Appendix B: Technical Projection Tables

Table B-1: Biomass Volume and Price Projections through 2030 (minus allocations for losses, chemicals, and pellets)

Feedstock Category	Feedstock Resource	Feedstock Available for Cellulosic Fuel Production (MM Dry Tons/Year)							
		SOT	Projection						
		2013	2014	2015	2016	2017	2018	2022	2030
Agricultural Residues	Corn Stover	70.7	83.2	106.7	131.8	138.1	150.7	154.1	172.5
	Wheat Straw	11.2	12.9	13.9	15.9	17.1	18.7	13.9	35.6
Energy Crops	Herbaceous Energy Crops	-	0.5	1.9	3.3	6.4	9.2	10.7	50.2
	Woody Energy Crops	-	-	-	-	-	0.2	5.0	22.9
Forest Residues	Pulpwood	0.8	1.2	1.6	2.1	2.7	3.3	1.7	31.4
	Logging Residues and Fuel Treatments	60.6	56.6	55.1	34.0	50.2	50.5	67.1	60.9
	Other Forestland Removals	0.6	0.8	0.4	0.6	1.3	1.2	0.9	2.9
	Urban and Mill Wood Wastes	32.3	31.3	31.0	27.0	29.9	29.7	31.0	33.8
Totals (MM Dry Tons/Year)		**176.1**	**186.5**	**210.6**	**214.7**	**245.7**	**263.4**	**284.5**	**410.2**
Average Price to Reactor (2011$/Dry Ton)		**102.12**	**101.45**	**92.36**	**86.72**	**80.00**	**80.00**	**80.00**	**80.00**

Table B-2: Terrestrial Feedstock Supply and Logistics Costs to Supply Feedstock to a Pyrolysis Conversion Process

Processing Area Cost Contribution ($2011)		2013 SOT	2014 Projection	2015 Projection	2016 Projection	2017 Projection	2018 Projection	2019 Projection
Delivered Feedstock Type		Pine	Pine	Blend	Blend	Blend	Blend	Blend
Total Delivered Cost	$/dry ton	$102.12	$101.45	$92.36	$86.72	$80.00	$80.00	$80.00
Grower Payment	$/dry ton	$25.00	$25.00	$24.43	$23.45	$21.90	$21.90	$21.90
Total Feedstock Logistics	$/dry ton	$77.12	$76.45	$67.93	$63.27	$58.10	$58.10	$58.10
Harvest and Collection	$/dry ton	$22.24	$22.24	$16.68	$14.46	$10.47	$10.47	$10.47
Landing Preprocessing	$/dry ton	$12.17	$12.17	$11.37	$11.02	$10.24	$10.24	$10.24
Transportation and Handling	$/dry ton	$14.84	$14.84	$12.47	$8.48	$7.52	$7.52	$7.52
In-Plant Receiving and Processing	$/dry ton	$27.87	$27.20	$27.41	$29.31	$29.87	$29.87	$29.87
Total Delivered Cost	$/gal total fuel	$1.16	$1.15	$1.05	$0.99	$0.91	$0.91	$0.91
Grower Payment	$/gal total fuel	$0.28	$0.28	$0.28	$0.27	$0.25	$0.25	$0.25
Total Feedstock Logistics	$/gal total fuel	$0.88	$0.87	$0.77	$0.72	$0.66	$0.66	$0.66
Harvest and Collection	$/gal total fuel	$0.25	$0.25	$0.19	$0.16	$0.12	$0.12	$0.12
Landing Preprocessing	$/gal total fuel	$0.14	$0.14	$0.13	$0.13	$0.12	$0.12	$0.12
Transportation and Handling	$/gal total fuel	$0.17	$0.17	$0.14	$0.10	$0.09	$0.09	$0.09
In-Plant Receiving and Processing	$/gal total fuel	$0.32	$0.31	$0.31	$0.33	$0.34	$0.34	$0.34
Yield	gallons total fuel / dry ton	88	88	88	88	88	88	88

Table B-3: Unit Operation Cost Contribution Estimates (2011$) and Technical Projections for Algal Lipid Upgrading

