Feasibility Study of Biomass Fired District Energy System in Brattleboro, VT

Waldron Engineering & Construction, Inc.

for

Brattleboro Thermal Utility

Waldron Project Number 235.01

On behalf of Brattleboro Thermal Utility (BTU), Waldron Engineering & Construction, Inc. (Waldron) has conducted a feasibility study for the installation of a biomass-fired thermal energy plant with a district heating system to be located in Brattleboro, VT.

The main objective of this study was to make a macro-level evaluation of the viability of such a system in this community, and towards that end a parametric spreadsheet model was built. The spreadsheet model is intended to be a tool that BTU may use to study various thermal plant configurations as well as the impact of various operating parameters such as wood fuel costs, capital costs, and a number of district heating system factors. The model contains three basic plant configurations: an electric lead configuration, a thermal lead configuration, and a ”hybrid” configuration in which approximately 90% of the thermal energy supplied to the district heating loop is supplied from biomass, and the remainder from oil-fired boilers.

Of the three options studied, the general conclusion is that the hybrid configuration represents the most economical alternative. The reason is that one of the most significant economic drivers of the project is the capital cost to construct the facility, and wood-fired boilers and associated auxiliary systems are very capital intensive to install compared to other technologies. In the hybrid configuration, the wood-fired boiler system(s) are sized not for 100% of the district heating system demand, but only for about 60% of the maximum demand. The remaining installed thermal generating capacity is supplied by oil-fired boilers, for a much lower first cost, and this enables the scale of district energy system reviewed in this study to become viable.

The electric lead and thermal lead plants utilizing biomass exclusively have a higher first cost, and are not seen as economically viable based on the factors considered in this study.

Key factors that make the hybrid model viable are: a willingness of project investors to accept a modest return on investment (e.g. 5% - 6% ROI), a district energy installed customer base equivalent to approximately 1,500,000 square feet or more, and electric revenues comparable to the Standard Offer recently mandated in Vermont for plants of this type. The model is also very sensitive to the costs of district energy infrastructure and customer connections.

Plant Configurations

Electric Lead Plant

In the model, an electric lead plant is defined as a facility whose primary function is the generation of electricity, with thermal export to the district heating loop as a byproduct. The main implications of this are that the biomass boiler would be sized on the basis of a desired electrical generation capacity, and that it would be operated at full capacity throughout all seasons of the year in order to produce electricity in a condensing steam turbine.

In the summer, when the demands of the district heating loop are very low, nearly all of the steam would be sent through the steam turbine and condensed to produce maximum electrical generation.

Thermal Lead Plant

In contrast to the electric lead plant, the thermal lead plant configuration is one in which the biomass boiler is sized to match the peak thermal energy demand of the district heating system, and is operated only to supply the demands of the system. Thus, the boiler is operated little, if at all, during summer months.

Electricity is generated by a backpressure steam turbine, which reduces the steam pressure from the outlet pressure of the boiler (650 psig, 750°F) to a more reasonable level for distribution to the district energy system. Electricity is only generated as a byproduct.

Hybrid Plant

For the purposes of the model provided with this report, a hybrid plant is essentially a special case of the Thermal Lead plant. The model operates in the thermal lead configuration, but the biomass boiler is only sized for approximately 65% of the peak instantaneous thermal demand of the district energy system. Supplementary thermal energy production is provided by oil-fired boilers. Note that this results in an estimated annual thermal energy contribution from oil of just 10%. The reason is that the peak instantaneous thermal demand of the system may only happen for a few days of the year, and on the average the thermal demand is much lower.

The improved economics of the hybrid plant reflect the fact that capital invested into wood-handling and wood-firing systems is reduced significantly, with disproportionately less impact on the actual contribution of wood to the energy profile of the facility.

Thermal Demand Profile

The thermal demand profile has been determined by use of past heat demand studies for the area. This study is based upon monthly average demand factors as noted below. The value noted for each month represents the fraction of a theoretical maximum value for the month, with the theoretical maximum being the peak instantaneous demand of the district energy system applied continuously for the entire month.

Table 1. Average Monthly Heat Demand as a Fraction of Theoretical Maximum Demand

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0.53	0.57	0.49	0.37	0.14	0.14	0.12	0.12	0.14	0.30	0.41	0.49

In the model, the heating equipment is designed for the Theoretical Maximum Demand, however, the thermal sales are based upon the actual usage, which is given by the factors noted above.

The maximum heat demand for the district energy system was assumed to be the product of square footage and an instantaneous heat input of 35 Btu/(hr-ft^2). For an area of 2,000,000 sq. ft., the Theoretical Maximum Demand is thus 70 MMBtu/hr.

Plant Model

A model has been developed in an Excel Spreadsheet, and has been presented to BTU in detail during a previous meeting. Snapshots of the three models are contained in Appendix A.

User inputs are highlighted, and are logically linked throughout the model so that the user of the model may change these key factors and see the results on the overall project. The primary user inputs are the following:

- Cost of Wood Fuel
- Price of Electricity Sales
- Price of Thermal Energy Sales
- Square Footage Heated in District Energy System
- Peak Heat Input (Btu per Square Foot)
- Wood Fuel Heating Value
- Desired Electrical Production (Electric Lead Model)
- Oil Fuel Cost
- District Energy System Infrastructure Parameters

The model utilizes these inputs to calculate outputs such as monthly thermal energy production, quantity and cost of fuel burned, quantity of electricity generated, and various revenue streams.

Please refer to Appendix A for the results of the modeling. Note that the models are parametric in nature, and these outputs represent the results for just one configuration. The model has been developed to allow the user to study a broad range of configurations by changing the input parameters.

The capital cost estimates for each configuration included in the model are simple factors based upon the overall thermal size of the plant. These are noted below:

Electric Lead Cost Factor:	$4,000 per kW
Thermal Lead Cost Factor:	$2,700 per 9 lbs/hr of steam
Hybrid Plant Cost Factor:	$2,700 per 9 lbs/hr of steam

The basis of these factors is provided in the following descriptions.

Electric Lead Configuration

The cost estimate of $4,000 per kW of installed electrical generation capacity is a factor selected based upon recent experience in biomass projects in this area. Waldron has participated in detailed, built-up cost estimates and/or firm price general contractor bids for biomass fuel power generation facilities in the 15 MW – 50 MW range, and the market value costs to design, construct, and commission such facilities has consistently come in around this value.

Thermal Lead Configuration

The same methodology utilized in developing the factor for the Electric Lead Configuration has been applied to the Thermal Lead Configuration. In the Electric Lead case, the capital cost factor of $4,000/kW is multiplied by the electrical generation capacity of the plant, expressed in kW, to determine the approximate project cost.

In the Thermal Lead case, the same approach is taken, however two additional steps are taken so that the methodology applies correctly. First, it is not appropriate to consider electrical generation capacity as the primary multiplier for a thermal lead plant, so the thermal output of the plant is “converted” to an equivalent electrical generation potential. This is accomplished by dividing the boiler steam generation capacity by a factor of 9 lbs steam per kWh, the steam rate of a plant in the Electric Lead Configuration.

The result of this conversion is that the thermal output of the plant is considered in an electrical generation potential equivalent. The second step in applying the methodology was to reduce the $4,000 per kW to a value that is reasonable for this size and type of facility. Waldron recently supplied a detailed, built-up cost estimate on a wood-fired boiler facility producing 50,000 lbs/hr of steam, and used this estimate to scale the $4,000 per kW to $2,700 per thermal equivalent kW.

So, the capital cost of a biomass-fired plant in the Thermal Lead Configuration is $2,700 per thermal equivalent kW.

Hybrid Configuration

The capital cost of the hybrid configuration is determined in a manner identical to the above methodology for the Thermal Lead Configuration. The reason a lower cost is predicted is that the $2,700 per thermal equivalent kW is multiplied by the biomass boiler capacity, and this is reduced for the hybrid configuration as described previously.

