Work in Progress

The Sustainability of Biomass Energy in the Pacific Northwest: A Framework for the PNW Region of the Sun Grant Initiative

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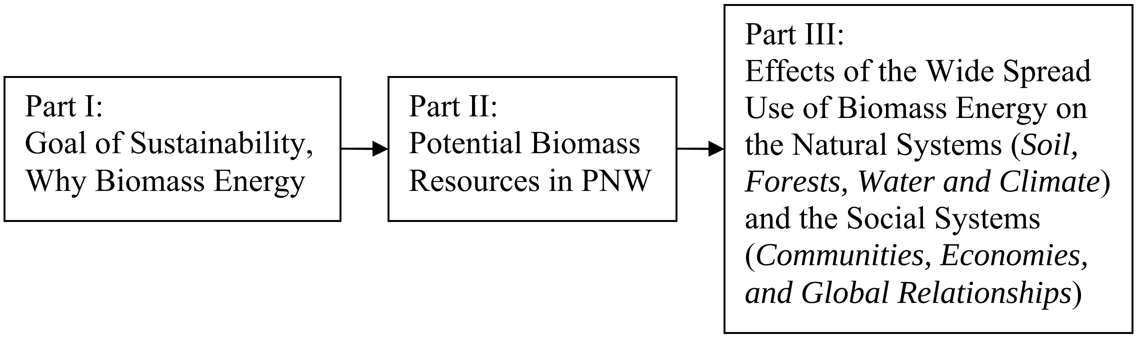
Introduction

Since the fuel crisis in the 1970's, the Pacific Northwest region has been investigating the use of plant matter and biotic wastes to produce energy. However, within the last five years, the investigations have reached an unprecedented level of interest and support. Governments, private industries, and academics have partnered together to show that there are many ways of producing energy from these biological sources. In many ways, these processes are superior to using fossil fuels as energy because they are able to be harvested continuously or annually. Unlike fossil fuels, many of these sources are able to be rapidly regenerated, and therefore represent an attractive alternative. However, no one process has been shown overwhelmingly to be environmentally superior, financially competitive, and producible on a large enough scale to completely replace the need for fossil fuels in the short run. Biomass energy is not likely a panacea for the U.S. energy woes, our changing economic base, or our worries about the environment, however, with carefully crafted policies, they can represent a step in the right direction for the environmental, positive economic opportunity for many, especially in rural communities, and a source of minor alleviation on the already overburdened world-wide demand for energy.

This report examines the effects of producing biomass energy in the Pacific Northwest on a large scale. We discuss the goal of sustainability followed by an introduction to biomass resources from a Pacific Northwest. This is followed by researching the likely effects of the wide spread use of biomass energy on the natural systems (e.g. soil, forests, water, and climate) and the social systems (e.g. communities, economies, and global relationships) (See below).



Part I

Sustainability

Sustainability was a buzz word of the late twentieth century. Today many academics and policy makers refuse to use the word, as they feel it has lost all meaning. In presenting a report of the sustainability of biomass energy, we are reasserting the deep message of sustainability. It is not just a buzz word, but a way of thinking. Sustainability can certainly mean many things to many people, but it truly represents the ideas of balance and limits. One of the most fundamentally important definitions of sustainability comes from the Brundtland Commission (United Nations, 1987). This commission established the notion of sustainable development as meeting the needs of the present without compromising the ability of future generations to meet their own needs. This definition is purposefully vague. It alludes to a notion of sustainability that encompasses balancing the environment, economics, and culture. What ever order our personal beliefs dictate these should be listed does not change that they are all equally important. Not one of these interests operates in a vacuum and no review of sustainability would be complete without careful consideration of each.

Generally there are four dimensions of sustainable development: economic, social, environmental and institutional (Fig1). Like the objectives of sustainable development, three of the sustainable dimensions, as we mentioned above, are reduction of environmental pressures, social cohesion, and competitive economy. The institutional dimension is the key tool for the governance of sustainable development. It is essential to take the inter-linkages of these dimensions into account when crafting policies. Compromises and synergies must be sought between each of the four dimensions in order to achieve true sustainability.

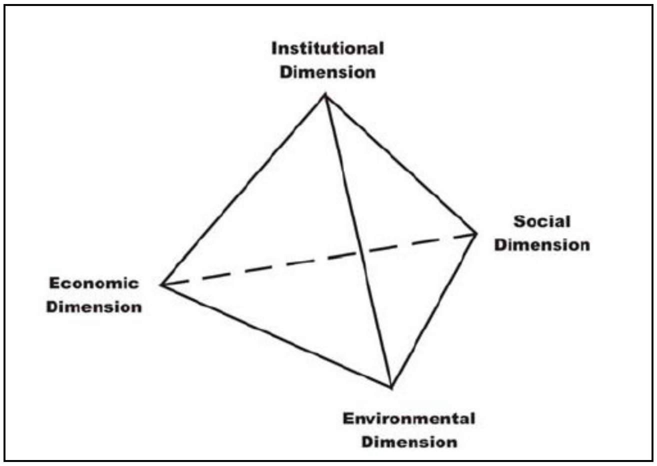


Figure 1: Sustainability Prism
(Governance for Sustainable Development, 2004)

Why Biomass Energy?

The U.S. Department of Energy, Energy Information Administration reports that 90% of global energy depends on oil, coal and natural gas. Unfortunately, the continued use of fossil fuels is not sustainable and has likely resulted in global warming (Ritter, 2007) and acid rain (Hooper, 2006), which seriously threaten our environment, natural systems and our human health. In an effort to preserve our natural resources and sustain environment quality, we are now in search of renewable and clean energy sources. Examples of such energy sources are wind power (Karki, 2007), solar power (Lund, 2007), biomass energy (Fernandes *et al*, 2007), hydro-electric power (Malley *et al*, 2007), and geothermal energy (Tester *et al*, 2007). One that has received considerable attention in the last five years has been biomass energy, the renewable energy made from biomass. In U.S., biomass energy contributed 3% to the nation’s energy supply (Fig 2). It is believed that biomass products could play a vital role in reduction of the need for oil and gas imports, in the growth of agriculture, forestry, and rural economies, and in support of new domestic industries (USDA, 2005).

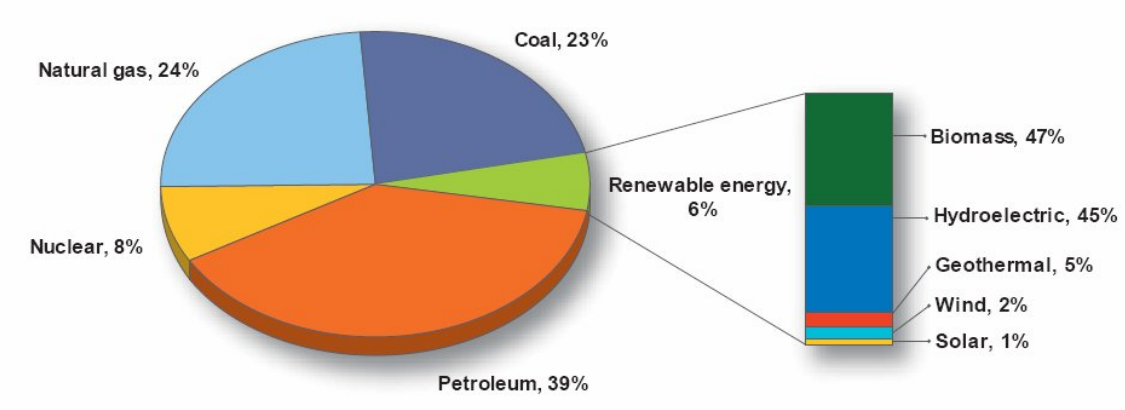
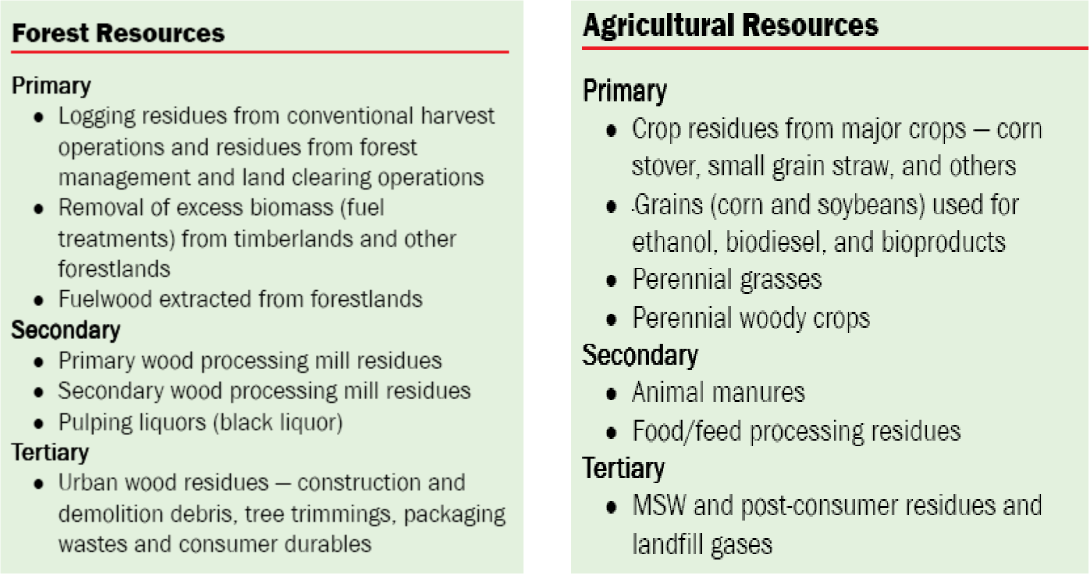


