Energy Conversion Systems Analysis
for a
Biomass Utilization Project in Central Oregon
using CROP Modeling

October 2005

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A Reconnaissance Evaluation
prepared by Mater Engineering, Ltd. in conjunction with T.R. Miles Consulting, Inc.
for
Bonneville Environmental Foundation (BEF)

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***List Of Acronyms* - Technical:**

BDT	Bone Dry Ton
BEF	Bonneville Environmental Foundation
BHP	Boiler Horsepower
CF	Cubic Feet
CHP	Combined Heat and Power
COIC	Central Oregon Intergovernmental Council
CFB	Circulating Fluidized Bed
COE	Cost of Electricity
DB	Moisture Content, Dry Basis
DBH	Diameter Breast Height
DG	Distributed Generation
DEQ	Department of Environmental Quality
EPA	U.S. Environmental Protection Agency
FB	Fluidized Bed boiler or gasifier
HHV	Higher Heating Value
kWe	Kilowatts, electric
kWth	Kilowatts, thermal
LCOE	Levelized Cost of Electricity
LHV	Lower (or Net) Heating Value
LRF	Lumber Recovery Factor
MMBF	Million board feet
MBF	Thousand board feet
MC	Moisture Content
MCF	Thousand Cubic Feet of natural gas
MCR	Maximum Continuous Rating for the boiler
MMBtu	Million British Thermal Units
MWe	Megawatts (electric)
MWth	Megawatts (thermal)
OD	Oven Dry
O&M	Operation and Maintenance
PFI	Pellet Fuels Institute
U.S. DOE	United States Department of Energy
VOC	Volatile Organic Compound
WB	Moisture Content, Wet Basis

***List of Abbreviations* – Species:**

DF	Douglas fir
Mt. Hem	mountain hemlock
PP	ponderosa pine
WF	white Fir
LP	lodgepole pine
GF	grand fir
Jun.	Juniper
NF	noble fir
HW	mixed hardwoods
WH	western hemlock

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Introduction

In addition to small wind, large wind, and solar generating projects, the Bonneville Environmental Foundation (BEF) has been looking for an approach to biomass that possessed the near-term potential to produce climate-neutral (or better) cost-competitive electricity. The goal has been to identify another project arena besides White Creek Wind that could generate net revenues back to BEF. One new venue for consideration is a biomass strategy that would involve recovery of small-diameter culls and forest floor debris, a key component of most forest fire management plans. Although a great deal of technical focus has been generated around small log (up to 7 inch dbh) conversion to valued product, lack of adequate small log processing infrastructure has often constrained financial viability. Additionally, financial viability of many smaller-scale biomass-to-energy project efforts sans a solid wood production component has been constrained by raw resource transportation costs. BEF approached Mater Engineering (Corvallis, Oregon), in conjunction with T. R. Miles - Technical Consultants (Portland, Oregon), to consider undertaking a ***Biomass Reconnaissance Project*** that would focus on the conceptual design and preliminary feasibility analysis of a portable fuel processing, pyrolysis and gasification system to be employed within defined 'collection circles' based on fuel load reduction projections in selected Oregon forests.

The scope of work for this project encompassed the following five (5) key tasks:

- **Fuels access analysis** within defined CROP (coordinated resource offering protocol) 'collection circles' in targeted Central Oregon forests. CROP modeling - developed by Mater Engineering – is nation's first model based on coordinating fuel load reduction planning between public agencies within a defined investor landscape (usually a 100-mile radius from a defined centerpoint). The USFS has just adopted the CROP model for pilot project application in six regions across the US as part of its national strategy for woody biomass utilization;

- **Preliminary markets and value analysis o**f defined energy and woody biomass by-product(s) that could be generated from the project**;**

- **Evaluation of technology options for energy conversion –** with focus on potential for 'portable' application working within defined biomass collection circles**;**

- **Conceptual design of a possible energy conversion facility** given the results of tasks a) through c) above; and

- **Preliminary economic analysis** of an energy conversion facility given the results of tasks a) through d) above.

Biomass Resource

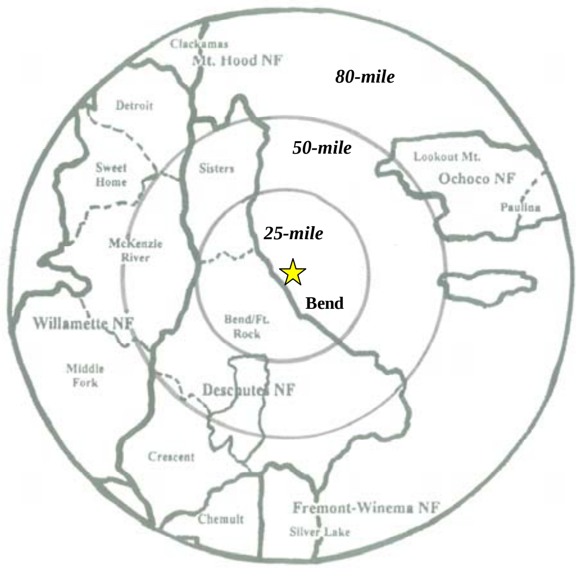
Fuels Access Data and Correlation to BEF CROP Collection Circles

Under this task a project landscape area needed to be defined where fuel loading is sufficiently dense within a collection circle and where the center is adjacent to a three-phase electric transmission line into which a generator could be interconnected. The collection circle area would be defined by factors including density of and access to projected fuel load reduction primarily from public lands, high forest fire risk areas in a wildfire urban interface (WUI) category, and the economics of collecting and transporting fuels to circle center. For this project effort, the Central Oregon Intergovernmental Council (COIC) region served as the target project area for collection circle consideration. Selection of the COIC region was primarily based on work completed for COIC in 2004 by Mater Engineering in establishing the nation's first CROP (*coordinated resource offering protocol*) model based on coordinated fuel load reduction planning between public agencies within a 100-mile radius from the Bend-Redmond area during the next five years. All projected removal data was provided to Mater Engineering by individual public agencies for CROP modeling. (Note: CROP collection circles are centrally focused on projected resource offering over time coming primarily from *public* forestlands. Access to information is more readily available, and financial and political capital is now keenly focused on responsible fuel-load reduction performance from these public lands.) For this reconnaissance effort, the initial 100-mile radius was reduced to 80-miles in order to better focus on WUI concerns. Further, only proposed resource offering up to 9" dbh (diameter at breast height) was used for BEF CROP analysis purposes – focusing exclusively on small diameter material. With these baseline parameters established, the following protocol for further data analysis was followed:

- Given the project requirement of looking at potential collection circles that would be sensitive to biomass transportation costs, data was further analyzed based on projected resource offering within three collection circles: a 25, 50, and 80-mile collection circle from the Bend-Redmond area.

- The data was analyzed by species offering per year from each collection circle and within three specific diameter groupings: biomass <4" dbh; biomass between 4" - 7" dbh; and biomass between 7"- 9" dbh. These diameter breakouts are essential for financial analysis in biomass-to-energy projects where additional resource values (and transportation cost offsets) may be captured through value-added processing of the wood resource *beyond* use in energy generation (ie lumber; charcoal, shavings, pellets, etc.). As example, new processing technologies for dedicated small log lines typically operate on steady diets of small logs from 5" to 11" in diameter. Best return-on-investments are often captured in the processing of logs sized 7"- 11" in diameter. Similarly, separate specie information is also important to investors as current small log "pond" values can vary as much as 50% between species.

- Resource offering maps or ROMS for each specie offering within the 25, 50, and 80-mile collection circles were then created (included in a separate appendix document). In all, over 69 ROMs encompassing 12 different species from fourteen (14) public agencies were created for this project effort. Public forestlands in the BEF CROP collection circles included: (see BEF CROP map)



  - ✓ Sisters, Bend/Fort Rock, and Crescent Ranger Districts within the Deschutes National Forest;
  - ✓ Middle Fork, McKenzie, Sweet Home, and Detroit Ranger Districts within the Willamette National Forest;
  - ✓ Lookout Mt. and Paulina Ranger Districts within the Ochoco National Forest;
  - ✓ Clackamas River Ranger District within the Mt. Hood National Forest;
  - ✓ Silver Lake and Chemult Ranger Districts within the Fremont-Winema National Forest; and
  - ✓ BLM districts: Prineville, Eugene, Salem, and Lakeview.

Summarized, results of the BEF CROP collection circle analyses are as follows:

1. As noted in Tables 1 and 2 (attached), during the next five years public agencies owning forestland within the 25-mile BEF CROP collection circle are projecting to offer over **40 million board feet (mmbf)** of biomass for removal and sale. The volume will be primarily split between 4”-7” diameter material and 7”-9” diameter material. Seven species will be reflected in the resource offering as follows:

    - ponderosa pine (43% of total volume)
    - lodgepole pine (24%)
    - other mixed species (21%)
    - white fir (4%)
    - Mt. Hemlock (3.6%)
    - Douglas fir (3%)
    - juniper (1%).

2. Tables 3 and 4 (attached) show that during the next five years public agencies owning forestland within the 50-mile BEF CROP collection circle are projecting to offer over **153 million board feet (mmbf)** of biomass for removal and sale. 53% of the volume will be 7”-9” diameter material and 41% will be 4”-7” diameter material. Eleven species will be reflected in the resource offering as follows:

Table 1

25-mile radius (5-year volume):	DF	Mt. Hem	PP	WF	LP	Jun.	Other
Deschutes NF:							
Sisters RD (25%)	.18	.17	2.26	.206	1.21		1.1
Bend/Ft Rock RD (50%)	1.12	1.4	16.07	1.62	9		7.84
BLM:							
Prineville (25%)	.12		.16	.6		.26	
Total (42 mmbf)	**1.42**	**1.57**	**18.49**	**1.89**	**10.21**	**.26**	**8.93**

25-Mile Radius:

- 5 yr. Total = 42.78 mmbf
- Annual = ~8.5 mmbf

7"-9" = 49%
4" – 7" = 48%
<4" = 3%

Table 2

	5-yr. Total (mmbf)			*Annual (mmbf)*		
	<4	***4 – 7***	***7 – 9***	***<4***	***4 – 7***	***7 – 9***
Douglas Fir: *(1.42 mmbf or ~ .28 mmbf/yr.)*	.16	.609	.652	.03	.12	.13
Mt. Hemlock: *(1.57 mmbf or ~ .18 mmbf/yr.)*	0	.786	.786	0	.09	.09
Ponderosa Pine: *(18.49 mmbf or 3.7 mmbf/yr.*	.44	8.89	9.16	.07	1.78	1.85
White Fir: *(1.89 mmbf or ~ .38 mmbf/yr.)*	.06	.914	.914	.02	.18	.18
Lodgepole Pine: *(10.21 mmbf or ~2.04 mmbf/yr.)*	.087	5.02	5.10	.02	1	1.02
Juniper: *(.26 mmbf or ~ .05 mmbf/yr.)*	.26	0	0	.06	0	0
Other: *(8.93 mmbf or ~1.79 mmbf/yr.)*	.141	4.33	4.46	.04	.86	.90
Totals	***1.15***	***20.55***	***21.07***	***.22***	***4.03***	***4.17***

Table 3

50-mile radius (5-yr. volume):	DF	W. Hem.	Mt. Hem	PP	WF	GF	LP	Jun.	Other	NF	HW
Deschutes NF:											
Sisters RD (100%)	.72		.68	9.04	.825		4.83		4.41		
Bend/Ft Rock RD (100%)	2.25		2.8	32.2	3.245		17.99		15.67		
Crescent RD (50%)	.45		.55	6.35	.63		3.54		3.1		
BLM:											
Prineville (50%)	.24			.32	.12			.52			
Eugene (50%)	3.33										.175
Salem (30%)	6.47	2.74							.56		
Lakeview (25%)								2.68			
Willamette NF:											
Middle Fork RD (20%)	1.53	.383							.38	.256	
McKenzie RD (80%)	7.45	1.86							1.86	1.24	
Sweet Home RD (50%)	1.956	.49							.49	.326	
Detroit RD (25%)	1.44	.36							.361	.24	
Ochoco NF:											
Lookout Mt. RD (50%)	.611			1.62		.718			.38		
Fremont-Winema NF:											
Silver Lake RD (20%)				1.07			1.014				
Chemult RD (10%)				.515			.445				
Total (153 mmbf)	**26.42**	**5.84**	**4.03**	**51.06**	**4.82**	**.71**	**27.87**	**3.2**	**27.22**	**2.06**	**.17**

50-Mile Radius:

- 5 yr. Total = 153.43 mmbf
- Annual = ~30 mmbf

7"-9" = 53%
4" – 7" = 41%
<4" = 6%

Table 4

	5-yr. Total (mmbf)			Annual (mmbf)		
	<4	*4 – 7*	*7 – 9*	*<4*	*4 – 7*	*7 – 9*
Douglas Fir: *(26.42 mmbf or ~5.3 mmbf/yr.)*	5.12	6.45	14.85	1.01	1.29	2.97
Mt. Hemlock: *(4.03 mmbf or ~ .8 mmbf/yr.)*	0	2.018	2.018	0	.4	.4
Ponderosa Pine: *(51.06 mmbf or 10.2 mmbf/hr.*	1.35	24.28	25.42	.27	4.9	5.0
White Fir: *(4.82 mmbf or ~ .96 mmbf/yr.)*	.12	2.35	2.35	.02	.47	.47
Lodgepole Pine: *(27.82 mmbf or ~5.5 mmbf/yr.)*	.27	13.52	14.01	.05	2.7	2.8
Noble Fir: *(2.06 mmbf or ~ .41 mmbf/yr.)*	.22	.11	1.71	.05	.02	.34
Grand Fir: *(.71 mmbf or ~ .14 mmbf/yr.)*	.09	.27	.36	.02	.05	.07
Western Hemlock: *(5.84 mmbf or ~ 1.16 mmbf/yr.)*	.34	2.09	3.39	.07	.42	.67
Juniper: *(3.20 mmbf or ~ .80 mmbf/yr.)*	.52	0	2.68	.03	0	.67
Other: *(27.22 mmbf or ~5.44 mmbf/yr.)*	.76	12.06	14.40	.15	2.41	2.88
Mixed Hardwoods: *(.17 mmbf or ~ .03 mmbf/yr.)*	.17			.03		
Totals	***8.96***	***63.15***	***81.18***	***1.8***	***12.66***	***16.27***

- ponderosa pine (33% of total volume)
- lodgepole pine (18%)
- other mixed species (18%)
- white fir (3%)
- Mt. Hemlock (3%)
- Douglas fir (17%)
- juniper (2%).
- grand fir (<1%)
- noble fir (1%)
- mixed hardwoods (<1%)
- western hemlock (4%)

3. Tables 5 and 6 (attached) show that during the next five years public agencies owning forestland within the 80-mile BEF CROP collection circle are projecting to offer over **250 million board feet (mmbf)** of biomass for removal and sale. 54% of the volume will be 7”-9” diameter material and 38% will be 4”-7” diameter material. Eleven species will be reflected in the resource offering as follows:

- ponderosa pine (28% of total volume)
- lodgepole pine (16%)
- other mixed species (14%)
- white fir (2%)
- Mt. Hemlock (2%)
- Douglas fir (24%)
- juniper (5%).
- grand fir (<1%)
- noble fir (2%)
- mixed hardwoods (<1%)
- western hemlock (6%)

Quadrant Analysis Based on BEF CROP Collection Circles

Based on the collection circles data, the largest volumes of levelized biomass supply over time would come from public agencies within the Northwest and Southwest quadrants of the 80-mile collection circle. To verify, a quadrants analysis of the 80-mile collection circle was conducted. Anticipated percentages of annual volume to be offered from each contributing public agency was determined as reflected in Table 7.

