NET ENERGY STUDY

as commissioned by Pellet Fuels Institute and related Thesis work applicable to PFI

Research by:

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PFI Annual Conference

Presented by:
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Presentation Outline

- Introduction, Problem Statement & Objectives
- Life Cycle Analysis (LCA) Components & Methodology
- Thesis Background & Research
- Outcomes
  - Fuel Comparisons
  - Additional Questions

INTRODUCTION

"The Pellet Fuel Institutes (PFI) … expressed interest in uncovering wood fuel pellets life-cycle process costs and net energy output compared to other space heating fuel options. "

"…… study examined the processing costs, net energy output, and fossil energy ratios for: heating oil, natural gas, liquid petroleum gas (LPG), switchgrass, corn, geothermal, green wood chips, and wood pellet fuel.

A functional unit of 1 million Btu (MMBTU) was established as an input energy value.

Existing studies, the Department of Energy, the Argonne National Laboratory Greenhouses gases, Regulated Emissions, and Energy use in Transportation (GREET) Model , as well as personal interviews were utilized in calculating life-cycle costs and energy expenditures. The GREET Model has been used in a host of life-cycle reports, technical papers, and presentations[1].

Life-cycle paths of highest and lowest efficiency were determined for each space heating fuel. Averages taken from the highest and lowest efficiency life-cycles were computed and utilized to make overall comparisons of the process cost, fossil energy ratio, and net energy ratio……"

Two Research Phases

I. This baseline study would provide PFI a window as to whether the LCA of pellet fuel is indeed a benefit to the US nationally.

II. The PFI study grew into a foundation for Josh's thesis work that further dissected the findings, energy balance & greenhouse gas emissions as it focused on Wisconsin.

Thesis Problem Statement

How does the life cycle cost, energy balance, and greenhouse gas emissions of wood fuel pellets compare to other Wisconsin space heating fuels?

Used Wisconsin space heating fuel options as a base for comparison

- Natural Gas
- Petroleum
  - Heating oil (#2 diesel)
  - LPG
- Geothermal
- Corn
- Wood pellets
- Green wood chips
- Switchgrass

Objectives

- Compare life cycle:
  1. Energy expenditures
  2. Fossil energy expenditures
  3. Greenhouse gas emissions
  4. Process costs

LCA Components

- System Boundaries
  - ISO standards
- Define Unit Process steps
- Functional Unit
  - MMBtu
- Outcomes

Methodology

- Examine existing life cycle data
- Coordinate with Pellet Fuel Institute members
- Develop the LCA boundary
- Perform sensitivity analysis
- Analyze results

Example LCA

Table 1 - Wood Pellets

Most Efficient Life-Cycle

		1	2	3	4	5			6	7	8
	Energy Input	Feedstock Transport (140 miles)	Plant Operations	Product Transport (195 miles)	Water Vaporization (8% M.C.)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	974,400	945,071	931,556	912,273	775,432		775,432	0.78	11.3	204.6
Total BTU Required	0	25,600	29,329	13,515	19,283	136,841	224,568				
Fossil BTU Required	0	25,600	29,329	13,515	0	0	68,444				
Process Efficiency (%)	100%	97.44%	96.99%	98.57%	97.93%	85.00%	77.54%				
Process Cost	0	$0.49	$0.51	$0.26	$0.28	$1.97	$3.51				
Carbon Dioxide (lbs)	0.0	4.1	11.7	2.3	→	186.6	204.6				