Appendix A.

Brattleboro Thermal Utility
Model for Evaluating Various Scenarios
for Combined Heat and Power Plant
with District Heating

Thermal Lead Case

District Heating Parameters		
Square Footage Included	1,600,000	sq ft
Peak Heat Input	35	Btu/hr-sq ft
Wood Fuel Heating Value	4,700	Btu/lb, HHV

Economic Inputs		
Fuel Cost	$35	$/ton
Elec. Sale	$0.09	$/kWh
Elec. Purchases	$0.13	$/kWh
Thermal Sale	$16	$/MMBtu
Renewable Energy Credit	$0.04	$/kWh

Boiler Plant Metrics		
Peak Heating Requirement	56	MMBtu/hr
Design Boiler Capacity	56,000	lb/hr
Turbine Throttle	33,600	lb/hr

Infrastructure Metrics		
Piping In Trench	$675	$/ft
Linear Feet (plant to load pocket)	2,000	ft
Load Pocket Network Piping	3,000	ft
Piping Distribution Cost	$3,375,000	$
Manhole Unit Cost	$15,000	$/mh
Number of Manholes	10	
Manhole Total Cost	$150,000	
Customer Connection Unit Cost	$35,000	$/cust
Number of Connections	50	
Interconnection Costs	$1,750,000	
Total Infrastructure Cost	$5,275,000	

Electric Lead Case

District Heating Parameters		
Square Footage Included	2,000,000	sq ft
Peak Heat Input	35	Btu/hr-sq ft
Wood Fuel Heating Value	4,700	Btu/lb, HHV

Economic Inputs		
Fuel Cost	$35	$/ton
Elec. Sale	$0.09	$/kWh
Elec. Purchases	$0.13	$/kWh
Thermal Sale	$16	$/MMBtu
Renewable Energy Credit	$0.04	$/kWh

Boiler Plant Metrics		
Desired Electrical Output	15	MW
Design Boiler Capacity	145,800	lb/hr
Turbine Throttle	145,800	lb/hr
Minimum Electrical Output	15	
Condensing Section Design Flow	131,220	lb/hr

Infrastructure Metrics		
Piping In Trench	$675	$/ft
Linear Feet (plant to load pocket)	10,000	ft
Load Pocket Network Piping	3,000	ft
Piping Distribution Cost	$8,775,000	$
Manhole Unit Cost	$15,000	$/mh
Number of Manholes	10	
Manhole Total Cost	$150,000	
Customer Connection Unit Cost	$35,000	$/cust
Number of Connections	50	
Interconnection Costs	$1,750,000	
Total Infrastructure Cost	$10,675,000	

Hybrid Thermal Lead Case

District Heating Parameters		
Square Footage Included	2,000,000	sq ft
Peak Heat Input	35	Btu/hr-sq ft
Wood Fuel Heating Value	4,700	Btu/lb, HHV

Economic Inputs		
Wood Fuel Cost	$35	$/ton
Oil Fuel Cost	$2.00	$/gal
Elec. Sale	$0.09	$/kWh
Elec. Purchases	$0.13	$/kWh
Thermal Sale	$19	$/MMBtu
Renewable Energy Credit	$0.04	$/kWh

Boiler Plant Metrics		
Peak Heating Requirement	70	MMBtu/hr
Wood-Fired Boiler Sizing Basis	75%	% of Peak
Wood-Fired Boiler Capacity (Output)	52.5	MMBtu/hr
Design Boiler Capacity	52,500	lb/hr
Turbine Throttle	39,375	lb/hr
Oil-Fired Boiler Sizing Basis	50%	% of Peak
Oil-Fired Boiler Capacity (Output)	35	MMBtu/hr
Oil-Fired Boiler Capacity	35,000	lb/hr

Infrastructure Metrics		
Piping In Trench	$675	$/ft
Linear Feet (plant to load pocket)	2,000	ft
Load Pocket Network Piping	3,000	ft
Piping Distribution Cost	$3,375,000	$
Manhole Unit Cost	$15,000	$/mh
Number of Manholes	10	
Manhole Total Cost	$150,000	
Customer Connection Unit Cost	$35,000	$/cust
Number of Connections	50	
Interconnection Costs	$1,750,000	
Total Infrastructure Cost	$5,275,000	

Option Description (e.g. Wood-Fired Boiler, Backpressure Steam Turbine, Thermal Lead, Boiler Sized for Heating Peak, Turbine Sized for 60% of Boiler Output)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	**Totals**
Hours in Month	744	672	744	720	744	720	744	744	720	744	720	744	8760
Steam Production (Mlb)	21,750	21,138	20,093	14,517	5,588	5,590	4,717	4,721	5,522	12,153	16,056	19,975	151,819
District Heating Load Factor	0.53	0.57	0.49	0.37	0.14	0.14	0.12	0.12	0.14	0.30	0.41	0.49	
Steam to District (Mlb)	20,139	19,572	18,605	13,441	5,174	5,176	4,367	4,371	5,113	11,253	14,867	18,495	140,573
Parasitic Steam (Mlb)	1,611	1,566	1,488	1,075	414	414	349	350	409	900	1,189	1,480	11,246
Turbine Throttle Flow, %	87%	87%	74%	56%	21%	21%	17%	17%	21%	45%	61%	74%	
Steam Rate, (lb/kWh)	20.2	20.1	20.4	25.6	50.4	49.7	53.7	53.7	50.0	31.0	23.4	20.5	
Electric Generation, Front End (MWh)	1,079	1,050	984	567	0	0	0	0	0	391	687	975	5,732
Gross Electric Generation (MWh)	1,079	1,050	984	567	0	0	0	0	0	391	687	975	5,732
Parasitic Power (MWh)	177	172	164	118	46	46	38	38	45	99	131	163	1,237
Net Generation - Sales (MWh)	901	877	820	448	0	0	0	0	0	292	556	813	4,708
Purchased Electricity - (MWh)	0	0	0	0	-46	-46	-38	-38	-45	0	0	0	-213
Fuel Input, tons/mo	4,108	3,992	3,795	2,742	1,055	1,056	891	892	1,043	2,295	3,033	3,773	28,674
Revenues													
Electrical Sales	$81,119	$78,956	$73,818	$40,350	$0	$0	$0	$0	$0	$26,322	$50,047	$73,145	$423,757
Thermal Generation Revenue	$354,444	$344,468	$327,446	$236,566	$91,061	$91,091	$76,862	$76,928	$89,994	$198,054	$261,661	$325,512	$2,474,087
Renewable Energy Credits	$31,546	$30,705	$28,707	$15,692	$0	$0	$0	$0	$0	$10,236	$19,463	$28,445	$164,794
Total	$467,109	$454,129	$429,971	$292,607	$91,061	$91,091	$76,862	$76,928	$89,994	$234,613	$331,171	$427,102	$3,062,638
Fuel Costs													
Fuel Costs	-$143,778	-$139,731	-$132,826	-$95,961	-$36,938	-$36,950	-$31,178	-$31,205	-$36,506	-$80,339	-$106,141	-$132,042	-$1,003,595