Table 5

80-mile radius (5-yr. volume):	DF	W. Hem.	Mt. Hem	PP	WF	GF	LP	Jun.	Other	NF	HW
Deschutes NF:											
Sisters RD (100%)	.72		.68	9.04	.825		4.83		4.4		
Bend/Ft Rock RD (100%)	2.25		2.8	32.16	3.24		17.99		15.67		
Crescent RD (100%)	.9		1.1	12.7	1.9		7.08		6.2		
BLM:											
Prineville (100%)	.48			.64	.24			1.04			
Eugene (100%)	6.66										.35
Salem (100%)	21.58	9.14							1.87		
Lakeview (100%)								10.75			
***Willamette NF*:**											
Middle Fork RD (100%)	7.76	1.91							1.91	1.28	
McKenzie RD (100%)	9.31	2.33							2.33	1.55	
Sweet Home RD (100%)	3.91	.98							2.34	.65	
Detroit RD (10%)	5.77	1.44							1.44	.96	
***Ochoco NF*:**											
Lookout Mt. RD (100%)	.245			3.24		1.44			.77		
Paulina RD (100%)	.5			1.37		.479			.249		
***Fremont-Winema NF*:**											
Silver Lake RD (100%)				5.33			5.07				
Chemult RD (100%)				5.15			4.45				
***Mt. Hood NF*:**											
Clackamas River RD (100%)	.5	.5									
Chemult RD (100%)											
Total (251 mmbf)	**61.5**	**16.31**	**4.59**	**69.92**	**5.57**	**1.9**	**39.42**	**11.79**	**35.84**	**4.44**	**.35**

<u>80-Mile Radius</u>:

- 5 yr. Total = 251.15mmbf
- Annual = ~50 mmbf

7"-9" = 54%
4" – 7" = 38%
<4" = 8%

Table 6

	5-yr. Total (mmbf)			***Annual (mmbf)***		
	<4	***4 – 7***	***7 – 9***	***<4***	***4 – 7***	***7 – 9***
Douglas Fir: *(61.5 mmbf or ~12 mmbf/yr.)*	10.6	17.35	33.45	2.12	3.47	6.69
Mt. Hemlock: *(4.59 mmbf or ~ .9 mmbf/yr.)*	0	2.295	2.295	0	.45	.45
Ponderosa Pine: *(69.62 mmbf or 13.9 mmbf/hr.*	2.84	31.93	34.85	.56	6.39	6.97
White Fir: *(5.57 mmbf or ~1.1 mmbf/yr.)*	.24	2.66	2.66	.04	.53	.53
Lodgepole Pine: *(39.42 mmbf or ~7.8 mmbf/yr.)*	.67	18.39	20.35	.13	3.67	4.06
Noble Fir: *(4.44 mmbf or ~ .89 mmbf/yr.)*	.52	.26	3.65	.11	.05	.73
Grand Fir: *(1.9 mmbf or ~ .38 mmbf/yr.)*	.24	.72	.95	.05	.14	.19
Western Hemlock: *(16.31 mmbf or ~ 3.26 mmbf/yr.)*	.83	6.99	8.44	.16	1.4	1.7
Juniper: *(11.79 mmbf or ~ 2.95 mmbf/yr.)*	1.04	0	10.75	.26	0	2.69
Other: *(35.84 mmbf or ~7.17 mmbf/yr.)*	1.33	15.24	19.26	.26	3.05	3.85
Mixed Hardwoods: *(.35 mmbf or ~.07 mmbf/yr.)*	.35			.07		
Totals	***18.66***	***95.83***	***136.65***	***3.76***	***19.15***	***27.86***

Table 7

	NW Quad	*NE Quad*	*SW Quad*	*SE Quad*
BLM:				
Prineville	20%	40%	20%	20%
Salem	100%			
Eugene	50%	50%		
Lakeview				100%
Mt Hood NF:				
Clackamas	100%			
Willamette NF:				
Detroit	100%			
Sweet Home	100%			
McKenzie	60%		40%	
Middle Fork			100%	
Deschutes NF:				
Sisters	100%			
Bend/Fort Rock	10%		60%	30%
Crescent			100%	
Ochoco NF:				
Lookout		100%		
Paulina		100%		
Fremont-Winema NF:				
Silver Lake			60%	40%
Chemult			100%	

From volumes to be provided per quadrants, it was determined that the NE and SE quadrants would provide only 20% (~51 mmbf total; 10 mmbf/yr) of the total anticipated 5-year volume within the 80-mile collection circle. The NW and SW quadrants would provide 80% of the volume, with quadrant offerings by species, volumes, and diameter size determined as follows:

- For the **NW quadrant**: 90 mmbf to be offered over 5-years with over 50% in the 7”- 9” diameter category (Table 8):

Table 8

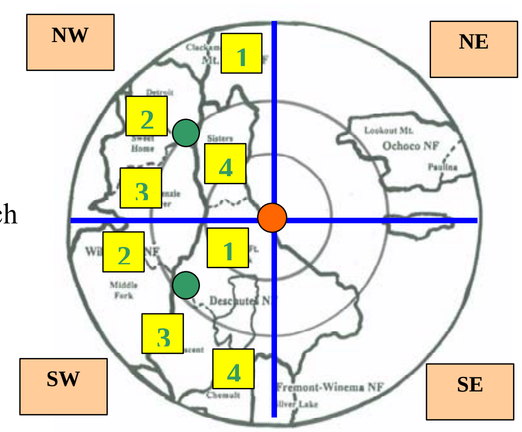
NW Quad	*Total 5-yr. (mmbf)*	*mmbf by diameter*		
		4” or less	**>4” – 7”**	**>7” – 9”**
Douglas fir	41.757	8.3514 (20%)	12.5271 (30%)	20.8785 (50%)
Mt. Hemlock	.9115	0	.4557 (50%)	.4557 (50%)
Ponderosa pine	12.411	.1985 (2%)	5.957 (48%)	6.2055 (50%)
White fir	1.164	0	.582 (50%)	.582 (50%)
Lodgepole pine	6.699	.6029 (9%)	2.9475 (44%)	3.0815 (46%)
Noble fir	2.546	.3055 (12%)	.1527 (6%)	2.0622 (81%)
Grand fir	0	0	0	0
Western Hemlock	13.445	.5378 (4%)	6.4536 (48%)	6.319 (47%)
Juniper	.206	.016 (8%)	0	.19 (92%)
Other	11.310	.6786 (6%)	3.166 (28%)	7.646 (66%)
Mixed hardwoods	.175	.175 (100%)	0	0
Totals	***90.626***	12%	36%	52%

- For the **SW quadrant**: 109 mmbf to be offered over 5-years with over 50% in the 7" – 9" diameter category (Table 9):

Table 9

SW Quad	*Total 5-yr. (mmbf)*	*mmbf by diameter*		
		4" or less	**>4" – 7"**	**>7" – 9"**
Douglas fir	13.695	1.0956 (8%)	2.32815 (17%)	10.1343 (74%)
Mt. Hemlock	2.949	0	1.4745 (50%)	1.4745 (50%)
Ponderosa pine	40.935	.8187 (2%)	19.6488 (48%)	20.4675 (50%)
White fir	2.997	0	1.4985 (50%)	1.4985 (50%)
Lodgepole pine	25.167	.050334 (2%)	12.08016 (48%)	12.5835 (50%)
Noble fir	1.897	.1897 (10%)	.09485 (5%)	1.59338 (85`%)
Grand fir	0	0	0	0
Western Hemlock	2.846	.2846 (10%)	.1423 (5%)	2.4191 (85%)
Juniper	.206	.016 (8%)	0	.19 (92%)
Other	18.329	.54987 (3%)	8.06476 (44%)	9.71437 (53%)
Mixed hardwoods	0	0	0	0
Totals	***109.02***	3%	42%	55%

With the NW and SW quadrants as the logical areas to focus on for potential siting of a portable energy conversion system that could move within NW and/or SW CROP quadrants every 3-5 years, the next task was to identify variable resource haul distances given some defined centerpoints within the quadrants. The Bend/Redmond area was selected as one centerpoint for each of the quadrants, and a second centerpoint within each quadrant was identified: Marion Forks for the NW quadrant; and Willamette Pass for the SW quadrant. Four (4) "harvest points" were selected within each of the quadrants and road haul distances were then calculated (see map).



Results of the road haul distance evaluation are as follows:

Zone #	***~ Road Miles to Centerpoint*** NW: *Bend/Redmond*	**NW:** *Marion Forks*	**SW:** *Bend/Redmond*	**SW:** *Willamette Pass*
1	80	130	20	80
2	100	40	130	50
3	80-100	65	80	90-100
4	40	62	40-75	45-55

Preliminary Markets Evaluation

Market Demand and Values for Small-Diameter Logs

a. Technology

With over 50% of biomass volume from the BEF CROP quadrants to be in the 7”-9” dbh range, conversion of that biomass to product other than directed to energy conversion systems may be financially advisable. Only a few years ago logs of <11” dbh were considered ‘non-merchantable’ by public land managers. Today, new technology has been introduced that focuses specifically on the efficient processing of small diameter logs (typically from forest restoration and fuel load reduction sites). These dedicated small log production technologies that process 3” to 12” diameter logs are relatively new in the US, but are gaining ground as important investment options matched with biomass-to-energy conversion technology. The small log processing machinery is designed to produce cants and lumber in a single-pass process. A curve saw option can be added to the small log processing center allowing the machinery to cut logs curved like a C (“sweep”) and like an S (“snake”) by sawing along the grain and producing longer, higher-value lumber from small logs than conventional mills. Curve sawing reduces the downfall resulting from trying to cut a straight piece of lumber from a curved log. The small log processing equipment processes small logs very quickly, compensating for the low board feet per log, and produces lumber volume at rates similar to conventional mills. Production features of two small log systems currently sold in the PNW are shown in Table 10.

Table 10

Manufacturer	***Log Lengths***	***Diameter Range***	***Feed Rate***
HewSaw Machines	Logs: 4’ to 20’	2.5” to 12”	Logs: 250’ to 500’ fpm Cants: 400 fpm
CAE/Neunes (McGeeHee)	Logs: 8’ to 12.6’	3” and up	500 fpm 33 9’ pcs/min, or 33 8’ pcs/min when optimized (300 fpm)

Recent test results in processing small logs of same species found in the BEF CROP quadrants show potential for adding value to this biomass material. In 2002, two truckloads of small diameter ponderosa pine logs provided from a WUI fuel load reduction site in Flagstaff, Arizona were sent to the Kinzua Resources mill in Pilot Rock, Oregon. Kinzua was selected because they currently process ponderosa pine small logs from inland western states and they have a CAE/McGehee, SL 2000, single pass, small log processing system. Kinzua was instructed to process the logs in the same manner they process ponderosa pine from the Inland Pacific Northwest. Other than separating the logs and lumber for inventory and tracking purposes, the logs and lumber were processed along with their normal pine run. The results were noteworthy:

- *Log scale and quality:* A total of 249 logs were received, with an average small end diameter (sed) of 7.08”

- *Green lumber production*: All logs received were processed through the mill. No problems were experienced due to log form, quality, or size. Overrun of approximately 1.52 and a lumber recovery factor (LRF) of 6.42 bf/cf were realized.

- *Finished lumber results:* Lumber was graded by the mill’s certified graders and separated by grade on the sort chain. Kiln and trim loss was approximately 3.5, within norms for ponderosa pine. Grade recovery for the small diameter test logs was good. Almost 80% of the lumber produced was graded as 2 & Btr, with approximately 30% grade as 2 common or better, the highest grade that should be expected from these logs**.**

b. Potential Purchase Interest for Small-Diameter Logs

Mater Engineering has just completed research involving direct interviews with sawmills in the mid-Willamette Valley area that focused on existing mill interest and capacity to purchase added volume of small diameter logs from fuel-load reduction efforts off of public lands in Oregon CROP landscapes. Eighteen mills were interviewed for the research effort, resulting in the following information:

a. Mills interviewed represented more than 1 billion board feet of lumber production annually.
b. Fifteen of the 18 mills interviewed indicated they had additional capacity and were interested in purchasing resources from CROP landscapes in Oregon.
c. Eleven of the 15 mills interested in purchasing small diameter logs already process 4”-7” logs with an average of 15% of their total annual volume falling in this diameter range;
d. Eleven of the 15 mills interested in purchasing small diameter logs also already process 7”-9” logs with an average of 23% of their total annual volume falling in this diameter range;
e. 100% of those interested in purchasing small diameter logs already purchase, on average, 30% of their combined annual volume from > 100-miles away.
f. Several of the mills are currently in the process of up-grading their production lines to handle a *steady diet* of small diameter logs.

c. Prices for Small-Diameter Logs

Current prices for small logs can vary as much as 50%, depending on specie. As example, prices for inland resources of #3 log grades (6” minimum diameter; 12’ length) and #4 log grades (5” minimum diameter; 12’ length) average as follows:

- Douglas fir: $575/mbf
- Hemlock; grand/noble/white firs: $445/mbf
- Ponderosa pine: $338/mbf
- Lodgepole pine: $440/mbf

Market Potential and Demand for Other Value-Added Wood Products

For this project effort, market analyses focused on two key product areas: ***charcoal*** and ***wood shavings/pellets***. Results are as follows:

a. Charcoal

Mater Engineering conducted extensive markets research on charcoal product development potential from BEF CROP biomass resource. This included specific product and company research and direct interviews with targeted potential product purchasers from the BEF CROP region. In all, thirteen (13) different charcoal or activated charcoal product lines were examined. These included:

- **Charcoal for use in cooking; charcoal briquettes**. Companies producing these types of products are typically located in the Northeastern part of the US, and in Missouri, Texas, Canada, and overseas. The types of wood fiber used in briquettes are almost always hardwoods, tropical woods, and coconut shell. Main manufacturers are Royal Oak, Big Green Egg, Kingsford, Instant Light, and Big Briq. For the most part – most of the woody biomass in the BEF CROP landscape would not be appropriate for this type of product application as almost 100% of total volume to be offered is comprised of softwoods.

- **Charcoal or activated carbon cloth:** The charcoal or carbon cloth uses identified and researched are: clothing and cloth inserts for human odor adsorption and odor adsorbing pet garments; and pollutant removing cloth used in museum showcases.

  For odor absorption: There are several companies located in the US producing innovative carbon cloth products targeted to order absorption. These include (Table 11):

Table 11

Producer	***Product***	***Carbon material used***
Scent-Lok® Muskegon, MI 49442	Manufacturers and produces clothing, headgear, tents, footwear inserts, and sprays made from carbon cloth	100% coconut fiber
Eastman Outfitters Flushing, MI 48433	Hunting blinds, fabric being a polyester shell lined with ExScent™, Eastman Outfitters' own Carbon Scent Elimination System.	Not identified.
Flat-D Innovations, Inc. Cedar Rapids, IA 52410	Manufactures the Flatulence Deodorizer™ charcoal underpants for adults and children. product is promoted as beneficial to people who suffer from excessive flatulence associated with various medical conditions causing excessive gas. A similar product is available for dogs.	Not identified.

For museum use: Activated charcoal cloth (ACC) is touted as one of the smartest and most effective ways of addressing the problems of protecting museum artifacts from a variety of pollutants. ACC is 100% activated charcoal produced in a flexible textile form. It has a large internal surface area for adsorption composed entirely of micropores that have been proven to adsorb more effectively than the pores found in granular forms of activated charcoal. The British Museum advises the use of ACC, as tests conducted in the museum since 1978 highlighted the cloth's effectiveness against other products. Museums taking items on loan from the British museum are normally required to have their display cases fitted with ACC as a condition of the loan.

Although an interesting product line, research information suggests that significant use of non-woody biomass (coconut shell fiber) may be used in the manufacture of these products, and therefore not a good fit for BEF CROP biomass.

- **Activated charcoal filters for wine and spirits:** Charcoal filters are used in the manufacture of liquors, wines, and some beers to take impurities out of the product – producing a "smoother" taste. Mater Engineering contacted distilleries and winery shops in the Pacific Northwest to determine originating wood source of charcoal used; how much product is used; and sources of existing filters for the industry. Hood River Distillers, for example, confirmed that activated charcoal filters are used – mostly for filtering liquors before bottling. Many vineyard and winery supply operations suggested contacting wine chemical suppliers such as Gusmer Enterprises (sales operation in Hillsboro, Oregon; headquarters in Fresno, CA.). Gusmer Enterprises confirmed the following:

  a. charcoal filters are used in the industry;
  b. the filters are made of both hardwood and softwood sources;
  c. both granular and powder form of activated carbon is used;
  d. five different grades of filters are used;
  e. any new filter product would have to be FDA approved in order to have access to the market;
  f. to test a new charcoal source: they would need a 200 gram sample; production trial would need 1000 lbs to determine if product meets or exceeds performance of current product.

  Gusmer Enterprises also confirmed that they are always looking for new sources of food grade charcoal filters for their customers.

  Although many carbon filter products are supplied by international sources, this product line may have unique opportunity for BEF CROP biomass in the future given the following facts regarding the production and economic impacts of a growing wine industry in Oregon alone (Table 12):

Table 12

Production:	• There are over 700 vineyards in Oregon, planted on over 13,700 acres. • In 2004 vintage, there were 19,400 tons of wine grapes harvested, and nearly 1.2 million cases of wine made. • Oregon is second in the United States in number of wineries, and fourth in the country for gallons produced. • Oregon produces over 40 different varietals of wine grapes. • Oregon currently has seven appellations (or wine growing regions) as defined by the Bureau of Alcohol, Tobacco Tax and Trade Bureau: Columbia Valley, Umpqua Valley, Walla Walla Valley, Willamette Valley, Rogue Valley, Applegate Valley and Columbia Gorge.
Economics:	• The total value of wine grapes harvested in 2004 was $32.2 million. • Total sales for Oregon wines in 2004 were nearly 1.3 million cases. • Of the nearly 1.32 million cases of Oregon wine sold last year, 665,635 cases were sold in Oregon, 592,684 cases were sold in other U.S. states, and the balance was exported to other countries. • The total economic impact to the state from the Oregon wine industry is approximately $1 billion.

- **Charcoal use in potting soils and larger agricultural applications:** Charcoal is used to sweeten sour soil, and in larger applications, to increase crop yield and carbon sequestration (note: ½ of the carbon in cropland soils has been lost due to intensive agriculture and human induced degradation). Low temperature woody charcoal has an interior layer of bio-oil condensates that microbes consume and is equal to glucose in its effect on microbial growth**.** In 2004, Dr. Ogawa, from Kansai Environmental in Japan, a division of Kansai Power (the 2nd largest electric producer in that country), presented their research on charcoal addition to soil at a carbon conference held at the University of Georgia. Their work, which has been ongoing for more than 15 years, has been studying the causes of the charcoal effect that led to the Japanese government approving charcoal additive as an official land management practice. The impact of many studies in Brazil to Thailand to Japan, showing increased crop yields of 20-50% and total biomass yields increasing as much 280%, led Kansai Electric to fund a reforestation research plantation in Australia for producing charcoal and returning it to grow more trees and crops in the arid west of that country.

  Charcoal soil additive product is sold by many agricultural supply companies in Oregon and the Pacific Northwest. Whitney Farms, Black Magic, and Super Soil are all products of the Rod McClellan Company located in Independence, Oregon. Whitney Farms offers more than 100 products, including Horticulture Charcoal, as a potting soil amendment used to sweeten sour soil and offered as an orchid mix (note: there are over 20 affiliated societies of the American Orchid Society in Washington and Oregon alone). Whitney Farms products are available at various garden nurseries, home centers, and hardware stores throughout the Pacific Northwest and in Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, Utah, and Wyoming.

  Development of a soil additive product would likely be combined with development of a charcoal slurry product for the nursery and grass seed industries (see below).

- **Charcoal use as slurry for seedlings in the nursery and grass seed industry**: Of all the charcoal products evaluated, this product arena may hold the best immediate opportunity for BEF CROP biomass directed toward non-energy production use (outside of small log sales for lumber production). Carbon is used in controlling seed and plant damage from herbicide residues. Activated charcoal slurry is sprayed on the soil (after the herbicide application) and before seeding, or is applied by dipping transplant's roots into a slurry of activated charcoal before planting. The charcoal slurry adsorbs the herbicide, allowing protection for the seedlings.

  In Oregon there are approximately 1,500 grass seed growers and more than 1,500 Oregon Association of Nurseries members including stock producers, greenhouse operators, retailers, landscapers, and allied industry suppliers. There are also many native plant growers in Oregon and Washington. All offer good product purchase potential. Consider: in 2004, the Oregon Association of Nurseries reported that the state horticultural industries set a record high with total sales of $884 million, 8% above 2003 and more than twice the sales of 1995. By 2007, industry experts anticipate sales in Oregon to hit the one billion-dollar mark.