Figure 2: U.S. Energy Sources Pie
(USDA, 2005)

Part II

Biomass Feedstocks in the Pacific Northwest

Generally speaking, biomass is composed of forestry resources and agricultural resources based on where the feedstocks come from, and they both have three levels of resources- the primary level (direct from photosynthesis), the secondary level (residues from central processing), and the tertiary level (salvage after secondary use as post-consumer residues) (Fig 3). The Pacific Northwest, which include all of Idaho, Oregon, and Washington, counties in Montana west of the Continental Divide, and northern counties in California (NRC, 2000) has a tradition of using biomass energy, and thus analysis of the local feedstocks is of interest when we examine the sustainability of biomass energy in this region.


Forest Resources

Primary
- Logging residues from conventional harvest operations and residues from forest management and land clearing operations
- Removal of excess biomass (fuel treatments) from timberlands and other forestlands
- Fuelwood extracted from forestlands

Secondary
- Primary wood processing mill residues
- Secondary wood processing mill residues
- Pulping liquors (black liquor)

Tertiary
- Urban wood residues — construction and demolition debris, tree trimmings, packaging wastes and consumer durables

Agricultural Resources

Primary
- Crop residues from major crops — corn stover, small grain straw, and others
- Grains (corn and soybeans) used for ethanol, biodiesel, and bioproducts
- Perennial grasses
- Perennial woody crops

Secondary
- Animal manures
- Food/feed processing residues

Tertiary
- MSW and post-consumer residues and landfill gases

Figure 3: Biomass Feedstocks Levels
(USDA, 2005)

A. Forest-Derived Resources

Forests in the Pacific Northwest region are complex in view of various patterns of precipitation, soils, elevation, disturbance, management, use, and ownerships (Fig 4) (NRC, 2000). The local forests can provide us with a huge amount of biomass from different levels.

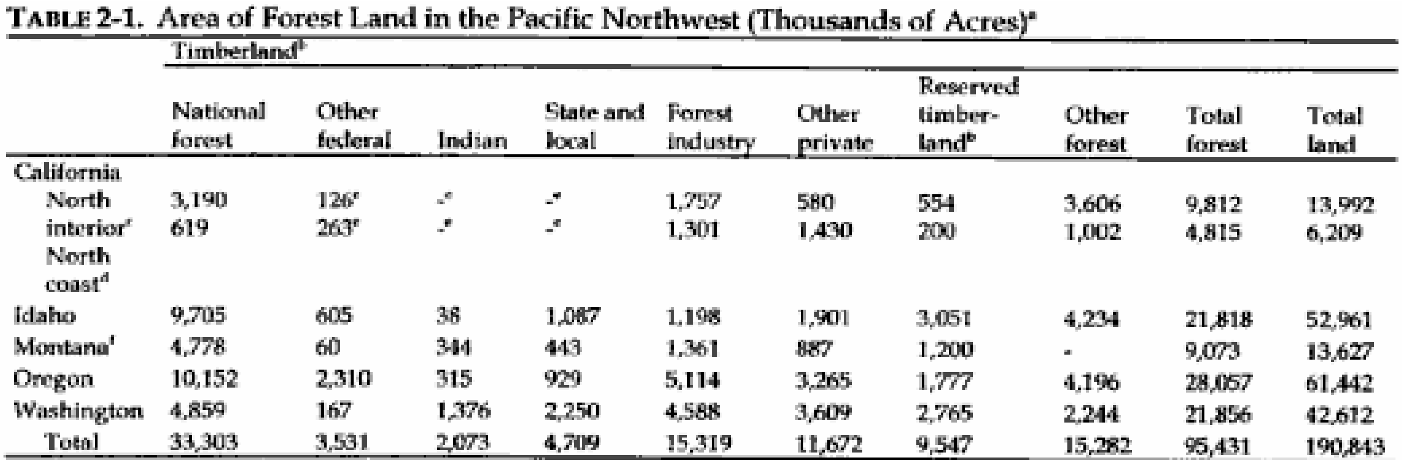


TABLE 2-1. Area of Forest Land in the Pacific Northwest (Thousands of Acres)[a]

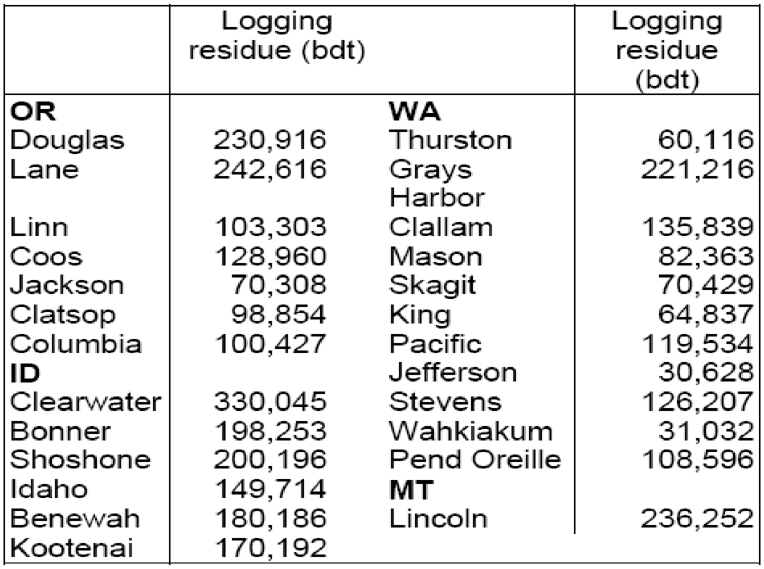
	Timberland[b]									
	National forest	Other federal	Indian	State and local	Forest industry	Other private	Reserved timber-land[b]	Other forest	Total forest	Total land
California										
North interior[c]	3,190	126[e]	-[f]	-[f]	1,757	580	554	3,606	9,812	13,992
North coast[d]	619	263[e]	-[f]	-[f]	1,301	1,430	200	1,002	4,815	6,209
Idaho	9,705	605	38	1,087	1,198	1,901	3,051	4,234	21,818	52,961
Montana[f]	4,778	60	344	443	1,361	887	1,200	-	9,073	13,627
Oregon	10,152	2,310	315	929	5,114	3,265	1,777	4,196	28,057	61,442
Washington	4,859	167	1,376	2,250	4,588	3,609	2,765	2,244	21,856	42,612
Total	33,303	3,531	2,073	4,709	15,319	11,672	9,547	15,282	95,431	190,843

Figure 4: Forest Area in the Pacific Northwest

(NRC, 2000)

a. Primary Level:

Tree tops, limbs, and cull materials discarded in logging activity have great potential in providing biomass energy. They have a bulk density of 18 to 22 pounds per cubic foot and have an energy value of 4,500 Btu per pound (Oregon's Biomass Energy Resources, 2007). Logging residues were estimated for a number of select counties in the Pacific Northwest region (Fig 5). Much of the logging residues can be utilized for energy production.