Option Description (e.g. Wood-Fired Boiler, Condensing-Extracting Steam Turbine, Electric Lead, Extraction Based Upon District Heating Needs)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	**Totals**
Hours in Month	744	672	744	720	744	720	744	744	720	744	720	744	8,760
Boiler Steam Generation (lb/hr)	145,800	145,800	145,800	145,800	145,800	145,800	145,800	145,800	145,800	145,800	145,800	145,800	1,749,600
Steam Production (Mlb)	108,475	97,978	108,475	104,976	108,475	104,976	108,475	108,475	104,976	108,475	104,976	108,475	1,277,208
District Heating Load Factor	0.53	0.57	0.49	0.37	0.14	0.14	0.12	0.12	0.14	0.30	0.41	0.49	
Steam to District (Mlb)	25,174	24,465	23,256	16,802	6,467	6,470	5,459	5,464	6,392	14,066	18,584	23,119	175,716
Parasitic Steam (Mlb)	8,678	7,838	8,678	8,398	8,678	8,398	8,678	8,678	8,398	8,678	8,398	8,678	102,177
Steam to Condenser (Mlb)	74,624	65,674	76,541	79,776	93,330	90,108	94,338	94,334	90,186	85,731	77,994	76,678	999,315
Steam Rate, Front End (lb/kWh)	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	20.5	
Electric Generation, Front End (MWh)	5,291	4,779	5,291	5,121	5,291	5,121	5,291	5,291	5,121	5,291	5,121	5,291	62,303
Back-End Flow, %	76%	74%	78%	84%	96%	95%	97%	97%	95%	88%	83%	79%	
Steam Rate, Condensing Section (lb/kWh)	14.6	14.7	14.5	14.4	15.5	15.5	15.7	15.7	15.5	14.6	14.4	14.5	
Electric Generation, Condensing End (MWh)	5,115	4,456	5,284	5,522	6,022	5,827	6,020	6,020	5,827	5,868	5,412	5,296	66,669
Gross Electric Generation (MWh)	10,406	9,235	10,576	10,643	11,313	10,948	11,312	11,312	10,948	11,159	10,532	10,587	128,972
Parasitic Power (MWh)	1,145	1,016	1,163	1,171	1,244	1,204	1,244	1,244	1,204	1,228	1,159	1,165	14,187
Net Generation - Sales (MWh)	9,262	8,219	9,412	9,472	10,069	9,744	10,067	10,067	9,744	9,932	9,374	9,423	114,785
Fuel Input, tons/mo	20,488	18,505	20,488	19,827	20,488	19,827	20,488	20,488	19,827	20,488	19,827	20,488	241,227
Revenues													
Electrical Sales	$833,559	$739,750	$847,123	$852,520	$906,174	$876,918	$906,055	$906,057	$876,929	$893,852	$843,653	$848,051	$10,330,642
Thermal Generation Revenue	$443,055	$430,585	$409,307	$295,707	$113,826	$113,864	$96,077	$96,161	$112,493	$247,567	$327,076	$406,891	$3,092,609
Renewable Energy Credits	$324,162	$287,681	$329,437	$331,536	$352,401	$341,024	$352,355	$352,355	$341,028	$347,609	$328,087	$329,798	$4,017,472
Total	$1,600,776	$1,458,016	$1,585,867	$1,479,763	$1,372,400	$1,331,805	$1,354,487	$1,354,573	$1,330,449	$1,489,029	$1,498,816	$1,584,740	$17,440,722
Fuel Costs													
Fuel Costs	$717,073	$647,678	$717,073	$693,941	$717,073	$693,941	$717,073	$717,073	$693,941	$717,073	$693,941	$717,073	$8,442,951

Option Description (e.g. Wood-Fired Boiler, Backpressure Steam Turbine, Thermal Lead, Boiler Sized for Heating Peak, Turbine Sized for 60% of Boiler Output)													
Month	January	February	March	April	May	June	July	August	September	October	November	December	**Totals**
Hours in Month	744	672	744	720	744	720	744	744	720	744	720	744	8760
District Heating Load Factor	0.53	0.57	0.49	0.37	0.14	0.14	0.12	0.12	0.14	0.30	0.41	0.49	3.80
Steam to District (Mlb)	25,174	24,465	23,256	16,802	6,467	6,470	5,459	5,464	6,392	14,066	18,584	23,119	175,716
Parasitic Steam (Mlb)	2,014	1,957	1,860	1,344	517	518	437	437	511	1,125	1,487	1,850	14,057
Steam Production (Mlb)	27,187	26,422	25,117	18,146	6,985	6,987	5,896	5,901	6,903	15,192	20,071	24,968	189,774
Wood-Fired Load Factor	80%	75%	85%	100%	100%	100%	100%	100%	100%	100%	100%	85%	
Wood-Fired Annual Duty Contribution	0.43	0.43	0.42	0.37	0.14	0.14	0.12	0.12	0.14	0.30	0.41	0.42	3.40
Wood-Fired Steam Production (Mlb)	21,750	19,817	21,349	18,146	6,985	6,987	5,896	5,901	6,903	15,192	20,071	21,223	
Turbine Throttle Flow, %	74%	75%	73%	64%	24%	25%	20%	20%	24%	52%	71%	72%	
Steam Rate, (lb/kWh)	20.4	20.4	20.6	22.6	47.4	46.6	51.0	51.0	46.9	27.3	21.0	20.7	
Electric Generation, Front End (MWh)	1,330	1,297	1,217	804	0	0	0	0	0	556	957	1,206	7,368
Gross Electric Generation (MWh)	1,330	1,297	1,217	804	0	0	0	0	0	556	957	1,206	7,368
Parasitic Power (MWh)	177	172	164	118	46	46	38	38	45	99	131	163	1,237
Net Generation - Sales (MWh)	1,153	1,125	1,054	685	0	0	0	0	0	457	826	1,044	6,344
Purchased Electricity - (MWh)	0	0	0	0	-46	-46	-38	-38	-45	0	0	0	-213
Wood Fuel Input, tons/mo	4,108	3,743	4,032	3,427	1,319	1,320	1,114	1,114	1,304	2,869	3,791	4,008	32,149
Oil Fuel Input, gal/mo	45,697	55,513	31,662	0	0	0	0	0	0	0	0	31,475	164,347
Revenues													
Electrical Sales	$103,738	$101,263	$94,836	$61,686	$0	$0	$0	$0	$0	$41,136	$74,354	$93,934	$570,947
Thermal Generation Revenue	$443,055	$430,585	$409,307	$295,707	$113,826	$113,864	$96,077	$96,161	$112,493	$247,567	$327,076	$406,891	$3,092,609
Renewable Energy Credits	$40,343	$39,380	$36,881	$23,989	$0	$0	$0	$0	$0	$15,997	$28,916	$36,530	$222,035
Total	$587,136	$571,229	$541,023	$381,382	$113,826	$113,864	$96,077	$96,161	$112,493	$304,701	$430,346	$537,354	$3,885,590
Fuel Costs													
Fuel Costs	-$235,171	-$242,025	-$204,452	-$119,951	-$46,173	-$46,188	-$38,973	-$39,007	-$45,632	-$100,424	-$132,676	-$203,245	-$1,453,916

Customer Site Heating Parameters		
Square Footage Included	50,000	sq ft
Peak Heat Input	35	Btu/hr-sq ft
District Energy Cost	$19.00	$/MMBtu
Heating Oil Heating Value	138,000	Btu/gal*
Heating Oil Cost	$2.40	$/gal
Heating Oil Cost (LHV Basis)	$18.43	$/MMBtu

Month	January	February	March	April	May	June	July	August	September	October	November	December	Totals
Hours in Month	744	672	744	720	744	720	744	744	720	744	720	744	8,760
Heating Load Factor	0.53	0.57	0.49	0.37	0.14	0.14	0.12	0.12	0.14	0.30	0.41	0.49	
Heating Demand, MMBtu	692	673	640	462	178	178	150	150	176	387	511	636	4,832
Boiler Efficiency, LHV	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	90%	
Oil Purchased, gallons	5,908	5,742	5,458	3,943	1,518	1,518	1,281	1,282	1,500	3,301	4,362	5,426	41,241
Purchased Oil Cost, $	$14,180	$13,781	$13,100	$9,464	$3,643	$3,644	$3,075	$3,078	$3,600	$7,923	$10,468	$13,022	$98,978
District Energy Cost	$13,153	$12,783	$12,151	$8,779	$3,379	$3,380	$2,852	$2,855	$3,340	$7,350	$9,710	$12,080	$91,812

