Woody Energy Crops Processing Pathway
Summary Description

DOE Pathway Objectives

The Biomass Program objective for this pathway is to develop and demonstrate new commercially-viable processes and systems to convert woody energy crops to biofuels – defined by the Program as biomass derived liquid transportation fuels that are fungible in today's transportation fuel supply. Both biochemical and thermochemical conversion technologies are under evaluation.

Fuel production from high-volume, dedicated energy crops is the foundation of the long-term strategy of the Biomass Program. Conversion technologies and processes for energy crop feedstocks will build on the experience gained through processing agricultural and forest residues and process intermediates in commercial-scale facilities. Other potential product options include hydrogen; organic chemicals and petrochemical replacements; and electricity.

Pathway Overview

The block flow diagram shown in Figure 1 outlines the process steps and multiple options for producing fuels, chemicals and power from energy crops (herbaceous crops shown but not part of this document). Bold lines highlight the routes to biofuels; and the dotted lines identify routes to bioproducts. This diagram is not intended to be all inclusive. Other viable processing options should be considered for addition.

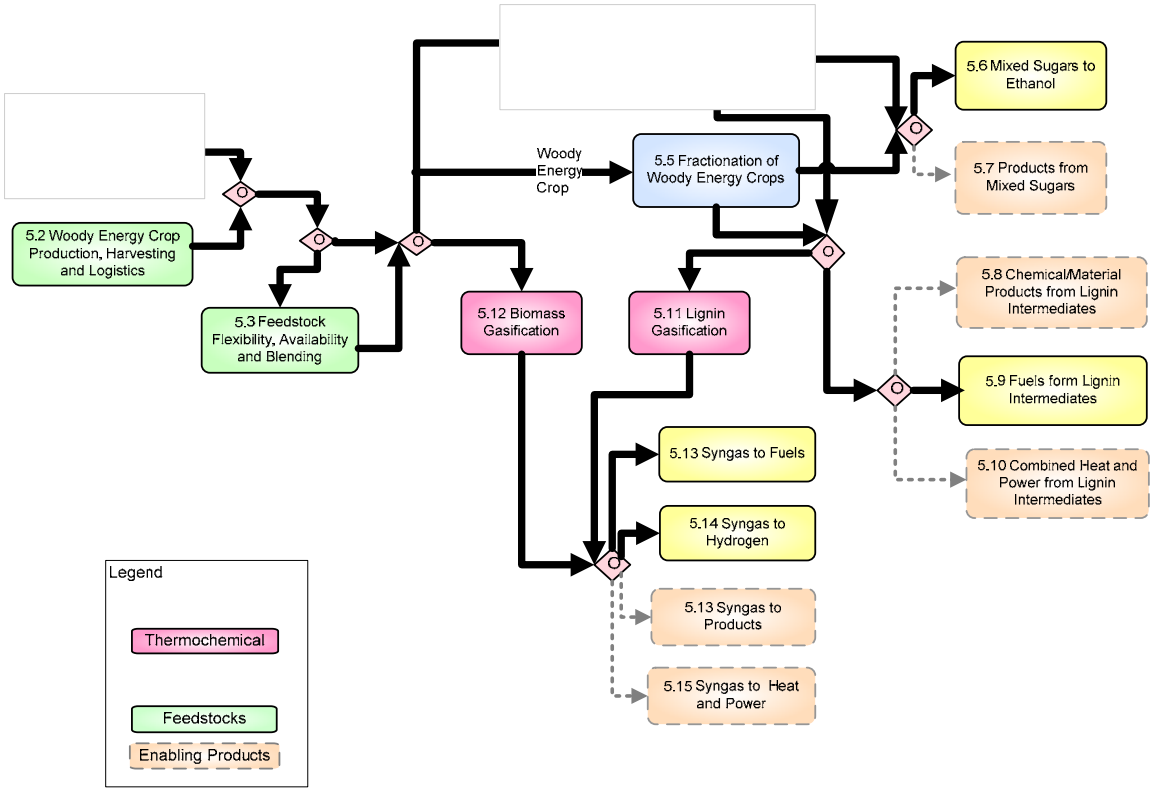

Figure 1: Woody Energy Crops Processing Pathway Diagram

Woody Energy Crops Processing for Fuel Production

Fuel production options for woody energy crops are focused on developing and demonstrating integrated biochemical and thermochemical processes and systems for converting wood to biofuels, as described in Table 1.