  For this project, Mater Engineering interviewed agricultural supply companies in Oregon and Southern Washington to ascertain potential market demand and pricing for activated charcoal to be supplied from the BEF CROP region. Approximately 20 major supply companies were interviewed, resulting in the following information:

  a. Activated charcoal is used in the agriculture and nursery industry in the region;
  b. Annual usage per supplier ranges from 50 tons/year up to 300 tons per year;
  c. Buyer requirements: fine powder form (100 mesh to 325 mesh screen); 40-50 lbs. bags;
  d. Use is increasing, causing supply shortages;
  e. Currently, largest supplies coming Texas coal-based operation. Many purchasers are looking for another charcoal source;
  f. Wood-based charcoal would have to be tested against the Texas coal-based product for performance;
  g. Purchase prices quoted (limited imput): $.60/lb. delivered;
  h. There is keen product interest with some Willamette Valley purchasers, as they have trucks going to central Oregon on a daily basis and could transport their own purchases.

b. Wood Shavings/Pellets

Based on recent direct buyer interviews conducted by Mater Engineering in US western states (n=~70), the following is noted:

1). *Market demand:* Over 50% of buyers indicated market demand was increasing. This increase was primarily attributed to two key factors:

- an increase in horse ownership and horse boarding facilities, and an increased use of wood shavings or mulches as landscape material; and

- a noted and further anticipated shortage of straw as farms are sold and subdivided into ranchettes. Additionally, state restrictions in the transport of straw trucks going into other states due to concern over import of noxious weed seeds has also increased the demand.

Length of time required by suppliers to re-order appears to be another indicator of increasing demand for wood shavings matched with diminishing supply.

Wood pellets for horse bedding are a burgeoning new product line likely to impact regular wood shaving sales. The pellets are made of a combination of pine and spruce, and companies that manufacture these purport the following added benefits over typical woods shavings: better water absorption (more than double the performance of wood shavings); more cost efficient; reduction in labor, maintenance and disposal costs.

2). Most buyers purchase wood shavings/pellets in package form.

3). Bags purchased ranged in size from 3 cu. ft. to 4.5 cu. ft. of compressed wood shavings weighing between 40 to 50 lb. These sizes were identified by the feed stores, nurseries, and livestock owners. Some pet stores purchase larger bags of wood shavings, 4 cu. ft. – 50 lbs. These purchases were primarily for in-store use or infrequent sales to customers who desire slightly larger packages. Some repackage the larger bags into smaller bags for customer purchase. However, the majority of buyers who offer smaller bag product purchase smaller bags of wood shavings for resale to customers rather than repackaging themselves. The smaller bag sizes ranged from 270 cu. in. to 300 cu. in.

4). *Annual volume ranges*:
<u>Feed stores</u>: purchased volumes <u>typically</u> ranging from 200 bags/year to 2,500 bags per year. Some purchase as many as 10,000 bags a year.

<u>Pet stores</u>: purchased both large bags and a variety of smaller bag sizes. The typical year-round purchase range was between 144 to 416 bags annually of various sizes.

<u>Nurseries</u>: typically buy in *bulk* with purchases ranging between 200 to 2,000 cubic yards per year. Buyers of *packaged* mulches indicated ranges of 1,040 to 3,744 bags per year.

<u>Livestock operations</u>: purchase from as low as 1 bag of *packaged* wood shavings per year to an annual purchase of 2,800 bags. Purchases in *bulk* ranged from 4 beet truckloads per year to 12 semi-loads.

5). *Prices per bags*:
Average prices paid by feed stores for a 40-50# bag *including freight* ranged from $3 to $4, with a high-end price of $7.00 per bag, and a low-end price of $2.50 per bag. Average prices paid for a 40-50# bag *without freight charges* ranged overall from $2.45 - $3.50 per bag, with the high-end price being $8.00 per bag, and the low-end price being $2.05 per bag.

Pet stores identified delivered prices paid for smaller bags of various sizes. Those prices ranged from $1.50 to $4 per bag. High end stated price was $4 per bag; low-end price stated was $.99 per bag. Pet stores also identified prices paid for smaller bags of various sizes *excluding freight,* which tended to match delivered product costs. Those prices ranged from $1.50 to $3.50 per bag, with a high-end price of $4 per bag and a low-end price of $1.25 per bag.

Nursery bulk prices for pine ranged from $6.50 to $18 per cu. yd. including freight.

Livestock owner bulk prices varied according to truck size – the lowest being $20 for a truckload and the highest being $650/semi-load.

6). *Purchase practices:* a majority of wood shavings/pellets buyers purchase year-round.

7). *Packaging requirements:* Packaging needs to be of heavy, clear plastic that is labeled and has a UPC code. The packaging requirements most often identified were: heavy duty sealed plastic bags of clear plastic and no metal staples. Buyers noted that if the packaging is not clear and the product cannot be seen, is not likely to be purchased.

Energy Conversion Systems Analysis

1. Summary

The purpose of this Biomass Reconnaissance Project is to identify energy conversion opportunities for the design of a "portable" facility to produce fuel or electricity from timber residues in Central Oregon. Alternative systems for converting forest residues to energy were investigated including gasification, carbonization to charcoal and activated carbon, pyrolysis to oil and char and byproduct wood pellet manufacturing. Proforma capital and operating costs were developed for candidate technologies. Systems were compared using the levelized cost of electricity.

Resources are dispersed. Mater Engineering identified up to 125,000 dry tons of residues 80 miles from forest treatment areas; 75,000 tons within 50 miles and 21,250 tons within 25 miles. This could provide biomass for conversion facilities up to 431, 259 and 73 tons per day or 18, 11, and 3 tons per hour respectively. More than 50% of this volume is 7" to 9" diameter timber which could be recovered as higher value solid wood products; small-scale energy facilities could share handling equipment with wood processing.

Market studies by Mater Engineering identified high value products that could be co-products to energy generation including wood shavings, charcoal, activated carbon, and wood pellets. These could become primary products of a conversion facility with electrical generation as a by-product. Forest residues are delivered at a cost of $50 per bone dry ton. Market values for activated carbon were $500-$1000/ton, charcoal $60-$100/ton, wood pellets $75-$100/ton, and electricity $0.05/kWh. At typical yields electricity is worth $40/dry ton of wood; activated carbon $60-120/ton; charcoal $20/ton; wood pellets $60/ton. Combinations of electricity and fuels can return $60-90/ton for processing. Electricity alone will only return part of the cost of harvesting and transportation without conversion to energy.

Portable or mobile wood processing with supply circles of 25, 50, and 80 miles were considered to offset transportation costs. Reduced transportation could potentially save about $18/bdton. This study found that it is more practical to consider operation at a single site for as much as 10 years rather than to move a "mobile" facility every five years. Mobile processes for charcoal production have been demonstrated in the past but there are none currently in commercial operation. Small decentralized systems have higher costs due to minimum sizes for wood handling, higher costs for fuel preparation, lower yields and no economies of scale. Some processes require host services such as steam or power. Connection to a power line was determined to be prohibitive and costly for mobile plants. Small-scale systems require high availability for profitable operation but several areas are closed to access in winter or during the fire season. Three candidate sites were selected that represent an average transportation distance of 50 miles with a delivered cost of $50/ton. The sites are active or former sawmill sites that are close to grid connections.

Gasification systems from 300 kWe to 4 MWe were surveyed to select possible candidates for a preliminary system design. Many pilot facilities were found that are less than 200 kWe. Few pilot facilities were found above 300kWe. No commercial facilities were found that did not generate electricity or heat at highly subsidized rates. Capital costs are high in developed

economies at $5,000/kWe with target future costs expected to be $3,000/kWe. A 1 MWe plant would cost $3-$5 million. Estimated generation costs are $0.12-0.15/kWh even where fuel is inexpensive. Few gasifiers with IC engines have been demonstrated to be commercially reliable. In Europe there are promising projects in construction but none have an annual production of 7,000 hours or more. Few gasifiers operate more than 4,000 hours per year. India has the most wood gasifiers in operation. Out of 1800 gasifiers less than 20 are larger the 100 kWe. Costs are low. Labor is cheap and environmental impacts are ignored.

Activated carbon was suggested as a co-product by a Pacific Northwest gasifier developer. Gasifiers produce about 5% char. Pyrolysis produces about 15% char. From 3,000 to 9,000 tons of activated carbon per year could be produced within a 50-mile working circle. Mater found markets for activated carbon in the nursery and grass seed industries in the Willamette Valley where supplies have become scarce and prices have increased. Most of the activated carbon used in these markets is from Texas. There are seven US suppliers of activated carbon producing 217,500 tons per year. Two plants each produce 25,000 tons of high quality activated carbon per year as byproducts of the wood industry. There are also low cost supplies of activated carbon from India, China and Southeast Asia. A new technology developed at the Hawaii Natural Energy Institute, called flash carbonization, promises higher yields of activated carbon. A commercial facility has not yet been built.

A 1 MWe gasifier generates 180 lbs of carbon per day which could be converted to 250 tons of activated carbon per year. The cost of activation at this scale has not been determined. Char from gasifiers is partially activated during thermal decomposition but it does not have the adsorption properties of activated carbon. Surface area and other adsorption values for gasifier char are about 50% of typical activated carbons. It is clear it must be reprocessed with steam or chemical activation to increase properties such as surface area and micropore or macropore adsorption. Forest residues may also contain too much ash for activated carbon markets.

One option is to produce activated char with electricity as a byproduct. Approximately 75,000 dry tons of residues are available in a 50-mile radius which would deliver 10 dry tons per hour to a conversion process. A plant of this size is under commissioning in Australia. The $25 million Enecon Pty plant will convert 60,000 dry tons of eucalyptus wood, leaves and twigs to oil, charcoal, activated carbon (4,000 tons) and 5 MWe of electricity. The developers prefer low cost wood and co-location with a wood products company. They seek sites in Texas and Louisiana.

Three companies in North America are developing systems for pyrolysis oils. Only one has commercial plants in operation with the largest, processing wood at 80 dry tpd, to be commissioned in 2005. Developers of these semi-commercial pyrolysis processes indicate that the char resulting from pyrolysis can be used as activated carbon. No yields, product specifications or market experience has been reported for these chars. They expect to develop commercial plants that will process more than 100,000 dry tons of fuel per year to be economically viable.

Wood pellets are a mature market with more than 800,000 tons of pellets produced each year in the US. New markets suitable to wood species in Central Oregon are pine pellets for use as horse bedding. The smallest plant could produce about 5,000 tons per year. Economic feasibility would depend on the price of electricity. Another alternative would be to produce power as a co-product of wood pellet production. A 1MWe wood fired gasifier with an engine-generator would make enough heat and power to process three tons of pellets. The wood pellet plant would provide the labor and services necessary to justify power generation without heat recovery.

Proforma estimates showed that it is not feasible to generate electricity alone at the small scale without shared labor, heat recovery or a co-product. Preliminary analysis showed that at capital costs of $5,000/kW gasifiers could generate power for $0.17/kWh. Costs reduce to $0.15-0.16/kWh with federal and state incentives. Costs reduce further to $0.12/kWh by reducing labor costs and by offsetting fuel costs by producing co-products such as wood products or shavings. The lowest costs of $0.09/kWh are obtained when heat is recovered from the engine jacket for space heating or kiln drying, or when the delivered fuel cost is zero. At capital costs of $3,000/kW power costs are $0.13/kWh. They reduce to $0.12/kWh with federal and state incentives; to $0.09 to $0.12/kWh by reducing labor and producing co-products. The lowest costs are $0.06/kWh when heat is recovered or fuel costs are zero. Results suggest that a gasifier should be built for less than $2,500/kWe. Co-products or heat recovery should be employed to reduce equivalent fuel costs to $20/od ton.

When the cost of fuel is $50/odt there are no clear options for small scale power and energy production. In all cases the delivered cost of wood fuel is difficult to recover in energy products. Subsidy of harvesting and transportation may be necessary to make energy conversion feasible. Mobile systems are not feasible. Preferred locations are former or existing wood processing facilities located near power lines. Commercial demonstrated options include: power generation with recovery of solid wood products and power generation with shavings or wood pellets. Pyrolysis to oil has not yet demonstrated commercial viability. More detailed technical and economic analysis is required to assess the potential of activated carbon.

2. Availability Of Biomass Fuels For Energy

Mater Engineering identified 251 mmbf of small diameter round wood available for conversion to energy over a five year period.[1] The average annual harvest would be approximately 8.5 mmbf within 25 miles, 30 mmbf within 50 miles and 50 mmbf within 80 miles. Timber availability by size is shown in (Table 13).

Table 13: Amount of Wood Available By Working Area

	25 Miles	*50 Miles*	*80 Miles*
5 yr total mmbf	42.78	153.43	251.33
Annual mmbf	8.5	30	50
OD tons[2]	21,250	75,000	125,000
Diameter class			
7"-9"	49%	53%	54%
4"– 7"	48%	41%	38%
<4"	3%	6%	8%

[1] Mater Engineering Crop Modeling Inventory, June 2005.
[2] 1 mbf = 5 green tons = 2.5 bdt

There is sufficient fuel available for a processing facility to convert 73 to 431 dry tons per day to energy products. [3] If all of the wood were recovered for energy then the fuel available would generate 2.4 MW, 8.6 MW and 14.4 MWe at distances of 25, 50 and 80 miles respectively[4] (Table 14). Potential conversion to charcoal, activated carbon, bio-oil and wood pellets is shown.

Table 14: Potential Energy Products

		25 Miles	50 Miles	80 Miles
Annual	***Mmbf***	8.5	30	50
	OD tons	21,250	75,000	125,000
	OD tpd/290day[5]	73	259	431
	OD tph/24hr	3.1	10.8	18
	Electricity, MW[6]	2.4	8.6	14.4
Electricity	***MWh/yr***	17,000	60,000	100,000
Charcoal	***Tons/yr[7]***	6,375	22,500	37,500
Activated Carbon	***Tons/yr[8]***	2,550	9,000	37,500
Bio-Oil	***Gals/yr[9]***	2,550,000	9,000,000	15,000,000
Densified Pellets	***Tons/yr***	21,250	75,000	125,000

More than half of the volume is in the small diameter timber class of 7-9 inches and should be considered for solid wood recovery which has a higher value than energy. The volume of wood available 9" dbh or less is small for solid wood processing or energy conversion processes that operate 24 hours per day. [10]

More than 80% of the timber is located in the Northwest and Southwest quadrants of the 80-mile radius. Volumes and potential products for the Southwest and Northwest quadrants are shown in Table 15. The amount of wood available for energy in each quadrant is small for an independent power producer. At 5-6 MWe they are more suitable for cogeneration systems in wood processing facilities.

[3] Conversion factors used to achieve mmbf data were as follows: 1 cubic foot = 5 board feet; 100 cubic feet = 500 board feet; 5 green tons = 1 mbf = 2.5 odt 50% MC. The volume of wood available can be converted to dry tons from log scale factors and average wood density where oven dry weight = density/log scale ratio x 1000 bf/Mbf. For species distribution in this study the average specific gravity is 0.40 x 62.4 lb/ft3 = density of 25 lb/ft3. Oven dry weight = 25 lb/ft3/5.93 BF/ft3 (East side ratio) = 4,216 lb/MBF or 2.108 od ton/MBF. Conversion to electricity was estimated at 1.25 MWe per ton of dry wood. A plant would operate 7008 hours per year.
[4] A 1 MWe gasifier-generator would require about 1.25 odt per hour, 30 tpd or 8,000 odt/year.
[5] Operating year 290 days x 24 hours = 6960 hours per year. 6960/8760 = 80% capacity factor
[6] 20,000 Btu/kWh or 800 kWh/od ton (1.25 od ton/MW) at 17% fuel to power efficiency is typical for small gasification systems. Large biomass steam generators generate electricity at 14,000 Btu/kWh. Proposed combined cycle gas turbines can produce power at 9,000 Btu/kWh.
[7] Charcoal yield of pine and spruce 30%-32%. From Michael J Antal, Jr, and Morten Gronli, 2003, "The Art, Science and Technology of Charcoal Production", Ind. Eng. Chem. Res. 2003 42, 1619-1640.
[8] Activated carbon is produced from char. Typical yield is 40% of charcoal.
[9] Assumes bio-oil yield of 60% of heating value or 120 gal/od ton at 80,000 Btu/gal.
[10] Mater Engineering. June 2004. CROP and Small-Log Processing Feasibility for the Central Oregon Region. COIC, NFP.

Each area could support 2-3 generations systems in the 1-3 MWe size; 14-16,000 tons of charcoal; 5-6,000 tons of activated charcoal; 5-6 million gallons of bio-oil or 45-50,000 tons of wood pellets.

Table 15: Potential Energy Products in the SW and NW Quadrants

		SW	NW	Total
5 yr total	*Mmbf*	109.09	90.63	199.64
Annual	*Mmbf*	29.80	18.13	39.93
	OD tons	54,500	45,313	99,813
	OD tpd/290day[11]	188	156	344
	OD tph/24hr	7.8	6.5	14.3
	Electricity, MW[12]	6.3	5.2	11.5
Electricity	*MWh/yr*	43,600	36,250	79,850
Charcoal	*Tons/yr*[13]	16,350	13,594	29,944
Activated Carbon	*Tons/yr*[14]	6,540	5,438	11,978
Bio-Oil	*Gals/yr*[15]	6,540,000	5,437,500	11,977,500
Densified Pellets	*Tons/yr*	54,500	45,313	99,813

a. Costs of Wood Fuels

Table 16 shows estimates of wood fuel costs from similar studies in the region.[16] The cost of logging and fuel treatment is $30-$40/bdt for forest fuels compared with $15-18/bdt from hog fuel. In Idaho small diameter timber is purchased by the ton: $0-$34/ton for fuel and mulch; $50/ton or more for pulp wood or sawn timber. Kerstetter and Lyons found that in-woods costs of recovering logging residues start at $30/dry ton for the most accessible materials and increase without considering transportation costs.[17] Lazarus et. al used $15/dry ton for mill residues and $45 and $55/dry ton for evaluating the cost of fuels from forest health treatments and logging residues through the year 2020.[18]

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[11] Operating year 290 days x 24 hours = 6960 hours per year. 6960/8760 = 80% capacity factor
[12] 20,000 Btu/kWh or 800 kWh/od ton (1.25 od ton/MW) at 17% fuel to power efficiency is typical for small gasification systems. Large biomass steam generators generate electricity at 14,000 Btu/kWh. Proposed combined cycle gas turbines can produce power at 9,000 Btu/kWh.
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[14] Activated carbon is produced from char. Typical yield is 40% of charcoal.
[15] Assumes bio-oil yield of 60% of heating value or 120 gal/od ton at 80,000 Btu/gal.
[16] TSS Consultants, 2002, Prineville, Oregon Market Area Wood Fuel Availability Assessment, prepared for Central Oregon Intergovernmental Council.
[17] James D. Kerstetter and John K. Lyons, 2001, Logging And Agricultural Residue Supply Curves for the Pacific Northwest. Department of Energy Contract #DE-FC01-99EE50616, January.
[18] M. Lazarus, D. von Hippel, S. Bernow, 2002, Clean Electricity Options for the Pacific Northwest, An assessment of Efficiency and Renewable Potentials through the Year 2020, A Report to the NW Energy Coalition, Tellus Institute. October.