1,000,000 Btu

THESIS BACKGROUND & RESEARCH

Energy Consumption by Sector

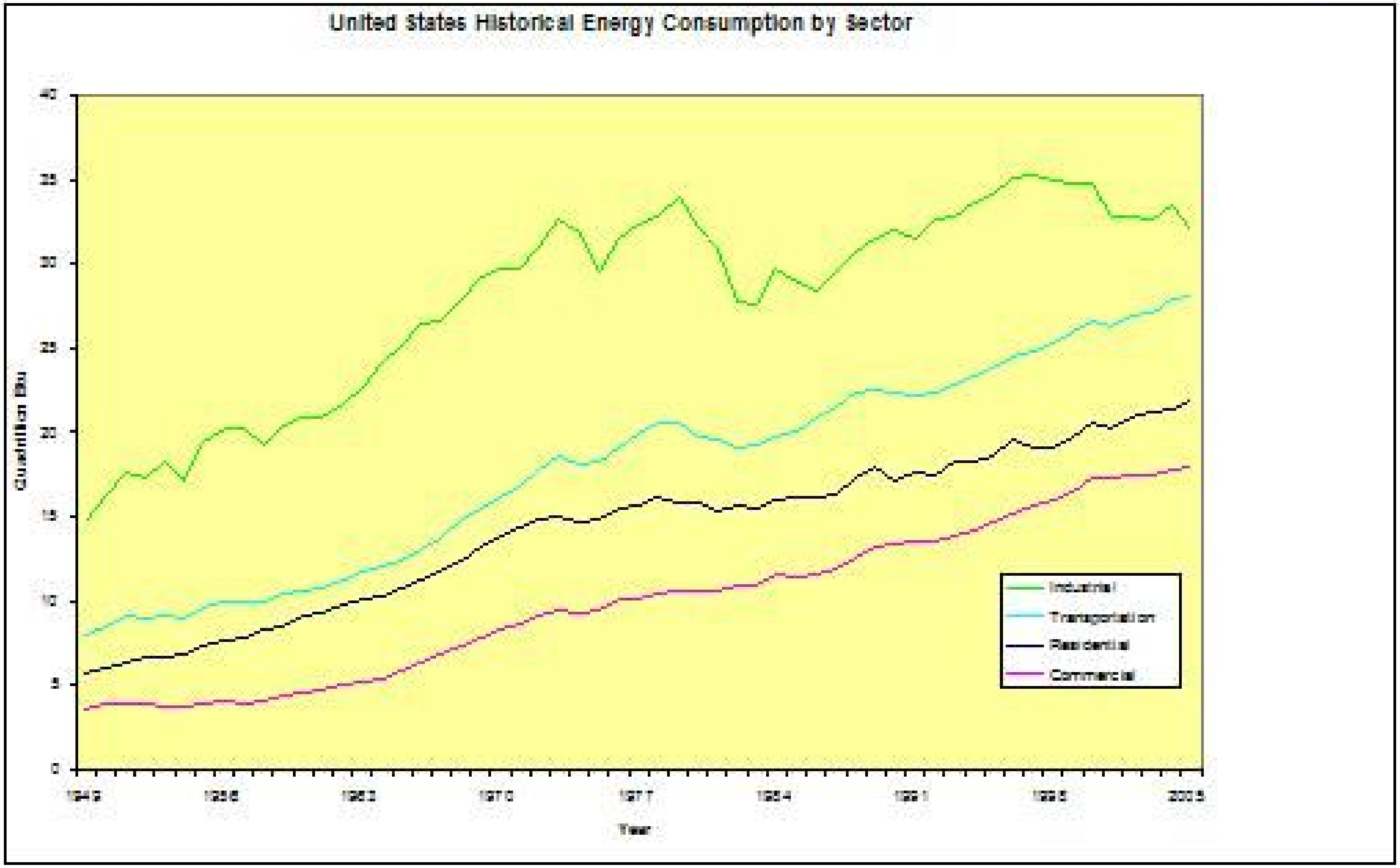
