Strategic Development of Bioenergy in the Western States

Section 4: Benefits Model

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Introduction

The biomass energy industry produces two distinct and important products: renewable energy, and environmentally-preferred productive use of wastes and residues. Like all energy options, the production and use of energy derived from biomass resources entails environmental costs. On the other hand, biomass energy use displaces the production and use of fossil fuels, and the serious environmental, social, and political risks associated therewith. In addition, when the biomass resources used for energy production are wastes and residues that would otherwise require some form of disposal or disposition, the energy alternative also displaces the alternative disposal fate for the residues. Seen in this framework the net impact of biomass energy production and use can be determined as the difference between the effects of pursuing the biomass energy pathways, less the sum of the effects of the avoided fossil energy use, plus the effects of the avoided alternative disposal fates for the wastes and residues used as energy feedstocks. In order to analyze the net environmental implications of using biomass for energy production, it is necessary to determine what the alternative fate of the biomass would be if it were not used as a fuel.

The biomass benefits model developed for this study is an extension of the biomass benefits model that was developed previously for the electricity sector.[1] Adapting the model to the transportation fuels sector for this study required extensive reworking of the model, including changing the basic metric used for reporting the results from impacts per kWh of electricity produced, to impacts per gallon of fuel produced. This, in and of itself, introduces a whole new layer of complexity to the model, because while all kWhs generated in the electricity sector are essentially the same, in terms of the services they can provide for, all gallons of liquid fuels are NOT at all the same. Different kinds of liquid fuels have different energy contents (btu/gal), and in addition, different liquid fuels tend to serve different segments of the transportation sector (e.g. gasoline and ethanol tend to power passenger cars and smaller vehicles, while diesel fuels tend to power commercial and larger vehicles), with the result that comparability among different liquid fuel products is difficult even on a per-mile-of-transportation-services basis (e.g. passenger miles vs. cargo miles).

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[1] Morris, G., *The Value of the Benefits of U.S. Biomass Power*, NREL Report No. NREL/SR-570-27541, November 1999; Morris, G., *Biomass Energy Production in California: The Case for a Biomass Policy Initiative*, NREL Report No. NREL/SR-570-28805, November 2000; WGA Clean and Diversified Energy Initiative, *Biomass Task Force Report*, January 2006.

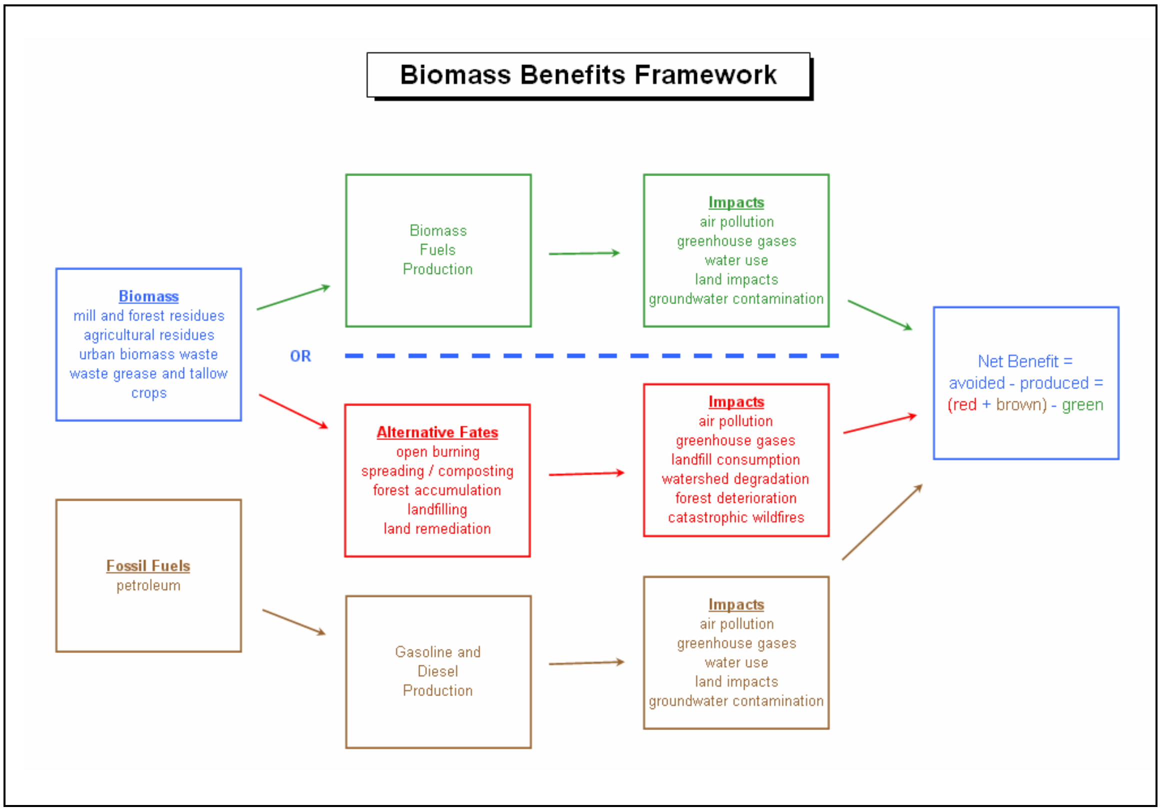
Framework for Biomass Benefits Assessment