Processing Area Cost Contributions & Key Technical Parameters	Metric	2014 SOT*		2022 Projected†
Diesel selling price	$/gal diesel	$15.57		$4.49
Conversion Contribution, Diesel	$/GGE	$2.36		$1.18
Performance Goal	$/GGE	-		$3
Diesel Production	mm gallons/yr	34		54
Production Co-Product Naphtha	mm gallons/yr	11		11
Diesel Yield (AFDW algae basis)	gal/US ton algae	77		122
Naphtha Yield (AFDW algae basis)	gal/us ton algae	25		25
Natural Gas Usage (AFDW algae basis)	scf/U.S. ton algae	2,805		2,946
Feedstock				
Total Cost Contribution	$/gge fuel	$13.21		$3.31
Feedstock Cost (AFDW algae basis)	$/U.S. ton algae	$1,092		$430.00
AHTL				
Total Cost Contribution	$/gge fuel	$1.78		$0.62
Capital Cost Contribution	$/gge fuel	$1.36		$0.46
Operating Cost Contribution	$/gge fuel	$0.42		$0.16
AHTL Oil Yield (dry)	lb /lb algae	0.40		0.59
AHTL Oil Hydrotreating to Finished Fuels				
Total Cost Contribution	$/gge fuel	$0.34		$0.35
Capital Cost Contribution	$/gge fuel	$0.22		$0.14
Operating Cost Contribution	$/gge fuel	$0.12		$0.21
Mass Yield on dry AHTL Oil	lb/lb AHTL oil	0.86		0.83
Catalytic Hydrothermal Gasification of AHTL Aqueous Phase				
Total Cost Contribution	$/gge fuel	$0.74		$0.63
Capital Cost Contribution	$/gge fuel	$0.39		$0.37
Operating Cost Contribution	$/gge fuel	$0.35		$0.26
Balance of Plant				
Total Cost Contribution	$/gge fuel	($0.50)		($0.42)
Capital Cost Contribution	$/gge fuel	$0.24		$0.18
Operating Cost Contribution	$/gge fuel	$0.24		$0.04
Naphtha Credit ($3.25/gal)	$/gge fuel	($0.99)		($0.63)
Models: Case References		TO1014-SOT		030114P

* Jones et al. "Process Design and Economics for the Conversion of Algal Biomass to Hydrocarbons: Whole Algae Hydrothermal Liquefaction and Upgrading" Pacific Northwest National Laboratory Report 23227 (2014)

† S.B.Jones, Y. Zhu, L.J. Snowden-Swan, D.B. Anderson, R.T. Hallen, A.J. Schmidt, K.A. Albrecht, D.C. Elliott, "Whole Algae Hydrothermal Liquefaction: 2014 State of Technology Pacific Northwest Laboratory, June 2014

Table B-4: Unit Operation Cost Contribution Estimates (2011$) and Technical Projections for Whole Algae Hydrothermal Liquefaction and Upgrading to Diesel