		Condensing Turbine w/extraction *Electric Lead*	Back Pressure Turbine *Thermal Lead*	Hybrid Thermal w/Backpressure Turbine *Thermal Lead*
District Energy Metrics				
Square Footage Heated		2,000,000	2,000,000	2,000,000
Biomass Plant Ratings				
Steam Turbine Output	*MW*	15.0	2.0	1.9
Wood-Fired Boiler Capacity	*lb/hr*	145,800	70,000	52,500
Oil-Fired Boiler Capacity	*lb/hr*			35,000
Power Generation				
Electric Value (REC + Grid Sales)	*$/(kWh)*	$0.13	$0.13	$0.13
Electric Sales	*kWh*	114,784,911	5,885,513	6,087,835
Electric Sales Revenue	*$*	$14,348,114	$735,689	$760,979
Thermal Generation				
Heat Value	*$/MMBtu*	$16	$16	$19
Thermal Sales	*MMBtu*	193,288	193,288	193,288
Thermal Sales	*$*	$3,092,609	$3,092,609	$3,672,473
Wood Fuel Consumption				
Wood Fuel Unit Cost	*$/ton*	$35	$35	$35
Annual Consumption	*ton/yr*	241,227	35,843	32,149
Annual Consumption	*MMBtu/yr*	2,267,535	336,921	302,202
Wood Fuel Annual Cost	*$/yr*	$8,442,951	$1,254,494	$1,125,221
Oil Fuel Consumption				
Oil Fuel Unit Cost	*$/gal*			$2.00
Annual Consumption	*gal/yr*			164,347
Oil Fuel Annual Cost	*$/yr*			$328,695
Add'l Operating Expenses				
Total	*$*	$4,148,181	$1,871,601	$850,000
Net Revenue	*$*	$4,849,590	$702,203	$2,129,536
Plant Capital Cost				
Budgetary Capital	*$/kW*	$4,000	$2,700	$2,700
EPC Cost		$60,000,000	$21,000,000	$15,750,000
ProjectTotal	*$*	$78,000,000	$27,300,000	$18,900,000
Distribution Infrastructure Cost		$10,675,000	$5,275,000	$5,275,000
Simplified Financial Analysis				
Total Installation Capital		$88,675,000	$32,575,000	$24,175,000
Desired Capital Recovery	*%*	15%	15%	5%
Capital Recovery Period	*yrs*	25	25	25
Capital Recovery Payment		-$13,717,970	-$5,039,333	-$1,715,276

Appendix B.

Brattleboro Thermal Utility
Sample Pipe Specification for
Steam/Hotwater Buried Pipe
For Heat Distribution

WALDRON ENGINEERING & CONSTRUCTION, INC.	**Brattleboro Thermal Utility** **Cogeneration Expansion** **Pipe Specification** **FT1 - Piping System Material Specification** **Hot Water/Low Pressure Steam**

Designation: **FT1**
Services Included: **Hot Water, Steam**

Governing Code: ASME B31.1, Power Piping Code

Design Conditions:
Pressure: 150 psig
Temperature: 50°F-400ºF

Piping
Material: Carbon Steel, ASTM A53 Grade B ERW
Pipe Schedule: Standard
Pipe Size: 12"

Fittings: ASME B16.9 Wrought Steel Butt weld Fittings, ASTM A234 Gr. WPB, bore for applicable bore
All fittings shall be factory prefabricated and preinsulated.
Straight lengths shall be added to all ends allowing all field joints be strait sections of pipe.

Joints: Welded in accordance with ASME B31.1, Power Piping Code
Butt Weld (Passes may be either SMAW or GTAW)
Welding Preheat: N/A
Weld Examination: Visual, In Accordance with ASME B31.1, Power Piping Code

Testing: Pressure Test, per ASME B31.1, Power Piping Code
Test Pressure: 225 psig
Test Medium: Water

Insulation
Density: Polyurethane Foam with 2 lbs/ft3 minimum density.
Conductivity: Maximum initial thermal conductivity shall be 0.16 Btu-in/hr-ft2-°F.
Thickness: 1 1/2"
Installation:
- Insulation shall completely fill the space and between and be bonded to the pipe and jacket.
- Field insulation of fittings is not permitted.
- All field applied insulation shall be placed only in straight sections.

Jacket
Material:
- Jacket shall be seamless high density polyethylene (HDPE) in accordance with ASTM D1248, Type 3, Class C.
- PVC materials are not permitted.

Fittings: Elbow sections are constructed of seamless molded HDPE.
Thickness: Minimum jacket thickness shall be 0.175".

Installation
- Internal piping shall be hydrostatically tested prior to insulating field joint locations.
- Installer shall seal field joint area with a heat shrinkable adhesive backed sleeve. Gluing, taping, or hot air welding of jacket is not permitted.
- Backfilling is not permitted until heat shrink has cooled.

Backfill
Type:
- A 4" layer of sand or fine gravel shall be used to provide a uniform bedding for the pipe.

Installation:
- Entire trench width shall be evenly backfilled with a similar material as the bedding in 6" compacted layers to a minimum height of 6" above the top of the insulated pipe.