Table 16: Cost of Wood Fuels

	$/bd ton
Forest residues, logging	$28-$32
Fuel treatment/thinning	$33-$55
Wood waste (hog fuel)	$15-$18

The minimum cost of forest fuel is probably $25-30/bdt before transportation. At 1.25 odt/MWe the fuel cost would be approximately $ 0.0375/kWh to which must be added the cost of owning and operating the plant.

b. Transportation and Portability

Since fuels are disperse and transportation costs are significant conversion systems were sought that could be portable to offset transportation costs. One objective of this study is to determine if it is feasible to build a portable energy conversion system that could move with the harvest working circle every 3-5 years. Portable or mobile processing with supply circles of 25, 50, and 80 miles were considered. Reduced transportation could potentially save about $18/ton. Table 17 shows transportation costs for the three working circles considered.

Table 17: Transportation Costs for Forest Residues, $/bd ton

		Hauling Distance		
	Average	***25 mile***	***50 mile***	***80 mile***
Transportation		$11	$22	$35
Total Cost	$30	$41	$52	$65

Note: $0.44/ton mile

There have been several attempts to build portable gasifiers to offset transportation costs. Typically these are trailer mounted with capacities of not more than about 3 tons per day (100 kWe). Portable pyrolysis systems have been built to process up to 72 odt/day into 24 tons of charcoal.[19] There are currently no commercial gasification, pyrolysis or densification systems that operate in a portable mode. Systems designed for portability are typically operated in a fixed location.

Portable gasification and pyrolysis systems have processed up to 6 tons per day (200 kWe). Fixed systems process from 3 tons per day (100 kWe) up to 120 tpd (4 MWe). Some small scale systems for charcoal and bio-oil have been sized in portable modules of 60 od tons per day and may fit a 50 or 80 mile working circle. The largest fixed bio-oil processing plant processes 80 od tons per day. The target size for industrial bio-oil production is 400 od tpd. Fuel densification may be combined with gasification or pyrolysis. Wood pellets can be produced in quantities as small as 20 tpd (5,000 tpy).

[19] Enerco Model 24D trailer mounted rotary kiln processed 3.75 tons of wood waste at 20% MC and produced 1 ton per hour char (24 tpd), 0.5 tph oil and 1 ton per hour of producer gas. It consumed 30 kW. Miles Thompson, Enerco, 1979.

Modularity or portability does not necessary translate into lower system costs. Actual costs for small gasification systems are $1.5-$2 million for fixed 300 kWe systems, or $12 million for a 2.5MWe bio-oil system, or about $5,000/kWe. This compares with $1,500-$2,500/kWe for larger biomass power plants (>10 MWe).

c. Processing Sites

Mater Engineering analyzed the geographical distribution of the timber for potential working circles and found concentrations of timber on the West side of the project area. Karl Friesen investigated 25 potential sites and found that there may be access problems for several sites within the forest to utilities and difficult access during summer fire season and winter snow.[20] The project team concluded that three potential sites should be considered for energy generation; La Pine, Century Drive near Bend, and Gilchrest. These are sites of existing or former wood processing and are good locations in the working circle. With this selection it is possible to consider systems that can accept larger volumes over longer periods. These sites are located in the Southwest quadrant of the study area.

Small scale systems require high operating time for profitable operation but several areas are closed to access in winter or fire season. Small decentralized systems have higher costs due to minimum sizes for wood handling and fuel preparation. They also have lower yields and lack of economies of scale. Some processes require host services such as steam or power. Connection to a power line was determined to be costly for a mobile operation. Mobile processes for charcoal production have been demonstrated in the past but there are none currently in commercial operation. Even with increasing costs of transportation it is more practical to consider operation at a single site for as much as 10 years rather than moving a facility every five years. The three candidate sites that were selected are active or former sawmill sites that are close to the power lines. They represent an average transportation distance of 50 miles with a delivered cost of $50/ton. At $50/odt and 800 kWh/odt the cost of the wood in the electricity is $0.0625/kWh. Typical prices for electricity are $0.05/kwh.

3. Energy Products And Values

In order to design an appropriate conversion facility it is necessary to identify possible energy business opportunities for generating electric power and co-products. Energy products are electricity, char, bio oil or densified fuels. Selection of a conversion process depends on the specific products to be made. When solid wood is converted to a gas three products are formed: gas, char and liquid. Conversion processes favor one product or another: gasification converts as much of the product as possible to combustible gas with minimum char residue; pyrolysis for carbon converts the solid to char and oil; pyrolysis for oil converts the solid to oil with byproducts of oil and char. Typical energy values are shown in Table 18. Values for competing fuels such as fuel oil, propane, and hog fuel are provided for reference.

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[20] Karl Friesen & Associates, 2005, Small Scale Power Systems Forest Wood waste Power Generation Project: Potential Central Oregon Power Grid Interconnection Location Investigation. September 19, 2005. For the Bonneville Environmental Foundation.

Table 18: Comparative Fuel/Energy Values and Costs

		Heat Value	***Delivered Cost $***	***Cost/Value $/MMBtu***
Electrical Energy	Btu/kWh	3,412	.05	14.60
Charcoal fines	Btu/lb	12,000	60.00	2.50
Charcoal	Btu/lb	12,000	100.00	4.17
Activated carbon	Btu/lb	12,000	500.00	20.83
Bio-Oil	Btu/gal	80,000	1.00	12.50
Heating Fuels:				
Fuel Oil	Btu/gal	140,000	2.00	14.29
Propane	Btu/gal	91,500	1.50	16.39
Natural gas	Btu/scf	1000	10.00	10.00
Solid Fuels				
Sawmill residues, od	Btu/lb	8,000	18.00	1.12
Forest residue, od	Btu/lb	8,000	50.00	3.12
Pelleted wood, 10% MC bagged	Btu/lb	8,000	120.00	7.50
Bulk	Btu/lb	8,000	75.00	4.88

Table 18 illustrates that the cost of forest residues delivered at $50/bdt is significantly lower than fuel oil and propane. This will increase as transportation fuels rise. Wood pellets represent a value added product that could be produced in combination with power or carbon. However these products will have to compete with products made from residues of little or no value.

Market studies by Mater Engineering identified high value products that could be co-products to energy generation including shavings, activated carbon, and wood pellets. These products could become the primary product of a conversion facility with electrical generation as a by-product. Market values of activated carbon are $500-$1000/ton, charcoal $100/ton, wood pellets $100/ton, and electricity $0.05/kWh. At typical yields electricity is worth $40/dry ton of fuel; activated carbon $60-120/ton; charcoal $18-30/ton; wood pellets $75-120/ton. Combinations of electricity and fuels can return $60-70/ton for conversion to energy after the cost of fuel. Electricity alone will only return part of the cost of transportation of the fuel to a plant without the conversion to energy.

a. Electricity and Char

Portable electricity generation is the primary objective of this reconnaissance study. Technologies for producing electricity at this scale are reviewed in section 4. Gasification is the principal technology available for generating electricity on a mobile basis. Electricity from bio-oil is considered separately.

Table 19 shows a typical distribution of products from gasification. The efficiency of conversion from fuel to electricity via gasification is about 17%, or 20,000 Btu/kWh, or 800 kWh/odt. This project has assumed that this energy would be sold to the grid. Char is produced as a by-product of gasification at about 5% of the wood input or 100 lb/odt. Approximately 67% of the energy in the fuel is available in the form of waste heat. Of that about half is from engine cooling and can be recovered. A portion of the exhaust heat can also be recovered by using a catalytic converter with a gas-to-liquid heat exchanger. Some of the waste heat can be used to dry incoming fuel. Unless the heat is substituted for a fossil fuel there is no increased net revenue to the generating facility.

Table 19: Electricity and Co-products from One Dry Ton of Fuel

		Heat Value	(Cost)/Value $	Cost/Value $/odt	Equivalent Value $/kWh
Fuel Input	Ton od	1	(50)/odt	(50)	(0.0625)
Heating Value	Btu	16,000,000			
Electricity	kWh	800	0.05/kWh	40	0.05
Char	Lb	100	60/ton	3.00	$0.00375
Gross products				43.00	0.05375
Gross margin				(-7.00)	(0.00875)
Or, Activated Carbon	Lb	40	500/ton	10.00	0.0125
Gross products, AC				53.00	0.0725
Gross margin				3.00	0.00375
Heat available	Btu	5,200,000			
Heat for drying fuel	Btu	2,500,000			
Excess heat available	Btu	2,700,000	11.40/MMBtu	30	0.038000

Typical electricity contracts for biomass power in cogeneration are about $0.05/kWh. This will not offset the total cost of generating power which is $0.08-0.12/kWh in existing facilities. Heat is worth $11.40/MMBtu if it is used to displace fuel oil. One ton of dry wood per hour will generate electricity worth $40, and char worth $3. The gross margin - products less fuel cost - to own, operate and maintain the plant is $-7/odt or about -$0.00875/kWh.

Recoverable heat is worth $30/odt equal to about $0.038/kWh produced. Ordinarily this heat is used for process heat as in a lumber dry kiln, or district heating. The challenge for portable electricity production is to find a use for the heat such as a pellet mill or dry kilns.

b. Charcoal and Activated Carbon

Small amounts of carbon (5%) can be recovered as co-products of gasification. Or, a pyrolyzer can be used to make carbon and char products. Table 20 shows the products from carbonization of 1 bone dry tone of wood. The only semi commercial portable char pyrolysis unit available today produces 25 od tons of char from 60 dry tons of fuel (17,400 tpy). The quality of this char has not been verified but system developers estimate that char can be sold at the plant for $60/ton.[21] A much smaller system of 3 tons per day has been developed in France but has not yet been commercialized.[22]

[21] John Flottvik, JF Bioenergy, Bar Harbour, B.C. Canada. 2005. www.jfbioenergy.com
[22] Pro-Natura, France 2005. http://www.pronatura.org.br

Table 20: Charcoal and Co-products from One Dry Ton of Fuel

			Heat Value MMBtu	*(Cost)/Value $*	*Cost/Value $/odt fuel*
Fuel Input	***Ton od***	1	16	($50/ton)	($50)
Char Fines	***Tons***	0.33		$60-100/ton	$19.80 - $33.00
Bio-Oil	***gal***	50	6	$1.00	$50
Gross products					$69.80 - $83.00
Gross margin					$19.80 - $33.00
Waste Heat	***Btu***		5.2	$11.40	$60

Basis: JFBioenergy 2005

Charcoal sale and distribution is complex requiring the annual production to be bagged and stored for distribution to markets in a few short months through major outlets. Packaged charcoal is usually sold to wholesale outlets that have seasonal, large volume requirements. There are no clear lines of distribution for char. Local agricultural markets may be able to take smaller quantities in bulk. Most charcoal and activated carbon is made from hardwoods. Markets and uses for charcoal and activated carbon from softwoods must be verified.

Charcoal has an important role as a soil amendment with nutrients such as phosphorous. Phosphorous is not the only mineral that interacts with charcoal but it is an important one. In normal soil some 80% to 95% of the phosphorous is not accessible to the plant due to low pH and inactivation through reaction with iron. Mycorrhizal fungi transform this complex into phosphorous that can be assimilated, transport it to the next plant root and exchange it with carbohydrates. The extensive network of fungus mycelium is also an excellent water storage system.[23]

Torrefied wood has also been suggested for this application. In this process wood is subjected to temperatures up to 300° C for 2 hours which guarantees the carbonization of the lignin and the transformation of the cellulose and hemi-cellulose into volatiles. Torrified wood is easy to grind into a very fine powder which can be mixed with water and molasses and sprayed in a slurry. Volatiles in the torrefied wood are consumed slowly by adapted bacteria. In torrefaction the pure carbon structure is left which has a wide spectrum of pore diameters and an enormous surface for adsorption of minerals and water. There are no commercial torrefaction systems in use.[24]

Activated carbon markets were suggested by a Pacific Northwest gasifier supplier. Gasifiers produce about 5% char. Pyrolysis produces about 15% char. Charcoal is converted to activated carbon at about 40% efficiency for a net yield of about 12% of the oven dry wood. Newer technologies can double that yield. Table 21 shows the value of activated carbon from charcoal

[23] Nikolaus Foidl, Soil Scientist, Nicaragua.
[24] James Arcate. Transnational Technology LLC http://www.techtp.com/

and bio-oil using a process like the JFBioenergy system. The higher potential value must be weighed against the higher cost of activated carbon processing.

Table 21: Activated Carbon from One Dry Ton of Fuel

			Heat Value MMBtu	***(Cost)/Value $/odt***	***Cost/Value $/odt fuel***
Fuel Input	***Ton od***	1	16	($50)	($50)
Activated Carbon	***Tons***	0.12		$500 - $1000	$60 - $120
Bio-oil	***gal***	50	4	$2.50	$15
Gross products					$75 - $135
Gross margin					$25 - $85
Waste Heat	***Btu***		5.2	$11.40/MMBtu	$60

Basis: JFBioenergy and AC at 40% yield, Net 12% yield.

From 3,000 to 9,000 tons of activated carbon per year could be produced within a 50-mile working circle. Mater found markets for activated carbon in the nursery and grass seed industries in the Willamette Valley. It is used at rates of up to 200 lbs per acre to deactivate herbicide and pesticide residues by adsorbing them on the carbon surface or at rates of 25 lbs per acre to protect grass seed during planting using a seeding technique called carbon banding.[25] Activated carbon supplies have become scarce and prices have increased. Most of the activated carbon used in these markets is from Texas. There are seven US suppliers of activated carbon producing 217,500 tons per year. Two plants each produce 25,000 tons of high quality activated per year as byproducts of the wood industry. Low cost supplies of activated carbon are available from India, China and Southeast Asia.

A 1 MWe gasifier generates 180 lbs of carbon per day which could be converted to 250 tons of activated carbon per year. The cost of activation at this scale has not been determined. Char from gasifiers is partially activated during thermal decomposition but it does not have the adsorption properties of activated carbon. Surface area and other adsorption measures are about 50% of typical activated carbons. Few detailed analyses of the properties of gasifier chars have been made so there is no evidence that it could be used directly for the herbicide applications. Blending with activated carbon was been suggested for one gasifier char in England. It is clear that gasifier char needs to be reprocessed with steam or chemical activation to increase properties such as surface area and micropore or macropore adsorption. Since the feedstock comes from forest residues there may be too much ash in the char for activated carbon markets.

Production of activated char with electricity as a byproduct is an option with approximately 75,000 dry tons of residues available in a 50-mile radius which would deliver 10 dry tons per hour to a process. A plant of this size is under commissioning in Australia. The $25 million Enecon Pty plant will convert 60,000 dry tons of eucalyptus wood, leaves and twigs to oil,

[25] PNW Weed Handbook 2005: Ray D. William, "Testing for and Deactivating Herbicide Residues"; Jed Colquhoun, "Grass Seed Crops", http://weeds.ipps.orst.edu/pnw/weeds; North Carolina Cooperative Extensions Service, Using Activated Charcoal to Inactivate Agricultural Chemical Spills. http://www.bae.ncsu.edu/programs/extension/publicat/wqwm/ag442.html

charcoal, activated carbon (4,000 tons) and 5 MWe of electricity.[26] It uses a new technology for making activated carbon that was developed at the Australian CSIRO. The developers prefer low cost wood and co-location with a wood products company. They seek sites in Texas and Louisiana. Another new technology has been developed at the Hawaii Natural Energy Institute. Called flash carbonization, it promises higher yields of activated carbon. A commercial facility has not yet been built.

c. Bio-Oil

Conversion of forest residues to bio-oil has been an area of intense research and development. Bio-oil puts the energy into a form that is more easily transportable. There are many demonstration plants but very few commercial plants. The market has not yet developed prices for the bio-oils so the value of the oil and char products must be estimated from the cost of existing fuels.

Of the three North American companies offering oil processing facilities one concentrates on high value oil products for food and flavoring.[27] A second facility attempts to use a 2.5 MWe combustion turbine to make electricity.[28] A third facility attempts to make a fuel oil at a small scale that can be used in diesel engines in agricultural economics.[29]

As noted in Table 22, if the bio-oil is valued at $1.00/gallon ($12.50/Mmbtu) then it represents the highest value product with the greatest margin for processing ($70/odt). Burning the oil for fuel to generate electricity does not have any greater value than gasification. Energy in the char is consumed in the process. The significant unknown for bio-oil is the actual cost of processing since the few plants built to date are small in scale and in development. As with the other processes there could be significant value in the waste heat if used directly ($36/odt) or converted to electricity in an engine (225 kWe x 0.06 = $13/odt). Since none of the bio-oil processes are commercial there is uncertainty in these estimates.

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[26] Enecon Pty Ltd. http://www.enecon.com.au

[27] Ensyn Group Inc. http://www.ensyn.com
[28] Dynamotive Energy Systems Corporation http://www.dynamotive.com/
[29] Renewable Oil International LLC http://renewableoil.com/

Table 22: Bio-oil and Co-products from One Dry Ton of Fuel

		Heat ValueMMbtu	(Cost)/Value $	(Cost)/Value $/odt	(Cost)/ Value$/kWh
Fuel Input	***Ton***	1	(50)	($50)	($0.05)
	Btu	16,000,000			
Bio-oil	***Gal***	120	1.00	$120	$0.150
Energy in oil (60%) 80,000 Btu/gal	***Btu***	9,600,000			
Or, Electricity from Oil (28% eff).	***kWh***	800	0.05	$40	$0.05
Char	***Btu***	3,200,000	Consumed		
Gross products				$120	$0.15
Gross margin				$70	$0.0875
Heat, off gas 14,220 Btu/ Kwh =225 kWe	***Btu***	3,200,000	$11.40/MMBtu	$36	$13.50

Basis: Renewable Oil international

d. Densified Fuel

Densified wood fuels now have mature markets in North American Europe. North America produces more than 800,000 tons of densified wood per year for domestic fuel. New markets for pine pellets for horse bedding have emerged. The value of pellets can range from $75/ton to $120/ton. (Table 23).

