown
Oregon Department of Agriculture - Stephanie Page
Oregon Environmental Council - Jana Gastellum
Oregon State University - Jan Auyong, Bill Boggess
Parametrix - Dwight Miller
Roundtable on Sustainable Biofuel - Matt Rudolf, Peter Ryus, Barbara Bramble
Spokane Industries - Nathan Batson
Stoel Rives, LLP - Graham Noyes
Sun Grant Initiative – National – C.E. Watson
Sun Grant Initiative – Western Region – Bill Boggess
United States Department of Agriculture – Rural Development and Agricultural Research Services - Chris Cassidy
United States Department of Defense, Defense Logistics Agency Energy - Pamela Serino
United States Department of Energy – Brian Duff
UOP, Honeywell Company - Amar Anumakonda
Washington Environmental Council - Joan Crooks, Becky Kelly

Washington State Department of Commerce - Peter Moulton
Washington State Department of Natural Resources - Rachael Jamison
Washington State University - Bill L. Pan, Ashley Warren Hammac, Birgitte Ahring, Jim Jensen
Weyerhaeuser - Cassie Phillips, Edie Sonne Hall
William D. Ruckelshaus Center - Michael Kern
Wilson Sonsini Goodrich & Rosati - John Pierce

OBSERVERS

U.S. Senator Patty Murray - Jamie Shimek
U.S. Senator Maria Cantwell - Wyatt King
U.S. Representative Jay Inslee - Sharmila K. Swenson, Mark McIntyre
U.S. Congressman Adam Smith - Debra J. Entenman
Westbrook Associates LLC - Pat Binns

Appendix 4:
Bibliography

Adrian Ares et al. "The Fall River Long-Term Site Productivity Study in Washington State: Site Characteristics, Methods, and Biomass and Carbon and Nitrogen Stores Before and After Harvest." USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-691, Jan. 2007

Air Transport Action Group. "UNFCC Climate Talks: The right flight path to reduce aviation emissions." November 2010. PDF file.

Air Transport Administration. "21st Century Aviation - A Commitment to Technology, Energy, and Climate Solutions." 2011.

Air Transport Association. "When America Flies, it Works." Prod. ATA. 2010. PDF file. Alaska Air Group. "Improving Our Environmental Footprint: Alaska Air Group 2009 Environmental Report". Alaska Airlines. 2009.

Amyris Biotech

Ares, Adrian, et al. "The Fall River Long-Term Site Productivity Study in Coastal Washington: Site Characteristics, Methods, and Biomass and Carbon and Nitrogen Stores Before and After Harvest." Prod. USDA Forest Service Pacific Northwest Research Station. Olympia, WA. January 2007. PDF file.

The Assistant Secretary of the Air Force for Installations, Environment and Logistics "U.S. Air Force Energy Plan." 2010. PDF file.

Baffes, John and Tassos Haniotis. "Placing the 2006/08 Price Boom into Perspective." The World Bank Development Prospects Group July 2010. PDF file.

Banowetz, Gary M., et al. "Assessment of straw biomass feedstock resources in the Pacific Northwest." *Elsevier*. 8 February 2008. PDF file.

Bauen, Ausilio, et al. "Review of the Potential for Biofuels in Aviation." Prod. *E4Tech*. August 2009. PDF file.

Bio Economic Research Associates. "U.S. Economic Impact of Advanced Biofuels Production: Perspectives to 2030." February 2009. PDF file.

Blackwelder, Brad D. and Erin Wilkerson. "Supply System Costs of Slash, Forest Thinnings and Commercial Energy Wood Crops." Idaho National Labratory. September 2008. PDF file.

Brundtland, Gro Harlem. The Report of the Brundtland Commission, "Our Common Future." Oxford University Press, 1987.

Bureau of Economic Analysis. "Regional Economic Accounts: State Annual Personal Income." Bureau of Economic Analysis. U.S. Department of Commerce. 2008.

Chester, Mikhail and Elliot Martin. “Cellulosic Ethanol from Municipal Solid Waste: A Case Study of the Economic, Energy, and Greenhouse Gas Impacts in California.” Prod. Department of Civil and Environmental Engineering, UC Berkeley. Berkeley, CA. 20 May 2009. PDF file.

Choren

Clarens, Andres F., et al. “Environmental LIfe Cycle Comparison of Alge to Other Bioenergy Feedstocks.” *Environmental Science and Technology*. 19 January 2010.

Clean Energy Leadership Council. “Recommendations and Report Submitted to the Governor and the Legislature.” *Washington Clean Energy Leadership Council*. 20 January 2011.

Cobalt Technologies

Coskata

Coyle, William T. “Next-Generatioin Biofuels: Near-Term Challenges and Implications for Agriculture.” Prod. USDA Economic Research Service. May 2010. PDF file.

Darzins, Al, Philip Pienkos and Les Edye. “Current Status and Potential for Algal Biofuels Production: A Report to IEA Bioenergy Task 39.” T39-T2 BioIndustry Parterns and National Renewable Energy Laboratory. 6 August 2010. PDF file.