Energy production from biomass offsets the production of a like amount of energy from conventional (fossil) sources. At the same time, the use of biomass energy avoids the need for alternative disposal of many of the feedstocks. While biomass energy production causes environmental impacts during fuels preparation and conversion to energy, these impacts have to be balanced against the avoidance of both the impacts associated with an equivalent amount of energy generation from fossil fuels, and the avoidance of the environmental impacts that would otherwise be caused by the alternative (conventional) disposal of the biomass feedstocks that are converted to fuels. The latter effect, avoidance of alternative disposal of biomass residues, quantitatively is the most important source of the environmental benefits associated with the production of energy from biomass resources in the West.

The net environmental impacts of biomass energy production are defined as the impacts of the energy-production pathway, less the sum of the impacts of the alternative production of the same amount of energy from fossil fuels plus the impacts of alternate disposal of the biomass residues that are converted to fuel. In order to analyze the net environmental implications of using biomass resources for energy production, it is necessary to determine what the alternative fate of the biomass would be if it were not used for energy production. Most of the solid-fuel biomass that is currently used for energy production in the western US would meet one of three alternative fates if it were not converted to energy: open burning, burial in a landfill or open pile, or accumulated as overgrowth in the region's forests.

Open burning produces as much as 100 times more conventional pollutants than conversion to fuel and controlled combustion of the fuel in an engine, and greater quantities of greenhouse gases due to poor (incomplete) combustion conditions in open burning. Accumulation of forest overgrowth can have negative consequences for fish and wildlife habitat, reduces forest growth and resiliency to natural disturbance regimes (insects, disease, drought and weather events), increases the risk of devastating wildfires, and degrades the functioning of forested watersheds, both with respect to the amount and seasonality of water production, as well as water quality and sediment delivery to domestic water impoundments. Landfill burial of segregated woody biomass that can be diverted for productive uses such as recycled products or energy production consumes available landfill space, and produces much greater quantities of greenhouse gas emissions than controlled combustion of the diverted material. The energy production pathway provides an environmentally superior beneficial use for the biomass residue that is being converted than any of the alternative disposal options that are available.

A framework for understanding the social and environmental benefits associated with energy production from biomass is illustrated in the figure below.



The biomass benefits model analyzes a variety of quantifiable environmental impact categories, including air pollutants, water use, solid waste disposal, and land remediation. However, one impact category, greenhouse gas emissions, is the most important category for biomass energy systems in terms of its contribution to the calculated value of the ancillary benefits of biomass energy use. The greenhouse gas implications of energy production from biomass are far more complex and subtle than the greenhouse gas implications of energy production from other energy resources. Energy production from fossil fuels removes carbon from geological storage, and adds it to the atmosphere. Energy production from non-bioenergy renewables and other non-fossil sources produces energy without any significant greenhouse gas emissions. Biofuels are carbon-based fuels, but the carbon in biofuels is already part of the active global carbon cycle in which carbon exchanges rapidly between the atmosphere and the biosphere. Bioenergy production does not add any new carbon to the active carbon cycle, making it a carbon-neutral energy source

Bioenergy production and use is carbon-neutral, but it can affect global greenhouse gas levels in a couple of important ways. Biomass energy production converts wastes and residues that produce even greater amounts of greenhouse gas emissions when conventionally disposed of than when used for energy. When the net emissions are properly accounted for, biomass energy use actually reduces the net greenhouse gas emissions associated with the disposal of some of society's waste and residue materials. This is in addition to the benefit common to all renewables that fossil carbon emissions are displaced by renewable energy production.

In addition to being carbon neutral, biomass energy production can affect atmospheric greenhouse gas concentrations in two important ways. First, the total amount of carbon that is sequestered in terrestrial biomass affects the amount of carbon in the atmosphere. By contributing to forest health and fire resiliency in currently at-risk, overstocked forests across the West, in the long term energy production from forest fuels can increase the amount of carbon that is stored on a sustainable basis in the earth's forests, making a positive contribution to efforts to control atmospheric greenhouse gas levels. Second, biomass energy production can change the timing and relative mix (oxidized vs. reduced) of carbon forms emitted to the atmosphere associated with the disposal or disposition of the biomass resources. From a greenhouse gas perspective reduced carbon (CH_4) is twenty-five times more potent than oxidized carbon (CO_2) on an instantaneous, per-carbon basis, so the form in which carbon is transferred from the biomass stock to the atmospheric stock is critically important from the standpoint of greenhouse forcing impact. The biomass benefits model takes these impacts into account.

Description of the Benefits Model

The biomass benefits model has been designed to compute the value of the environmental costs and benefits associated with the production and use of transportation fuels from biomass feedstocks under a variety of input assumptions. The model begins with an accounting of the types and quantities of feedstocks used for the production of transportation fuels in any given scenario, and a description of the pathways to fuel. The model calculates the amount of fossil energy production and use that is avoided by the biomass pathways, and tracks the impacts associated with the biomass fuels pathways, as well as the avoided fossil energy pathways and the avoided alternative fates for the biomass feedstocks. The table below summarizes the key inputs that are required to run the model.