Table 23: Densified Fuel from One Dry Ton of Wood

			(Cost)/Value $	Cost/Value $/odt
Fuel Input	***Ton od***	1	($50)/odt	($50)
Heating Value	***Btu***	16,000,000		
Fuel Products[30]	***Tons***		$75 - $120/odt	$75 - $120
Power required	***kWh***	100	$0.11/kWh	($11)
Heat consumed	***Btu***	3,000,000	Included	
Gross Margin				$14 - $59

Basis: ESA & Associates

Wood can also be densified to cubes or briquettes. These are undeveloped markets but the briquettes can be used in gasifiers to produce electricity on site. Waste heat from gas cooling and from the engine-generator can be used to dry the wood fuel for densification. So drying for gasification and densification becomes a way to recover value from the waste heat from power generation. The power generated from one dry ton is sufficient to densify 8 tons of wood. Waste heat from gasifying one dry ton is sufficient for drying two tons of wood. Since it is convenient but not necessary to densify the wood to gasify it the dryer could be run 24 hours per day. It could dry fuel for the gasifier and during 8 hours per day provide dry fuel to the pellet mill. Four tons per hour would yield 72 tpd densified fuel and 120,000 kWh net (800 kWh x 24 – 300 kWh x 8 hr). The value of the densified product would be greater than the value of the power. Table 24.

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[30] Assumes processing losses and wood used for drying wet fuel (3 MMbtu/od ton) at 20% of wood input.

Table 24: Electricity and Densified Fuel from Four Dry Tons of Wood

		Heat Value	*(Cost)/ Value $*	*Cost/ Value $*	*Equivalent Value $/kWh*
Fuel Input	***Ton od***	4	(50)	(200)	(0.50)
Heating Value	***Btu***	16,000,000			
Wood Pellets	***Tons***	3	75	225	0.45
Power produced	***kWh***	800			
Power required	***kWh***	300			
Net power produced	***kWh***	500	$0.05	25	0.05
Char	***Ton***	.05	$60/ton	3	0.006
Heat consumed	***Btu***	12,000,000	Included		
Gross products				258	0.516
Gross margin				58	0.116

Basis: ESA & Associates

e. Value Added Products from Small Diameter Timber

Half of the harvest could be converted to higher values products as small diameter timber. Table 25 shows that 4 to 27 mmbf could be recovered as solid wood. If the residues from processing the logs are combined with the forest residues than the fuel available is only reduced by 25% when the higher value wood is recovered. Solid wood processing would reduce the delivered cost of fuel to the conversion facility. Hauling costs could partly be borne by the solid wood products.

Table 25: Potential Recovery of Solid Wood and Fuel

		25 miles	*50 miles*	*80 miles*
5 yr Total	***Mmbf***	42.78	153.43	251.33
Annual	***Mmbf***	8.5	30	50
	OD tons	21,250	75,000	125,000
Diameter	***7"-9"***	49%	53%	54%
	4" – 7"	48%	41%	38%
	<4"	3%	6%	8%
Solid Wood	***Mmbf/yr***	4.125	16	27
Residues	***OD tons***	5,206	19,875	33,750
Fuel	***OD Tons***	10,838	32,250	57,500
Total fuel	***OD Tons***	16,044	55,125	91,250
	OD ton/day 290	55	190	315

Table 26 shows the distribution of 7"-19" dbh timber that could be recovered in the Northwest and Southwest quadrants.

At current log prices of $338 to $575/mbf the weighted average value of the recoverable wood in the Southwest quadrant is $165/odt ($412/mbf /2.5 odt/mbf) and $192/odt ($479/mbf/2.5 odt/mbf) in the Northwest quadrant compared with $50/odt as fuel. Sale of the saw logs or sale of recovered solid wood products should reduce the cost of wood fuel delivered to a facility. For the economic analysis we assumed that the recovery of solid wood products would reduce the cost of the fuel delivered to the facility from $50/odt to $15/odt. (See the Economic Analysis section of this report).

Table 26: Species Distribution 7-9" DBH in the Southwest and Northwest Quadrants

	Log Value	*Southwest Quadrant*		*Northwest Quadrant*	
Group/Species	***$/mbf***	***5 yr mbf***	***Avg mbf/yr***	***5 yr mbf***	***Avg mbf/yr***
Douglas fir	575	10,134	2,027	20,879	4,176
Mt. Hemlock,	445	1,475	295	456	91
Western Hemlock,	445	2,419	484	6,319	1,264
Ponderosa pine	338	20,468	4,094	6,206	1,241
Lodgepole pine	440	12,584	2,517	3,082	616
Other		9,714	1,943	7,465	1,492
Juniper		190	38	190	38
Total		***59,885***	***11,977***	***47,239***	***9,448***

Tables 26 and 27 show that 12 mmbf could be recovered annually as solid wood in the Southwest and 9.4 mmbf could be recovered annually as solid wood in the Northwest quadrant. These volumes are small for a small log mill so they may have to be shipped to other processing sites.

Other co-processing could include the production of shavings or wood pellets. These could also lower the delivered cost of the fuel delivered to the conversion facility. For the economic analysis we assumed that production of shavings would reduce the cost of the fuel delivered to the facility from $50/odt to $25/odt. (See the Economic Analysis section of this report).

Table 27: Potential Solid Wood Recovery in the SW and NW Quadrants

		SW	***NW***	***Total***
5 yr Total	***Mmbf***	109.09	90.63	199.64
Annual	***Mmbf***	29.80	18.13	39.93
	OD tons	54,500	45,313	99,813
Diameter	***7"-9"***	55%	52%	54%
	4" – 7"	42%	36%	39%
	<4"	3%	12%	7%
Solid Wood	***Mmbf/yr***	12	9.4	21.6
Process Residues	***OD tons***	14,988	11,781	26,949
Forest Fuel	***OD Tons***	24,525	21,750	45,914
Total fuel	***OD Tons***	39,513	33,531	72,863
	OD ton/day 290	136	116	251
	OD Ton/hr	5.7	4.8	10.5

f. Conclusions

Low yields in energy products for electricity, carbon and oil leave very low margins for covering ownership and operating costs if wood residues cost $50/odt and electricity is sold to the grid at $0.05 kWh. It is not likely that any of these processes are economically viable on their own unless other markets are found for heat that can be recovered for other uses. In the few cases where power or charcoal are produced directly from wood the fuel is usually low cost or heat is recovered for cogeneration or combined heat and power. Waste heat from charcoal kilns is often burned in boilers for process heat or power. Waste heat from gasifiers is used in district heating plants or dry kilns.

Char products, in general are low value ($20-30/odt fuel) compared with the costs of the wood feedstock at $50/odt or more.

Densified fuel or fiber products have a higher gross margin by themselves but require heat and power for their production.

Integration of densified fuels and power production with co-products of heat and power appear to have the highest value. Waste heat from the gasification process can be recovered to dry fuels for gasification and densification. Power generated from dry wood can provide power for densification. The combined products have the highest gross margin of the energy products considered.

4. Technology Options For Energy Conversion

Technology options were reviewed for mobile production of the energy products considered in Section 3 to determine if a facility can be installed in a central location where it can process forest fuels for a few years then move to another location. Transportation costs would suggest that a 50-mile radius would be a useful working circle. Capacities would be 1-8 MWe electric from a volume of up to 75,000 tons of wood fuel (259 od tpd).

Technologies for small scale power production include:

- Gasification and combustion in an internal combustion or Stirling engine
- Pyrolysis and combustion of oil or gas in a combustion turbine
- Steam engine or “screw” turbine

Other technologies to produce carbon and fuel products are

- Conversion to carbon or activated carbon
- Densification

Gasification and pyrolysis are the principal technologies considered for this survey. While no electricity is generated commercially using gasification with IC engines in North America there are gasifiers in Europe and Asia that may become commercial here in the near term.[31]

Stirling engines are still in development. The largest biomass fired Stirling engine, developed by Danish Technological University, is in operation in Austria.[32] [33] At 85 kWe it is small. However it may be used in combination with a biomass gasifier.
One bio-oil plant that will generate power is in commissioning in Canada.

There is at least one commercial steam engine in the Pacific Northwest and new steam "screw" technologies have been developed to generate up to 2.5 MW but steam generation from biomass is not portable and it is highly dependent on low cost residue fuels from wood processing.[34]

Electricity from distributed generation (DG) is the primary product of interest in this study. DG is the development of small sources of power generation. The most common example is a 100 kWe natural gas fired generator. Wood gas fired generators of this size have been demonstrated by the US Forest Service using wood gas producers and gas generating sets.[35] While there is sufficient fuel from harvesting and processing small diameter timber and forest residues for a small power plant the costs are high, volumes are generally low, and there are few markets for electricity. Capital costs are more than $1,500,000 for a 300 kWe generator ($5,000/kW) compared with $3 million for a 1,000 kW steam plant ($3,000/kW) or $30 million for a 20 MW steam power plant ($1,500/kW). Costs of operating small systems are high, $0.12-0.15/kWh, compared with production costs for new plants from 5MWe to 15 MWe at $0.08-09/kWh.[36] Some recent studies have been made for biomass plants in Central Oregon.[37] [38] Forest residues like those from small log harvesting are expensive fuels for generating power. There are also marketing and financial limitations to implementing distributed generation.

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[31] IEA Task 33 Biomass Gasification. Status of Countries Participating. 2004 and presentation at IEA Innsbruck, Austria, September 2005.
[32] J. Fischer, Technologies for small scale Biomass CHP-Plants –an actual survey
Risoe, May, 20th 2003 Biomass Information Centre, Institute for Energy Economics and Rational Use of Energy, IER, University of Stuttgart Hessbrühlstr. 49A. , D-70565 Stuttgart, Germany Tel.: ++49-711/7813909, Fax: ++49-711/7806177 www.biomasse-info.net December 2003
[33] OPET, Micro and Small Scale CHP from Biomass (<30 kW), Technology Paper 2, NE Res 37/2/2002
[34] Mt. Baker Plywood. 2004. 800 kWe 1930's Skinner engine installed 2003.
[35] US Forest Service, 2004. Biomass for Small-Scale Heat and Power. Techline, Forest Products Laboratory, State and Private Forestry Marketing Unit, One Gifford Pinchot Drive, Madison, WI 53726-2398. WOE-2 April. www.fpl.fs.fed.us
[36] Antares Group, Inc. 2003, Assessment of Power Production at Rural Utilities Using Forest Thinning and Commercially Available Biomass Power Technologies. Prepared for US Department of Agriculture and US Department of Energy and National Energy Renewable Laboratory, Task No. TOA KDC-9-29462-19.
[37] Central Oregon Partnerships for Wildfire Risk Reduction (COPWRR), EPRI Presentation and Discussion, December 3, 2001.
[38] TSS Consultants, 2002, Prineville, Oregon Market Area Wood Fuel Availability Assessment, prepared for Central Oregon Intergovernmental Council, December 18.

Gasification

Table 28 shows possible sizes of gasification systems based on the availability of wood fuel. A BEF project would probably start at 300 kWe or use multiples of 300 kWe as shown for a 1 MWe facility.

Table 28: Gasification Systems and Sizes

Size	***300 kW***	***1000kW***	***1500kW***	***2000 kW***
Gasifier-engines, units	1	1-3	3-5	3-6
Fuel, pph od[39]	750	2500	3750	5000
Tpd, od	9	30	45	60
Tpy, fuel	2,610	8,700	13,050	17,400
Char 5% tpy	130	435	652	870
MWh/yr	2,100	7,000	10,500	14,000

a. Commercial Experience

Wood gasification has been demonstrated up to 2.5 MWe in installations with several gasifiers and engines or with larger fixed gasifiers.[40] There are more than 1800 gasifiers in India where highly subsidized systems operate in off-grid applications for 8-10 hours per day, and usually less than 4,000 hours per year. Approximately 20 installations are larger than 100 kWe. Most are duel fueled with diesel engine generators but recent installations have been converted to 100% wood gas. These systems are manually fed and are not in locations that are sensitive to operator safety or environmental protection.[41] [42]

Several gasifiers are in various stages of development in developed countries where they must meet tight standards for air, water and land quality and operator safety. Most are under 100 kWe. The most ambitious is a 5 MWe CHP project in Skive, Denmark using a fluidized bed.[43] A 4 MWe olive waste gasifier in Rossano, Italy, is still under commissioning while developers figure out how to clean the gas.[44] A 1.8 MWe project is under construction at the Kokemaki CHP plant in Finland.[45] There is a 2 MW demonstration project in Geussing, Austria. Electrobel in Belgium, has built three gasifier installations supplied by the Belgian company, Xylowatt. One is 150 kWe and two each have a gasifier and two 300 kWe engines.[46] The engines are reportedly under repair. It is suspected that the longest that either system has run is about 3,000 hours. Xylowatt is testing a scale-up of their system to 1 MWe.[47] A 1 MWe updraft gasifier has

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[39] 20,000 Btu/kWh/8,000 Btu/od lb = 2.5 od lb/kWh
[40] See Renewable Energy Portfolio Project Gasification Discussion and Reference pages, www.repp.org/discussiongroups/resources/gasification
[41] Ankur Scientific www.ankurscientific.com
[42] Hitofume Abe, 2005. Status of Biomass Energy in India. For Japan International Aid Organization, University of Western Australia.
[43] Carbona, USA. James Patel. 2005.
[44] Emanuel Lenetti, INEA, Italy, 2005 and Ron Bailey, Jr. PRMEnergy. 2005.
[45] Condens Oy, Finland www.condens.fi
[46] Xylowatt Ltd., Belgium, 2005. www.xylowatt.com
[47] Presentation to be made at the 14th European Conference on Biomass, October 17-21, 2005.

operated more than 16,000 hours in Harboore, Denmark.[48] Menga Group, a CHP company in Switzerland, has demonstrated a 200 kWe downdraft gasifier based on an Indian design at a sawmill since 2001.[49] Exus Energy has demonstrated a 200 kWe downdraft CHP system in the U.K. Figure 1. All of these applications recover heat from gasification for district heating systems.[50]

Figure 1: Exus Energy 200 kWe Gasifier and Engine, UK, 2005 (Barker)

The following barriers for biomass gasification in the UK are typical of other countries:[51]

- Poor reputation of the technology
- Poor evidence of reliability
- High purchase cost
  - No mass market to support volume production.
  - Every project is special, large engineering costs.
- Environment - discharges to water and air
- Connection to network, high cost and institutional difficulty.

Table 29 shows two of the larger gasifiers in Europe that use fluidized bed gasifiers. Fluidized beds are currently more expensive than fixed beds, often requiring a larger capacity to justify the larger auxiliary equipment. The developers, Condens Oy, Finland, and Carbona, USA, expect catalytic tar reduction and economies of scale to offset problems of gas quality and reliability that have retarded IC engine projects.

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[48] Gasification Breakthrough in Biomass, Danish Board of District Heating Issue 2 2005 http://www.dbdh.dk/pdf/ren-energy-pdf/side14-17.pdf
[49] Menga Group is a supplier of more than 1100 CHP systems in Europe. It acquired Xylowatt SA of Switzerland in 2005 which is a licensee of the Indian Institute of Science (IISc), http://www.menag-group.ch
[50] For a list of gasifiers an their applications see IEA Bioenergy Task 33 Report: Status of Gasification in Countries Participating in the IEA and GasNet Activity, August 2004 http://www.etn.wsr.ac.at/pdf/status_of_gasification_08_2004.pdf and Technical Presentations from the Fall 2005 Meeting September 26-28, Innsbruck, Austria , http://www.gastechnology.org
[51] Nick Barker, 2005. UK Country report, Presented to IEA Task 3 Biomass Gasification, Sept 26, Innsbruck Austria, Future Energy Solutions, UK.

Table 29: CFB Gasifiers with Gas Engines

Location	Plant	Capacity MWe	Status
Geussing, Austria	Fast internal circulating fluidized bed	2	Operational on gas engine, more than 15,152 hours (August 2004)
Skive, Denmark	Carbona 16-20 MWth, CFB NG engines, Pellets	4	Under construction

Source: IEA Bioenergy Task 33 Country Reports 2005

Table 30 (see attached) shows the fixed bed gasifiers in countries participating in the IEA Bioenergy Task 33. Most are 200 kWe or less. Few suppliers have more than one gasifier or engine in operation.

Fixed bed downdraft gasifiers in India are often cited as example of commercial power generation. By 2004 India had 1,817 gasifiers with an installed capacity of 55 MWe.[52] Table 31. One supplier, Ankur, supplies 67% of all gasifiers in India. Most gasifiers are small. In 2004 Ankur sold 60 gasifiers in the Tamil Nadu state alone. Of these 57 were 9 kWe in capacity. The other three were one each of 4 kWe, 40 kWe and 250 kWe.