Department of Ecology State of Washington. “Washington State's Waste Reduction Plan.” Washington State Department of Ecology. 2011.

Dowdell, Maj. Richelle. “Officials certify first aircraft for biofuel usage.” U.S. Air Force. 10 February 2011.

Dynamotive

Enerkem

Ensyn

Enviro.aero

Environment Blog. *The Guardian.* United Kingdom. 8 March 2011.

Environmental Leader: Environmental and Energy Management News. “Airlines to Be Second Biggest Sector in EU Carbon Market; Energy Firms Want Tough Targets.” 7 March 2011.

Environmental Protection Agency. “EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels.” Washington, D.C., February 2010. PDF file.

Ewing, Phillip. “Cut half of oil use by 2020.” *Navy Times*. 14 October 2009.

Federal Aviation Administration. “The Impact of Civil Aviation on the U.S. Economy.”
December 2009. PDF file.

Forest Concepts. "Biomass Baling Technology." 3 February 2001.

Range Fuels

Fulcrum Bioenergy

Hegerl, G.C., F. W. Zwiers, P. Braconnot, N.P. Gillett, Y. Luo, J.A. Marengo Orsini, N. Nicholls, J.E. Penner and P.A. Stott. "Understanding and Attributing Climate Change." *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY., USA. 2007.

Holladay, JE, et al. "Top Value Added Chemicals from Biomass Volume II - Results of Screening for Potential Candidates from Biorefinery Lignin." Prod. U.S. Department of Energy. Washington, D.C. PDF file.

Hornby, Catherine. "FAO food price index hits record high in December." *Reuters.* 5 January 2011.
International Air Transport Association. "Outlook Downgraded to $8.6 Billion - High Oil Price Cuts Airline Profits by Almost 50%." 2 March 2011.

Janowiak, Maria K. and Christopher R. Webster. "Promoting Ecological Sustainability in Woody Biomass Harvesting." *Journal of Forestry*. 2010. 108: 16-23.

Jones, SB, Y Zhu and C Valkenburg. "Municipal Solid Waste to Liquid Fuels Synthesis, Volme 2: A Techno-economic Evaluation of the Production of Mixed Alcohols." Prod. Pacific Northwest National Laboratory. Richland, WA. April 2009. PDF file.

Kerstetter, James D. and John Kim Lyons. "Logging and Agricultural Residue Supply Curves for the Pacific Northwest." Washington State University Energy Program, Pullman, WA. January 2001. PDF file.

King County Solid Waste Division. "Fees - Solid Waste Disposal, Recycling, and Unsecured Loads." 1 January 2008.

Kiser, Jonathan V.L. "Recycling and Waste-to-Energy: The Ongoing Campatibility Success." *MSW Management.* June 2003.

LS9

Lakeview Federal National Forests. "Collaborative Forest Landscape Restoration Program." Lakeview, OR.13 May 2010. PDF file.

LanzaTech

Lardon, Laurent, et al. "Life-Cycle Asessment of Biodiesel Production from Microalgae." *Environmental Science and Technology.* 27 July 2009.

Lee, Carrie, et al. Greenhouse gas and air pollutant emissions of alternatives for woody biomass residues." Prod. Stockholm Environment Institute. November 2010. PDF file.

Maron, Dina Fine. "Much touted cellulosic ethanol is late in making its mandated appearance." *ClimateWire*. 11 Jan. 2011

Mason, C. Larry, et al. "Wood to Energy in Washington: Imperatives, Opportunities, and Obstacles to Progress." Seattle, WA. June 2009. PDF file.

Mitchell, Stephen R., Mark E. Harmon and Kari E.B. O'Connell. "Forest fuel reduction alters fire severity and long-term carbon storage in three Pacific Northwest ecosystems." Prod. Oregon State University Department of Forest Science. Corvalis, OR. 7 July 2009. PDF file.

Mote, Philip W. and Eric P. Salathe. "Future Climate in the Pacific Northwest." *Climatic Change*. 2010. PDF file.

NASA. "NASA Research Finds 2010 Tied for Warmest Year on Record." *Goddard Institute for Space Studies.* 12 January 2011.

Netmanifold.com. "LRI Landfill." 2002.

Oneil, Elaine, Bruce Lippke and Larry Mason. "Eastside Climate Change, Forest Health, Fire and Carbon Accounting." Prod. ruraltech.org. July 2007. PDF file.

Oregon Department of Forestry. "Environmental Effects of Forest Biomass Removal." 1 December 2008. PDF file.

Pacific Region Bioenergy Partnership. "Pacific Biomass." December 2010.

Perlack, Robert D., et al. "Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply." Prod. Oak Ridge National Laboratory. Oak Ridge, TN. April 2005. PDF file.

Peterson, G. and T. Werpy. "Top Value Added Chemicals from Biomass Volume I - Results of Screening for Potential Candidates from Sugars and Synthesis Gas." Prod. U.S. Department of Energy. Washington, D.C., August 2004. PDF file.

The Pew Project on National Security, Energy, and Climate. "The Armed Services Climate and Energy Initiatives: U.S. Navy." PDF file.

