Agricultural Residues 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 farm residues from current grain crop production activities (e.g., corn stover and wheat straw) 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.

The use of existing agricultural residues is seen as a mid-term strategy to bridge the gap between near-term, niche, low-cost biomass supplies and long-term high-volume dedicated perennial energy crops. Initially, agricultural residue supply and conversion systems will be demonstrated in existing primary facilities (e.g. corn or other grain processing mills) and ultimately in new dedicated 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 agricultural residues. The 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.

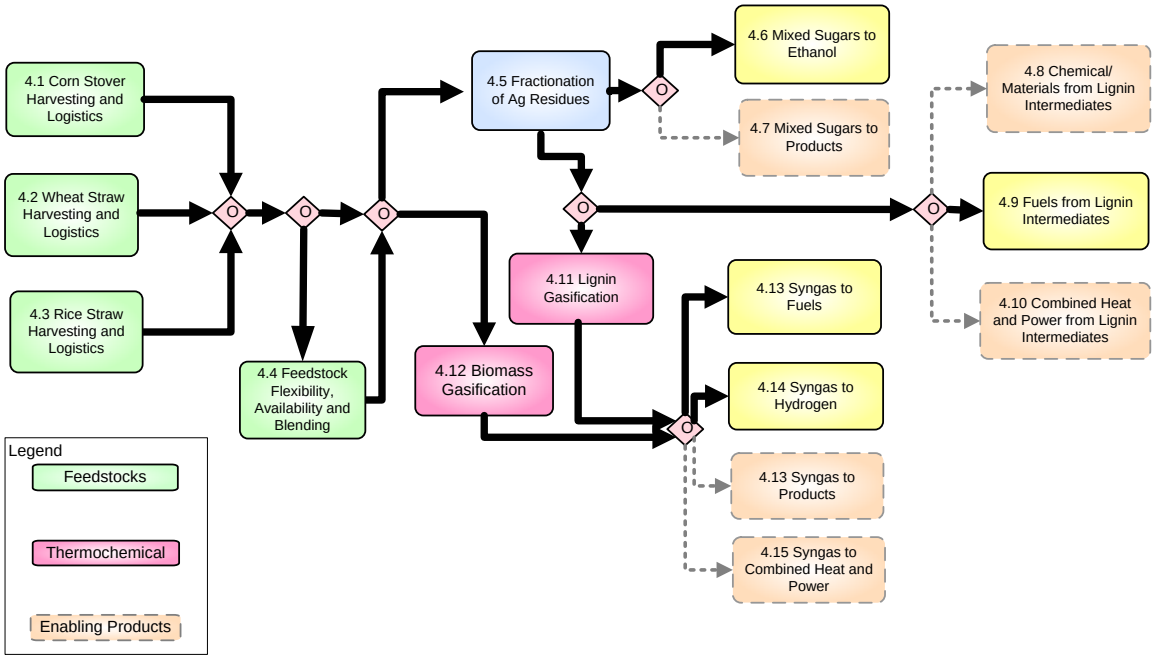

Figure 1: Agricultural Residues Processing Pathway Diagram

Agricultural Residues Processing for Fuel Production

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

Table 1. Agricultural Residues Processing for Fuel Production

Process Category	Process Step(s)	Description
Feedstock Logistics	4.1 Corn Stover Harvesting and Logistics	Collect, store, transport and preprocess corn stover to meet cost, quality, quantity and sustainability requirements.
Feedstock Logistics	4.2 Wheat Straw Harvesting and Logistics	Collect, store, transport and preprocess wheat straw to meet cost, quality, quantity and sustainability requirements.
Feedstock Logistics	4.3 Rice Straw Harvesting and Logistics	Collect, store, transport and preprocess rice straw to meet cost, quality, quantity and sustainability requirements.
Feedstock Logistics	4.4 Feedstock Flexibility, Availability and Blending	Integrate/blend multiple agricultural residues in flexible feedstock assembly/preprocessing system (“depot concept”).
Biomass-to-Sugars	4.5 Fractionation of Agricultural Residues	Produce mixed sugars from agricultural residues with cost-effective pretreatment and enzymatic hydrolysis, using low-cost enzymes, with optional heat and power production
Sugars-to-Fuel	4.6 Mixed Sugars to Ethanol	Ferment mixed sugars to ethanol and separate/purify ethanol
Lignin Intermediates-to-Fuel	4.9 Fuels from Lignin Intermediates	Convert lignin intermediates to fuel that meets desired specifications
Lignin Intermediates-to-Syngas	4.11 Lignin Gasification	Feed lignin intermediates to high-pressure gasifier, convert to syngas and cleanup to meet required syngas specifications for downstream operations
Biomass-to-Syngas	4.12 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	4.13 Syngas to Fuel	Convert conditioned syngas to biofuels (mixed alcohols, DME, FTL) and separate fuel to meet required specifications
Syngas-to-Fuel	4.14 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 4.7); syngas can be converted to products, including heat and power (Process Steps 4.13 and 4.15); and lignin intermediates can be converted to products, including heat and power (Process Steps 4.8 and 4.10).