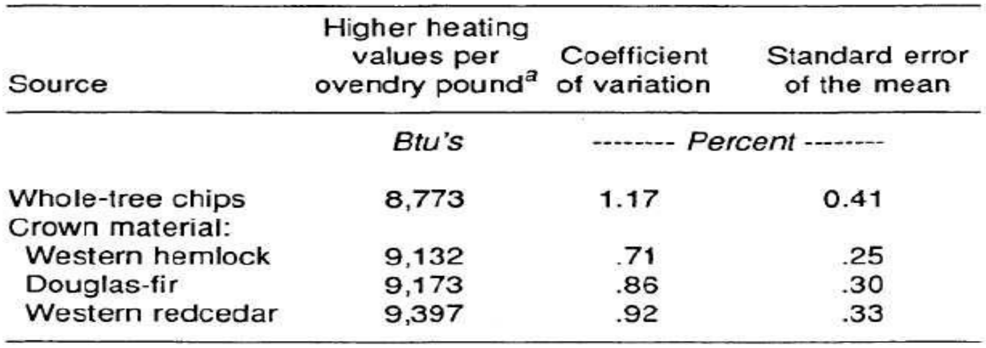
	Logging residue (bdt)		Logging residue (bdt)
OR		**WA**	
Douglas	230,916	Thurston	60,116
Lane	242,616	Grays Harbor	221,216
Linn	103,303	Clallam	135,839
Coos	128,960	Mason	82,363
Jackson	70,308	Skagit	70,429
Clatsop	98,854	King	64,837
Columbia	100,427	Pacific	119,534
ID		Jefferson	30,628
Clearwater	330,045	Stevens	126,207
Bonner	198,253	Wahkiakum	31,032
Shoshone	200,196	Pend Oreille	108,596
Idaho	149,714	**MT**	
Benewah	180,186	Lincoln	236,252
Kootenai	170,192		

Figure 5: Total Logging Residues for Select Counties

(Kerstetter & Lyons, 2001)

Moreover, excessive accumulation of forest biomass would result in a threat to the health of live trees by increasing susceptibility to disease, insect infestations and high-intensity fires. Therefore, selective thinning that removes the excessive biomass is important. Studies show that the cost of fighting forest fires is about $216 per acre, while the cost of thinning activities ranges from $50 to $150 per acre (Sampson *et al*, 2001), which would indirectly encourage the utilization of the forest biomass.

Lastly, fuelwood is another main product of the forests. Forestlands in the contiguous United States produce 52 million dry tons of fuelwood annually, and 35 million dry tons would be consumed per year for residential and commercial use and electric use (USDA, 2005). Major fuelwoods in the Pacific Northwest include western hemlock, coast Douglas-fir, and western red cedar, which have enormous energy potential. The heating values of them are shown below (Fig 6).



Source	Higher heating values per ovendry pound[a]	Coefficient of variation	Standard error of the mean
	Btu's	-------- *Percent*	--------
Whole-tree chips	8,773	1.17	0.41
Crown material:			
Western hemlock	9,132	.71	.25
Douglas-fir	9,173	.86	.30
Western redcedar	9,397	.92	.33

Figure 6: Heating Values and Statistical Data for Whole-Tree Chips, and Crowns for Western Hemlock, Douglas-Fir, Western Red Cedar
(Howard, 1988)

b. Secondary Level:

Wood processing mill residues is a byproduct of timber milling and wood products manufacturing. At sawmills, harvested timber is converted into wood products by means of debarking, chipping, sawing, peeling, planning, shaving, trimming and sanding. The mill waste can be used as fuels after being ground in a hog. They are usually burned to heat industrial boilers for process-stream generation. It is discovered that low-quality hog fuels have 50% moisture content, 4,500 Btu per pound energy content, and 16~22 pounds per cubic foot bulk density (Oregon's Biomass Energy Resources, 2007). High-quality wastes generated from more modern and more efficient mills can be applied to the pulp and paper industry.

Pulping converts wood or lignocellulosic nonwood material to separated pulp fibers to make paper. In the process, a waste stream of spent pulping liquor is produced, which has the potential to increase electricity generation (Farahani & Worrell, 2004). It has been reported that there have been two pulp mills in Oregon that use boilers to cogenerate steam and electricity (Oregon's Biomass Energy Resources, 2007). In addition to electricity, pulping liquor can be converted into bioethanol as well (Kadam and McMillan, 2003).

c. Tertiary Level:

Urban wood wastes include:

1. wood wastes disposed of with, or recovered from the municipal solid waste stream. industrial wood wastes such as wood scraps and sawdust from pallet recycling, woodworking shops, and lumber yards, and
2. wood in construction/demolition and land clearing debris. 1,300 MW of electricity energy per million people is consumed in the US, and urban
3. wood wastes can generate 5~50 MW per million people, accounting for roughly 0.4%~4% of the urban electricity needs (Wiltsee, 1998). In the Pacific Northwest, recovery rates for urban wood wastes have been driven to unprecedented levels because of a rising demand for wood fiber in recent years. Studies estimate that 640,000 tons of urban wood wastes were recovered in Washington in 1994 and 142,000 tons of commercial and residential urban wood residuals were recovered in 1993 in Oregon (Conrad, 1995).

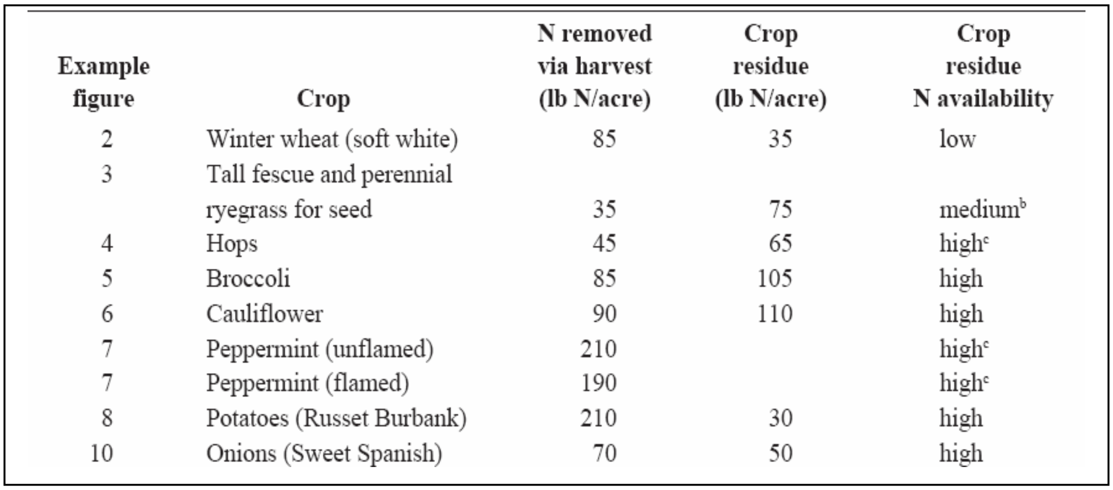
B. Agriculture-Derived Resources

As the third largest use of land in the United States, agriculture directly or indirectly provides a wide range of biomass resources such as crop residues, grains, secondary residues like animal manures, and tertiary residues like landfill gases.

a. Primary Level:

Crop residues:

Crop residues, the leftovers after the harvest of field crops, often refer to straw, stalks, stubble, leaves, and seed pods. The average moisture content of the crop residues is 15 percent. The average heat content is 7,500 Btu per pound. Bulk density of them ranges from 10 to 16 pounds per cubic root. The supply of crop residues is not constant due to the annual cycles of growth and harvest. In 2003, around 1.5 million dry tons of crop residues were available in Oregon, the energy content of which was 27 trillion Btu. This could be converted into 213 average megawatts of electricity (Oregon Department of Energy). However, another important role of crop residues we cannot neglect is maintenance of soil nutrients. Different crop residues may have different nutrient content. Let's take nitrogen for example. Studies of PNW crops show that the local crops vary in the nitrogen availability which should be taken into consideration when we explore the tradeoffs of biomass energy from crop residues (Fig 7).