Table 31: Status of Fixed Bed Gasifiers for Power Production in India

Location	System, supplier	Power, Mwe	Status
Arashi Hi Tech Biopower Ltd, Coimbatore, Tamil Nadu	(4) Ankur gasifiers and 250 kW Cummins Engines	1	Startup 2002 dual fuel Spark ignition Dec 2004 4,000 hrs operation
Gosaba Island, Sunderbans	Ankur (5) 100 kW dual fuel	0.500	June 1997, 1150 households 15 hrs/day \$0.12-0.18/kWh
Chhotomollokhali, Sunderbans	Ankur	0.500	2001, 16 hrs per day

Source: IEA Bioenergy Task 33 Country 2004, Reports 2005

Micro-turbines are also being tested with gasifiers for remote power generation. Flexenergy will use a 200 kWe Ankur gasifier at University of North Dakota for testing up to three 30 kWe micro-turbines.[53] Technocentro has been developing an 80 kWe pyrolysis to electricity project in Terni, Italy using a micro-turbine. So far it is not in commercial operation.[54]

The only US company that has supplied a gasifier for engine applications at a large scale is Tulsa based PrimEnergy which has installed a 4 MWe system in Southern Italy with the Spanish engine

[52] Hitofumi Abe, "Summary of Biomass Bower Generation in India," July 2005. School of Plant Biology, University of Western Australia
[53] Flexenergy, Edan PRabu, www.flexenergy.com
[54] Andrea Moriconi, Catia Quirini, Daniele Moriconi, Erica Moriconi, 2005. "Gas Turbine Fed By Gas Produced From Biomass Pyrolysis" Presented to ASME Turbi Expo 2005, June 6-9, 2005. Paper GT2005-69032. and Gainni Bidini, Umerto Desideri and Francesco Fantozzi, 2003. Distributed Generation of Electricity from Biomass Using Pyrolysis Technology. Wood Energy No. 1, 2003.

supplier Guascor.[55] The plant has been in commissioning and development since 2001. Foreign suppliers with US representation include Pudhas Energia, Finland, and Ankur Scientific of India. US suppliers like Community Power Corporation, Colorado, and Bioenergy Limited, Washington, do not yet have commercial operations or have not built gasifiers larger than 100 kWe.[56]

The largest gasifier IC engine project currently under construction in North America is a 300 kWe system sponsored by the Connecticut Clean Energy Fund.[57] Figure 2. A three-day supply of fuel chips is delivered by front loader from a sawmill to the square fuel bin. Chips are metered to a vertical silo dryer and then transferred to a surge silo. From the surge silo they are transferred to a pressurized metering bin which delivers fuel on demand to the gasifier. The gasifier is a pressurized downdraft reactor. The building houses the gasifier and a (20%) duel fuelled diesel engine generator. A diesel generator was selected because the potential owner wanted the reliability of diesel as a backup fuel in case of a failure in the gasifier. The system was designed by a US engineering firm. The gasifier was supplied by Pudhas Energy[58] of Finland and the engine generator was supplied by Schmitt-Enertec[59] of Germany. Still in commissioning it is expected to enter full operation in 2006. It is intended to operate more than 7,000 hours per year.

The system is configured to send power to the grid and use power at the sawmill as necessary. In Connecticut a generator smaller than 350 kWe does not pay demand charges. Renewable energy receives $0.05/kWh above the market rate. Use of the waste heat as a substitute for fossil fuel is important additional income for gasification projects in developed economies. In this case waste heat will be used to dry lumber at the mill.

Figure 2: 300 kWe Gasifier at Tallon Lumber, Canaan, Connecticut, 2004

[55] Primenergy Ltd. Tulsa., Oklahoma www.primenergy.com Rossano Energia, under commissioning since 2001. Primary challenge is cleaning the gas (2005).
[56] The geometry of small scale gasifiers favors gasifiers below 100 kWe. It is more difficult to make a clean, tar-free gas above this level.
[57] Connecticut Clean Energy Fund, 2005.
[58] Pudhas Energy, Tampere, Finland www.pudhasenergy.com
[59] Schmitt-Enertec, Germany, www.schmittenertec.com

Table 30: Status of Fixed Bed Gasifiers for Power Production

Location	System, supplier	Power, Mwe	Status
Kokemaki, Finland	Condens Oy, updraft, catalyst 30% efficiency 3.3 MW thermal	1.8	Under commissioning startup 2004/2005
Tergola, Finland	Entimos, downdraft engines	0.080	Shut down, unsuccessful
Harboore, Denmark	Babcock & Wilcox, Volund updraft, CHP with gas cleaning and 2 gas engines	1.5	500-700 hrs continuous operation
Seco-Bois, Belgium	Menag Group (Xylowatt SA), downdraft CHP	0.6	Under commissioning
Gedinne, Belgium	Menag Group (Xylowatt SA), downdraft CHP, Wood chips	0.6	Under commissioning
Greasted, Denmark	BioSynergi, open core, wood chips, engine (80-100 kWel /200 kJ/s)	0.075	Engine optimization
Gjøl, Denmark	TKEnergi NG engine	0.650	In construction
Viking gasifier	DTU, Denmark 2-stage developed at DTU used for long-term testing	0.017	Operational since June 2002, scale foreseen
Viking	WEISS/COWI scaleup	0.200	200 kWel / 650 kWth design
Eckenförde, EVN, Domsland, Germany	Downdraft AHT technology	0.018	Discontinued operation since 2001
Austria	Grübl, wood gasifiers	0.05	Two in operation at farms
Londonderry, Northern Ireland, UK	Rural Generation, downdraft on farm, runs partially on energy crops	0.100	In operation, 16,000 hrs
Blackwater Valley Museum, N-Ireland	Exus Energy, downdraft on farm, runs partially on energy crops	0.200	In operation, 1,000 hrs Operating
Ballymena ECOS Centre, UK	Biomass Engineering, Downdraft	0.075	In operation, 2,500 hrs
Spiez, Switzerland	Pyroforce gasifier, high temperature gasification	0.200	Operational since 2002 > 1400 hrs
Bulle, Switzerland	Xylowatt (Menga), open-top	0.200	Operational since June
Beddington Zed, UK	Exus Energy, downdraft	0.130	Under commissioning
Legnano, Italy	CCT, downdraft and updraft (2) Guascor 500 kWe engines.	1.00	Functional Testing of gas cleanup system
Rossano, Italy 4.5	PRM Energy, Guascor Engines, updraft, olive pits	4.5	Modifying gas cleaning system
Tallon Lumber, Canaan, MA, US	Pudhas Downdraft, Schmitt-Enertec Dual Fuel CHP	0.300	Under commissioning

Source: IEA Bioenergy Task 33 Country 2004, Reports 2005

The Connecticut gasifier is a demonstration project. It is not yet in commercial operation. It has commercial power contracts. Air quality requirements are deferred under demonstration and development terms until the system is fully commissioned and in operation. It is expected to comply with permit requirements. Solid waste consists of char that may be blended with soil amendments that are made on site. Condensate is used to cool the char. There are no water effluents. Figure 3 shows the elements of the project in relation to the host mill. Figure 4 shows the fuel inputs and energy products of the system.

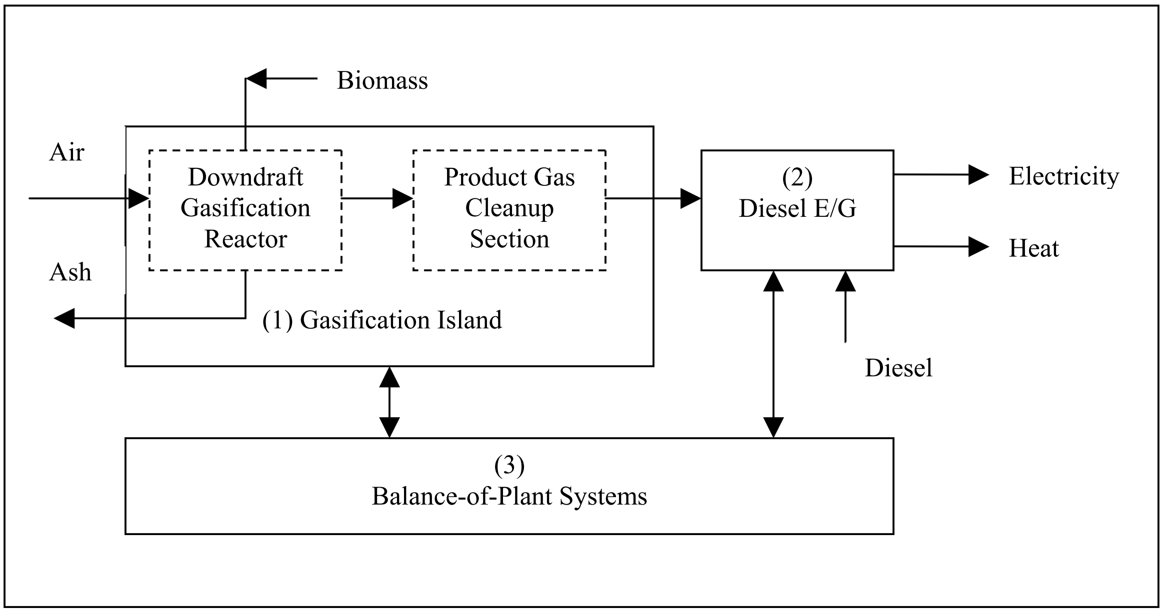

Figure 3: Schematic of relation of the gasifier to the host plant at Tallon Lumber. (Renova Engineering).

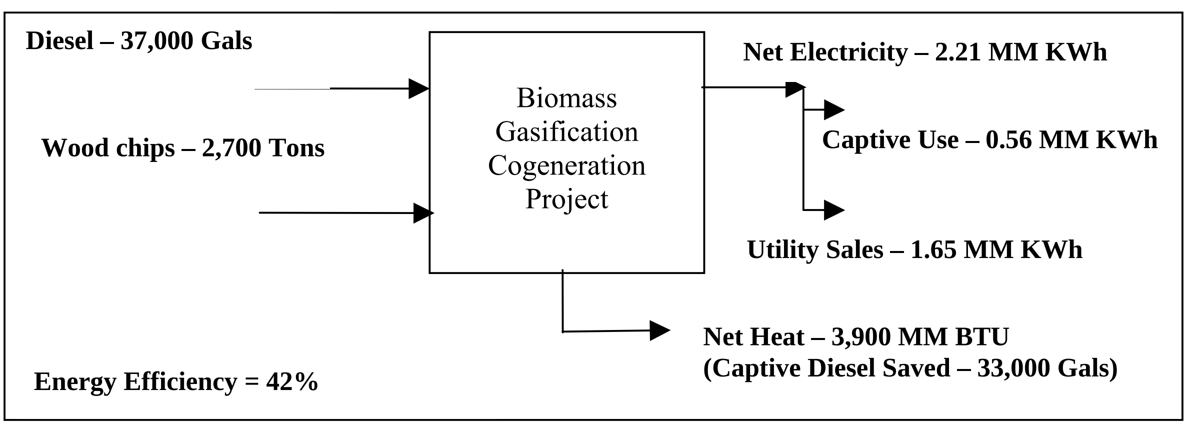

Figure 4: Energy Use in the Tallon Gasifier (Renova Engineering)

A 200 kWe demonstration gasifier was developed by University of North Dakota EERC for FlexEnergies Ltd.[60] Figure 5. The trailer mounted system will be used to demonstrate power generation using microturbines. It has a portable fuel feeding bin, a conveyor to elevate the fuel to the top of the gasifier, automated fuel feed into the gasifier, the gasifier and gas cooling and cleaning system, char and ash removal, and a flare for bypassing the turbine and a final cleaning filter. The top of the gasifier is removable for transport using a jib crane mounted on the trailer.

Figure 5: Trailer Mounted 200 kWe Gasifier, FlexEnergy Ltd, 2005

Three 30 kWe microturbines with controls and switchgear will be mounted on the trailer. The system has been used to test wood chip fuels, densified wood fuel and has produced gas to run a 150 horsepower John Deere diesel engine in dual fuel mode. It has demonstrated reliable operation and fuel flexibility. It requires sized and dried fuels. There is no fuel dryer.

Lack of engine experience, or experience with extended engine operation, are significant problems for implementing gasification technology. Engine suppliers will not guarantee performance on wood gas so some CHP suppliers modify engines to suit.[61] One such supplier recommends engine maintenance every 1000 hours (42 days). No US supplier advertises expertise with wood gas. The most engine operating experience among current suppliers was by Gus Johansson, developer of the SJG gasifier in South Africa.[62] SJG gasifiers have operated for up to several thousand hours on wood gas. Engines specialists attest to the clean condition of SJG engines after prolonged operation. SJG insisted on wood fuel quality, including the size, species and moisture content of the fuel, extensive gas cleaning and engine maintenance.

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[60] Darren Schmidt, Energy and Environmental Resources Center, University of North Dakota, www.nodac.edu/eerc and Edan Prabhu, Flex Energies Ltd. www.flexenergies.com 2004.

[61] Schmitt-Enertec, Germany, MDE, Germany, and Menag Group, Switzerland are three CHP suppliers that provide and service engines for wood gas systems. Jenbacher, Austria, also supplies engines for select applications.

[62] Now supplied by Carbo Consult Pty, Guenter Freundheim, South Africa.

Gas quality has been a significant challenge for small scale systems. When the char particles are chips size or larger then gasification is more efficient. Small scale gasifiers depend on the geometry of chunks of fuel to develop a tar cracking zone within the gasifier. By reducing the tars in a high temperature zone they are able to produce clean gas. Johansson of SJG used wood chunks made with a Finnish chunker to ensure good gas flow through the char bed. His gasifier was not optimized for wood chips.[63] Other gasifiers like the Ankur also rely on this fuel geometry to maintain gas quality. Receiving round wood from the forest rather than wood chips provides the opportunity to make chunks for a gasifier(s) which could ensure quality gas in existing designs.

Wood chips have been successfully gasified in open core downdraft gasifiers like the IISc gasifier supplied by Menga/Xylowatt, the Xylowatt (Belgium) gasifier or by Pudhas Energy, however these suppliers continue to test gas cleanup systems that will improve the apparently lower quality of gas from wood chips.[64]

Some gasifiers such as the DTU two-staged Viking gasifier or the TK Energi three-phase gasifier are designed to be less sensitive to wood quality. In this design wood is first pyrolyzed and the resulting char is gasified in a char bed.[65]

b. Implications of Gasification Experience for BEF

It is clear from the review of operating gasifiers that wood gasification is still very much in development. The systems mentioned are almost all being developed in stationary applications with public subsidy for development and demonstration. A recent solicitation for a 300 kWe system for a sawmill in Massachusetts demonstrated that few suppliers are prepared to provide a complete system with guarantees.[66]

All commercial gasifiers in Europe and North America depend on recovery of waste engine heat for economic operation in stationary applications. There are no mobile applications of significant size.

Fuel preparation, drying and sizing, is critical to performance of gasifiers and engine generators. Design of a gasification system must include fuel sizing and drying suited to the gasifier selected.

Most of the industry is still under development and demonstration. Few gasifiers have significant commercial operating experience. This is particularly true of gas cleaning for engine applications. Selection of gas cleaning equipment is important to reliable operation of the engine

[63] Laimet chipper, Finland http://www.laimet.com/eng/chippers.html
[64] Pasquale Giordano, Presentation to IEA Task 33, October 2004 http://www.gastechnology.org/webroot/downloads/en/IEA/4XylowattPasqualeGiordano.pdf
[65] TK Energi, Denmark www.tkenergi.dk and Danish Technological University being developed commercially for combined heat and power applications by COWI Engineers, Denmark. http://bgg.mek.dtu.dk/
[66] Biomass Energy Resource Center, Vermont, Solicitation for 300 kWe gasifier for Heyes Forest Products CHP Demonstration, Orange, MA June 2005.

generator. There is still appreciable experimentation especially in the new large systems (Kokemaki, Skive) where catalysts will be used.

Standards for health, safety and environmental aspects of gasification have been the subject of international research organizations.[67] Discharge from wet scrubbing systems used in Indian gasifiers may not be acceptable in the US.[68] Emissions standards for power generation with IC engines are evolving. Gasifiers will not yet pass US air quality standards for stationary generators.

Charcoal and Activated Carbon

a. Charcoal

Charcoal is produced in the US by large processors that have supplies of low cost wood waste. Charcoal is usually made in multiple deck kilns called Herreshoff furnaces. Energy from volatile gases is recovered in industrial boilers to generate steam and power. High value carbon products such as activated carbon are made by a small number of suppliers and usually imported from areas where the base carbon has been produced in labor intensive economies.

Table 32 shows the potential for charcoal production in the Central Oregon. Char yields from wood pyrolysis are typically 25%-30% which corresponds to the fixed carbon content of the wood. Volatile carbon converts to gas which is consumed in the process or condensed as oil.

Table 32: Char Production Systems and Sizes

Distance		*25 miles*	*50 miles*	*80 miles*
Wood	*Odt/y*	21,250	75,000	125,000
	Odtpd	73	259	431
Charcoal	*Tpy*	6,375	22,500	37,500
Or tpd	*Tpd*	22	76	129
Activated carbon	*Tpy*	2,550	9,000	15,000
	Tpd	9	31	52

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[67] Workshop led by IEA Bioenergy Task 33 Biomass Gasification, Health, Safety and Environment in Biomass Gasification, Innsbruck, Austria, October 2005.
http://www.gastechnology.org/webroot/downloads/en/IEA/HSEworkshopFlyer.pdf

[68] A US DOE funded gasifier demonstration for the Alaska Village Electric Cooperative (AVEC) by Marenco Inc. 1980-1983 became a hazardous site. due to discharge of pyrolysis oils, tars and condensate. "During the dismantling of the wood gasification equipment, a considerable amount of liquid, semi-liquid, and solid gasifier waste was discovered on the property. The waste contained creosote -wood tar and related chemical agents (benzo (a)pyrene and phenols) classified as hazardous waste by the EPA (see photos included in Attachment A taken by an EPA representative in 1985). The waste was contained in various system holding tanks, open and closed 55-gallon drums, open tanks located in the warehouse, and in a waste (ash) pile east of the warehouse near the trees (Figure 2-3). The waste gave off vapors causing various toxic reactions among the BPA team members dismantling the equipment and limiting the use of the adjoining truck shop facilities (EPA, 1985)." Preliminary Assessment Alaska Wood Gasifier Site, Anchorage, Alaska, Ecology and Environment, Inc, Seattle, WA, 1996.

b. Commercial Experience

During the 1970s and 1980s several charcoal systems were under development in Europe and Southern Africa for the European market. Some mobile or semi mobile systems were developed at that time. Two commercial mobile pyrolyzers were developed in the 1970s by Enerco of Pennsylvania.[69] The 24 tpd units were built and demonstrated with support from the USDOE and the Tennessee Valley Authority. They are no longer in commercial operation.