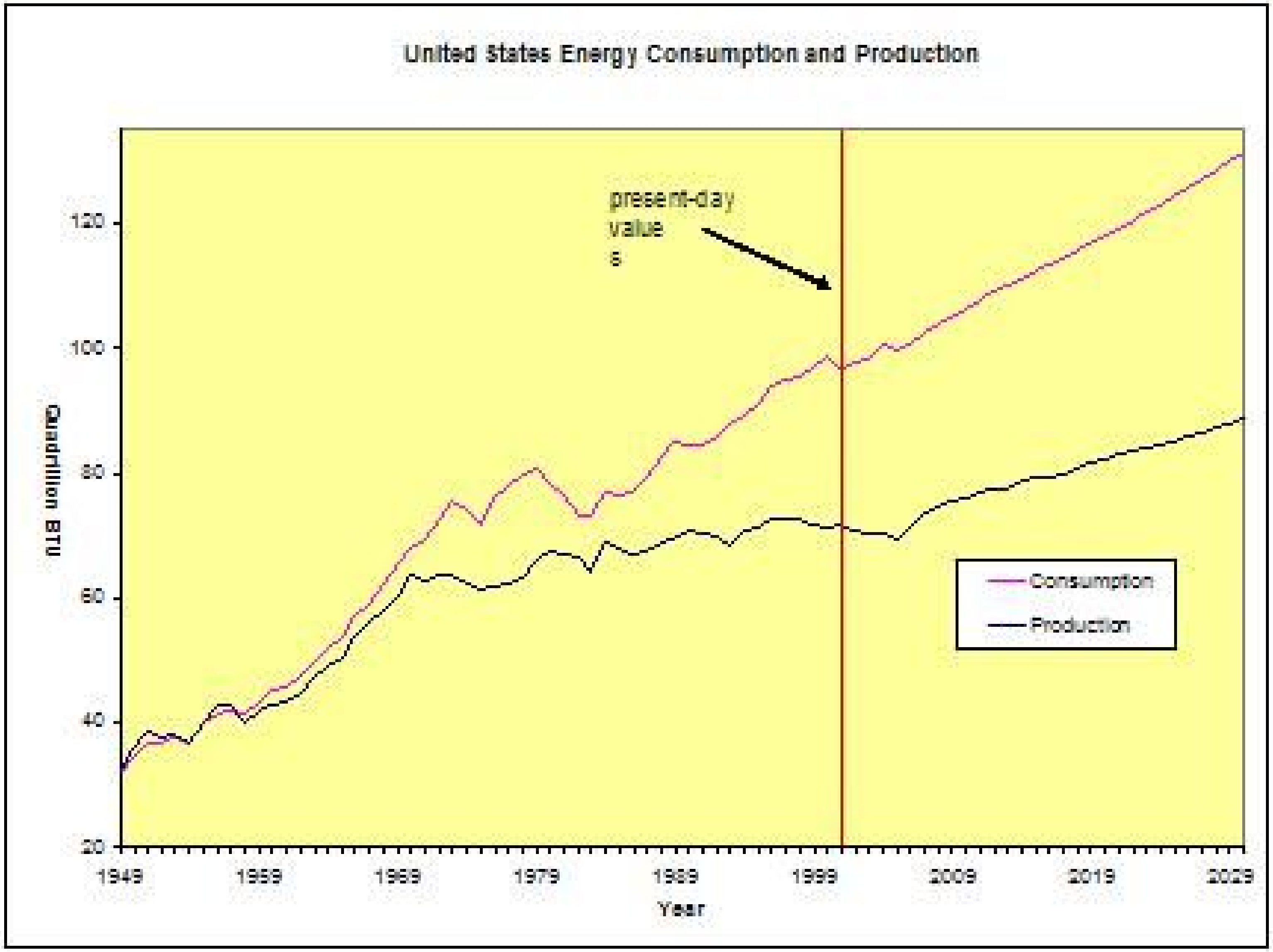
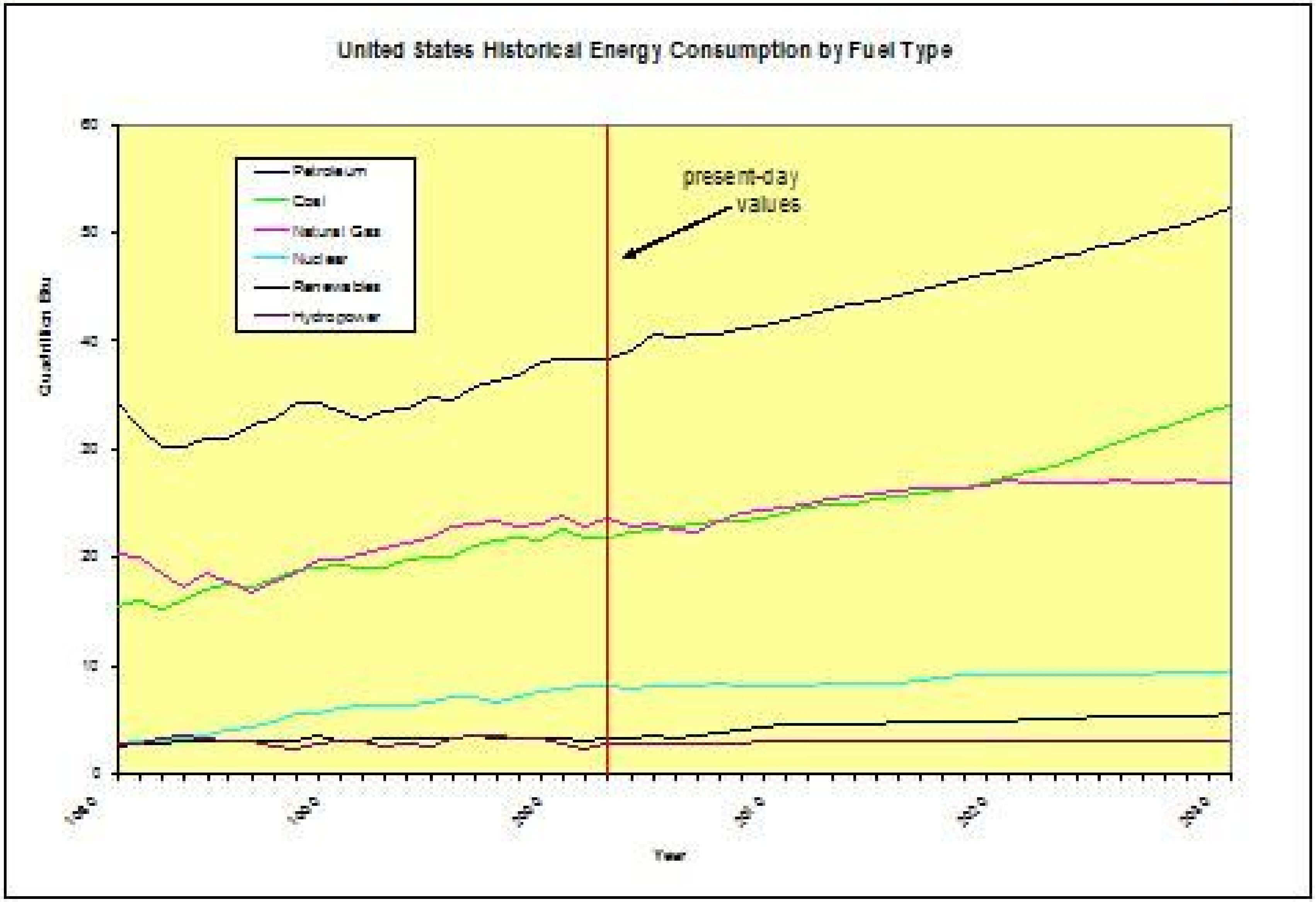