Example figure	Crop	N removed via harvest (lb N/acre)	Crop residue (lb N/acre)	Crop residue N availability
2	Winter wheat (soft white)	85	35	low
3	Tall fescue and perennial ryegrass for seed	35	75	medium[b]
4	Hops	45	65	high[c]
5	Broccoli	85	105	high
6	Cauliflower	90	110	high
7	Peppermint (unflamed)	210		high[c]
7	Peppermint (flamed)	190		high[c]
8	Potatoes (Russet Burbank)	210	30	high
10	Onions (Sweet Spanish)	70	50	high

Figure 7: Nitrogen Removed from the Field and Recycled via Crop Residues
(Sullivan & Hart, 1999)

Oilseeds:

Oilseeds are used to produce most of the bioethanol, biodiesel, and bioproducts. The Pacific Northwest has a unique climate, and therefore can support a number of featured primary feedstock inputs. Below are some types of the feedstock available in this region.

►Yellow mustard – *sinapsis alba* can produce about 100 gallons per acre at a projected 3000 lbs per acre seed yield. The oil concentration in the seed is lower than canola (27% vs. 40%) and the meal is high in glucosinolates, making the meal not suitable for consumption by livestock. The meal might be saleable in the natural pest control market.

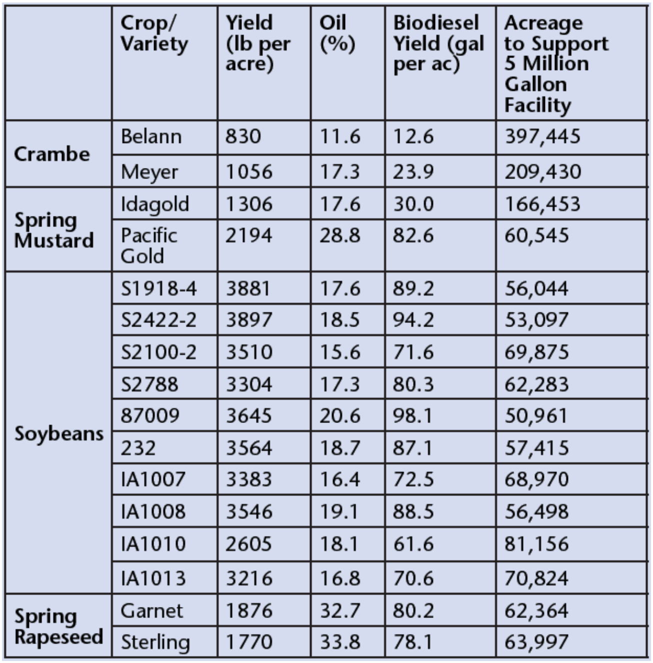
►Sunflower - Grown under irrigation, the oil yields of sunflower are very good, ranging from 90 to 100 gallons of oil per acre. The high cost of irrigation and low availability of water in late summer would likely prevent the economic culture of sunflower for biodiesel in the Willamette Valley.

►Canola - Winter canola is often projected to produce more oil per acre (100 to 200 gallons per acre) than any other potential biodiesel feedstock in the region. The meal remaining after processing is a rich source of protein, which can be fed to livestock and would be an additional source of income (Chastain *et al*, 2005). Winter Canola cultivars can be planted in late August or early September (depending on location) and will be ready for harvest in about 10 months (June or July). In rotation, canola reduces the levels of these pathogens (Russian wheat aphid, Hessian fly, and certain wheat diseases, such as take-all (Gaunmanomyces graminis) and eyespot (*Pseudocerospoelle hepitricoides*) in subsequent wheat crops.

On the other hand, risks of planting canola have received great attention and conflicts with the vegetable production industry have been obvious. Since commercial vegetable seed production in the United States takes place in the west coast (Bonina & Cantliffe, 2004), a great many conventional and organic seed companies from Europe, Asia, South and North America depend on the Willamette Valley, Skagit Valley, and much of the northern Puget Sound region for vegetable seed production (Dillon, 2007). Concerns are mainly from the following aspects (WSU NWREC, 2006). **A:** Canola is potential to cross-pollinate other crucifer vegetable seed crops. Scientists have suggested that the vegetable seed crops field should be isolated from the canola fields to prevent the crosspollination. In addition, since canola is a genetically modified species, GMO contamination should also be considered (discussed in GMO section). **B**: Canola can act as a source of inoculums for black leg and black rot, which are two significant threats to canola production as well as crucifer vegetable seed crop production. **C**: Volunteers/crucifer weeds from canola field are likely to persist in fields and along roadsides, affecting the growth of crucifer vegetable seed crops. **D**: Due to reasons described above, expansion of canola production may lead to a decrease of crucifer vegetable seed from vegetable seed companies, jeopardizing small-seeded vegetable seed industry. If crucifer vegetable seed acreage is removed, then production of other vegetable seed crops such as carrot, spinach, beet, onion, etc. may not be attractive enough to pull vegetable seed contracts.

►Safflower (*Carthamus tinctorius*) can tolerate extreme weather conditions, and is considered a low input and drought tolerant crop. It is planted in early spring, and matures in five months. It yields 3000 to 3500 pounds of seed with oil concentrations of 42 to 48% (Collins *et al*, 2006).

►Soybean-Studies show that when the maturity group is properly chosen, soybean can grow very well with irrigation in this region. Inoculation of soybean seed with *Bradyrhizobium japonicum* would yield highly on land not previously planted to soybean. Yields of soybean range from 3500 to 4000 pounds per acre under irrigation. Soybean has a lower oil concentration (15-20%) than canola or rapeseed, but it possesses high protein meal that provides a high quality livestock feed (Collins *et al*, 2006). Figure 8 shows some regional oilseed biomass yields.



	Crop/ Variety	Yield (lb per acre)	Oil (%)	Biodiesel Yield (gal per ac)	Acreage to Support 5 Million Gallon Facility
Crambe	Belann	830	11.6	12.6	397,445
	Meyer	1056	17.3	23.9	209,430
Spring Mustard	Idagold	1306	17.6	30.0	166,453
	Pacific Gold	2194	28.8	82.6	60,545
Soybeans	S1918-4	3881	17.6	89.2	56,044
	S2422-2	3897	18.5	94.2	53,097
	S2100-2	3510	15.6	71.6	69,875
	S2788	3304	17.3	80.3	62,283
	87009	3645	20.6	98.1	50,961
	232	3564	18.7	87.1	57,415
	IA1007	3383	16.4	72.5	68,970
	IA1008	3546	19.1	88.5	56,498
	IA1010	2605	18.1	61.6	81,156
	IA1013	3216	16.8	70.6	70,824
Spring Rapeseed	Garnet	1876	32.7	80.2	62,364
	Sterling	1770	33.8	78.1	63,997

Figure 8: Biofuel Variety Trials at Paterson, WA (preliminary yield data) (2004~2005)
(Collins *et al*, 2006)