New technologies have been developed for high charcoal yields. These are industrial chemical plant scale systems. It is not clear where the markets are for the conversion.[70] [71] Until a few years ago charcoal was produced commercially in France by Entropie using the Delacotte process which was a blend between gasification and pyrolysis. The plant manager, interviewed in 2003, indicated that it was impossible to compete with low cost charcoal from developing countries, especially Southeast Asia.[72]

Current systems are under development by JFBioenergy of British Colombia and Enviro of South Africa. While JFBioenergy has a small mobile demonstration unit neither system has been in commercial operation and both continue under development. Figure 6 shows the flow diagram for the JF Bioenergy 120 tpd plant. Figure 7 shows a mobile demonstration system that is still under development. Markets and yields are not yet clear. JF Energy projects a cost of $2 million for a 120 tpd plant.

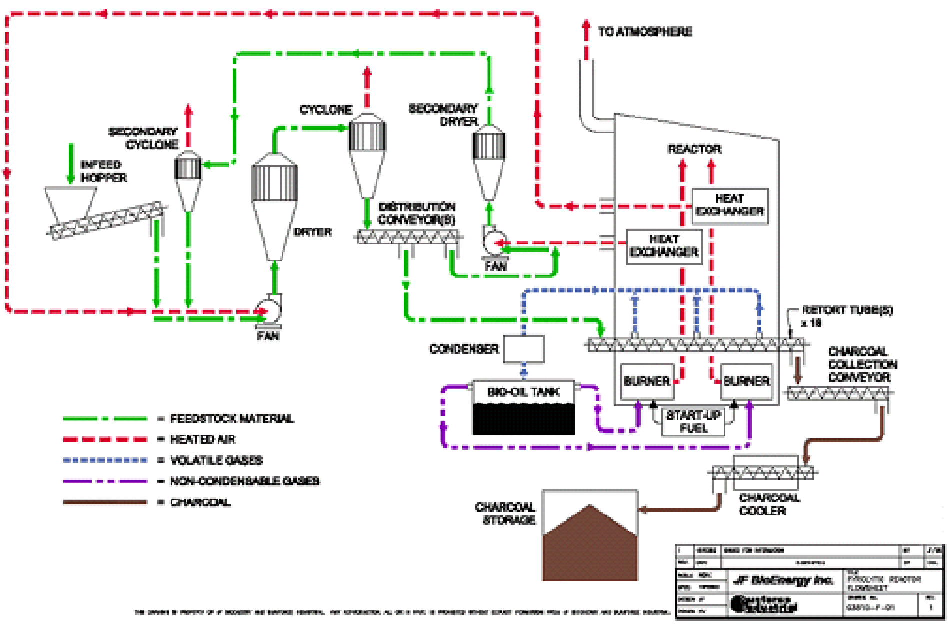

Figure 6: Char and Oil Making Process 120 TPD (JF Bioenergy Inc)

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[69] Miles Thompson, Enerco.1979.
[70] Michael Antal, HNEI, James Arcate. Transnational Technology LLC http://www.techtp.com/
[71] Charles W. Aguas Ellis , US Patent 6,647.903 November 18, 2003
[72] Entropie, European Gasnet Conference, Florence, April 2003.

Figure 7: Char and Bio-oil Demonstration Facility 25 tpd (JF Bioenergy Inc.)

c. Activated Carbon

Activated carbon was suggested as a co-product by a gasifier developer in the Pacific Northwest. Gasifiers produce about 5% char. Pyrolysis produces about 15% char. From 3,000 to 9,000 tons of activated carbon per year could be produced from residues from a 50-mile working circle.

Char from gasifiers is partially activated during thermal decomposition but it does not have the adsorption properties of activated carbon. Surface area and other adsorption values are about 50% of typical activated carbons.[73] Few detailed analyses of the properties of gasifier chars are available so there is no evidence that it could be used directly for the herbicide applications. One laboratory in England suggested that a gasifier char should be blended with activated carbon to meet market requirements.[74] It is clear that gasifier char needs to be reprocessed with steam or chemical activation to increase properties such as surface area and micropore or macropore adsorption. Since the feedstock comes from forest residue the ash levels in the char may be too high for activated carbon markets. When fuel ash in a gasifier is 3% the ash in the char will be 7%. This will concentrate to 14% during activation unless the activated carbon is washed. Typical markets require 10% ash or less. A 1 MWe gasifier would generate 1500 lbs of char that could be converted to 180 lbs of activated carbon per day. The cost of activation at this scale has not been determined.

Another new technology from the Hawaii Natural Energy Institute called flash carbonization promises higher yields – up to 45% – of activated carbon. A commercial facility has not yet been

[73] Michael J Antal, Jr, and Morten Gronli, 2003, "The Art, Science and Technology of Charcoal Production", Ind. Eng. Chem. Res. 2003 42, 1619-1640.
[74] CRE Group, Ltd., for B9 Energy Biomass Ltd (now Exus Energy Ltd.)), Further Investigation of the Potential of Manufacturing Barbecue Fuel From the Residue of a Wood Gasifier and Preliminary Evaluation of the Wood Char as an Active Carbon. June 2000.

built. [75] The process requires steam, a pressurized reactor, and there are some process issues yet to be solved to prevent explosions.[76]

d. Implications of Charcoal and Activated Carbon for BEF

Favorable markets have been found for charcoal and activated carbon in the Willamette Valley. The suitability of charcoal and gasifier char for these uses must be investigated.

Low cost charcoal is produced where low cost residues are available waste heat can be recovered by host facilities.

Current small scale systems are not mobile or commercial. Good data is not available for operating costs.

Environmental impacts of charcoal producing systems are not apparent. While air emissions may be acceptable the composition and disposal of liquid effluents is not determined.

Activated carbon markets and processes are promising but the suitability of gasifier chars must be investigated. The cost of activation must also be determined.

Pyrolysis to Bio Oil

Figure 8 shows the typical conversion of wood to bio-oil. Wood is dried and fed to a reactor where heat is supplied externally to convert the solid wood to combustible gas (15%), char (15-20%) and oil (60%). Oil is the primary product. Combustible gas and char are used to provide heat and power for the process. The bio-oil can be used in combustion turbines or engines to generate power at a remote site.

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[75] Kazuhiro Mochidzuki, Lloyd S. Paredes, and Michael J. Antal, Jr. 2002. Flash Carbonization of Biomass. Presentation at AIChE 2002 Annual Meeting, Indianapolis, IN, November 3-8, Reactor Engineering for Biomass Feedstocks. http://www.hnei.hawaii.edu/bio.r3.asp

[76] Teppei Nunoura and Michael J. Antal 2004. Catalytic emission control in Flash Carbonization of biomass. Presented to the AICHE Annual Meeting, Austin, TX, November 11, 2004 Reactor Engineering for Biomass Feedstocks.

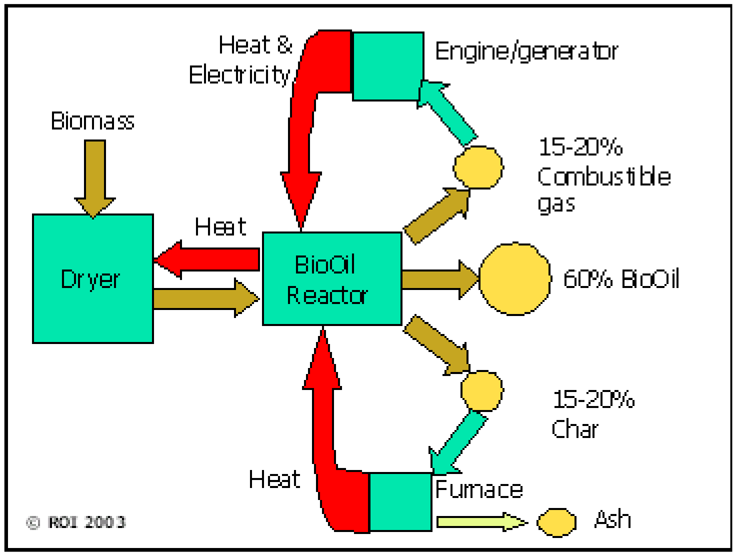

Figure 8: Bio-Oil Generation and Use (Renewable Oil Inc. 2003)

Table 33 shows a possible size and products for a pyrolysis system for Central Oregon.

Table 33: Bio-Oil Systems and Sizes

Size	125
Units	1
Fuel, pph	10,416
Tpy	
Tpd	125
Oil, gal/day	15,000

a. Commercial Experience

Conversion of biomass to oil has been the subject of extensive research, development and demonstration in Europe and North America.[77] A major result of the development has been a trend toward fast pyrolysis which has increased oil yields and quality compared with the older slow pyrolysis systems.

There are currently three developers of bio-oil systems in North America: Ensyn Technologies, Canada, Dynamotive, Canada, and Renewable Oil Inc., of Canada and Alabama. The Ensyn and Dynamotive systems use fluidized sand media for rapid heating of the solid biomass. Ensyn has been in development since 1980. They have four commercial systems. The largest system now under commissioning is 80 od tons per day. Their systems are all stationary.

[77] See ThermalNet and PyNet www.thermalnet.uk

Dynamotive has been in development since 1995. They are constructing an oil plant at a wood processing facility in Ontario, Canada. Wood waste will be converted to oil. The oil will be burned in a 2.5 MWe combustion turbine. This is their first commercial installation. The system cost is $12 million. It is still in commissioning. It is also a stationary application. Dynamotive emphasizes the importance of collocating at a site with low cost waste and a demand for waste heat.

Renewable Oil Inc. (ROI) has a 5 tpd pilot facility under development in Alabama shown in Figure 9. A 15 kWe used oil generator is shown in Figure 10. ROI has projected a 125 tpd plant at a cost of $2 million. Bio-Oil production would be 15,000 gal/day or 5 million gal/yr. Waste heat would be suitable for 2.5 MWe power production. Power generation equipment is not included in cost estimates. ROI projected costs of $1.50/MMBTu plus the cost of the feedstock have not been verified with actual installation.

Figure 9: 5 TPD Bio-Oil Pilot Plant (Renewable Oil International)

Figure 10: 15 kWe Used Oil Genset (Renewable Oil International)

b. Implications of Bio-Oil Experience for BEF

While conversion of solid wood waste to oil is an interesting option there is no evidence from commercial experience that pyrolysis to oil can be mobile or scaled down for general fuel or electricity production. Systems appear to be under development and demonstration with no clear commercial operation. It is a process that might be located at a central plant where economies can be derived from other products. North American suppliers are not yet prepared for mobile production. Similarly there are no mobile systems in operation in Europe that can be easily adapted.

Densified Wood Products

Wood pellets are a mature market with more than 800,000 tons of pellets produced each year in the US. New markets suitable to wood in Central Oregon are pine pellets for use as horse bedding. The smallest plant could produce about 5,000 tons per year. Economic feasibility would depend on the price of electricity. Another alternative would be to produce power as a co-product of wood pellet production. A 1MWe gasogen would generate enough power to process three tons of pellets from a ton of wood. The wood pellet plant could provide the labor and services necessary to justify power generation without heat recovery.

The costs in Tables 18, 24 and 25 show that there may be an opportunity to dry and densify, or pelletize, wood fuels in combination with a gasifier for power generation. An Oregon pellet manufacturer and a pellet fuel equipment supplier think that whole tree chips from forest cleanup can be used to make fire logs. Some pellets could be sold in bulk to homes and schools. Manufacturers are interested in locating a plant where wood supply can be reliable. Production can start small (5,000 tons) but should be built up to a minimum of 20,000 tons per year, which at $120/ton would be worth $2.4 million in sales. (Table 34). A 5,000-ton per year plant can be built from used equipment for $500,000 or more.[78]

Table 34: Densified Fuel Systems and Sizes

Plant Size	***Tpy***	***5,000***	***10,000***	***20,000***
Pelletizers		2	2	3
Fuel	***pph***	5000	5000-8000	10000
Tpd	***Tpd***	20	40	80

a. Commercial Experience

Wood pellet production is commercial with many suppliers in North America and markets expected to increase with rising fuel prices. There are many plants in the size range of suitable for Central Oregon. In several locations pellet mills are integrated with or located adjacent to existing wood processing plants where heat or power is shared with the host plant. The largest

[78] Eric Smith, ESA Associates, Vancouver, WA. Pellet fuel equipment supplier.

plant of this kind, in Koge, Denmark, produces more than 30 tph pellets for use in power generation.

Some pellet mills are powered by fixed or standby generators which are usually fueled with diesel. Mills could be powered by dual fuelled diesel or producer gas powered engines.

Conclusions

Gasification has been selected as an energy system for this study. The reconnaissance of available technologies shows that current systems recover 17-30% of the energy in the wood fuel. Higher yields require recovery of low grade waste heat in combined heat and power arrangements.

Gasification and pyrolysis systems are still being demonstrated at a small scale. The value of energy from existing technologies must be verified. Claims for ownership and operating costs of the systems reviewed have not been substantiated by long term commercial operation for any of the technologies. Most small scale systems are being developed or demonstrated using public subsidies. None are generating carbon, heat or power for commercial use without public incentives. Typical subsidies are for 30% to 50% of the costs of operation. BEF, or a BEF supplier, will need to cover these costs. Significant development is still required to demonstrate reliable gasification for periods of 7,000 hours per year, 80% availability, needed for commercial viability.

Portable systems for converting wood to carbon or electricity are not readily available or proven in commercial operation. There are no portable systems larger than 200 kWe equivalent. The values of the products from remote portable systems do not cover the operating costs. No mobile systems are integrated with the grid for power generation. Portable densification systems have operated intermittently.

Char and char dust are considered in this study as products that can be sold. Char can be generated from a gasifier up to about 10% yield in combination with electricity. The technical suitability of gasifier char for potential markets must be verified.

A gasification system should be co-located at another operation that is paid for by other sources, such as forest cleanup, so that the labor and operating costs for fuel sizing and mobile equipment can be shared with other sources of income. Fuel densification has the potential to operate at a profit. Integration with a gasification or energy system should be considered.

The environmental performance of some gasification technologies is still being determined. Gasifiers used in developing countries have no emissions control and wastewater effluents from gas cleaning that are acceptable for use in the US. System developers must incinerate or dispose of toxic and hazardous pyrolysis liquids such as tars that result from the pyrolysis or incomplete gasification of biomass fuels. Air quality standards have not yet been established in Europe or the US. It is not likely that gasifiers will pass proposed standards for small scale power generation for natural gas or diesel fuels.

Gasification to electricity with fuel densification appears to have good potential for a commercial operation. The gasifier would have to be operated a site that could share the costs of labor and equipment such as a forest restoration operation, log sorting yard, or fuel preparation yard that would chip and export fuels to other uses.

5. Plant Description

A 1000 kWe gasifier consists of the following components:

- Fuel Handling System
- Gasification System
- Gas Cleaning System including Flare
- Engine Generator including Switchgear
- Electric Switchgear for Plant

a. Operating Conditions for 1 MWe Gasifier

The gasifier would generate 1000 MWe net for sale to the grid for 7,008 kWh/year. It would consume 1.25 od tons per hour, 30 od tons per day or 8,000 tons per year, equal to 3.2 mmbf. Up to 250 tpy gasifier char would be recovered and sold. Heat available equal to 11,555 MWh could be recovered for space heat or industrial processing. Table 35.

Table 35: Operating Conditions for 1 MWe Gasifier

Net Power Generated	***kWe***	1000
Fuel Consumed	***Odt/y***	7966
	MMbf	3.186
Capacity Factor	***%***	80
	Hrs/y	7,008
Power generation	***1,000 kWH/yr***	7,008
Char	***t/y***	
Heat recovered	***1,000 MWh***	0-11,555
CHP Efficiency	***%***	24-62

b. Fuel Handling System

Whole tree chipped fuel will be received at the plant in self unloading trailers. It will be dumped on the ground and handled using a loader. The loader can manage a storage pile for the fuel and load it onto a reclaimer or into a metering bin.

Fuel processing from the reclaimer/bin will be continuous until the fuel reaches the dry fuel meter bin for the gasifier. Fuel will be metered to a screen where oversized fuel will be removed and rejected. An onsite chipper is not planned for further size reduction. Sized fuel will be dried in a continuous belt dryer using waste heat from the gas cleaning and engine-generator. About 15% of the heating value in the dry fuel is required to dry the fuel from 50% MC to 15% MC (at 1500 btu/lb). Dry chips will be stored in a metering bin prior to the gasifier.

Fuel will be processed at a rate of 600 ft^3 per hour (3 odt/h) to match the waste heat available from the engine generator and the demand rate. Dry chip storage will be 450 ft^3 or about two hours. This size bin is easily installed and affordable. If the fuel system is not operating longer than 2 hours the gasifier will shut down and operators will be notified.

c. Gasification System

Fuel will be metered from the dry chip storage to the gasifier at a rate of 250 ft3/h for 1000 kWe generation.

An open core pressurized down draft gasifier has been selected for this system. This type of gasifier has been built up to 300 kWe by three commercial suppliers.[79] It has been demonstrated at 1 MWe by a former supplier.[80] The pressurized open core gasifier had shown its adaptability to a variety of fuels including chips or chunks. The design of the reduction zone and grate are of particular importance since this is where the tars are cracked at temperatures of 1800-2000°F. The grate must be designed so that the char reduction zone is porous and can maintain good gas flow at high enough temperatures to reduce the tar. Char is intermittently removed from the grate with an auger.

The gasifier is started using an electric device. This permits the gasifier to be easily started or restarted after shutdown. Starting the gasifier takes about one half hour. Stable operation is achieved with an hour.

Auxiliary equipment for the gasifier includes a blower for gasification air, controls for startup/shutdown, valves and sensors for safety and for operation and control of the gas. Producer gas is toxic and flammable. Precautions must be taken in system design to prevent hazards of explosion.

The gasification system can be protected from rain in a building with sidewalls for protection against the weather. If the building is completely enclosed fire protection and gas monitoring may be required including a dry chemical or sprinkler system.

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[79] Xylowatt, Belgium www.xylowatt.be has two 600 MWe systems installed at Electrobel in Belgium. Each system has two 300 kWe Mercedes engines with generators. Pudas Energy, Another system has a 150 kWe engine-generator. Finland has two 1 MWthermal systems. One in operation in a thermal application. The second, in Connecticut is in commissioning with a 300 kWe Mercedes engine generator supplied by Schmitt-Enertec of Germany. A separate company Xylowatt, Switzerland has a 150 kWe system operating at a commercial application.