Key Modeling Inputs

Quantity of feedstocks used (th.bdt)
Pathways to fuels
Alternative fates
Fuel Production efficiency (gal / bdt)
Impacts by category (SOx, Nox, etc, appropriate units)

Biofuel	Avoided Fossil Fuel
field (prior to transport)	petroleum production
feedstock transportation	petroleum transportation
fuel production	fuel production
fuel transportation	fuel transportation
fuel use	fuel use

Avoided Alternative Fates for Biomass Feedstocks

$ value of impacts by category

A complete, four-page printout of the model is appended to this report as Attachment A. Input data blocks in the model are outlined, and input data are shown in red. Alphanumeric input cells (labels, units) are shown in blue. Calculated values in the model are shown in black and violet (summations). Data for crops grown specifically for energy production are shaded yellow. Data for fossil-fuel pathways are shaded grey. Biomass fuels trajectories are shaded green. Attachment A shows the base-case scenario and dataset in the input data blocks.

The first page of the model, titled Biomass Module, is composed almost entirely of input data blocks. The amounts of biomass feedstocks used for the production of liquid fuels in a given scenario are entered in the first data block. The pathways to liquid fuels that are employed for these feedstocks, and the alternative fates for the feedstocks that are wastes and residue resouces, and for feedstocks that are grown for purposes of land remediation or other environmental purposes, are specified on this page in the second and third data blocks. The Biomass Module also has input data blocks for the unit impacts (emissions, water use, etc.) of producing the biomass feedstocks (labeled "in field" in the model, this data block contains impacts for all activities involved in feedstock production prior to its transportation to a fuel production facility), and transporting the feedstocks to processing facilities where they are converted into transportation fuels. Comparable data for the avoided fossil fuel pathways (petroleum production and transportation to a refinery) are also input in these data blocks.

The second page of the model, titled Processing Module, has the input data block for the unit impacts (emissions, water use, etc.) of converting biomass feedstocks into transportation fuels using a variety of pathways from feedstocks to fuels. Unit impacts for the environmental impacts associated with the avoided fossil fuels trajectories, and with the alternative disposal pathways for wastes and residues, are also entered on this page. Information about fuel-production efficiencies (gal per bdt of feedstock) is also input on this page, and total biomass fuels production and avoided fossil fuels production are determined for the biomass fuels scenario under consideration (entered in the Biomass Module page). The lower part of the page shows calculations of the total annual impacts of producing and transporting feedstocks to a processing facility, and converting them to fuels, as well as the total annual avoided impacts of alternative disposal of the wastes and residues, and of the avoided production of fossil fuels through the refinery stage.

The third page of the model, titled Fuel Module, contains input data blocks for the unit impacts (emissions, water use, etc.) of transporting (block one) and using (block two) liquid fuels made from biomass, as well as the displaced fossil fuel alternatives. The lower part of the page shows calculations of the total annual impacts of these activities, given the resource-use scenario that is input on the first page of the model.

The fourth and final page of the model, titled Calculation Module, shows calculations of the total annual impacts of the biomass fuels trajectories included in the model, as well as impacts of the avoided conventional fossil-fuel alternatives. The sole input data block on this page is where the modeler enters per-unit-of-impact dollar values for the various

impact categories included in the model. The lower part of the page shows calculations of the total annual costs of the biomass and conventional alternatives. The magnitudes of the values are then summed across the categories, and the two alternatives, biomass energy production vs. biomass residue disposal and fossil-fuel energy production, are compared. The page concludes with a computation of the net cost or benefit of the biomass alternative on a dollar-per-gallon basis.

Sample Calculation

In order to illustrate the flow of calculation in the model, we offer the following sample calculation for the example of the greenhouse gas emissions associated with the production of ethanol from orchard and vineyard waste (ovw). Relevant portions of the model printout are shown below. The amount of ovw feedstock used is the amount in the base-case scenario for the project. All of the ovw feedstock is converted to ethanol via the LCEthanol conversion pathway, and all of the material would meet an alternative fate of open burning if not used for fuel production. All other inputs are from the base-case dataset (see discussion below on base-case scenario and dataset).

Biomass Module	
	OVW
Fuel Use (th.bdt/yr)	3,032
Pathway to Fuel	
LCEthanol	100%
Alternative Fate (%)	
open burning	100.0%
Impacts--biomass in field	GHGs
unit/th.bdt	ton
OVW	20
Impacts--biomass trans.	GHGs
unit/th.bdt	ton
OVW	13

Processing Module		
Ultimate Impacts (unit/th.bdt)	**GHGs**	
unit	**ton**	
LCEthanol	814	
VS.		
open burning	301	
Fuel Production	**gal / bdt**	**th.gal / yr**
LCEthanol	82.2	249,230
Impacts	**th.ton/yr**	
open burning	913	
Total, no energy	**913**	
VS.		
LCEthanol	2,568	