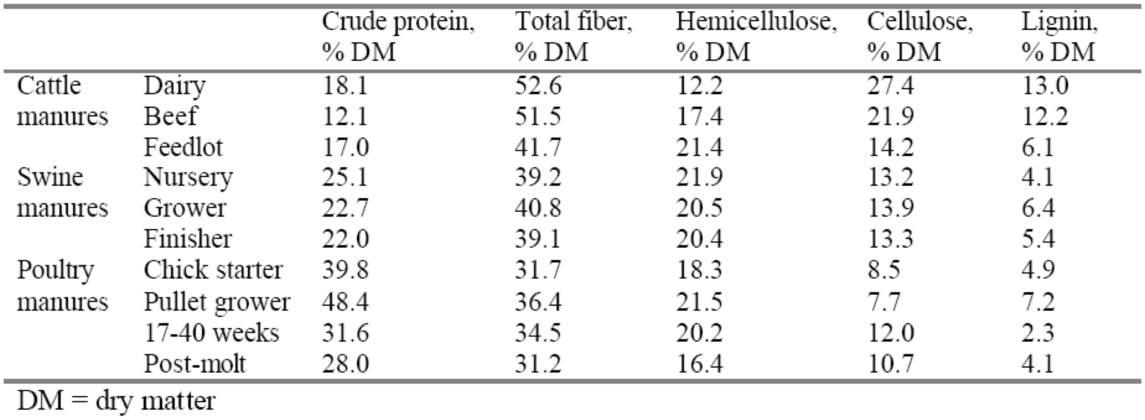
Grains:

In the Pacific Northwest region, wheat is grown on 4~5 million acres and is the primary cash crop in the non-irrigated regions. Wheat production is limited by water, and therefore effective tillage and residue management systems are necessary to conserve precipitation. For example, winter wheat grown in rotation with spring cereals and legumes are used where winter precipitation is sufficient (>450 mm) to recharge the soil profile. A winter wheat-spring cereal-fallow system can be applied in areas receiving 330 to 450 mm annual precipitation. If annual precipitation is less than 330 mm, a winter wheat-fallow system is a good idea. Summer fallow is carried out on approximately 60% of the dry-farmed cropland. To make wheat a sustainable biomass resource, various systems should be developed to maintain a high yield of wheat (Hammel, 1996).

Perennial grasses/woody crops:
Other primary resources include perennial woody grasses or crops such as switchgrass which may also act as effective biomass. As a C4 species, switchgrass – Panicum fixes carbon by multiple metabolic pathways with high water use efficiency. In general C4 plants such as grasses will produce 30% more food per unit of water than C3 species such as trees and broadleaved crops and grasses and are well adapted to the more arid production areas of the mid-western US where growth is more limited by moisture supply. The ecological diversity of switchgrass can be attributed to three principal characteristics, genetic diversity associated with its open pollinated reproductive mode, a very deep, well-developed rooting system, and efficient physiological metabolism. Recent calculations of the net energy gains from ethanol production from a forage crop like switchgrass indicate that both net energy savings and net carbon savings will be achieved much more rapidly than with more energy-expensive processes such as conversion of corn grain to ethanol (McLaughlin and Walsh 1998).

b. Secondary Level:

Animal manures:
There are approximately 160 million tons of animal manures produced annually in the US (Council for Agricultural Science and Technology, 1995). They can cause environmental problems (e.g. greenhouse gas release, contamination of water, etc.) due the difficulty associated with disposal. Animal manures contain lignocelluloses, polysaccharides, proteins, and other biological materials. Among all these, protein contents are a critical factor for the utilization of animal manures as biomass resources, because proteins have negative effects on sugar yield due to the formation of colored materials in Maillard reactions, and inhibit the catalyst in hydrogenation of sugars. Therefore, the most valuable animal manures should have higher fiber content and lower protein concentration (Chen *et al*, 2003). Figure 9 compares fiber and protein contents in cattle, swine, and poultry manures. As is shown, cattle manures have the highest fiber and lowest protein, which are comparatively advantageous. Still, using animal manures is more complicated than using lignocellulosic biomass such as wood and straw, due to the complex composition and protein disturbance.

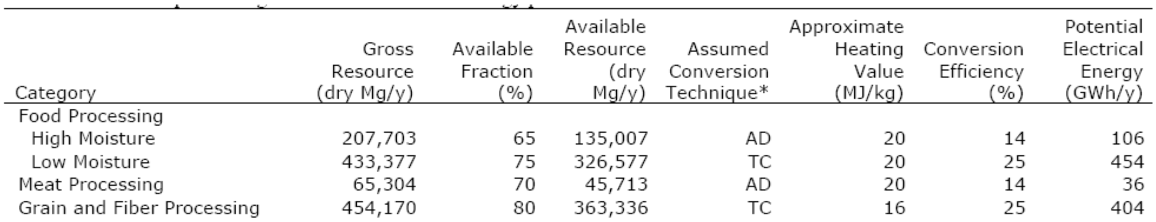


		Crude protein, % DM	Total fiber, % DM	Hemicellulose, % DM	Cellulose, % DM	Lignin, % DM
Cattle manures	Dairy	18.1	52.6	12.2	27.4	13.0
	Beef	12.1	51.5	17.4	21.9	12.2
	Feedlot	17.0	41.7	21.4	14.2	6.1
Swine manures	Nursery	25.1	39.2	21.9	13.2	4.1
	Grower	22.7	40.8	20.5	13.9	6.4
	Finisher	22.0	39.1	20.4	13.3	5.4
Poultry manures	Chick starter	39.8	31.7	18.3	8.5	4.9
	Pullet grower	48.4	36.4	21.5	7.7	7.2
	17-40 weeks	31.6	34.5	20.2	12.0	2.3
	Post-molt	28.0	31.2	16.4	10.7	4.1

DM = dry matter

Figure 9: Analysis of Fiber and Protein Contents in Cattle, Swine, and Poultry Manures
(Chen *et al*, 2003)

<u>Food/feed processing residues:</u>
The processing of food/feed would result in the generation of processing residues that have potentials in providing biomass for energy. Surveys about the potentials of the residues to generate electrical energy have been done in California (Fig 10). Techniques to better convert energy from the residues into electricity are still on the way.



Category	Gross Resource (dry Mg/y)	Available Fraction (%)	Available Resource (dry Mg/y)	Assumed Conversion Technique*	Approximate Heating Value (MJ/kg)	Conversion Efficiency (%)	Potential Electrical Energy (GWh/y)
Food Processing							
High Moisture	207,703	65	135,007	AD	20	14	106
Low Moisture	433,377	75	326,577	TC	20	25	454
Meat Processing	65,304	70	45,713	AD	20	14	36
Grain and Fiber Processing	454,170	80	363,336	TC	16	25	404

Figure 10: Processing Residue Resources and Energy Potentials
(Matteson and Jenkins, 2005)

c. <u>Tertiary Level:</u>

<u>Municipal solid waste:</u>
The moisture content of municipal solid waste is about 30~40% and its energy content is 4,500 Btu per pound on average. Its bulk density is 12 to 20 pounds per cubic foot. In Oregon, for example, 37% of the MSW is recycled or recovered while 8,100 tons of it is dumped in landfills. In 2004, 70% of the MSW that was dumped in landfills could have had value as an energy source equaling to 18 trillion Btu's. That amount could be converted into 121 average megawatts of electricity (Oregon's Biomass Energy Resources, 2007).

<u>Landfill gases:</u>
Landfills can be engineered to capture landfill gas produced by decomposing organic waste. The gas is composed of approximately 50% methane and 50% carbon dioxide. Currently there are around 360 landfill gas-to-energy projects in the US, most of which produce electricity by using the low BTU gas directly as fuel for internal combustion

engines or turbines. On August 8, 2005, the Energy Policy Act of 2005 was signed into law. This legislation (EPAct Summary, 2007):

- Includes provisions for renewed and expanded tax credits for landfill gas.
- Provides bond financing, tax incentives, grants, and loan guarantees.
- Extends renewable energy production incentives to landfill gas.

GMO:

Genetically modified organisms have been explored in the arena of biomass energy. Gene transfer technologies could accelerate the genetic improvement of biomass crops in resistance to insects and herbicides, which would facilitate energy production if proper assessment of potential environment risks has been referred to (James *et al*, 1998). Many other experts have opposite attitudes towards the role of GMO. Kirk Leonard held that "My observations over two decades of GMO's and their consequences have led me to conclude they belong in laboratories and controlled greenhouse conditions only. They are not environmentally sound yet, but that doesn't seem to concern their marketers." Julie Robson said "I personally feel they are less important than other biofuel issues, and could be considered as part of any criteria related to invasive species or biodiversity." (Bioenergywikipedia Website).