[80] In 1985 Syngas Systems Inc., Golden Colorado, demonstrated a 1 MWe system based on the pressurized downdraft developed at the Solar Energy Research Institute (now the National Renewable Energy Research Laboratory).

d. Gas Cleaning System including Flare

Dry gas cleaning has been selected for this application since water treatment may not be available at the operating sites. Gas exiting the gasifier will enter a primary cyclone to remove large char particles. It will then be cooled with a heat exchanger. The heat will be used to preheat gasification air and to dry incoming fuel. Raw gas will be further cooled and passed through a dry filter. Gas will be cooled to ambient temperature. Water condensed from the gas will be used for quenching the char. Filtered gas will be sent to the engine generator or flare.

e. Engine Generator

The engine generator(s) can be delivered to the site in self contained enclosure(s). They do not have to be located in a building.

Gas can be piped from the gas cleaning island and with a positive pressure to the inlet gas train of the engine. The gas train will have a proportioning valve, and a gas-air mixing device or carburetor for providing a gas-air mixture to the engine.

The engine can be a dual-felled diesel or a spark ignition engine. Dual fuelled diesels have been operated for several years. Typical diesel substitution is 70%. High quality gas can increase diesel substitution to 80%. If diesel is used then an auxiliary diesel tank with appropriate safety devices and containment is required.

A heat recovery system will be included in the engine enclosure. This will include recovery of heat from the engine jacket and from a catalytic afterburner for the engine exhaust. Heat in circulation water from the jacket and after burner will be transferred to the chip dryer via coils. The cooling system will include a radiator with cooling fans for times when the waste heat is not needed.

Power requirements:

The gasifier will have a parasitic load of approximately 50 kWe while running including all motors. It will have a connected load of 150 kWe. A 75 kWe auxiliary diesel generator can be used to supply this load when the engine generator is not operating. This should be a self-contained unit with electrical connection to the system.

The generator will be supplied complete with switchgear suitable for export to a parallel load or grid. Generator controls will be either combined or independent of the gasifier.

f. Utilities

The gasifier will require water for the engine cooling system and makeup water when necessary. Water is also required for fire protection.

g. Controls

Gasifier and generator controls will be low voltage and fully integrated. The fuel handling, transfers, dryer, gasifier, and engine generator will be integrated. Controls for the engine generator will be fully automated and capable of remote operation.

h. Environmental Impacts

Water Quality:

The process does not require any water input and there will be limited wastewater effluent. Possible liquid effluents could be cooling water from the engine and heat exchange systems, tars and pyrolysis liquids from gas cooling. Engine cooling water and heating would operate in a closed loop. Drain for the system would have to go to a tank if glycol is used. Storm water precautions would be taken. Water is typically used to cool and quench the char. Provision would be made cleanup and disposal of unexpected discharges of pyrolysis liquids and tars from gas cleaning equipment.

Air Emissions:

A small scale biomass conversion system produces emissions from the fuel dryer, flare, and engine exhaust stack. The dryer uses a heat input of approximately 1.5 million Btuh to evaporate 1000 pph of water vapor. A multiple cyclone on the dryer is typically sufficient to comply with air quality requirements.

A flare is used for startup and shutdown and for intermittent use for upsets in the gasification process. An electric igniter has normally been sufficient for producer gas flares. Diesel or fuel oil has also been used.

Engine exhaust is the primary product of gasifier. The gasifier will use an exhaust catalyst for NOx control. Actual emissions must be verified by testing and standards established by discussion with the DEQ. There are no EPA standards for emissions from wood gas fueled engines.

Solid Waste:

In char production water is typically used to cool and quench the char. Char will be disposed of by sale.

Noise Emissions:

An open building will house the gasification. Incremental noise emissions at the site boundary limits are expected to be negligible.

Economic Analysis

Capital and Fuel Costs

Gasification system costs are high compared with the amount of electricity produced. So the capital costs have a strong impact on electricity costs. The effect of capital and fuel costs on electricity costs was estimated by combining the cost of electricity due to capital with the cost of electricity due to the cost of fuel. Table 36 lists the assumptions used in this report. The cost of electricity derives from the capital cost as:

$$C_{e,c} = \frac{(K)(1+OM/100)(CRF)}{(h)} \qquad [1]$$

where $C_{e,c}$ = cost of electricity due to capital (\$/kWh),
K = capital cost (\$ kWe^{-1})
OM = non-fuel O&M cost (% of capital cost)

CRF = capital recovery factor (y^{-1}) =

h = hours per year of operation (h y^{-1})
i = interest rate (y^{-1})
n = term (y)

Table 36: Assumptions for Economic Analysis

Interest rate (%/y)	6.5	6.5	6.5
Term (y)	20	10	5
Capital Recovery Factor, CRF (1/y)	0.0908	0.1391	0.2406
Non-fuel O&M (% of Capital Cost)	3	3	3
Heat rate (Btu/kWh)	20000	20000	20000
Heat rate (MMBtu/kWh)	0.02	0.02	0.02
Capacity factor (%)	80	80	80
Hours per year (h/y)	7008	7008	7008
Heating value of fuel (Btu/lb) od	8000	8000	8000
Heating value of fuel (MMBtu/ton)	16	16	16
Gasifier efficiency (--)	0.92	0.92	0.92

Figure 11 shows the influence of capital cost and non-fuel O&M on the cost of electricity. The capacity factor of 80% or 7008 hours per year is typical of biomass facilities. The cost of electricity due to capital increases as the hours of operation decrease. Even at a 20-year payback the capital and O&M costs for a system costing \$5,000/kWe exceed the current price for electricity of about \$0.05/kWh. Capital costs would have to be reduced to the equivalent of \$1500-\$2000/kWe to reach these levels.

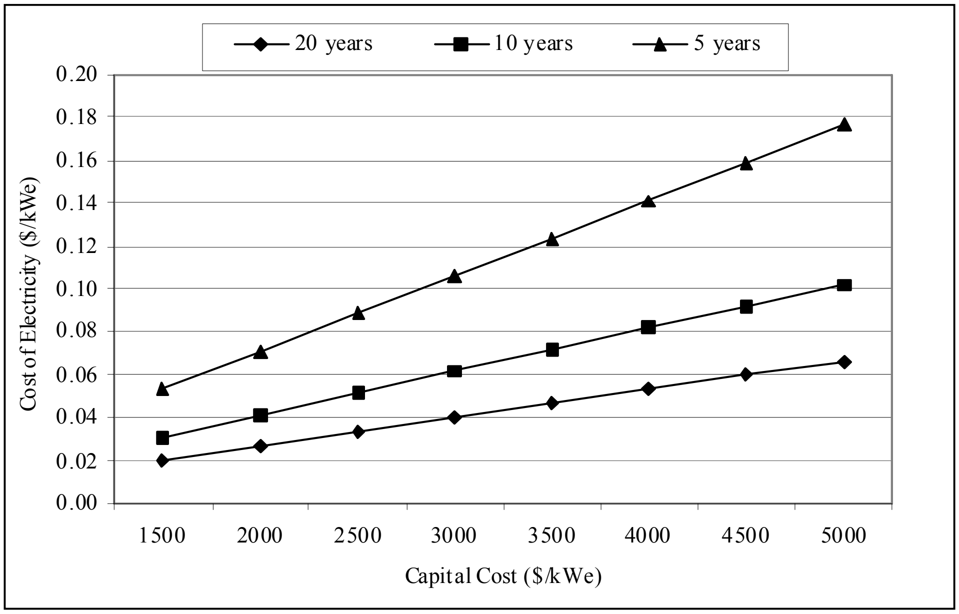

Figure 11: Effect of repayment term (y) and cost of capital and non-fuel O&M ($/kWe) on cost of electricity from gasifier during term of capital repayment. Does not include biomass fuel cost.

The cost of electricity due to fuel cost, $C_{e,f}$, is given by:

[2]

where $C_{e,f}$ = cost of electricity due to fuel ($/kWh),
C_f = biomass fuel cost ($/ton)
HR = heat rate, fuel to electricity, (MMBtu kWh^{-1})
Q = fuel heating value (MMBtu/ton)
η_g = gasifier efficiency (--)

and the other terms are as defined for equation [1].

Figure 12 shows the cost of electricity due to the cost of fuel ($/odt). At the low conversion efficiency of the gasifier system it takes about 2.5 od lb of fuel (20,000 Btu) to generate a kilowatt hour or 1.25 od ton/MWh. At $50/odt the cost of electricity due to fuel is approximately $0.06/kWh. A target price of $15/odton would result in an electricity cost due to fuel of $0.02/kWh.

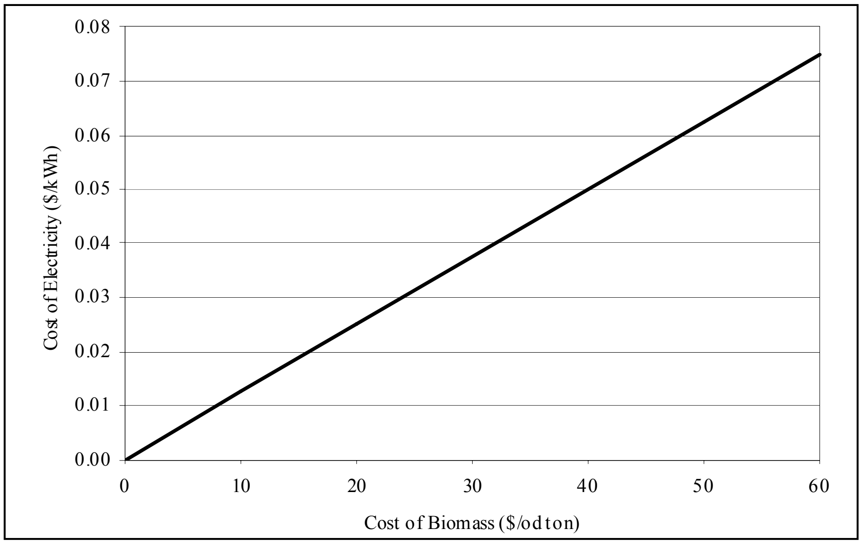

Figure 12: Effect of biomass fuel cost ($/ton) on cost of fuel gas from gasifier. Does not include capital or non-fuel O & M costs.

The cost of electricity due to capital repayment in equation [1] and the cost of electricity due to fuel in equation [2] are combined for a total cost of electricity in Figure 13. It requires a system costing less than $2,500/kWe with fuel cost of $20/od ton fuel to obtain electricity at current costs of less than $0.06/kWh.

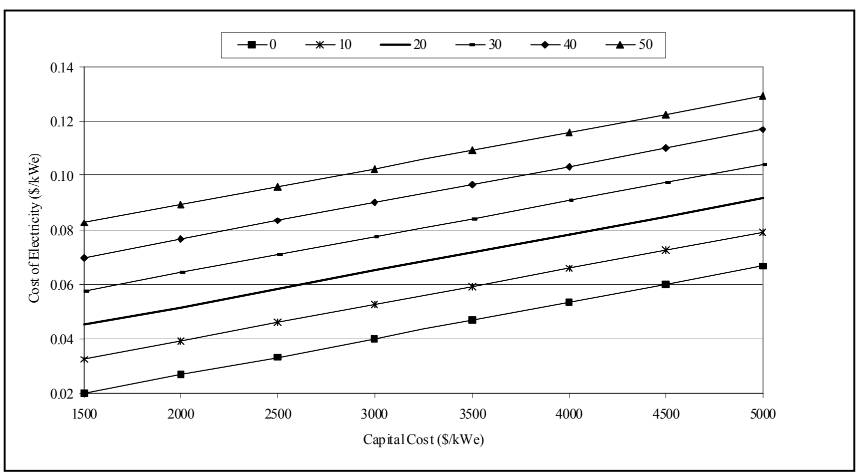

Figure 13: Effect of capital cost, non-fuel O&M ($/kWe) and fuel cost ($/odt) on cost of electricity from a gasifier for a 20-year term of repayment at 6.5% interest.

Analysis of Cases

Analysis of only capital and fuel costs does not include carbon offsets, federal or state subsidies, sale of charcoal or co products, heat recovery for combined heat and power (CHP) or other benefits. A model for gasification and combined heat and power generation was used to include these alternatives.[81] Table 37 lists the basic assumptions for the analysis. A capital cost of $5,000/kW and delivered fuel cost of $50/od ton is used for the base case.

Table 37: Assumptions for Analysis of Cases

Description		
Location		***La Pine***
Capacity	kWe	1000
Capital cost	$/kWe	$5,000
Delivered fuel cost	$/odt	$50
Capacity factor	% (hrs)	80 (7008)
O&M	% cap	On-site 3%
	% cap	Contracted 2%
Debt Financing		6.5%
Taxes		Exempt
Prices		
Electricity	$/kWe	$50
Charcoal	$/ton	$60
Carbon Offsets	$/kWe	$2.50

Sensitivity analyses were conducted on the base case with the following variables:

- Capital cost $3,000/kW
- Fuel cost zero (fuel collected/delivered by USFS or BLM at their cost)
- One stationary unit at La Pine and two additional units located at different sites within the Mid-State Electric Cooperative territory.
- O&M services contracted out and projects instrumented and telemetered for remote, non-attended operation
- Federal financial support equal to $0.01/kWh ($10/MWh) from production tax credits or Renewable Energy Production Incentive (REPI)
- State Renewable Energy Credit of 28% of capital costs (or, 35% spread over five years.)
- Electricity price at $0.06/kWh
- Added revenue from sales of small diameter logs
- Added revenue from sale of pine shavings
- Added revenue from sale of process heat

[81] Biomass Cost of Energy Calculator, 2004. Prepared by the University of California at Davis for the California Biomass Energy Collaborative http://faculty.engineering.ucdavis.edu/jenkins/CBC/Calculator/index.html

Cases were compared showing non-fuel expenses, total expenses including fuel and levelized cost of electricity using actual (non constant) dollars. Table 38 shows the LCOE for capital costs of $5,000/kWe, or $5 million for a 1 MWe plant. Costs for the base case are somewhat higher than estimated in Figure 13. Reduced O&M and credits have a small impact on LCOE. Significant reductions in LCOE are achieved by reducing the cost of fuel by processing higher value co-products such as shavings or small logs, heat recovery for dry kilns or space heating. The lowest cost is obtained by supplying fuel to the plant at no cost. In all cases the cost of electricity is higher than the utility is likely to pay.

Table 38: Levelized Cost of Electricity 1 MWe Gasifier at $5,000/kWe

	Fuel	*O&M*	*Federal Support/Credit*	*Non Fuel Expenses*	*Total Expenses (incl. fuel)*	*LCOE (actual)*
Case	***$/odt***	***% cap***	***$/MWh***	***$/kWh***	***$/kWh***	***$/kWh***
1 Base	$50	3		.027	.090	0.166
2 Reduced O&M	$50	2		.016	.079	0.153
3 Contract O&M	$50	3		.016	.079	0.153
4 Fed	$50	3	$10	.027	.090	0.156
5 Credit	$50	3	28%	.027	.090	0.146
6 Shavings	$25	3		.027	0.058	0.129
7 Small log	$15	3		.027	0.046	0.100
8 Heat recovery	$50	3		.027	0.090	0.100
9 "0" Fuel	$0	3		.027	.027	0.092

Table 39 shows the LCOE results for capital costs of $3,000/kWe or $3 million for a 1 MWe plant. Costs for this case are also somewhat higher than estimated in Figure 13. Reduced O&M and credits have a small impact on LCOE. Significant reductions in LCOE are achieved by reducing the cost of fuel by processing higher value co-products such as shavings or small logs, heat recovery for dry kilns or space heating. Costs approach current rates when heat is recovered or the fuel price is reduced.

Table 39: Levelized Cost of Electricity 1 MWe Gasifier at $3,000/kWe

	Fuel	*O&M*	*Fed Support/Credit*	*Non Fuel Expenses*	*Total Expenses (incl. fuel)*	*LCOE (actual)*
Case	***$/odt***	***% cap***	***$/MWh***	***$/kWh***	***$/kWh***	***$/kWh***
1 Base	$50	3		.018	.081	0.128
2 Fed Support	$50	3	$10	.011	.081	0.128
3 Reduced O&M	$50	2		.011	.073	0.119
4 Contract O&M	$50	3		.011	.073	0.119
5 Credit	$50	3	28%	.018	.081	0.116
6 Shavings	$25	3		.018	0.050	0.091
7 Small Log	$15	3		.018	0.037	0.077
8 Heat recovery	$50	3		.018	0.081	0.062
9 "0" Fuel	$0	3		.018	.018	0.055

This analysis shows that it is not feasible to generate electricity alone at the small scale without shared labor, heat recovery or a co-product. The analysis shows that at capital costs of $5,000/kW gasifiers could generate power for $0.17/kWh. Costs reduce to $0.15-0.16/kWh with federal and state incentives. Costs reduce further to $0.12/Wh by reducing labor costs and by offsetting fuel costs by producing co-products such as wood products or shavings. The lowest costs of $0.09/kWh are obtained when heat is recovered from the engine jacket for space heating or kiln drying, or when the delivered fuel cost is zero. At capital costs of $3,000/ton the power costs are $0.13/kWh. They reduce to $0.12/kWh with federal and state incentives; to $0.09 to $0.12/kWh by reducing labor and producing co-products. The lowest costs are $0.06/kWh when heat is recovered or fuel costs are zero.

This analysis suggests the following economic conditions are necessary for successful gasification:

- Capital cost $2,500/kWe or less
- Reduce fuel cost to $20/odton or less
- Recover engine heat

Conclusions

Central Oregon has the potential to generate 125,000 bdt/year from forest treatments and residues from harvesting 50 mmbf of timber within an 80-mile radius. There is sufficient fuel in the Southwest and Northwest quadrants to support small scale power generation.

At estimated costs of forest fuels there are no clear options for small scale power production. In all cases the delivered cost of wood fuel is difficult to recover in energy products. Mobile systems are not feasible. Preferred locations are former or existing wood processing facilities located near power lines. Commercially demonstrated options include: power generation with recovery of solid wood products from larger diameters and power generation with wood pellets. More detailed technical and economic analysis is required to assess the potential of activated carbon with power generation. Pyrolysis to oil has not been demonstrated commercially. A plant should be designed with a capital cost of $2,500/kWe and with fuel and transportation costs offset by co-products or heat recovery.