Figure 1: United States Historical Energy Consumption by Sector
(Figure data taken from the United States Department of Energy EIA, 2006d)

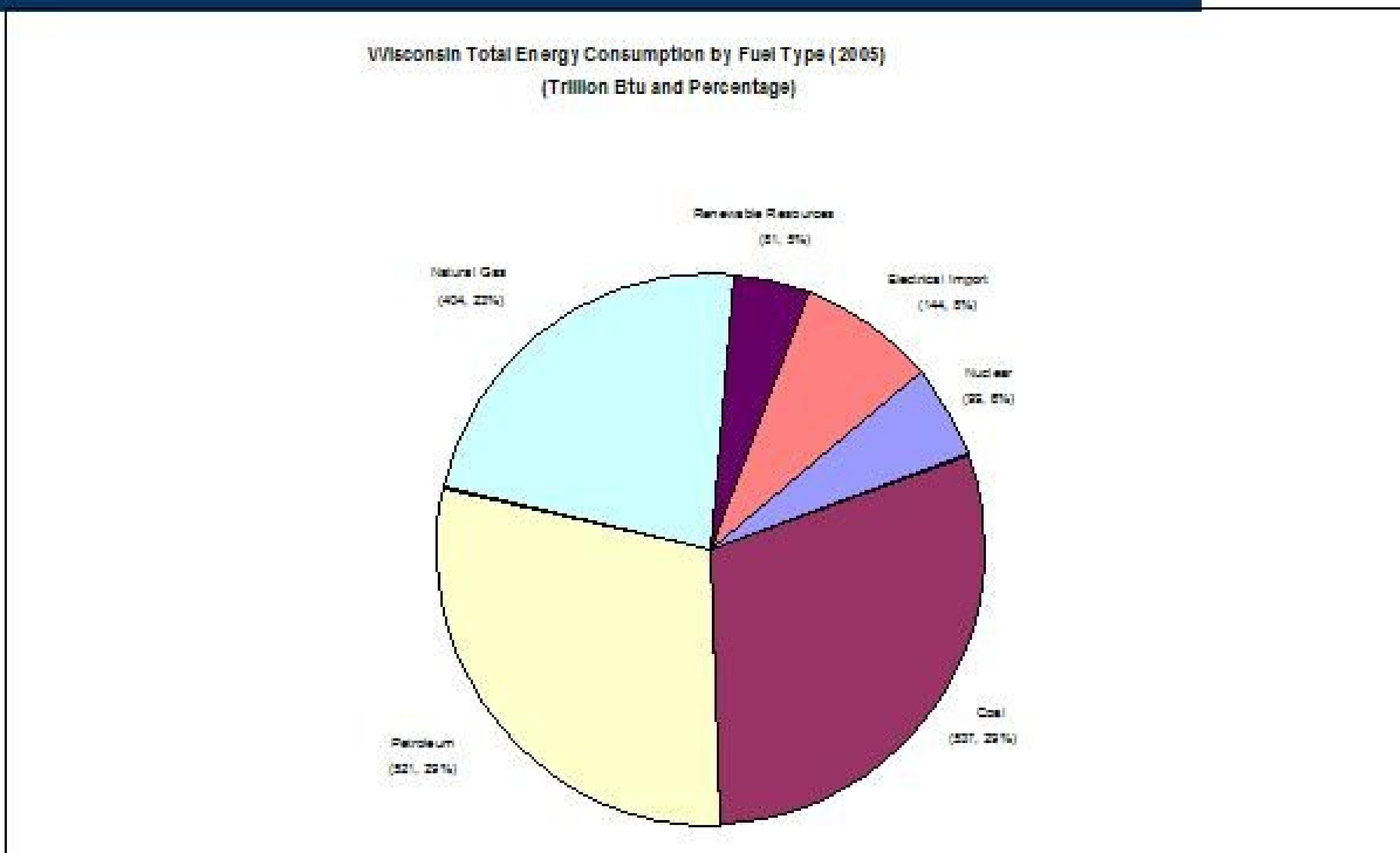
Energy Production vs. Consumption



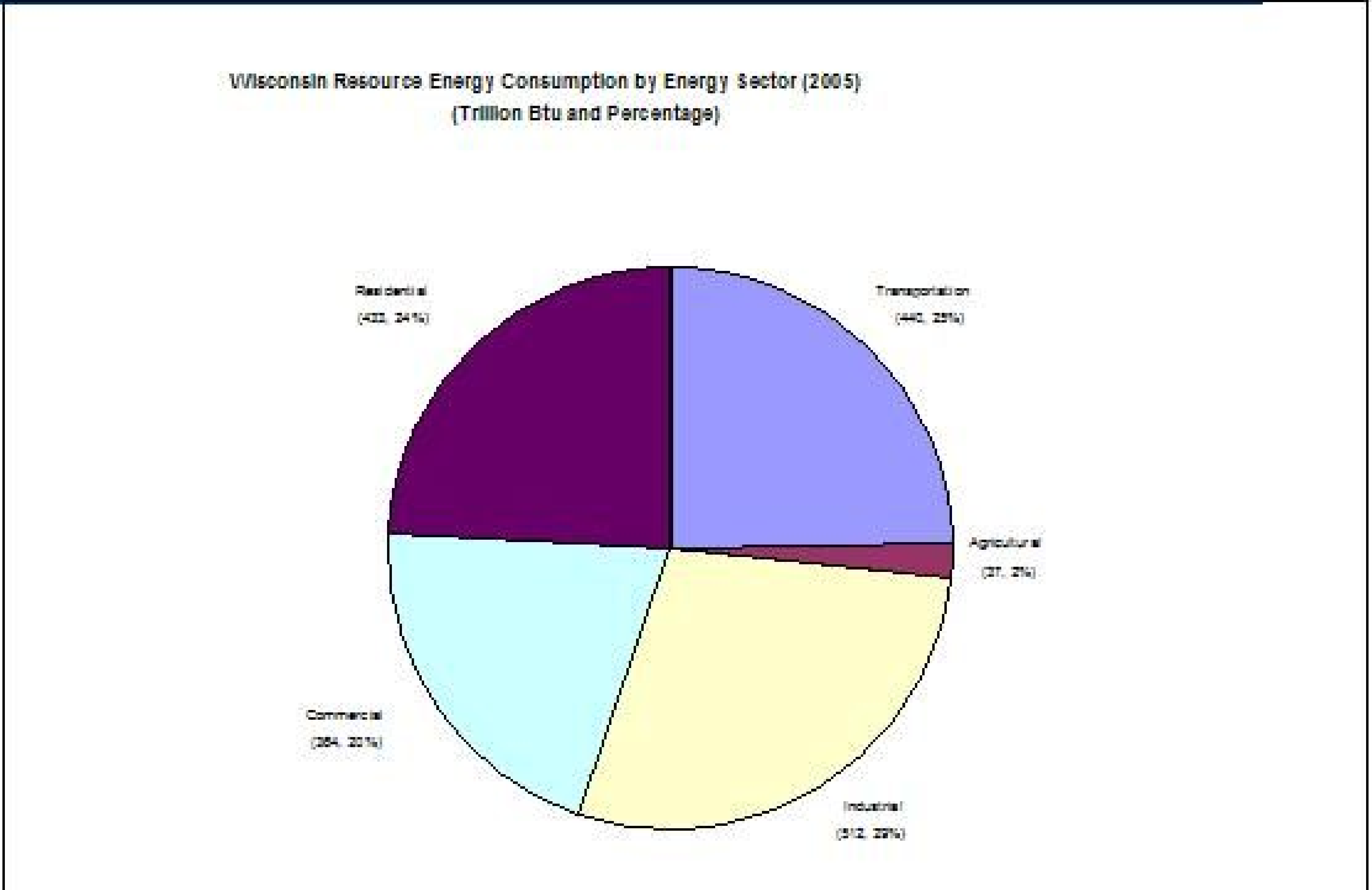
Consumption by Fuel Type



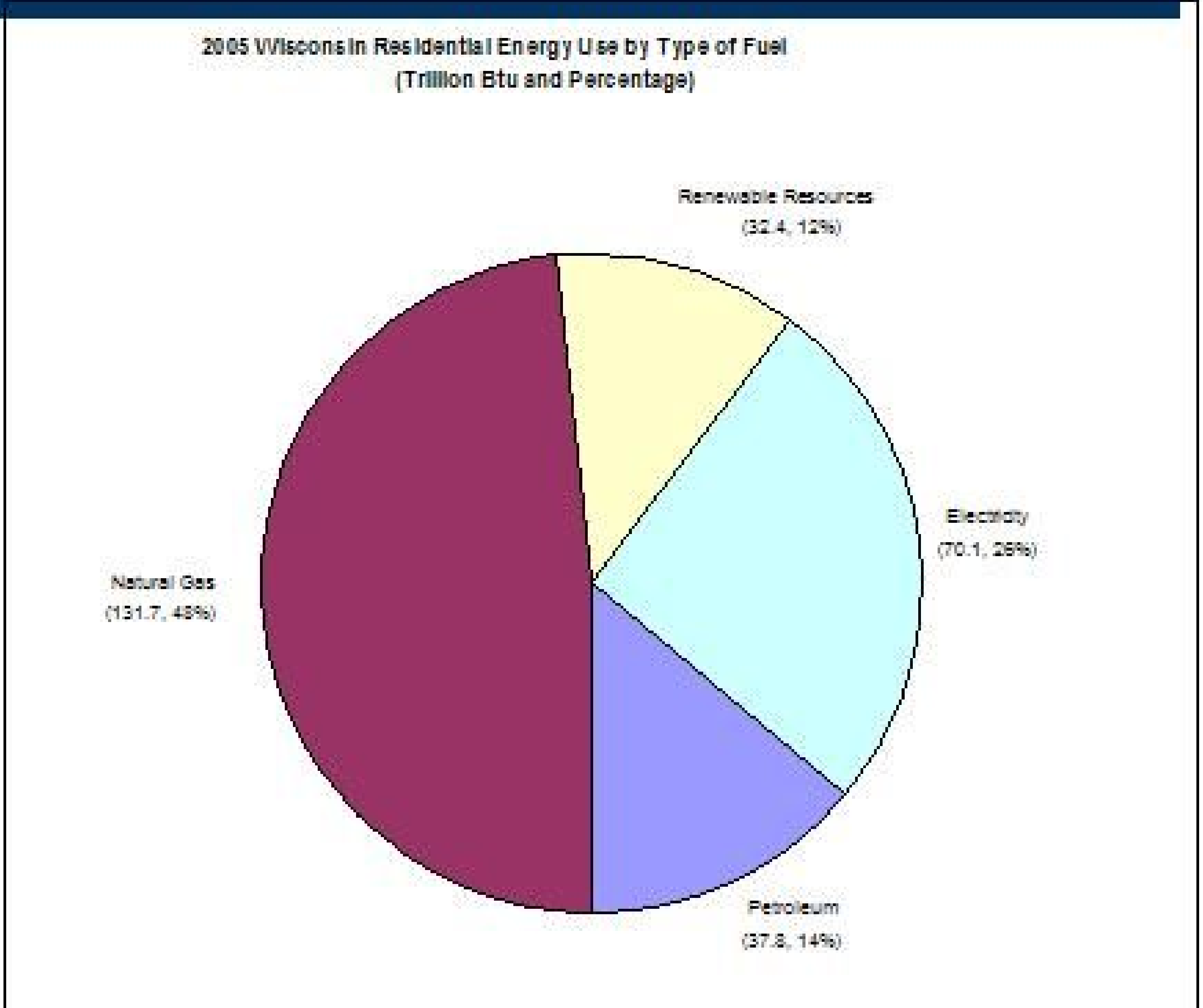
Thesis Focal Area---WISCONSIN



Wisconsin Energy Consumption by Sector



Wisconsin Residential Energy Use by Sector