Table 1. Perennial Herbaceous Energy Crops Processing for Fuel Production

Process Category	Process Step(s)	Description
Feedstock Logistics	5.2 Woody Energy Crop Harvesting and Logistics	Collect, store, transport and preprocess woody energy crops to meet cost, quality, quantity and sustainability requirements.
Feedstock Logistics	5.3 Feedstock Flexibility, Availability and Blending	Integrate/blend multiple types of energy crops in flexible feedstock assembly/preprocessing system ("depot concept").
Biomass-to-Sugars	5.5 Fractionation of Woody Energy Crops	Produce mixed sugars from woody energy crops with cost-effective pretreatment and enzymatic hydrolysis, using low-cost enzymes, with optional heat and power production
Sugars-to-Fuel	5.6 Mixed Sugars to Ethanol	Ferment mixed sugars to ethanol and separate/purify ethanol
Lignin Intermediates-to-Fuel	5.9 Fuels from Lignin Intermediates	Convert lignin intermediates to fuel that meets desired specifications
Lignin Intermediates-to-Syngas	5.11 Lignin Gasification	Feed lignin intermediates to high-pressure gasifier, convert to syngas and cleanup/condition to meet required syngas specifications for downstream operations
Biomass-to-Syngas	5.12 Biomass Gasification	Feed biomass to high-pressure gasifier, convert to syngas and cleanup/condition to meet required syngas specifications for downstream operations
Syngas-to-Fuel	5.13 Syngas to Fuel	Convert conditioned syngas to biofuels (mixed alcohols, DME, FTL) and separate fuel to meet required specifications
Syngas-to-Fuel	5.14 Syngas to Hydrogen	Convert conditioned syngas to hydrogen and separate/recover hydrogen to meet required specifications

The mixed sugars from the fractionation process can also be converted to bioproducts (Process Step 5.7); syngas can be converted to products, including heat and power (Process Steps 5.13 and 5.15); and lignin intermediates can be converted to products, including heat and power (Process Steps 5.8 and 5.10).

Woody Energy Crops Resource Potential

In the USDA/DOE Billion Ton Study[1] High Case, 55 million acres of agricultural land—cropland, cropland pasture and Conservation Reserve Program (CRP)[2] land—are assumed to be converted to the production of perennial crops as a biofuels market emerge and grows. A portion of the trees grown on CRP land are assumed to be energy crops available for bioenergy production. The total potential woody energy crops available for bioenergy production are summarized in Table 2. It is important to understand that the Billion Ton Study does not presuppose a split between perennial herbaceous and woody energy crops. The values in Table 2 for perennial crops assumes only woody energy crops would be grown on the 55 million acres available. The "Baseline" case is Scenario 1 in the Billion Ton Study based on the National Resources Inventory for 2001. The "High Case" is the high yield increase case of Scenario 3 in the Billion Ton Study which includes perennial crops and land use change. Table 4 provides more detailed energy crop information for all the scenarios and cases evaluated in the Billion Ton Study.

Table 2. Potential Woody Energy Crops Available for Biofuels Production [3]

Feedstock	Feedstock Case	Harvested Acreage (Million Acres)	Product Yield (Dry Tons/Acre)	Total Annual Output (Million Dry Tons)	Output Available for Biofuels Production (Million Dry Tons)
Trees - CRP	Baseline (2001)	2.2	2.0	4.4	0.0
	High Case	2.2	2.0	4.4	2.2
Perennial Crops	Baseline (2001)	0.0	0.0	0.0	0.0
	High Case	55.0	7.4	407.0	368.0

Woody Energy Crops Ethanol[4] Production Potential

The estimated ethanol production potential from woody energy crops is summarized in Table 3. Yield values are based on specific process configurations and technical performance levels.

- 2012 yield value is based on an evaluation of corn stover and includes hydrolysis and fermentation of carbohydrates and combustion of fermentation

[1] *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*. (April 2005). US Department of Energy and US Department of Agriculture. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf

[2] The Conservation Reserve Program (CRP) provides farmers with an annual per-acre rental payment of half the cost of establishing a permanent land cover in exchange for retiring environmentally sensitive cropland from production for 10 to 15 years.

[3] *Ibid.* High case with land use change to accommodate perennial crops.