Fuel Module	
Transport Impacts (unit/th.gal)	**GHGs**
unit	**ton**
LCEthanol	0.003
Fuel Use Impacts (unit/th.gal)	**GHGs**
unit	**ton**
LCEthanol	-
Impacts	**th.ton/yr**
LCEthanol	1

Calculation Module	
	GHGs
Net Impacts	**th.ton/yr**
Total, alternative disposal	**913**
VS.	
LCEthanol	2,569
Total, biomass fuels	**2,569**

There are three calculated values shown in the Processing Module: the amount of ethanol produced from the ovw feedstock (Fuel Production), and the greenhouse gas emissions associated with the production, transportation, and conversion of the feedstock to ethanol (LCEthanol), as well as the avoided open burning of the feedstock (open burning). The values shown are calculated as follows:

Amount of ethanol produced:

3,032 th.bdt/yr x 100% LCE x 822 gal/bdt = 249,230 th.gal/yr

Avoided open burning:

3,032 th.bdt/yr x 100% openburn x 301 ton/th.bdt / 1000 = 913 th.tonCO_2/yr

LCEthanol:

3,032 th.bdt/yr x 100% LCE x (20 + 13 + 814) ton/th.bdt / 1000 = 2,568 th.tonCO_2/yr

The Fuel Module shows a single calculated values, and the Calculation Module a couple more calculated values:

Impacts, LCEthanol (Fuel Module):

249,230 th.gal/yr x (0.003 + 0) tonl/th.gal / 1000 = 0.75 th.tonCO_2/yr

Total, alternative disposal (Calculation Module):

913 th.tonCO_2/yr from above

LCEthanol:

2,568 th.tonCO_2/yr (feedstock, trans, conv.) + 0.75 th.tonCO_2/yr (fuel trans & use) = 2,569 th.tonCO_2/yr

Although not shown in the tables above, the 250 million gal/yr of ethanol displaces 167 million gal/yr of gasoline and its associated 1,935 th.tonsCO_2/yr of greenhouse gas emissions (petroleum production, transportation, refining, fuel transp., consumption). Thus, the net greenhouse gas emissions from the ovw-to-ethanol portion of the base-case scenario is:

	2,569	th.tonsCO_2/yr energy pathway
less	913	th.tonsCO_2/yr avoided alternative disposal (open burning)
less	1,935	th.tonsCO_2/yr avoided fossil fuel pathway
	(279)	th.tonsCO_2/yr Net Impact

In other words, net greenhouse gas emissions are reduced by 279 th.tons of CO_2 equiv. annually as a result of converting three million bdt/yr of ovw biomass to ethanol across the West. At a value of $20 per ton of CO_2 equiv. this equates to an annual benefit of more than $5.5 million, or two cents per gal of ethanol produced.

Study Results

The first two input data blocks on the Biomass Module page of the model accept information that define the scenario that is under study by the modeler. The scenario includes a specification of the mix of biomass resources used for fuel production, and the

fuels trajectories that take the resources from raw biomass to fuels used for transportation. The remaining input data blocks in the model contain the model's basic dataset. The base-case input dataset used for the study is based primarily on values for unit impacts available in the literature. Assumptions about what the alternative fates are for western biomass resources (third data block in Biomass Module) are based on survey work performed in California, which has been generalized for the entire WGA region. Data on the environmental impacts of the alternative fates for biomass, which are contained in the non-shaded portion of the first input data block in the Processing Module, are based on previous work on biomass benefits that is referenced as footnote no. 1 above. The remainder of the base-case dataset and the data sources are described in more detail below.

The category of greenhouse gas emissions (GHGs) in the model refers exclusively to fossil carbon emissions. The biomass-to-fuels pathways are assumed to be carbon neutral with respect to biogenic carbon, thus the base-case dataset shows zero emissions from the use of biofuels for transportation, as well as zero biogenic carbon emissions from feedstock procurement and conversion. It is assumed, in the base-case dataset, that the diesel fuel used for the production and transportation of biofuels, like the fuels used for the production and transportation of fossil fuels, is of fossil origin. The use of biodiesel for these purposes would eliminate the emissions of fossil carbon greenhouse gases during fuels production, but it would subtract from the amount of product that makes its way to the greater (non-agricultural) marketplace.

As discussed previously, while biomass energy production and use is considered to be carbon neutral, there are two ways that the use of biomass fuels can actually reduce biogenic greenhouse gas emissions: first by substituting CO_2 emissions for CH_4 emissions, and second by enhancing forest health and productivity. Because the biomass benefits model tracks only fossil carbon greenhouse gases, emissions reductions associated with CH_4 avoidance and forest sequestration are treated as fossil-emissions offsets. Thus only the portion of the biogenic emissions from alternative disposal that exceed 100 percent conversion of the biomass carbon to CO_2 is counted as an offset. This makes the biogenic greenhouse emissions of the avoided alternative fates of the biomass comparable to the zero greenhouse gas emissions (carbon neutral) reported for biofuels fabrication and use in the model.

Base-Case Scenario

The base-case biomass fuels scenario, which specifies the amounts of biomass feedstocks used for fuel production in the WGA region and their pathways to fuels, is based on the modeling results reported in the previous chapters of this report. The printouts included in attachment A show the base-case scenario and dataset. In addition to the economic value of the base-case scenario, which has been reported on in previous chapters, the base-case scenario produces a calculated net benefit of 13 ¢ per gallon for the ancillary benefits of biomass fuels use, for the more than 8.25 billion gallon-per-year biofuels enterprise that makes up the base-case scenario.