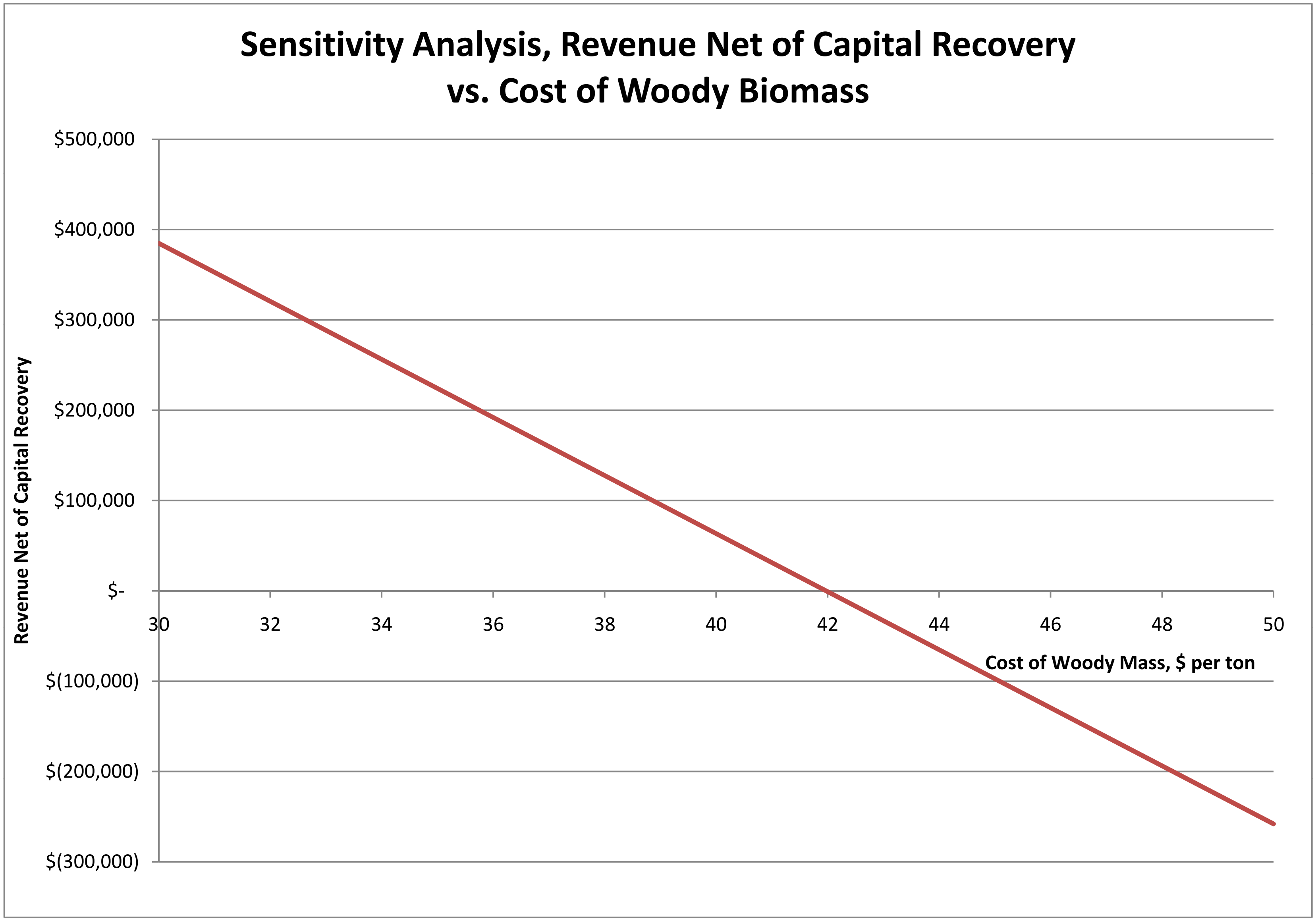
Heat Trace: N/A

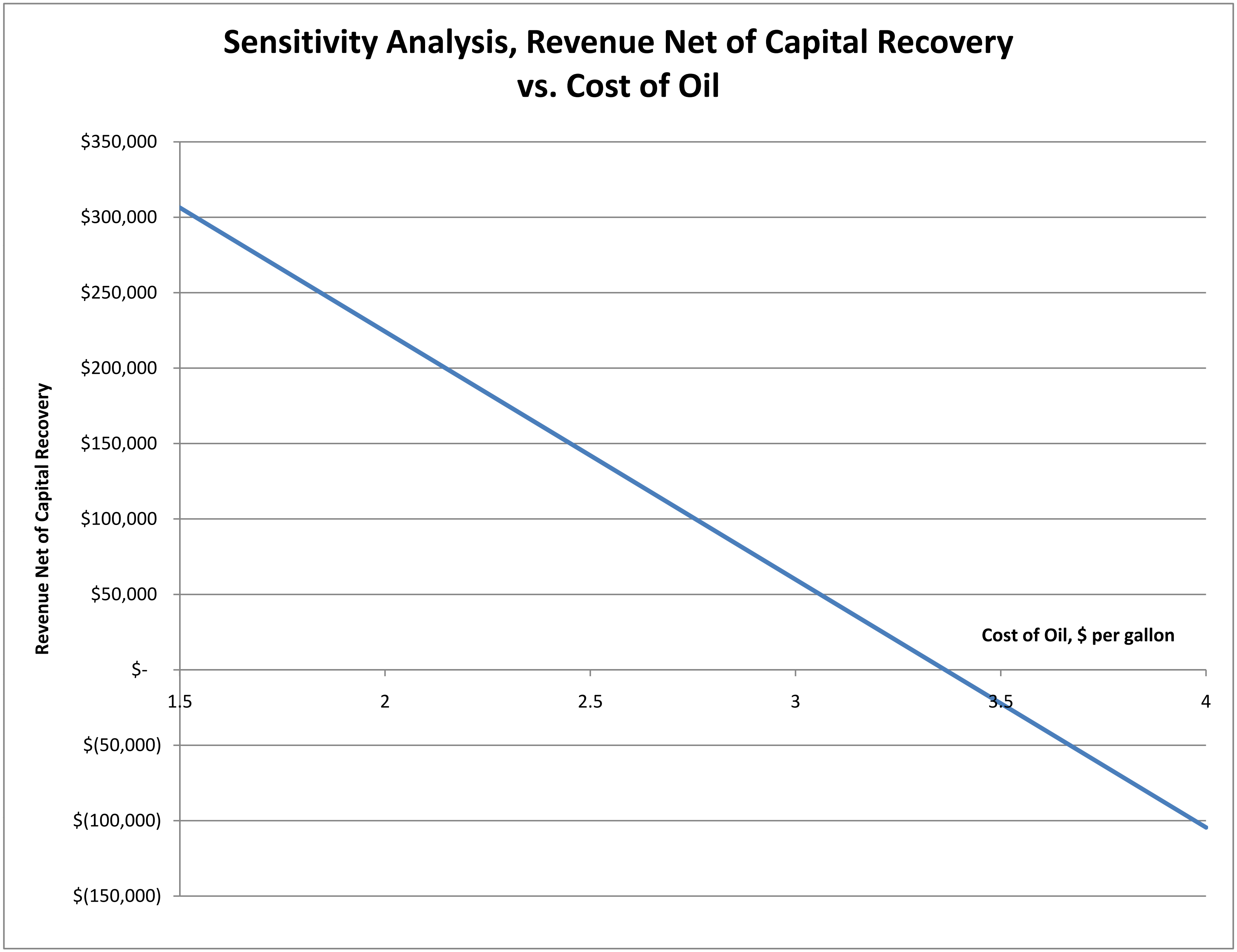
Notes: -

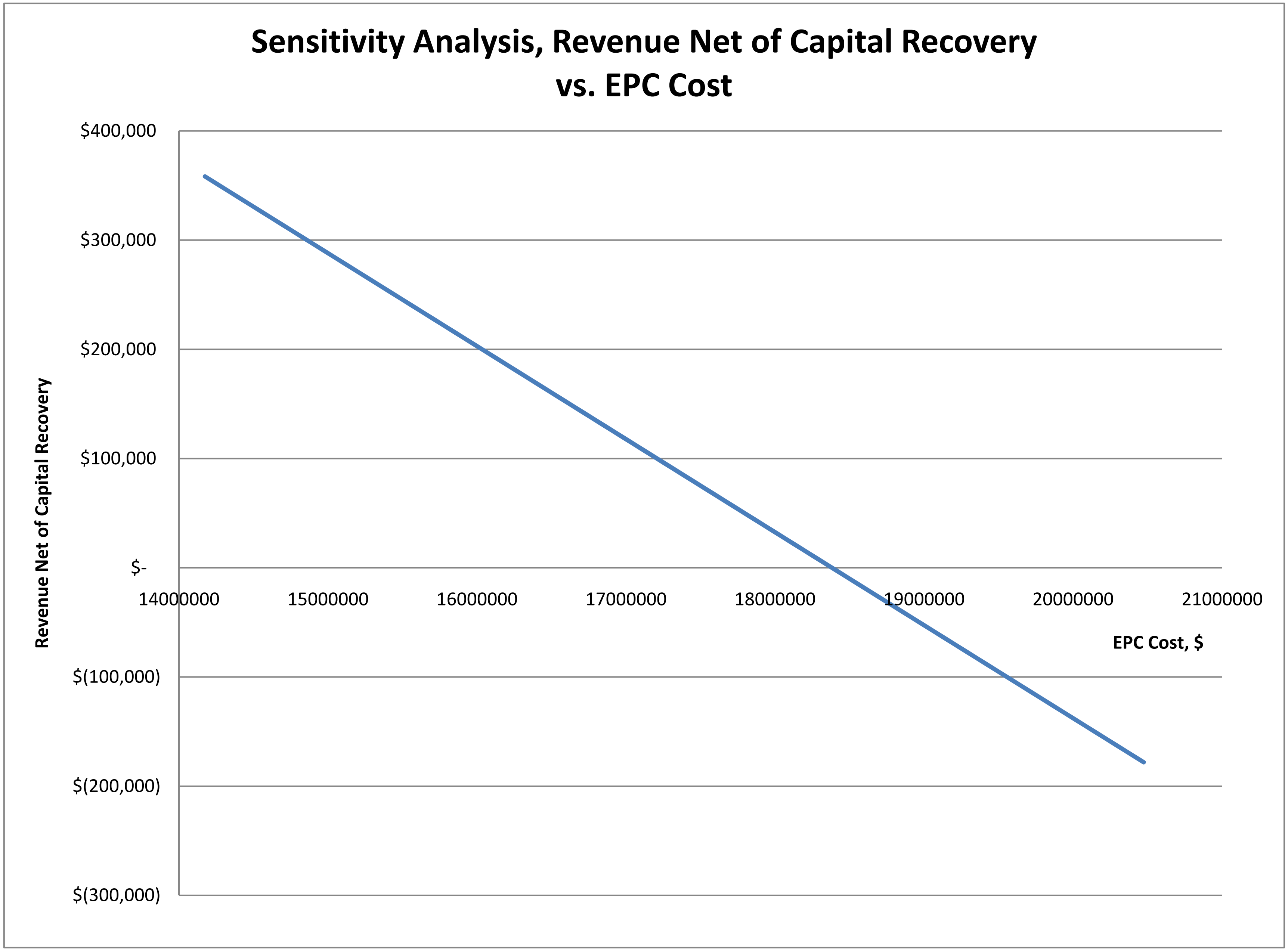
Date	Revision	Written By	Description	Approved
			Sample	