Space Heating was the focus

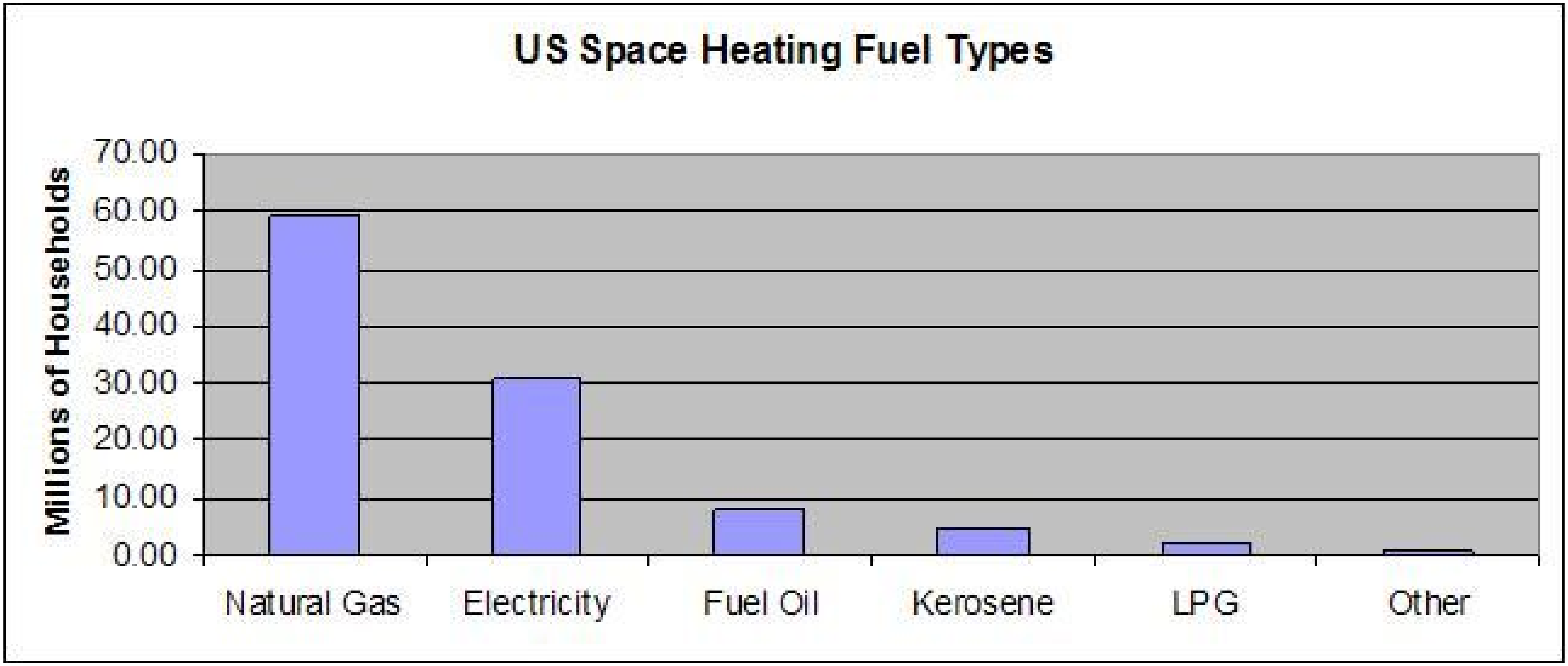


Table 1: U.S. Households with Space Heating Fuel and Cost in 2001
(Table data taken from the United States Department of Energy EIA, 2001)

Wood Pellets

Most Efficient Life-Cycle

	Energy Input	Feedstock Transport (140 miles) [1]	Plant Operations [2]	Product Transport (195 miles) [3]	Water Vaporization (8% M.C.) [4]	Combustion [5]	Totals	Net Energy Output	Net Energy Ratio [6]	Fossil Energy Ratio [7]	Total GHG emissions (lbs CO_2 eq.) [8]
Total BTU Remaining	1,000,000	974,400	945,071	931,556	912,273	775,432		775,432	0.78	11.3	204.6
Total BTU Required	0	25,600	29,329	13,515	19,283	136,841	224,568				
Fossil BTU Required	0	25,600	29,329	13,515	0	0	68,444				
Process Efficiency (%)	100%	97.44%	96.99%	98.57%	97.93%	85.00%	77.54%				
Process Cost	0	$0.49	$0.51	$0.26	$0.28	$1.97	$3.51				
Carbon Dioxide (lbs)	0.0	4.1	11.7	2.3	→	186.6	204.6				