The base-case scenario employs a range of biomass feedstocks to produce almost eight billion gallons annually of ethanol, and nearly 300 million gallons annually of bio-derived diesel fuel. Most of the ethanol is produced from cellulosic feedstocks, while the renewable diesel is produced from available waste tallow and grease resources. Cellulosic feedstock sources used in the base-case include forest-derived fuels, urban waste wood and paper (MSW in the model), orchard and vineyard prunings and removals, corn stover and other field straws, and herbaceous energy crops, such as switch grass. Twelve percent of the ethanol is derived from corn, the principal feedstock used for ethanol fuels production today. The resources included in the base-case scenario are described in detail in the first chapter of this report. The selection of resources and conversion-to-fuels pathways for the base-case scenario is described in detail in chapters two and three.

Base-Case Dataset

Most of the cellulosic feedstocks used for ethanol production in the base-case scenario are wastes or residues that would require disposition via an alternative fate if not used for energy production. In addition, we are assuming that 20 percent of the herbaceous crop that is included in the base-case scenario is grown on degraded lands as a means of long-term remediation of these lands (based on expert judgment of study staff member Richard Nelson). The use of these resources for energy production, in addition to displacing fossil fuel use, displaces the impacts associated with the alternative fates for these resources. Alternative fates include open burning, landfill burial, composting, tilling, combustion in kilns and fireplaces, accumulation as overgrowth material in the forest, and land remediation.[2]

The base-case alternative fate assumptions are based on extensive surveys performed on the existing California biomass power industry, and generalized, based on modeler's judgment, to the entire WGA region. Most of the forest residues used for fuels production would be left in the forest as overgrowth material in the absence of conversion to energy products. As of the beginning of the twenty-first century many western U.S. forests are severely overgrown, with the result that they are far more prone to destructive wildfires and pest and disease outbreaks compared with treated (thinned) forests. Most of the MSW would otherwise be landfilled, while the agricultural residues would otherwise be open-burned (orchard and vineyard residues), or tilled into the soil (straws and stover).

Each of the alternative fates for biomass residues entails environmental costs, including leaving forest residues in place (not performing forest treatment operations), and not performing land remediation activities on degraded land. Open burning of biomass produces smoke, air pollutants, and greenhouse gases. Burial of biomass in landfills depletes landfill space, causes water pollution, and leads to greenhouse gas emissions. Spreading and composting of biomass are beneficial uses for these residues. However, these activities lead to emissions of greenhouse gases and volatile organic compounds, and cause water pollution. Tilling of agricultural field residues into the soil provides

[2] Land remediation is a service that can be provided by HEC production on appropriate lands. The alternative fate is the opportunity cost of not receiving the remediation benefits if the HEC is not grown.

benefits in terms of soil protection and enrichment. For purposes of constructing the base-case scenario for this study, sufficient quantities of field residues are tilled into the soil in order to ensure sustainable agricultural use of the field, and only stover and straws that are surplus to that need can be collected and used as feedstocks for bio-fuels production. In-forest accumulation of biomass as overgrowth material degrades forest health, and increases the risks of destructive wildfires and pest and disease outbreaks. Failure to perform land remediation leaves tracts of land in poor condition. The data in the base-case dataset in the non-shaded portion of the first data block on the Processing Module are derived from Morris, 2000 (reference no. 1). The greenhouse gas emissions factors for the alternative fates in the reference are expressed as gross rather than net, so they were corrected by subtracting out 1,760 ton CO_2 per th.bdt, the equivalent of converting all of the biomass feedstock carbon to CO_2. Netting-out makes these data compatible with the carbon neutrality used in the model for biogenic carbon, by expressing the emissions as fossil carbon offsets.

Data on water use and greenhouse gas emissions for the production of feedstock crops (corn, oil seeds, HEC) in the base-case dataset are derived from the data developed for this study (chapter 1) . These are the rows highlighted in yellow in the data block labeled "Impacts—biomass in field" in the Biomass Module. Data on the greenhouse gas emissions from diesel fuel use in cellulosic feedstock production (forest, MSW, OVW, stover, straw) are from Morris, *Whitepaper: Bioenergy and Greenhouse Gases* (in press), March 2008. These are the data in the non-shaded rows of the data block labeled "Impacts—biomass in field" in the Biomass Module.

The data in the final input data block in the Biomass Module are the impacts of transporting feedstocks to a biofuels processing facility. The base-case dataset is based on unit emissions factors from Sheehan et. al. 1998, combined with transportation requirements determined in the modeling part of this study (chapter 3).

The input data blocks in the Processing Module include the impacts of conversion processing (green-shaded portion of the first data block on page) and the conversion efficiencies (gallons produced per bdt of feedstock, small data block in the middle of the page). The data on water use, greenhouse gas emissions, and conversion efficiency are derived from the technology models developed for this study (chapter 2). The data on air emissions for fuel production come from a variety of sources: Kim & Dale, 2005 (corn to ethanol), Sheehan et. al. 1998 (FAME biodeisel, LCEthanol), and Delucchi, 2003 (LCEthanol).