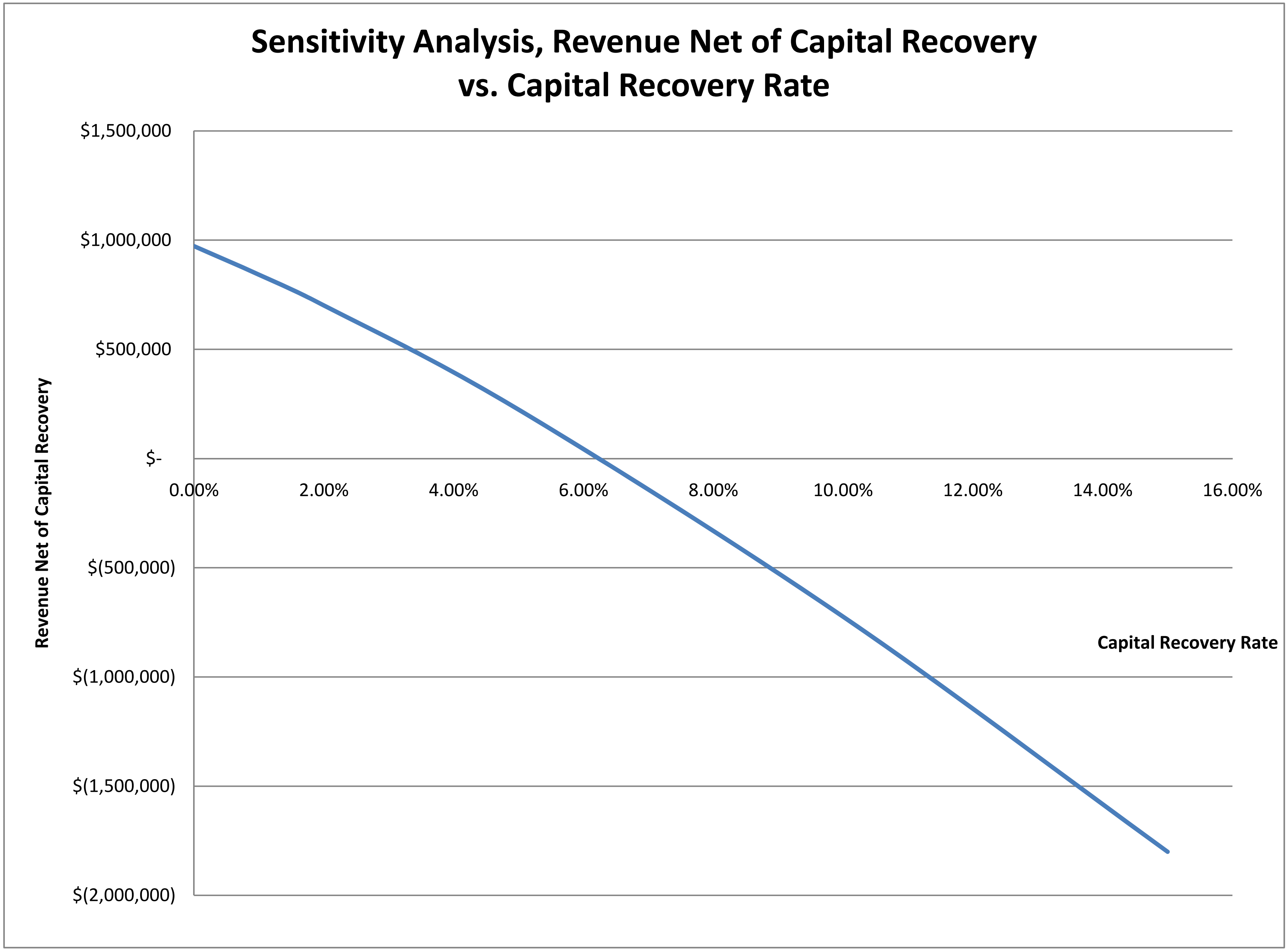
Appendix C.

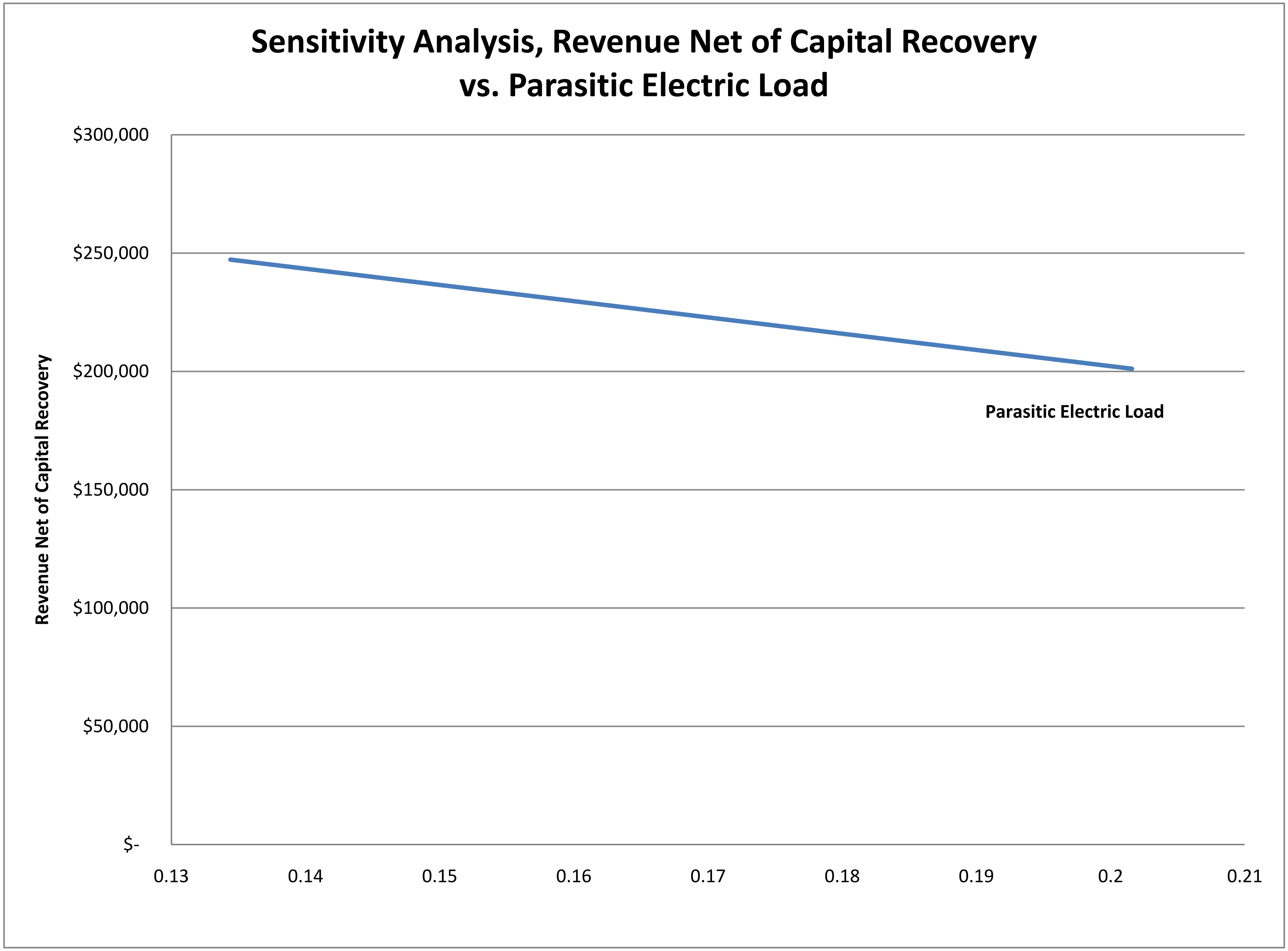
Brattleboro Thermal Utility Sensitivity Analysis for Combined Heat and Power Plant With District Heating