Agricultural Residues Resource Potential

The major agricultural residues available for biofuels production, as estimated in the USDA/DOE Billion Ton Study[1], are summarized in Table 2. Details of what is included in the "Other Residues" category are provided in Tables 4 and 5. 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. Tables 6 and 7 provide more detailed information for all the scenarios and cases evaluated in the Billion Ton Study.

Table 2. Agricultural Residues Output Available for Biofuels Production [2]

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)
Corn Stover	Baseline (2001)	68.8	3.3	227.0	74.8
	High Case	76.6	4.9	375.3	256.1
Wheat Straw *	Baseline (2001)	48.8	1.7	80.5	11.0
	High Case	47.3	2.3	109.0	66.8
Rice Straw	Baseline (2001)	3.3	4.3	14.2	5.7
	High Case	3.4	5.8	19.7	14.7
Other Residues	Baseline (2001)				21.6
	High Case				90.2
TOTAL	Baseline (2001)				113.1
	High Case				427.8

(* Total for winter and summer wheat harvest, yield is an average, output available for Biofuels also includes 15 Million Dry tons from double cropping winter wheat with soybeans).

Agricultural Residues Ethanol[3] Production Potential

The estimated ethanol production potential from the available agricultural residues 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] *Ibid.*

[3] 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. [4] 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. [5]
  - "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 all the agricultural residue types. Composition differences could be expected to impact yields by up to about plus or minus10 percent.

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 Agricultural Residues

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.)
Corn Stover	Baseline	74.8	90	103.5	114.5	26,510	29,320
	High Case	256.1					
Wheat Straw	Baseline	11.0	90	103.5	114.5	6,910	7,650
	High Case	66.8					
Rice Straw	Baseline	5.7	90	103.5	114.5	1,520	1,680
	High Case	14.7					
Other Residues	Baseline	21.6	90	103.5	114.5	9,340	10,330
	High Case	90.2					
TOTAL	Baseline	113.1				44,280	48,980
	High Case	427.8					

[4] *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.
[5] *30x30: A Scenario for Supplying 30% of 2004 Motor Gasoline with Ethanol by 2030*. (6/30/06 Draft). Appendix G, Figure G-1.

Table 4. Other Agricultural Residues Available for Biofuels Production [6]

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)
Sorghum Residue	Baseline	8.6	1.4	12.0	0
	High Case	6.8	1.9	12.9	4.0
Barley Straw	Baseline	4.3	1.8	7.7	0.7
	High Case	3.7	2.6	9.6	4.7
Oat Straw	Baseline	1.9	1.7	3.2	0.1
	High Case	1.6	2.1	3.4	1.2
Soybean Residue	Baseline	73.0	1.6	116.8	0
	High Case	63.4	2.6	164.8	47.9
Cotton Lint	Baseline	13.8	1.0	13.8	2.7
	High Case	12.3	1.2	14.8	8.9
Misc. Crop Residues	Baseline	20.1	1.0	20.1	18.1
	High Case	20.1	1.3	26.1	23.5
TOTAL	Baseline				21.6
	High Case				90.2

[6] *Ibid.*

Table 5: Biomass Residue Sources included in "Miscellaneous Crop Residue" Category in Table 4[7]

Other Oilseeds	
Canola	7.253%
Flaxseed	2.875%
Mustard seed	0.220%
Peanuts	7.024%
Rapeseed	0.015%
Safflower	0.881%
Sunflowers	12.835%
Tobacco & Sugar crops	
Sugar beets	6.187%
Sugarcane	5.114%
Tobacco	2.151%
Dry beans, peas, & lentils	**8.178%**
Potatoes & misc	
Sweet potatoes	0.465%
Potatoes	6.175%
Taro	0.002%
Ginger root	0.002%
Coffee	0.031%
Hops	0.179%
Peppermint oil	0.391%
Spearmint oil	0.097%
Vegetables	**15.907%**
Fruits, tree nuts & horticultural	**19.864%**
Proso millet	**2.885%**
Rye	**1.269%**
Total	**100%**

[7] Personal communication with Robert Perlack, ORNL regarding technical details that are the basis for summary information in Reference 1.