The input data blocks in the Fuel Module are for the transportation of fuels to the retailers, and use of the fuels. All of the input data on this page in the base-case dataset are from Sheehan et. al. 1998, combined with transportation requirements determined in the modeling part of this study (chapter 3).

The data in the base-case dataset on impacts associated with petroleum production and delivery to the refineries are from Sheehan et. al. 1998. Refining yield and impacts are from Sheehan et. al. 1998, and Delucchi, 2003. Impacts from delivery of gasoline and

diesel are from Sheehan et. al. 1998. Engine (tailpipe) emissions are from Sheehan et. al. 1998, Wu Wang and Hu, 2006, and Delucchi, 2003.

Data on the dollar value for the various impact categories is based on information available on the web from Evolution Markets, and from Cantor Fitzgerald Environmental Brokerage Services. As discussed previously, the category of greenhouse gases is the single most important impact category. The Chicago Climate Exchange provides data on the current, voluntary market for CO_2 in the US, which stands at a level of approximately $3 per ton. The European Climate Exchange reports a value of $30 per ton in the EU, where greenhouse gas regulations are already in effect. We bracket our results between these two values, and select $20 per ton of CO_2 equiv. for the base-case dataset. Up to now greenhouse gases have not been the target of environmental regulation in the U.S. However, that is likely to change radically over the next couple of years. It is widely believed that greenhouse gas regulation could become one of the major driving forces behind future energy development over the coming decades, and that regardless of the design of the greenhouse gas reduction regime that is eventually imposed, greenhouse gas emissions will acquire a real, significant negative value. We believe that $20 per ton is a reasonably conservative value to use in the base-case dataset.

Base-Case Results

Applying the base-case dataset to the base-case scenario for the WGA region produces an average value of 13 cents per gallon for the net environmental (non-market) benefits for the 8.25 billion gallons of biofuels that are produced. This benefit is provided in addition to the economic benefits provided by the enterprise. Of the various impact categories considered in the model, the greenhouse gases contribute approximately 50 percent of the total value of the ancillary benefits (7 ¢ per gallon). This value is calculated using the base-case dataset value of $20 per ton of CO_2 equiv. for greenhouse gases. Using the current US value for greenhouse gas emissions of $3 per ton as the lower boundary, and the current EU value for greenhouse gas emissions of $30 per ton as the upper boundary, produces a range of 7 – 16 ¢ per gallon of biofuel produced for the ancillary benefits of biomass fuels production. This is an economy-wide impact of $575 – 1,335 million per year of ancillary benefits across the West for the base-case biofuels scenario.

Value by Residue Type

In addition to analyzing the net benefits of an entire WGA-wide scenario for biofuels production, the benefits model can be used to determine the net benefits of utilizing individual components of the resource mix. The base-case scenario provides an overall average net benefit of 13 ¢ per gallon of biofuel. As shown in the Table below, biofuels derived from the various feedstock types provide net benefits of as large as 59 ¢ per gallon, to a slightly negative value per gallon.

Net Benefit of Biofuels Production

	Net Benefit $ / gal	GHG Benefit $ / gal
Forest Residues	0.59	0.25
MSW	0.34	0.21
OVW	0.21	0.02
Stover	-0.01	0.06
Straw	-0.01	0.06
Tallow	0.23	0.17
Grease	0.23	0.17
Corn	-0.08	0.10
HEC	0.03	-0.07
Base-Case Scenario	0.13	0.07

In general, the resources whose use provides the greatest amounts of ancillary alternative disposal services are the resources that have the greatest amount of net benefits in the table. The corn-production trajectories have a net cost, mainly because of the large amount of water and energy used in feedstock production (agriculture). HEC crops considered in this study are not irrigated, and so are not burdened with the environmental cost of water use. In addition, twenty percent of the HEC crops are assumed to provide land remediation services in addition to the energy product (ethanol).

The second column in the table shows the net benefit for the utilization of each biomass resource type that is attributable to net greenhouse gas reductions alone. Greenhouse gas reductions are the major component of the total net benefits for all resource types, with the exception of herbaceous energy crops, which, based on the base-case dataset, are small net emitters of greenhouse gases. Presumably this is due to the land areas that must be used for this crop, which is not irrigated; and to the handling and transportation requirements for this low density material (switchgrass).