Least Efficient Life-Cycle

	Energy Input	Thinning Harvesting and Loading	Chipping [9]	Feedstock Transport (140 miles)	Drying (55% M.C. to 12% M.C.) [10]	Plant Operations	Product Transport (195 miles)	Water Vaporization (8% M.C.)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	973,600	971,069	958,639	839,959	814,677	803,027	786,404	613,395		613,395	0.61	7.8	283.6
Total BTU Required	0	26,400	2,531	12,430	118,680	25,283	11,650	16,623	173,009	386,605				
Fossil BTU Required	0	26,400	2,531	12,430	0	25,283	11,650	0	0	78,294				
Process Efficiency (%)	100%	97.36%	99.74%	98.72%	87.62%	96.99%	98.57%	97.93%	78.00%	61.34%				
Process Cost	0	$0.51	$0.05	$0.24	$0.31	$0.46	$0.23	$0.24	$2.48	$4.52				
Carbon Dioxide (lbs)	0.0	4.2	0.4	2.0	24.5	18.2	2.3	→	232.0	283.6				

Carbon Dioxide Sequestered per MMBtu Feedstock (lbs/yr) 116.2

Sources:

1
Transportation energy Data - Department of Energy
Transportation Data - Personal interviews with 5 pellet fuel companies

2
Operations Data - from interviews with 2 pellet fuel companies
Process cost Data - Department of Energy ($.0578/kW-hr)

3
Shipping Data - from interviews with 5 pellet fuel companies
Transportation energy Data - Department of Energy

5
Combustion efficiency Data - Dept. of Energy
Fuel cost Data - $210/ton (Homefree LLC)

Notes:

4
1115 Btu/lb water vaporized

6
Net energy ratio = net energy output/ energy input

7
Fossil energy ratio=net energy output/ fossil energy used

8
Total greenhouse gas footprint (CO_2 equivalent)

9
Assume 500 HP Hammer Mill at 50 tons/hr output

10
Assume $20/ton feedstock price

Green Wood Chips

Most Efficient Life-Cycle

	Energy Input	1 Thinning, Harvesting, and Loading	2 Chipping Feedstock	3 Product Transport (25 miles)	4 Water Vaporization (20% M.C.)	5 Combustion	Totals	Net Energy Output	6 Net Energy Ratio	7 Fossil Energy Ratio	8 Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	973,600	971,069	966,990	927,827	695,870		695,870	0.70	21.1	268.9
Total BTU Required	0	26,400	2,531	4,078	39,163	231,957	304,130				
Fossil BTU Required	0	26,400	2,531	4,078	0	0	33,010				
Process Efficiency (%)	100%	97.36%	99.74%	99.58%	95.95%	75.00%	69.59%				
Process Cost	0	$0.51	$0.05	$0.08	$0.14	$0.84	$1.62				
Carbon Dioxide (lbs)	0.0	4.2	0.4	0.7	→	263.6	268.9				

Least Efficient Life-Cycle

	Energy Input	Thinning, Harvesting, and Loading	Chipping Feedstock	Product Transport (100 miles)	Water Vaporization (20% M.C.)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	973,600	971,069	943,296	905,093	497,801		497,801	0.50	8.8	272.8
Total BTU Required	0	26,400	2,531	27,773	38,203	407,292	502,199				
Fossil BTU Required	0	26,400	2,531	27,773	0	0	56,704				
Process Efficiency (%)	100%	97.36%	99.74%	97.14%	95.95%	55.00%	49.78%				
Process Cost	0	$0.51	$0.05	$0.53	$0.14	$1.48	$2.71				
Carbon Dioxide (lbs)	0.0	4.2	0.4	4.6	→	263.6	272.8				

Carbon Dioxide Sequestered per MMBtu Feedstock (lbs/yr)	1162

Sources:

1
Harvest Data - Corrim Special Issue Report

3
Transport energy Data - Department of Energy

5
Combustion efficiency Data - Biomass Energy Resource Center
Fuel cost Data - assume $50/ton

2
Assume 500 HP Hammer Mill at 50 tons/hr

4
1115 Btu/lb water vaporized

6
Net energy ratio = net energy output/ energy input

7
Fossil energy ratio = net energy output/ fossil energy used

8
Total greenhouse gas footprint (CO_2 eqivalent)

Switchgrass

Most Efficient Life-Cycle

	Energy Input	Establishment, Fertilization, and Harvest [1]	Pellet Mill Operations [2]	Product Transport (195 miles)	Water Vaporization (8% M.C.) [3]	Combustion [4]	Totals	Net Energy Output	Net Energy Ratio [5]	Fossil Energy Ratio [6]	Total GHG emissions (lbs CO_2 eq.) [7]
Total BTU Remaining	1,000,000	953,400	933,379	920,031	906,599	788,741		788,741	0.79	9.9	249.5
Total BTU Required	0	46,600	20,021	13,347	13,432	117,858	211,259				
Fossil BTU Required	0	46,600	20,021	13,347	0	0	79,969				
Process Efficiency (%)	100%	95.34%	97.90%	98.57%	98.54%	87.00%	78.87%				
Process Cost	0	$0.90	$0.27	$0.25	$0.21	$1.87	$3.50				
Carbon Dioxide (lbs)	0.0	16.3	8.1	2.3	--	222.8	249.5				