Processing Area Cost Contributions & Key Technical Parameters	Metric	2014 SOT*		2022 Projected†
Diesel selling price	$/gal diesel	$15.57		$4.49
Conversion Contribution, Diesel	$/GGE	$2.36		$1.18
Performance Goal	$/GGE	-		$3
Diesel Production	mm gallons/yr	34		54
Production Co-Product Naphtha	mm gallons/yr	11		11
Diesel Yield (AFDW algae basis)	gal/US ton algae	77		122
Naphtha Yield (AFDW algae basis)	gal/us ton algae	25		25
Natural Gas Usage (AFDW algae basis)	scf/U.S. ton algae	2,805		2,946
Feedstock				
Total Cost Contribution	$/gge fuel	$13.21		$3.31
Feedstock Cost (AFDW algae basis)	$/U.S. ton algae	$1,092		$430.00
AHTL				
Total Cost Contribution	$/gge fuel	$1.78		$0.62
Capital Cost Contribution	$/gge fuel	$1.36		$0.46
Operating Cost Contribution	$/gge fuel	$0.42		$0.16
AHTL Oil Yield (dry)	lb /lb algae	0.40		0.59
AHTL Oil Hydrotreating to Finished Fuels				
Total Cost Contribution	$/gge fuel	$0.34		$0.35
Capital Cost Contribution	$/gge fuel	$0.22		$0.14
Operating Cost Contribution	$/gge fuel	$0.12		$0.21
Mass Yield on dry AHTL Oil	lb/lb AHTL oil	0.86		0.83
Catalytic Hydrothermal Gasification of AHTL Aqueous Phase				
Total Cost Contribution	$/gge fuel	$0.74		$0.63
Capital Cost Contribution	$/gge fuel	$0.39		$0.37
Operating Cost Contribution	$/gge fuel	$0.35		$0.26
Balance of Plant				
Total Cost Contribution	$/gge fuel	($0.50)		($0.42)
Capital Cost Contribution	$/gge fuel	$0.24		$0.18
Operating Cost Contribution	$/gge fuel	$0.24		$0.04
Naphtha Credit ($3.25/gal)	$/gge fuel	($0.99)		($0.63)
Models: Case References		TO1014-SOT		030114P

* Jones et al. "Process Design and Economics for the Conversion of Algal Biomass to Hydrocarbons: Whole Algae Hydrothermal Liquefaction and Upgrading" Pacific Northwest National Laboratory Report 23227 (2014)

† S.B.Jones, Y. Zhu, L.J. Snowden-Swan, D.B. Anderson, R.T. Hallen, A.J. Schmidt, K.A. Albrecht, D.C. Elliott, "Whole Algae Hydrothermal Liquefaction: 2014 State of Technology Pacific Northwest Laboratory, June 2014

Table B-5: Unit Operation Cost Contribution Estimates (2011$) and Technical Projections for Thermochemical Conversion to Gasoline and Diesel Baseline Process Concept[5]

(Process Concept: Woody Feedstock, Fast Pyrolysis, Bio-Oil Upgrading, Fuel Finishing)*

Processing Area Cost Contributions & Key Technical Parameters	Metric	2009 SOT	2010 SOT	2011 SOT	2012 SOT	2013 SOT	2014 Projection	2015 Projection*	2016 Projection*	2017 Projection*
Conversion Contribution	$/gal gasoline blendstock	$12.40	$9.22	$7.32	$6.20	$4.51	$4.02	$3.63	$2.96	$2.44
	$/gal diesel blendstock	$13.03	$9.69	$7.69	$6.52	$5.01	$4.46	$4.03	$3.29	$2.70
Conversion Contribution, Combined Blendstocks	$/GGE	$12.02	$8.94	$7.10	$6.02	$4.59	$4.09	$3.69	$3.01	$2.47
Programmatic Target	$/GGE	$3	$3	$3	$3	$3	$3	$3	$3	$3
Combined Fuel Selling Price	$/GGE	$13.40	$10.27	$8.26	$7.04	$5.77	$5.26	$4.75	$4.01	$3.39
Production Gasoline Blendstock	mm gallons/yr	30	30	30	30	29	29	29	29	29
Production Diesel Blendstock	mm gallons/yr	23	23	23	23	32	32	32	32	32
Yield Combined Blendstocks	GGE/dry U.S. ton	78	78	78	78	87	87	87	87	87
Yield Combined Blendstocks	mmBTU/dry U.S. ton	9	9	9	9	10	10	10	10	10
Natural Gas Usage	scf/dry U.S. ton	1,115	1,115	1,115	1,115	1,685	1,685	1,685	1,685	1,685
Feedstock										
Total Cost Contribution	$/GGE fuel	$1.38	$1.33	$1.17	$1.03	$1.01	$1.17	$1.06	$0.99	$0.92
Capital Cost Contribution	$/GGE fuel	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Operating Cost Contribution	$/GGE fuel	$1.38	$1.33	$1.17	$1.03	$1.01	$1.17	$1.06	$0.99	$0.92
Feedstock Cost	$/dry US ton	$106.92	$102.96	$90.57	$79.71	$88.10	$102.12	$92.36	$86.72	$80.00
Fast Pyrolysis										
Total Cost Contribution	$/GGE fuel	$0.97	$0.93	$0.91	$0.90	$0.78	$0.78	$0.77	$0.76	$0.76
Capital Cost Contribution	$/GGE fuel	$0.82	$0.79	$0.76	$0.75	$0.66	$0.65	$0.65	$0.65	$0.64
Operating Cost Contribution	$/GGE fuel	$0.15	$0.15	$0.15	$0.15	$0.12	$0.12	$0.12	$0.12	$0.11
Pyrolysis Oil Yield (dry)	lb organics/lb dry wood	0.60	0.60	0.60	0.60	0.62	0.62	0.62	0.62	0.62
Upgrading to Stable Oil via Multi-Step Hydrodeoxygenation/Hydrocracking										
Total Cost Contribution	$/GGE fuel	$10.07	$7.05	$5.23	$4.17	$2.88	$2.39	$2.01	$1.35	$0.95
Capital Cost Contribution	$/GGE fuel	$0.71	$0.68	$0.66	$0.65	$0.59	$0.57	$0.51	$0.45	$0.42