Powers, Robert F., et al. "The North American Long-Term Soil Productivity Experiment: Coast-to-Coast Findings From the First Decade." Prod. USDA Forest Service. 2004. PDF file.

President's Biofuels Interagency Working Group. "Growing America's Fuel: An Innovation Approach to Achieving the President's Biofuels Target." Washington, D.C., February 2010. PDF file.

Rentech

Research and Innovative Technology Administration. "Energy Consumption by Mode of Transportation." 2002.

Roberts, Billy. "Biomass Resources of the United States: Resources by County." 23 September 2009. PDF file.

Roundtable on Sustainable Biofuels. "RSB Guidance on Principles & Criteria for Sustainable Biofuel Production." 11 December 2009. PDF file.

Sander, Kyle and Ganti S. Murthy. "Life cycle analysis of algae biodiesel." *The International Journal of Lifecycle Assessment*. 2010.

Schillinger, William F., et al. "Dryland Cropping in the Western United States." Pacific Northwest Conservation Tillage Handbook Series No. 28. December 2003. PDF file.

Schnepf, Randy. "Cellulosic Ethanol: Feedstocks, Converstion Technologies, Economics and Policy Options." Prod. Congressional Research Service. 22 October 2010. PDF file.

Serino, Pamela, Defense Logistics Agency-Energy, Presentation, 8 December 2010 and personal interview 13 April 2011.

Shalal-Esa, Andrea. "Mideast unrest shows need for alternative fuels: Navy Secretary." *Reuters.* 22 February 2011.

Sightline Institute. "Spending on Imported Fossil Fuels in 2008."

Solena Fuels

Stiles, Dennis, et al. "Biofuels in Oregon and Washington: A Business Case Analysis of Opportunities and Challenges." Prod. Pacific Northwest National Laboratory. February 2008. PDF file.

Stratton, Russell W., Min Hsin Wong and James I. Hileman. "Life Cycle Greenhouse Gas Emissions from Alternative Jet Fuels." Partnership for AiR Transportation Noise and Emissions Reduction. Massachusetts Institute of Technology, Cambridge, MA., June 2010. PDF file.

Sustainable Aviation Fuel Users Group. "Our Commitment to Sustainable Options." 2010.

Terrabon

U.S. Department of Agriculture. "A USDA Regional Roadmap to Meeting the Biofuels Goals of the Renewable Fuels Standard by 2022." Washington, D.C., 23 June 2010. PDF file.

U.S. Department of Energy. "National Algal Biofuels Technology Roadmap." Washington, D.C., May 2010. PDF file.

U.S. Energy Information Administration. "Energy Related Carbon Dioxide Emissions." 2010.

U.S. Energy Information Administration. "Petroleum and Other Liquids." 20 January 2011.

U.S. Energy Information Administration. "U.S. Imports of Crude Oil and Petroleum Products, 1973-2005."

U.S. Energy Information Administration. "U.S. States Overview: Energy Distribution." January 2011.

U.S. Energy Information Administration. "Renewable Energy Consumption in the Nation's Energy Supply." August 2010.

U.S. Government Accountability Office. "Aviation and Climate Change: Aircraft Emissions Expected to Grow, but Technological and Operational Improvements and Goverment Policies Can Help Control Emissions." Prod. Government Accountability Office. Washington, D.C., June 2009. PDF file.

Urbanchuk, John M. "Economic Impact of Eliminating the Biodiesel Tax Credit." LECG. Wayne, PA. 3 December 2009. PDF file.

Vajzovic, Azra et al. "Converting Washington Lignocellulosic Urban Waste to Ethanol: Part 1, Process Research." College of Forest Resources and Mechanical Engineering. University of Washington, Seattle, WA.

Valkenburg, C, et al. "Municipal Solid Waste to Liquid Fuels Synthesis, Volume 1: Availability of Feedstock and Technology." Prod. Pacific Northwest Laboratory. Richland, WA. December 2008. PDF file.

"WSU Poplar Research Program." Washington State University, Seattle, WA. 2011.

Welch, Craig and Michael Lindblom. "Agreement to stop burning coal at Centralia power plant." *Seattle Times*. 5 March 2011.

Western Governors Association. "Strategic Assessment of Bioenergy Development in the West." 1 September 2008. PDF file.

The White House. "Blueprint for a Secure Energy Future." Washington, D.C., 30 March 2011. PDF file.

The White House Office of the Press Secretary. "Remarks by the President on America's Energy Security." Washington, D.C., 31 March 2011.

Wijffels, Rene W. and Maria J. Barbosa. "An Outlook on Microalgal Biofuels." 13 August 2010. PDF file.

Wyden, Ron, U.S. Senator. "Oregon Eastside Forests Restoration, Old Growth Protection and Jobs Act."

Yoder, Jonathan. "Biofuel Economics and Policy for Washington State." Washington State University, Pullman, WA., February 2010. PDF file.

Zeachem

View the complete report www.safnw.com

Cover Photo Credit: Alaska Airlines
Printing: Premier Graphics, recycled paper
Graphic Design: Web Rodeo, www.webrodeo.com