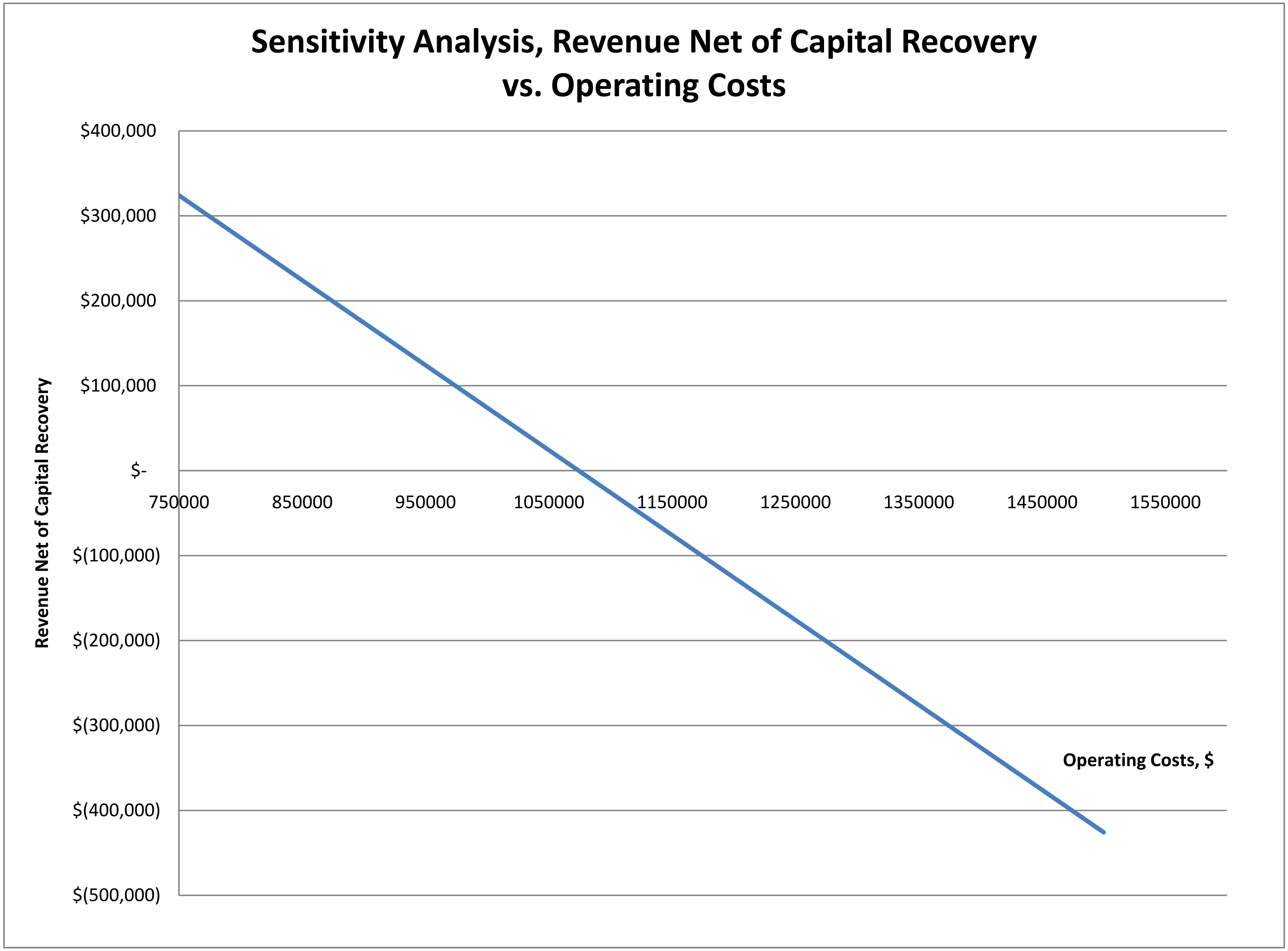

Sensitivity Analysis, Revenue Net of Capital Recovery
vs. Cost of Woody Biomass
$500,000
$400,000
$300,000
$200,000
$100,000
$-
$(100,000)
$(200,000)
$(300,000)
Revenue Net of Capital Recovery
30
32
34
36
38
40
42
44
46
48
50
Cost of Woody Mass, $ per ton