[4] Due to the emphasis of cellulosic ethanol in the President's Advanced Energy Initiative, estimates of fuel ethanol potential have been developed for all lignoocellulosic feedstocks. This is not intended to preclude consideration of other biofuels but rather to serve as a common fuel product to evaluate the relative contribution of different feedstock types as well establish a basis for comparing other biofuel options.

residue for heat and power production.[5] This yield is consistent with the conceptual process design that meets the $1.07 ethanol cost target.

- 2030 yield values also based on corn stover.[6]
  - "Biochem only" case includes hydrolysis and fermentation of carbohydrates, but at improved levels of performance compared to 2012.
  - "Bio and Thermo" case includes hydrolysis and fermentation of carbohydrates and gasification of fermentation residue followed by mixed alcohol synthesis.

While there will likely be differences in yields between feedstocks due to different feedstock compositions, the yield information for corn stover was applied to CRP trees and woody energy crops. Composition differences could be expected to impact yields by up to about plus or minus10 percent. The compositions of potential woody energy crops are somewhat different from corn stover although the overall ethanol potential is comparable.

Quantities of ethanol produced shown in Table 3 are calculated by multiplying the "High Case" feedstock available by the 2030 target yields.

Table 3. Total Fuel Potential of Woody Energy Crops

Feedstock Type	Feedstock Case	Output Available for Biofuels Production (Million Dry Tons)	2012 Target Ethanol Yield (Gal. per Dry Ton)	2030 Target Ethanol Yield (Gal. per Dry Ton, Biochem only)	2030 Target Ethanol Yield (Gal. per Dry Ton, Bio & Thermo)	2030 Potential Annual U.S. Ethanol Production (Million Gal., Biochem only)	2030 Potential Annual U.S. Ethanol Production (Million Gal., Bio & Thermo.)
Trees - CRP	Baseline (2001)	0.0	90	103.5	114.5	230	250
	High Case	2.2					
Perennial Crops	Baseline (2001)	0.0	90	103.5	114.5	38,120	42,170
	High Case	368.3					
TOTAL	Baseline	0.0				38,350	42,420
	High Case	370.5					

[5] *30x30: A Scenario for Supplying 30% of 2004 Motor Gasoline with Ethanol by 2030*. (6/30/06 Draft). Appendix D, Table D-2 for feedstock information and Appendix E, Table E-2 for conversion information.
[6] *30x30: A Scenario for Supplying 30% of 2004 Motor Gasoline with Ethanol by 2030*. (6/30/06 Draft). Appendix G, Figure G-1.

Billion Ton Study Resource Data for All Scenarios

Table 4. Potential Energy Crop (Herbaceous and Woody) Quantities for Baseline and 4 Cases[7]

Feedstock	Acres Harvested	Average Yield	Total Annual Production	Feedstock used or Available for Biofuels	% of Total used for Biofuels
	(million acres)	dry tons/acre/year	million dry tons/year	million dry tons/year	%
Scenario 1: Baseline					
Grasses - CRP	25.4	2.0	50.8	0.0	0.0%
Trees - CRP	2.2	2.0	4.4	0.0	0.0%
Subtotal				0.0	
Scenario 2- Case A: Moderate Crop Yield Increase, No Land Use Change					
Grasses - CRP	25.4	2.0	50.8	25.4	50.0%
Trees - CRP	2.2	2.0	4.4	2.2	50.0%
Perennial Crops			0.0	0.0	
Subtotal				27.6	
Scenario 3: Case A; Moderate Crop Yield Increase, With Land Use Change					
Grasses - CRP	15.4	2.0	30.8	15.4	50.0%
Trees - CRP	2.2	2.0	4.4	2.2	50.0%
Perennial Crops	35.0	4.7	164.5	146.5	89.1%
Subtotal				164.1	
Scenario 2- Case B: High Crop Yield Increase, No Land Use Change					
Grasses - CRP	25.4	2.0	50.8	25.4	50.0%
Trees - CRP	2.2	2.0	4.4	2.2	50.0%
Perennial Crops	0.0	0.0	0.0	0.0	
Subtotal				27.6	
Scenario 3- Case B: High Crop Yield Increase, With Land Use Change					
Grasses - CRP	15.4	2.0	30.8	15.4	50.0%
Trees - CRP	2.2	2.0	4.4	2.2	50.0%
Perennial Crops	55.0	7.4	407.0	368.3	90.5%
Subtotal				385.9	

[7] *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*. (April 2005). US Department of Energy and US Department of Agriculture. http://feedstockreview.ornl.gov/pdf/billion_ton_vision.pdf, Appendix B.