Attachment A: Model Printout

Value of the Environmental Benefits of Biomass Energy Production (pg.1)

Biomass Module	Residues and Wastes							Crops			
	Forest	MSW	OVW	Stover	Straw	Tallow	Grease	Corn	Oil Seeds	Herbaceous	
Fuel Use (th.bdt/yr)	9,273	17,288	3,032	628	21,127	908	197	8,504		34,467	

Pathway to Fuel	Forest	MSW	OVW	Stover	Straw	Tallow	Grease	Corn	Oil Seeds	Herbaceous	Total
Grain Ethanol Dry Mill								40%			3,402
Grain Ethanol Wet Mill								60%			5,102
LCEthanol	100%	100%	100%	100%	100%					100%	85,815
FAME Biodiesel						5%					45
Renewable Diesel						95%	100%				1,060

Alternative Fate (%)	Forest	MSW	OVW	Stover	Straw	Tallow	Grease	Corn	Oil Seeds	Herbaceous	Total
open burning	30.0%		100.0%								5,814
forest accum.	60.0%										5,564
controlled landfill		60.0%									10,373
uncontrolled landfill		25.0%									4,322
composting		15.0%									2,593
tilling				100.0%	100.0%						21,755
land remediation										20.0%	6,893
kiln boiler / firewood	10.0%										927

Impacts--biomass in field	SOx	NOx	particulate	CO	GHGs	water	landfill	thinned / remed
unit/th.bdt	lb	lb	lb	lb	ton	mgal	m3	acres
Forest					28			
MSW					18			
OVW					20			
Stover					28			
Straw					28			
Tallow								
Grease								
Corn					20	75,000		
Oil Seeds					25	250,000		
Herbaceous					11	-		
Petroleum (per th.ton crude)	2,332	438	350	189	105	34		

Impacts--biomass trans.	SOx	NOx	particulate	CO	GHGs	water	landfill	thinned / remed
unit/th.bdt	lb	lb	lb	lb	ton	mgal	m3	acres
Forest	237	1,525	220	551	20	0.81		
MSW	261	1,677	242	606	22	0.89		
OVW	157	1,006	145	363	13	0.53		
Stover	39	250	35	89	14	0.13		
Straw	44	283	40	101	15	0.15		
Tallow	116	1,163	83	249	42	0.38		
Grease	181	1,814	130	389	66	0.59		
Corn	119	757	108	273	41	0.47		
Oil Seeds								
Herbaceous	269	1,710	244	617	93	0.91		
Petroleum (per th.ton crude)	1,010	186	154	29	49	0.40		

Value of the Environmental Benefits of Biomass Energy Production (pg.2)

Processing Module

Ultimate Impacts (unit/th.bdt)	SOx	NOx	particulate	CO	GHGs	water	landfill	thinned / remed
unit	lb	lb	lb	lb	ton	mgal	m3	acres
Grain Ethanol Dry Mill	51	206	137	331	263	552,941		
Grain Ethanol Wet Mill	53	215	144	347	275	2,563,435		
LCEthanol	157	637	425	1,026	814	535,814		
FAME Biodiesel	4,639	772	341	119	310	7,736		
Renewable Diesel	1,028	876	174	730	842	-		
VS.								
open burning	150	7,000	15,000	150,000	301			
forest accum.	150	7,000	21,000	280,000	1,648			60
controlled landfill					623		2,400	
uncontrolled landfill					2,342			
composting					834			
tilling					485			
land remediation								300
kiln boiler / firewood	150	2,500	900	15,000	1,766		24.2	
Gasoline (unit / th.ton crude)	496	989	140	493	293	433		
Diesel (unit / th.ton crude)	270	230	46	192	71	67		

Fuel Production

Fuel Production	gal / bdt	th.gal / yr	
Grain Ethanol Dry Mill	117.6	400,028	
Grain Ethanol Wet Mill	105.1	536,262	**Total Ethanol**
LCEthanol	82.2	7,053,993	7,990,283
FAME Biodiesel	257.9	11,709	**Total Diesel**
Renewable Diesel (ton / ton)	0.2	296,688	308,397

	gal / ton crude	th.gal / yr
Gasoline	144.5	5,369,470
Diesel	67.1	288,659

Impacts	th.lb/yr	th.lb/yr	th.lb/yr	th.lb/yr	th.ton/yr	th.mgal/yr	th.m3/yr	th.acres/yr
open burning	872	40,697	87,209	872,085	1,750	-	-	-
forest accum.	835	38,947	116,840	1,557,864	9,169	-	-	334
controlled landfill	-	-	-	-	6,462	-	24,895	-
uncontrolled landfill	-	-	-	-	10,122	-	-	-
composting	-	-	-	-	2,163	-	-	-
tilling	-	-	-	-	10,551	-	-	-
land remediation	-	-	-	-	-	-	-	2,068
kiln boiler / firewood	139	2,318	835	13,910	1,638	-	22	-
Total, no energy	**1,846**	**81,962**	**204,883**	**2,443,859**	**41,855**	-	**24,917**	**2,402**
VS.								
Grain Ethanol Dry Mill	577	3,275	834	2,057	1,102	2,136,006	-	-
Grain Ethanol Wet Mill	877	4,960	1,284	3,163	1,714	13,462,353	-	-
LCEthanol	30,868	165,925	52,408	128,181	75,581	45,980,938	-	-
FAME Biodiesel	216	88	19	17	16	351	-	-
Renewable Diesel	1,225	2,289	282	1,065	941	0	-	-
Gasoline	62,774	26,372	10,523	11,624	7,309	7,645	-	-
Diesel	3,654	863	556	414	228	103	-	-

Value of the Environmental Benefits of Biomass Energy Production (pg.3)