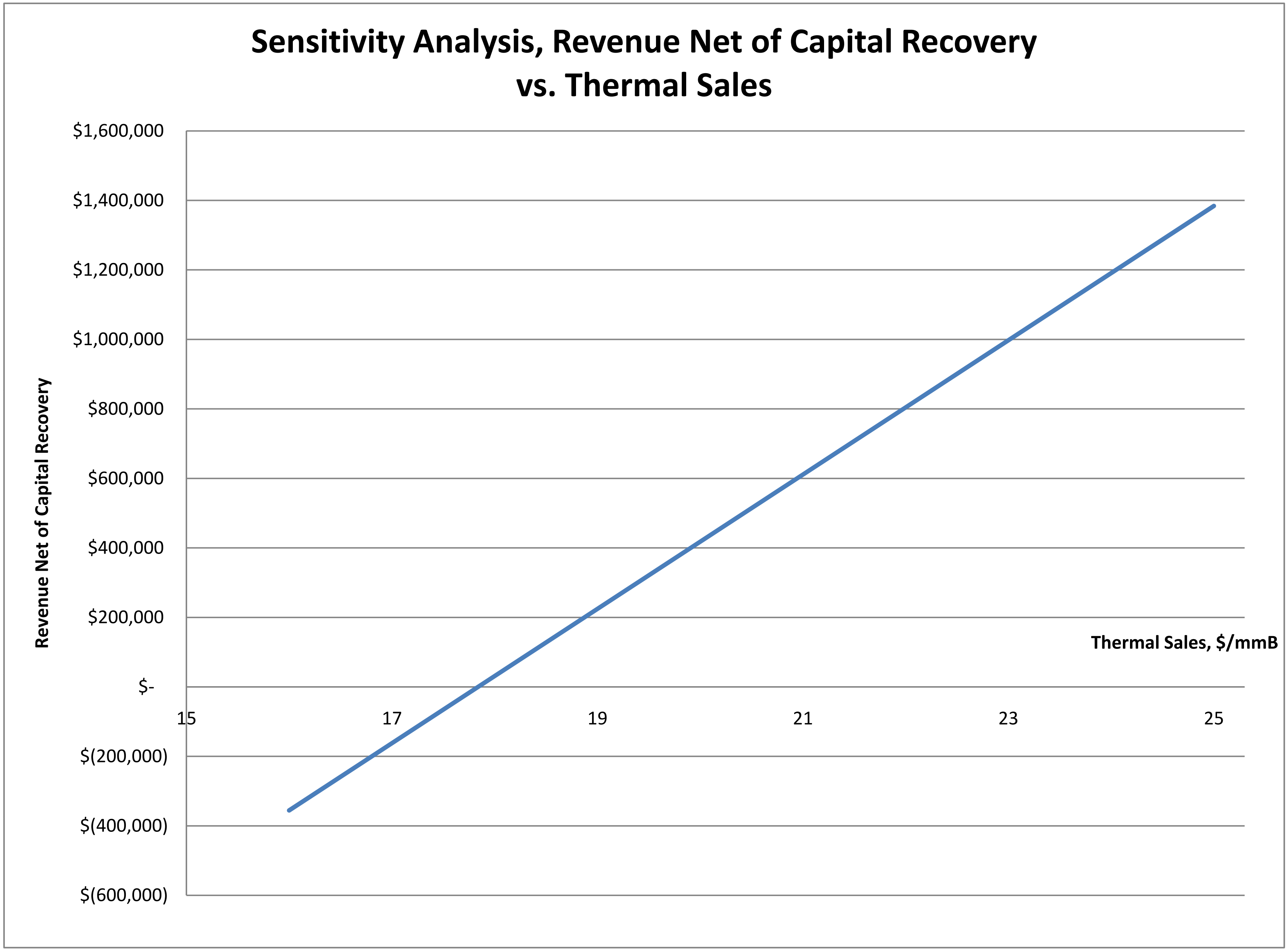

Sensitivity Analysis, Revenue Net of Capital Recovery
vs. Cost of Oil
$350,000
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$-
$(50,000)
$(100,000)
$(150,000)
1.5
2
2.5
3
3.5
4
Cost of Oil, $ per gallon
Revenue Net of Capital Recovery


Sensitivity Analysis, Revenue Net of Capital Recovery
vs. EPC Cost
$400,000
$300,000
$200,000
$100,000
$-
$(100,000)
$(200,000)
$(300,000)
Revenue Net of Capital Recovery
14000000
15000000
16000000
17000000
18000000
19000000
20000000
21000000
EPC Cost, $

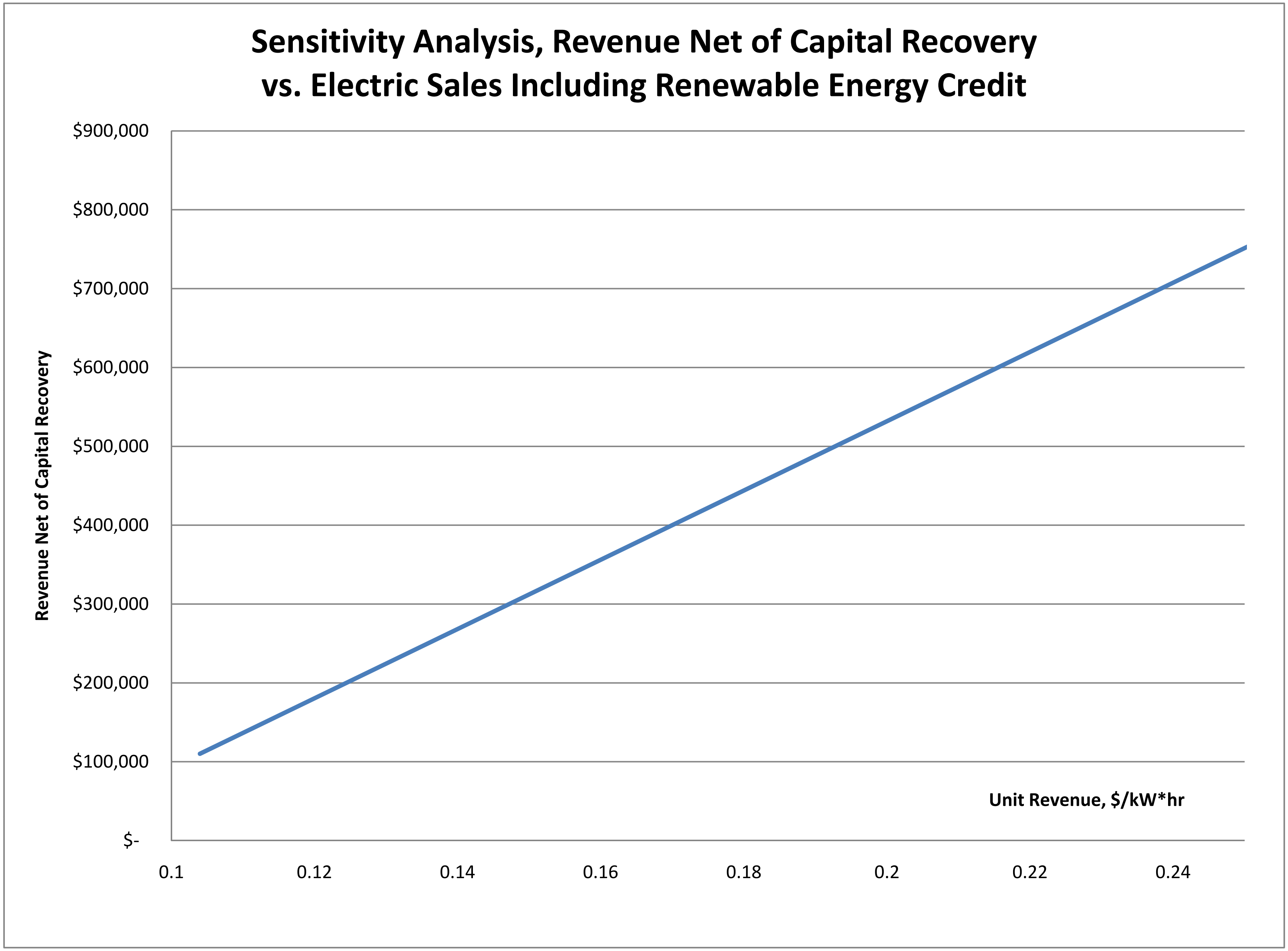

Sensitivity Analysis, Revenue Net of Capital Recovery
vs. Capital Recovery Rate
$1,500,000
$1,000,000
$500,000
$-
$(500,000)
$(1,000,000)
$(1,500,000)
$(2,000,000)
0.00%
2.00%
4.00%
6.00%
8.00%
10.00%
12.00%
14.00%
16.00%
Revenue Net of Capital Recovery
Capital Recovery Rate


Sensitivity Analysis, Revenue Net of Capital Recovery
vs. Parasitic Electric Load
$300,000
$250,000
$200,000
$150,000
$100,000
$50,000
$-
Revenue Net of Capital Recovery
0.13
0.14
0.15
0.16
0.17
0.18
0.19
0.2
0.21
Parasitic Electric Load


Sensitivity Analysis, Revenue Net of Capital Recovery vs. Operating Costs
$400,000
$300,000
$200,000
$100,000
$-
$(100,000)
$(200,000)
$(300,000)
$(400,000)
$(500,000)
750000
850000
950000
1050000
1150000
1250000
1350000
1450000
1550000
Revenue Net of Capital Recovery
Operating Costs, $



Sensitivity Analysis, Revenue Net of Capital Recovery
vs. Thermal Sales
$1,600,000
$1,400,000
$1,200,000
$1,000,000
$800,000
$600,000
$400,000
$200,000
$-
$(200,000)
$(400,000)
$(600,000)
Revenue Net of Capital Recovery
15
17
19
21
23
25
Thermal Sales, $/mmB


Sensitivity Analysis, Revenue Net of Capital Recovery vs. Electric Sales Including Renewable Energy Credit
Revenue Net of Capital Recovery
$900,000
$800,000
$700,000
$600,000
$500,000
$400,000
$300,000
$200,000
$100,000
$-
Unit Revenue, $/kW*hr
0.1
0.12
0.14
0.16
0.18
0.2
0.22
0.24