[5] Jones, S. et al. "Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels: Fast Pyrolysis and Hydrotreating Bio-Oil Pathway." PNNL-23053. (2013). Richland, WA: Pacific Northwest National Laboratory. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23053.pdf.

Processing Area Cost Contributions & Key Technical Parameters	Metric	2009 SOT	2010 SOT	2011 SOT	2012 SOT	2013 SOT	2014 Projection	2015 Projection*	2016 Projection*	2017 Projection*
Operating Cost Contribution	$/GGE fuel	$9.36	$6.37	$4.57	$3.52	$2.29	$1.82	$1.50	$0.90	$0.52
Fuel Finishing to Gasoline and Diesel via Hydrocracking and Distillation										
Total Cost Contribution	$/GGE fuel	$0.25	$0.24	$0.24	$0.24	$0.25	$0.25	$0.24	$0.24	$0.14
Capital Cost Contribution	$/GGE fuel	$0.16	$0.15	$0.15	$0.15	$0.16	$0.16	$0.16	$0.16	$0.07
Operating Cost Contribution	$/GGE fuel	$0.09	$0.09	$0.09	$0.09	$0.09	$0.09	$0.08	$0.08	$0.07
Balance of Plant										
Total Cost Contribution	$/GGE fuel	$0.74	$0.72	$0.71	$0.71	$0.68	$0.68	$0.67	$0.66	$0.63
Capital Cost Contribution	$/GGE fuel	$0.36	$0.34	$0.33	$0.33	$0.29	$0.29	$0.29	$0.29	$0.29
Operating Cost Contribution	$/GGE fuel	$0.38	$0.38	$0.38	$0.38	$0.39	$0.38	$0.38	$0.37	$0.34
Models: Case References		2009 SOT 090913	2010 SOT 090913	2012 SOT 090913	2012 SOT 090913	2013 SOT 122013	2014 P 122013	2015 P 123013	2016 P 123013	2017 P 093013

*Note that pyrolysis conversion performance tests conducted through 2017 are based on dried, debarked pine that has been ground to a 2mm particle size. As explained in Section 2.1.1.5, research funded by FSL aims to develop a blend that will support comparable conversion performance as a pure pine feedstock.

Note that while the blend is under development, research will continue to expand the specification accepted by the pyrolysis process, making it more robust. Relying solely on pine as a feedstock will not only limit the amount of material available for fuel production via pyrolysis, but will also influence the delivered cost of feedstock to the throat of the conversion process (Figure B-1).