Part III

Now that we have reviewed the processes by which many unique feedstocks can be made into biomass energy, it is important to think about the causes this will have on the natural environment. Some methods of producing biomass energy can improve the quality of the soil, water, forests, and atmosphere. Some processes, however, have the potential to provide more damage to the natural world. The delicate balance of nature in the Pacific Northwest gives us cause to hesitate and investigate the positives and negatives that large scale development of biomass based energy will likely have in this region.

Soil Sustainability

Positive Effects:

Some soil scientists raised an argument—ethanol byproduct from biomass energy production can improve soil. 'The byproduct of ethanol fermentation from corn stover can increase the structural stability and organic matter content of soil, particularly of highly eroded soil.' Jane Johnson from Agricultural Research Service pointed out 'the corn stover consists of stalk parts too tough for digesting by alcohol fermentation microbes and has a compost-like consistency' (Comis, 2004). If we apply this byproduct to the land, it may partially offset the harm caused by removing the crop residues. Further experiments are needed to evaluate the overall effects of utilization of crop residues.

Negative Effects:

Many efforts have been made to investigate the impact of biomass energy production on soil quality in soil erosion, organic matter and nutrients, beneficial and deleterious soil organisms, and available water and drought resistance (Andrews and Aschmann, 2006).

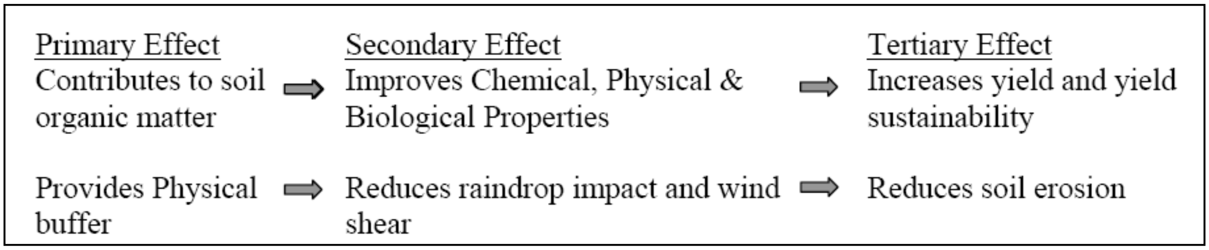
Soil Erosion:
Biomass residues can protect soil from water and wind erosion and maintain the water content and air content of soil by reducing runoff/sediment and air-borne particulates. It is predicted that up to 30% of biomass residues can be removed from some no-till systems with no increased erosion or runoff (Andrews and Aschmann, 2006).

Organic Matter and Nutrients
Soil provides carbon inputs that build the below ground ecosystem and maintain soil organic matter/carbon (SOM/SOC). Removal of biomass residue would result in decreased organic matter and nutrients, and thus increased fertilizer is required to provide more nutrients. A study on PNW Douglas-fir seedling growth discovered that residue retention affects soil N availability (Roberts & Harrington, 2005).

Beneficial and Deleterious Soil Organisms
Soil is also a habitat for certain types of organisms. The principal organisms include bacteria, actinomycetes, fungi, arthropods, nematodes, worms, insects, and mammals. Residue removal can affect the existence or living of them. Experiments performed in Olympic Peninsula revealed that forest harvesting practices for biomass production, such as clear cutting, would influence organisms to varying degrees (Edmonds *et al*, 2000).

Available Water and Drought Resistance
Since biomass residues help reduce evaporation from the soil surface, they have positive functions in moisture conservation and drought resistance.

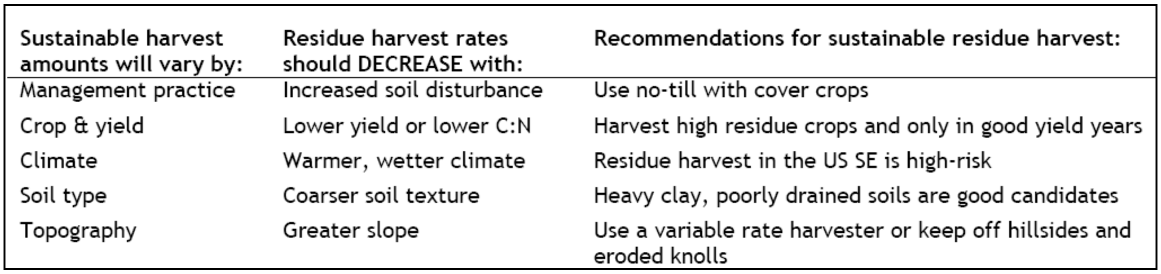
In sum, the general benefits of biomass residues to soil quality are shown below (Fig 11).



Primary Effect		Secondary Effect		Tertiary Effect
Contributes to soil organic matter	⇨	Improves Chemical, Physical & Biological Properties	⇨	Increases yield and yield sustainability
Provides Physical buffer	⇨	Reduces raindrop impact and wind shear	⇨	Reduces soil erosion

Figure 11: General Benefits of Biomass Residues
(Larson, 1979)

In light of the advantages of biomass residues to soil system, sustainable residue harvest should be guided under certain rules (Fig 12).



Sustainable harvest amounts will vary by:	Residue harvest rates should DECREASE with:	Recommendations for sustainable residue harvest:
Management practice	Increased soil disturbance	Use no-till with cover crops
Crop & yield	Lower yield or lower C:N	Harvest high residue crops and only in good yield years
Climate	Warmer, wetter climate	Residue harvest in the US SE is high-risk
Soil type	Coarser soil texture	Heavy clay, poorly drained soils are good candidates
Topography	Greater slope	Use a variable rate harvester or keep off hillsides and eroded knolls

Figure 12: Basic Guidelines for Sustainable Residue Harvest
(Andrews and Aschmann, 2006)

Water Sustainability

Positive Effects:
It has been found that perennial biomass crops, such as perennial grasses and short rotation woody crops could be used in the development of riparian buffer strips to mitigate pollutants. Located within and between agricultural fields and the water courses, the buffers are upslope from water bodies and are able to intercept and slow runoff and capture nutrients, soil particles, and pesticides. Therefore, they could reduce export of particulate pollutants and facilitate improvement of water quality (KooOshima, 2006).

Negative Effects:
Water depletion and water pollution are of our most concern when we determine water sustainability in biomass energy production.

Water Depletion
One threat bioenergy production would impose on water sustainability is water depletion. On a global scale, we consume 1,000-4,000 liters of water to produce 1 liter of biofuels, which is causing drought in many regions of the world (Inside Greentech, 2007). Since in many cases fresh water (groundwater and surface water) is being depleted by agriculture than it is being recharged, which has threatened current food supplies, not to mention biomass crops.

Can we turn to irrigation? In the production of biomass energy, irrigation is not considered a quick and effective way to avoid water shortages due to two reasons. First of all, irrigation may result in salinization, water logging and decreasing groundwater tables. Secondly, the establishment of irrigation infrastructure is unlikely (economically) profitable for many areas (Smeets *et al*, 2005).

Water Pollution
To protect biomass crops from weeds, plagues and diseases, agricultural chemicals are inevitably being applied. Common agricultural chemicals are herbicides, fungicides, insecticides and other pesticides. In addition, it is reported that ethanol plants generate 13 liters of wastewater for every liter of ethanol produced (Pimentel & Patzek, 2005). However, some model results suggested that not all energy crops do harm to water system. Some are able to reduce the amount of sediment and nutrients which are leached to surface water in comparison with annual crops and are capable of improving stream water quality (Hunsaker *et al*, 1997). Therefore, different types of energy crops may have different effects on water system.