Billion Ton Study Resource Data for All Scenarios

Table 6: Primary Agricultural Residue Quantities for Baseline and 4 Cases[8]

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					
Corn Stover	68.8	3.3	227.0	74.8	32.9%
Wheat Straw - winter	31.3	1.9	59.5	8.8	14.8%
Wheat Straw - w-dc*				0.0	
Wheat Straw - spring	17.5	1.2	21.0	2.2	10.5%
Rice Straw	3.3	4.3	14.2	5.7	40.2%
Subtotal				91.5	
Scenario 2- Case A: Moderate Crop Yield Increase, No Land Use Change					
Corn Stover	76.6	4.1	314.1	169.7	54.0%
Wheat Straw - winter	33.3	2.3	76.6	27.4	35.8%
Wheat Straw - w-dc*				10.0	
Wheat Straw - spring	19.0	1.4	26.6	7.4	27.8%
Rice Straw	3.4	5.1	17.3	10.3	59.4%
Subtotal				224.8	
Scenario 3- Case A: Moderate Crop Yield Increase, With Land Use Change					
Corn Stover	76.6	4.1	314.1	169.7	54.0%
Wheat Straw - winter	33.3	2.3	76.6	27.4	35.8%
Wheat Straw - w-dc*				10.0	
Wheat Straw - spring	19.0	1.4	26.6	7.4	27.8%
Rice Straw	3.4	5.1	17.3	10.3	59.4%
Subtotal				224.8	
Scenario 2- Case B: High Crop Yield Increase, No Land Use Change					
Corn Stover	76.6	4.9	375.3	256.1	68.2%
Wheat Straw - winter	33.3	2.7	89.9	44.9	49.9%
Wheat Straw - w-dc*				15.0	
Wheat Straw - spring	19.0	1.6	30.4	12.2	40.1%
Rice Straw	3.4	5.8	19.7	14.7	74.5%
Subtotal				342.9	
Scenario 3- Case B: High Crop Yield Increase, With Land Use Change					
Corn Stover	76.6	4.9	375.3	256.1	68.2%
Wheat Straw - winter	30.3	2.7	81.8	40.9	50.0%
Wheat Straw - w-dc*				15.0	
Wheat Straw - spring	17.0	1.6	27.2	10.9	40.1%
Rice Straw	3.4	5.8	19.7	14.7	74.5%
Subtotal				337.6	

* denotes winter wheat straw resulting from double cropping with soybeans.

[8] *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.

Table 7: Other Agricultural Residue Quantities for Baseline and 4 Cases[9]

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					
Sorghum Residue	8.6	1.4	12.0	0.0	0.0%
Barley Straw	4.3	1.8	7.7	0.7	9.0%
Oat Straw	1.9	1.7	3.2	0.1	3.1%
Soybean Residue	73.0	1.6	116.8	0.0	0.0%
Cotton Lint	13.8	1.0	13.8	2.7	19.6%
Other Residues	20.1	1.0	20.1	18.1	90.0%
Subtotal				21.6	
Scenario 2- Case A: Moderate Crop Yield Increase, No Land Use Change					
Sorghum Residue	6.8	1.7	11.6	1.3	11.2%
Barley Straw	3.7	2.2	8.1	2.8	34.4%
Oat Straw	1.6	1.9	3.0	0.7	23.0%
Soybean Residue	71.4	1.8	128.5	0.0	0.0%
Cotton Lint	12.3	1.1	13.5	5.5	40.7%
Other Residues	20.1	1.2	23.1	20.8	90.0%
Subtotal				31.1	
Scenario 3- Case A: Moderate Crop Yield Increase, With Land Use Change					
Sorghum Residue	6.8	1.7	11.6	1.3	11.2%
Barley Straw	3.7	2.2	8.1	2.8	34.4%
Oat Straw	1.6	1.9	3.0	0.7	23.0%
Soybean Residue	71.4	2.4	171.4	12.7	7.4%
Cotton Lint	12.3	1.1	13.5	5.5	40.7%
Other Residues	20.1	1.2	23.1	20.8	90.0%
Subtotal				43.8	
Scenario 2- Case B: High Crop Yield Increase, No Land Use Change					
Sorghum Residue	6.8	1.9	12.9	4.0	31.0%
Barley Straw	3.7	2.6	9.6	4.7	48.9%
Oat Straw	1.6	2.1	3.4	1.2	35.7%
Soybean Residue	71.4	2.0	142.8	0.0	0.0%
Cotton Lint	12.3	1.2	14.8	8.9	60.3%
Other Residues	20.1	1.3	26.1	23.5	90.0%
Subtotal				42.3	
Scenario 3-Case B: High Crop Yield Increase, With Land Use Change					
Sorghum Residue	6.8	1.9	12.9	4.0	31.0%
Barley Straw	3.7	2.6	9.6	4.7	48.9%
Oat Straw	1.6	2.1	3.4	1.2	35.7%
Soybean Residue	63.4	2.6	164.8	47.9	29.1%
Cotton Lint	12.3	1.2	14.8	8.9	60.3%
Other Residues	20.1	1.3	26.1	23.5	90.0%
Subtotal				90.2	

[9] Ibid.