Fuel Module

Transport Impacts (unit/th.gal)	**SOx**	**NOx**	**particulate**	**CO**	**GHGs**	**water**	**landfill**	**thinned / remed**
unit	**lb**	**lb**	**lb**	**lb**	**ton**	**mgal**	**m3**	**acres**
Grain Ethanol Dry Mill	0.01	0.11	0.00	0.02	0.003	0.00003		
Grain Ethanol Wet Mill	0.01	0.11	0.00	0.02	0.003	0.00003		
LCEthanol	0.01	0.11	0.00	0.02	0.003	0.00003		
FAME Biodiesel	0.00	0.03	0.00	0.01	0.001	0.00001		
Renewable Diesel	0.00	0.03	0.00	0.01	0.001	0.00001		
VS.								
Gasoline unit/gal)	0.01	0.12	0.01	0.02	0.004	0.00001		
Diesel unit/gal)	0.00	0.02	0.00	0.01	0.001	0.00001		

Fuel Use Impacts (unit/th.gal)	**SOx**	**NOx**	**particulate**	**CO**	**GHGs**	**water**	**landfill**	**thinned / remed**
unit	**lb**	**lb**	**lb**	**lb**	**ton**	**mgal**	**m3**	**acres**
Grain Ethanol Dry Mill	-	4.4	1.2	142.9	-			
Grain Ethanol Wet Mill	-	4.4	1.2	142.9	-			
LCEthanol	-	4.4	1.2	142.9	-			
FAME Biodiesel	29.8	112.4	0.9	23.4	-			
Renewable Diesel	29.8	112.4	0.9	23.4	-			
VS.								
Gasoline unit/gal)	0.5	5.3	1.6	105.8	10.2			
Diesel unit/gal)	29.8	99.2	3.2	48.5	11.7			

Impacts	**th.lb/yr**	**th.lb/yr**	**th.lb/yr**	**th.lb/yr**	**th.ton/yr**	**th.mgal/yr**	**th.m3/yr**	**th.acres/yr**
Gasoline	2,738	29,113	8,618	568,219	54,736	0	-	-
Diesel	8,603	28,642	924	14,001	3,389	0	-	-
Total, avoided fuels	**11,341**	**57,755**	**9,542**	**582,220**	**58,126**	**0**	-	-
VS.								
Grain Ethanol Dry Mill	4	1,805	481	57,173	1	0	-	-
Grain Ethanol Wet Mill	5	2,420	645	76,644	2	0	-	-
LCEthanol	71	31,835	8,486	1,008,178	21	0	-	-
FAME Biodiesel	349	1,316	11	274	0	0	-	-
Renewable Diesel	6	24	0	5	0	0	-	-

Value of the Environmental Benefits of Biomass Energy Production (pg.4)

Calculation Module

	SOx	NOx	particulate	CO	GHGs	water	landfill	hinned / remed
Net Impacts	th.lb/yr	th.lb/yr	th.lb/yr	th.lb/yr	th.ton/yr	th.mgal/yr	th.m3/yr	th.acres/yr
Gasoline	65,513	55,485	19,141	579,843	62,046	7,645	-	-
Diesel	12,257	29,505	1,480	14,416	3,617	103	-	-
Total, avoided fuels	**77,770**	**84,990**	**20,621**	**594,259**	**65,662**	**7,747**	-	-
Total, alternative disposal	**1,846**	**81,962**	**204,883**	**2,443,859**	**41,855**	-	**24,917**	**2,402**
VS.								
Grain Ethanol Dry Mill	581	5,080	1,316	59,230	1,103	2,136,006	-	-
Grain Ethanol Wet Mill	883	7,380	1,929	79,807	1,716	13,462,353	-	-
LCEthanol	30,938	197,760	60,894	1,136,359	75,602	45,980,938	-	-
FAME Biodiesel	565	1,404	30	291	16	351	-	-
Renewable Diesel	1,232	2,313	282	1,070	941	0	-	-
Total, biomass fuels	**34,198**	**213,937**	**64,450**	**1,276,756**	**79,379**	**61,579,648**	-	-

	SOx	NOx	particulate	CO	GHGs	water	landfill	hinned / remed
	$/th.lb	$/th.lb	$/th.lb	$/th.lb	$/th.ton	$/th.gal	$/th.m3	$/th.acres
Value of Impacts	(270)	(500)	(1,000)	(25)	(20,000)	(10)	(12,500)	(250,000)
(approx. mid points)								
Value (th.$/yr)								
biomass energy net	(9,234)	(106,969)	(64,450)	(31,919)	(1,587,572)	(615,796)	-	-
avoided alternative disposal	(498)	(40,981)	(204,883)	(61,096)	(837,100)	-	(311,465)	(600,462)
avoided fossil fuel	(20,998)	(42,495)	(20,621)	(14,856)	(1,313,248)	(77)	-	-
Net Biomass Benefit (th.$/yr)	12,263	(23,493)	161,054	44,034	562,776	(615,719)	311,465	600,462
Benefit in $ / gal	0.00	(0.00)	0.02	0.01	0.07	(0.07)	0.04	0.07

Total Value	**(th.$/yr)**			
biomass energy:	(2,415,940)	**Net Benefit:**	**0.13**	**$/gal**
no biomass energy:	(3,468,781)		**1,052,841**	**th.$/yr**