Sustainability of Forest Health

Positive Effects:
Fire Protection
In recent years fire suppression in the PNW has caused serious problems as well. Plant communities become dense so that the competition between them for limited resources is intense, which would possibly result in major diebacks. Biological decomposition is not fast enough to offset the fuel buildup due to the typical climate in the PNW. In this condition any ignition can lead to a violent and major wildfire which can kill plant communities and damage soil permanently. Removing excess fuels for biomass energy

production serves as a good approach to reduce the risk and provide fire protection (Sampson *et al*, 2001).

Negative Effects:
Apart from the potential loss of forest from converting it into farmland, bioenergy production from cellulosic biomass increases the pressure by fuelwood harvesting. Deforestation derived from the above practices would have negative impacts on the biodiversity conservation, carbon dioxide absorbance and species invasion.

Biodiversity Conservation
Forests provide valuable habitats for wildlife and destruction of the habitats are deleterious to biodiversity, especially for the endangered species, contributing to the ongoing Holocene extinction event.

Carbon Dioxide Absorbance
Forests act as CO2 sink that absorb CO2 from the atmosphere and store the carbon by photosynthesis. Researchers found that 25%-30% of the greenhouse gases released each year (1.6 million tons) is the result of deforestation, rather than the emissions from cars, trucks, etc (Matthews, 2006). Thus, it is not wise to reduce greenhouse gases by simply replacing forests of farmland.

Species Invasion
Ideal ecological traits of biomass energy crops are often found among invasive species (Fig 13). All traits shown below except perennial growth and sterility are responsible for species invasiveness. Examples of invasive biomass energy crops in the United States are *Arundo donax, Phalaris arundinacea, hybrid grass Miscanthus × giganteus, Panicum virgatum* and etc. Ecological risks must be assessed before planting certain species to avoid ecological disorders (Raghu *et al*, 2006).

C_4 photosynthesis
Long canopy duration
Perennial
No known pests or diseases
Rapid growth in spring (to outcompete weeds)
Sterility
Partitions nutrients to belowground components in the fall
High water-use efficiency

Figure 13: Ideal Traits of Biomass Energy Crops
(Raghu *et al*, 2006)

Atmospheric/Climate Sustainability

Positive Effects:

Mitigating Greenhouse Gasses

As mentioned previously, one of the main drivers behind the interest in bioenergy, and particularly biofuel is an increase in concerns over global climate change. The increase in greenhouse gas emissions from anthropogenic sources presents a great opportunity for bioenergy development and implementation. The UN Energy Commission report that the burning of fossil fuels has accounted for 75-85% of global CO2 emissions and land use changes along with deforestation has accounted for the other 15-25% of global CO2 emissions (Karlsson, 2007).

Both ethanol and biodiesel have been shown to hold potential for reducing greenhouse gas emissions either by combining them with traditional petroleum and diesel, respectively, or by using them as pure fuel sources. They have also shown potential for reducing criteria air pollutants, to some degree (Graf and Kohler, 2000, OBA/OEC, 2005). When evaluating the potential of biofuels however, it is important to remember that feedstock source must be taken into consideration. Each feedstock used around the world has a different energy ratio, chemical composition, and combustion composition. Since many of the Pacific Northwest feedstocks have not been tested in large scale operations, complete and accurate data about their affect on global climate change, air quality, and possible role in greenhouse gas emission mitigation are not yet known with certainty.

Negative Effects:

Increased Fertilizer Use

What has been shown is that biofuels do have a downside. Many biodiesel blends have been shown to release higher concentrations of nitrous oxides (NOx) than their diesel counterparts. This has been very well documented in biodiesel made from soybean oil, which represents the largest biodiesel feedstock in the U.S. Many reports indicate the need to find NOx mitigation techniques such as additives or filters. In a recent life cycle analysis of biodiesel, it was found that the economic or environmental case can no longer be made for the use of manufactured nitrogen fertilizer in soybean production (Rollefson *et al*, 2004). They suggest manure fertilization may remain a sustainable option where the prime value sought is in the phosphate and potassium addition. As soybeans enjoy a symbiotic relationship with rhizobia, they do not require the excess nitrogen input from fertilizer, but are often treated anyway which may contribute to their increase nitrogen content and subsequent NOx release when combusted. As biofuels are being produced on a larger scale, best management practices and policies will be needed to avoid unintended negative consequences.

Excess fertilizer use, touched upon briefly above, is one of the largest potential problems with biofuels in the U.S. In addition to their affects on water quality, increased fertilizer use will likely release additional toxic chemicals into the air (Ana *et al*, 2005). These toxics in the air and water are often not taken into account in a common life cycle analyses of biofuel production. Another common source of air toxins associated with biodiesel production in particular is the crushing of soybeans and canola seeds. This process releases dangerous levels of the volatile organic compound hexane into the air (Rollefson *et al*, 2004). The U.S. has recently implemented additional regulation to help safeguard workers and the environment from this release.

Deforestation and Global Climate Change

The last severe, global, unintended consequence of the wide scale production of biofuels is an increase in the rate of deforestation to clear land for agriculture (Karlsson, 2007). Biofuel production is expected to fulfill twenty to thirty percent of energy demand by 2030, and that could mean devastation to the remaining world forests, particularly in tropical countries (Dufey, 2006, Karlsson, 2007). While this problem does not have an easy solution by any means, treaties and economic incentives should be used to prevent a possible greenhouse gas mitigation strategy from contributing to one of the largest greenhouse gas release problems we face today. Domestically and particularly in the Pacific Northwest, there exists the opportunity to use current marginal lands to produce biofuel feedstocks that have a higher value both economically and environmentally than the current commodities being grown. When done correctly, the growing of biofuel feedstocks can increase soil health and sequester more carbon (Chan, 2004). Given that the global marketplace currently views biofuel primarily as a greenhouse gas mitigation strategy, it should also be noted that the UN Energy Commission reports that much greater gains could be made if bioenergy efforts were concentrated on replacing coal as an electricity generator rather than replacing transportation fuels (Karlsson, 2007).

Now that we have examined the possible positive and negatives effects of producing biomass energy in this region, we must balance that against the effects to our social systems. We will consider the impacts on communities and the economy as well as consider the impacts internationally.

Social/Community Sustainability

There are many factors that indicate biofuel production in the Pacific Northwest could be advantageous particularly for rural communities. The recent MTBE ban in California and Washington will increase the demand for ethanol. Changing economic conditions in natural resource extraction have left many communities with the need for new industry. California alone presents one of the worlds largest demands for both ethanol and biodiesel. The economic impacts of a new 40 million gallon ethanol plant (equally applicable to a biodiesel plant) would be a one-time boost of $142 million during construction, expanded local economic base by $110.2 million each year through direct spending of $56 million, and creation of 41 full-time jobs at the plant and 694 jobs throughout the entire economy. Annual household income for the community would increase by as much as $19.6 million. This would also increase state income and local property or business tax receipts. These benefits would increase proportionally with increased plant size (OBA/OEC, 2005).

There is some debate however, about the optimal level of operation to benefit communities. Rural communities benefit especially when the cultivation involves small-scale farmers and the conversion facilities are located near the crop sources in rural areas (Dufey, 2006). Because the process of converting oils, such as canola or used oil waste, is relatively straightforward, biodiesel conversion can often occur at a smaller scale allowing communities to invest and gain the monetary rewards of their value added product. Particularly in areas where large corporations dominate the future bioenergy industry, farmer cooperative and communities can serve the valuable role of linking these individuals together and providing them strength. In the best circumstances, it is not difficult to imagine rural communities benefiting from the booming demand of energy crops; however without properly implementation, increased biofuel production has the potential to create a concentration of power and market share in the hands of a few large companies which may drive our poorest farmers deeper into poverty (Karlsson, 2007).

Studies also found that the industry would benefit by an increase net farm income more than $4.5 billion, boost total employment by 192,000 jobs, improve the balance of trade by over $2 billion, add over $450 million to state tax receipts, and results in net budget savings of over $3.5 billion (OBA/OEC, 2005).

Limited state government actions combined with incentives already in place could lead to hundreds of sustainable traded-sector jobs, increase state and local tax collections, improved rural economies, and cleaner air through the use of renewable fuels (OBA/OEC, 2005).