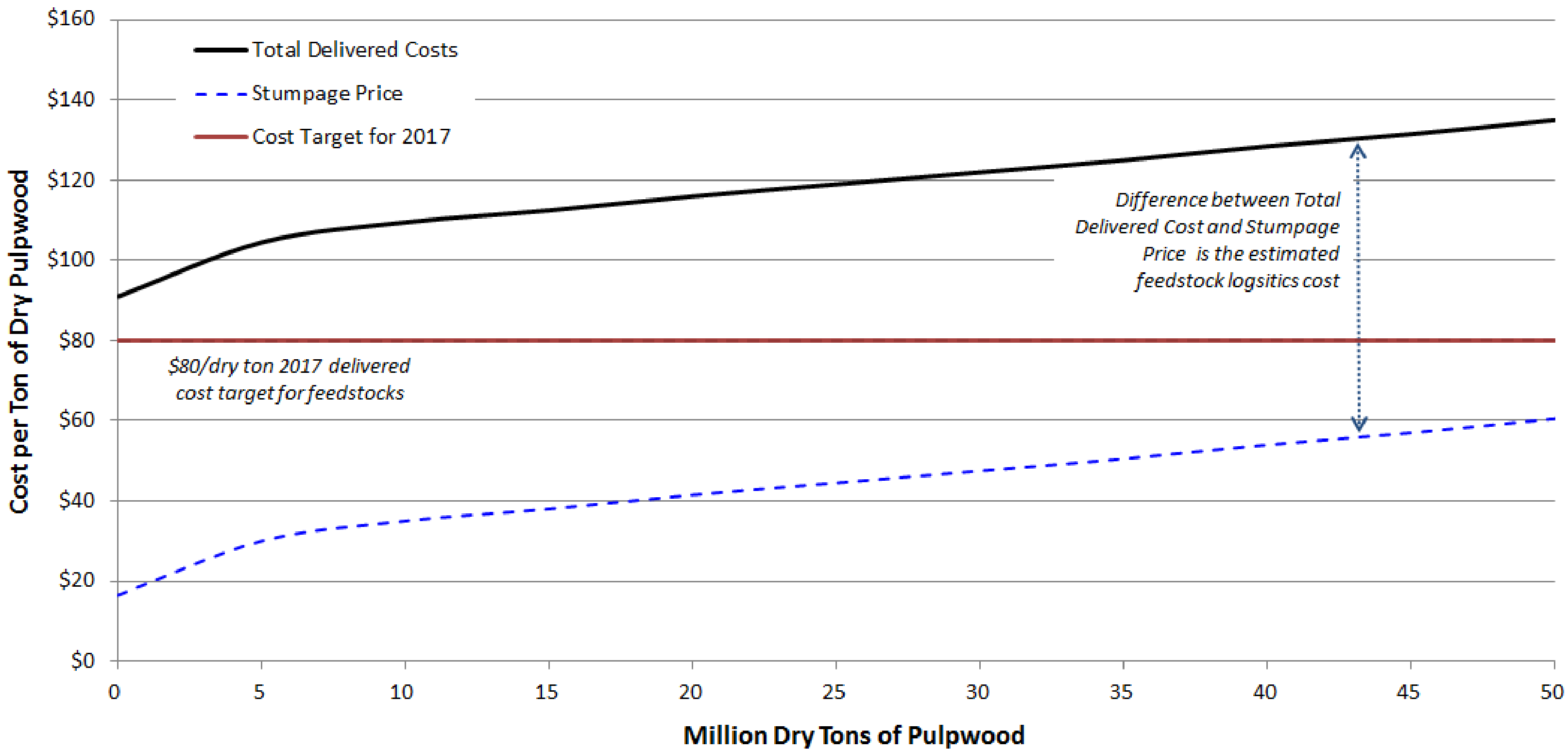

Figure B-1: Estimated total delivered cost of debarked, dried, ground pulpwood, delivered to the throat of the reactor and meeting the conversion specifications for pyrolysis. Pulpwood prices are based on values presented in the *U.S. Billion Ton Update* (2011) for the year 2017.

As demonstrated in Figure B-1, pulpwood resources are available for conversion in 2017; however, they are more expensive and available in lower volumes than the woody blend scenario presented in Table 2-3. The volumes presented in Figure B-1 are consistent with and are generated from the same data as those presented in Table B-1. However, the volumes presented in Table B-1 were constrained to those available at a low-enough stumpage price such that the total delivered cost target of $80/dry ton could be met.