By producing ethanol from waste resources or local feedstock crops, Oregon would have the ability to produce an in-state supply of renewable fuels versus exporting dollars to import its transportation fuel supply. In-state ethanol production would reduce the burden on landfills because it would divert the biomass fraction of the waste stream to an ethanol facility. This has been a motivating factor for several proposed ethanol projects around the country (Graf and Kohler, 2000).

Economic Sustainability

While the physical processes that produce biodiesel and ethanol may be very different, the economic factors associated with their wide spread use are quite similar. A great number of studies on biodiesel and ethanol production using a variety of feedstocks have shown that many of the proposed facilities in the Pacific Northwest are economically feasible, given certain conditions. The most important factors to consider when deciding about the economic sustainability of any new processing facility are plant capacity, price of the feedstock, price of the product, price of competing alternative energies, and the selling price of any co-products (Zhang *et al*, 2003, Berndes *et al*, 2003, Aden *et al*, 2000). It is also crucial to consider the strength of the investment in the project (Graf and Kohler, 2000).

The availability of feedstock supply is a point of uncertainty in any proposed plant. For example, high estimates of availability for a given area in the future can often be as much as nine times higher than the low estimates (Berndes *et al*, 2003). This level of uncertainty is one of the major hurdles to overcome in the wide spread production of either ethanol or biodiesel. Securing long-term contracts with favorable economics for feedstocks is a considerable challenge to developing new processing plants. Although the Pacific Northwest region has a large base of potential feedstocks, securing them with long-term contracts at a relatively stable price is necessary to attract major capital investment (Graf and Kohler, 2000).

Furthermore, the technologies involved in producing biofuels do not have a stock of profitable large scale facilities to serve as examples and build investor confidence. This decreases the likelihood of investment since most investors in "new" technologies will hold out until expected returns are thirteen percent or greater. However, there is an upside to the technology being new. The Department of Energy, Energy Information Administration reports that cellulosic ethanol can have as much as a 60 cent per gallon advantage over the established corn ethanol market (DiPardo, 2000). Government loans or partnerships can serve to strengthen the security of investments and may bridge the gap to allow for necessary start-up capital to realize the possible costs saving technology in production. This is especially important in the rural plants discussed previously where investments are low to start with and biofuel production is considered a revitalization strategy. In addition, the government loans may send market signals that will positively influence the growth of the market over the next ten to twenty years (Graf and Kohler, 2000).

This is not the only way, however, that the government is involved in the growth of the industry. Environmental regulations play an important role both where feedstock availability is concerned and in the increasing market for biofuels. Regulations affecting forest management strategies, air quality, and water quality play a key role in the development of the biofuels market. For example, the continuation of the federal oxygenated fuels program and the banning of MTBE in many states including California and Washington will substantially increase the demand for ethanol over the next couple of decades (Graf and Kohler, 2000).

Furthermore, regional and national goals by government may provide additional incentives for biofuel production and use. Raising oil prices and conflict in the Middle Eastern Region have served as political motivation for investment in biofuels. This has had two primary outcomes: tax incentives/subsidies that may make biofuels economically feasible and the goal of energy independence. Within the current academic literature, there are two conflicting theories about the goals of biofuels. For example, Hill *et al.* posits that in order for biofuels to be a viable alternative to fossil fuels, they aught to have a net energy gain, have environmental benefits, be economically competitive, and be producible in large quantities without reducing the food supply (2006). These are very high requirements where biofuels will likely fall short depending on how each of these is defined. We have previously discussed that environmentally, biofuels offer some solutions and some problems, and while they may be producible in large quantities using feedstocks that are not food supplies (corn or soybean) this is not yet a market reality. Economic competitiveness is a difficult requirement to judge because economic subsidies may help biofuels be competitive which may give the market time to mature making them competitive without subsidies, but this can be nothing more than speculation now. Others such as Jaeger *et al.* require less of biofuels to be considered viable (2007). Their analysis assumes that a biofuel must not create a net energy gain but just be more efficient than the fossil fuel it is replacing. This will positively contribute to the afore mentioned goal of energy independence.

While most of the feedstock options for the Pacific Northwest are not food crops, expanding their growth will likely take available land away from current food crops or put environmentally sensitive land at risk of being farmed (Schneider and McCarl, 2003). Therefore the expansion of biofuel crops will likely have an effect on food prices as the market will make adjustments for traditional crops and the competition among feedstock crops at their higher production rates (Walsh *et al*, 2003). This will have enormous effects on the economic sustainability of biofuel production.

International Sustainability

One of the most prominent topics related to the international stability of bioenergy is international trade. Currently, bioenergy and particularly biofuels are not widely exchanged between countries because the vast majority of that produced is consumed domestically. However, trade in biofuels is expected to expand rapidly, as many countries will not have the domestic capacity to supply their internal markets. This is a result of both the need for a fuel additive and an environmentally sound fuel source. In 2006, Brazil was the largest bioethanol exporter and the U.S. was the largest importer (Dufey, 2006).

While bioethanol and feedstocks are classified as agricultural products and their trade is governed by the Agreement on Agriculture from the World Trade Organization, biodiesel is categorized as an industrial good and subject to the general rules of the GATT. To ease the regulation on trading biofuels, they could be included in a list of “environmental goods” for accelerated trade liberalization under the current Doha Round. Without agreement among WTO Members on whether ‘biofuels’ are defined as industrial or agricultural goods, their trade will not reach its potential (Dufey, 2006).

In order to implement the European Directive 2003/30/EC that sets a target of 5.75 percent of biofuel within the mix of transport fuel by 2010, 18.6 million tons of oil equivalent of biofuels will be needed to be imported into the EU. Indeed, Malaysia and Indonesia are already expanding palm oil plantations to meet greater demand and are together expected to supply up to 20 per cent of this market. Brazil is also expected to be the main beneficiary of EU imports of soybean oil for biodiesel. Other promising import markets are likely to be Asian countries like Japan, Korea and Taiwan, which have very little land available for increased agriculture production. The bulk of future demand is likely to come from the industrialized world, while the most efficient producing countries are located in the developing world. Thus gaining many of the benefits from biofuels will depend critically on the possibility of international trade. The most common limitations and barriers to trade currently include tariffs, tariff escalation for value-added goods (seed oil for instance has a higher tariff than the plant itself), quotas, domestic support subsidies, and varying technical, social, and environmental standards (Dufey, 2006).

At the international level, efforts to reduce agricultural subsidies in rich countries and to allow free trade in agricultural commodities are inextricably linked to the development of liquid biofuels. In many countries, the current structure of agricultural markets means that the bulk of the profits go to a small portion of the population. One of the great challenges for bioenergy policy development is to effectively navigate the chaotic and often manipulated markets in which they operate-providing initial subsidies where appropriate, but minimizing their size and resulting market distortions perhaps in a countercyclical pattern such that subsidies will decrease as oil prices increase (Karlsson, 2007).

Some of the largest concerns associated with the world wide increase in bioenergy production from agriculture are deforestation, monocropping, water pollution, food security problems, poor labor conditions and unfair distribution of the benefits along the value chain. For example, food security at the household, national, and global levels could be affected through each of four major dimensions: availability, access, stability, and utilization. These effects could actually be positive or negative, depending on the situation. This would primarily depend on whether a country or household is a net buyer or seller of energy services and food products (Karlsson, 2007).

Increased bioenergy production certainly has the potential for positive outcomes as well. The most dramatic health benefits from modern bioenergy use are related to household applications. Dubbed the “kitchen killer”, smoke inhalation from cooking with traditional biomass indoors is one of the leading causes of disease and death in the developing world, responsible for more fatalities each year than malaria. Generally the poor in Southeast Asia and Sub-Saharan Africa suffer the highest death toll. Clean energy sources, including modern biomass derived cooking fuels, can drastically reduce harmful indoor air pollution, leading to reductions in respiratory diseases such as pneumonia in children and chronic obstructive pulmonary disease in adults, particularly in women. Biomass-derived cooking fuels provide on option for such energy upgrading (Karlsson, 2007).

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