Least Efficient Life-Cycle

	Energy Input	Establishment, Fertilization, and Harvest	Drying (20% M.C. to 12% M.C.) [8]	Pellet Mill Operations	Product Transport (195 miles)	Water Vaporization (8% M.C.)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	953,400	932,425	912,844	899,791	886,654	718,189		718,189	0.72	9.1	313.0
Total BTU Required	0	46,600	20,975	19,581	13,054	13,137	168,464	281,811				
Fossil BTU Required	0	46,600	0	19,581	13,054	0	0	79,235				
Process Efficiency (%)	100%	95.34%	97.80%	97.90%	98.57%	98.54%	81.00%	71.82%				
Process Cost	0	$0.90	$0.09	$0.37	$0.25	$0.21	$2.67	$4.49				
Carbon Dioxide (lbs)	0.0	16.3	4.5	12.9	2.3	--	277.1	313.0				

Carbon Dioxide Sequestered per MM Btu Feedstock (lbs/yr): 203

Sources:

1
Switchgrass Data - R.E.A.P. - Canada
Process cost Data - Department of Energy (Diesel at $2.67/gallon)

2
Pellet mill Data - taken from 2 studies completed by R.E.A.P. - Canada
Process cost Data - Department of Energy ($0.0578 per kW-hr)

4
Combustion Efficiency Data - R.E.A.P. Canada
Fuel cost Data - $210/ton (Homefree LLC)

Notes:

3
1115 Btu/lb water vaporized

5
Net energy ratio = net energy output/ energy input

6
Fossil energy ratio = net energy output/ fossil energy used

7
Total greenhouse gas footprint (CO_2 equivalent)

8
assume $50/ton feedstock price

Corn

Most Efficient Life-Cycle

		1	2	3			4	5	6
	Energy Input	Establishment, Fertilization, and Harvest	Water Vaporization (15% M.C.)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	884,400	855,126	751,740		751,740	0.75	6.5	285.1
Total BTU Required	0	115,600	29,274	103,386	248,260				
Fossil BTU Required	0	115,600	0	0	115,600				
Process Efficiency (%)	100%	88.44%	96.69%	85.00%	72.69%				
Process Cost	0	$1.11	$0.41	$1.46	$2.99				
Carbon Dioxide (lbs)	0.0	14.0	→	271.1	285.1				

Least Efficient Life-Cycle

			7							
	Energy Input	Establishment, Fertilization, and Harvest	Drying with LPG (25% to 15% moisture)	Water Vaporization (15% M.C.)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	884,400	839,561	855,126	641,345		641,345	0.64	4.0	293.3
Total BTU Required	0	115,600	44,839	29,274	213,782	403,494				
Fossil BTU Required	0	115,600	44,839	0	0	160,439				
Process Efficiency (%)	100%	88.44%	94.93%	96.69%	75.00%	60.88%				
Process Cost	0	$0.45	$1.05	$0.41	$3.02	$4.93				
Carbon Dioxide (lbs)	0.0	14.0	8.2	→	271.1	293.3				

	Conventional Till	No Till
Carbon Dioxide Sequestered per MMBtu Feedstock (lbs/yr)	0	26.20

Sources:

1
Planting and harvesting Data - Oak Ridge National Laboratory

3
Fuel cost Data - $4.00/bushel
Combustion efficiency Data - Penn State University; American Energy Systems

7
Drying Data - Agricultural harvest study, Purdue University
Process cost Data - Department of Energy (LPG at $2.15/gal.)

Notes:

2
1115 Btu/lb water vaporized

4
Net energy ratio = net energy output/ energy input

5
Fossil energy ratio = net energy output/ fossil energy used

6
Total greenhouse gas footprint (CO_2 equivalent)

Geothermal

Most Efficient Life-Cycle

	Energy Input	Utility Combustion (gasification technology) [1]	Heat Pump (4.33 COP) [2]	Totals	Net Energy Output	Net Energy Ratio [3]	Fossil Energy Ratio [4]	Total GHG emissions (lbs CO_2 eq.) [5]
Total BTU Remaining	1,000,000	600,000	487,500		487,500	0.49	1.0	190.2
Total BTU Required	0	400,000	112,500	512,500				
Fossil BTU Required	0	400,000	112,500	512,500				
Process Efficiency(%)	100%	60.00%	81.25%	48.75%				
Process Cost	0	$0.68	$3.29	$3.98				
Carbon Dioxide (lbs)		117.6	72.6	190.2				

Least Efficient Life-Cycle

	Energy Input	Utility Combustion (electrical production only)	Heat Pump (2.80 COP) [6]	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	330,000	233,310		233,310	0.23	0.3	315.4
Total BTU Required	0	670,000	96,690	766,690				
Fossil BTU Required	0	670,000	96,690	766,690				
Process Efficiency(%)	100%	33%	70.70%	23.33%				
Process Cost	0	$4.07	$2.83	$6.90				
Carbon Dioxide (lbs)	0.0	202.0	113.4	315.4				

Sources:

1

Process efficiency Data - U.S. Climate Change Technology Program

2

Heat pump Data - Specification catalogs of 3 geothermal manufacturers

6

Heat pump Data - Department of Energy

Process cost Data - Department of Energy ($0.0999/kW-hr)

Notes:

2,6

COP = Coefficient of Performance

3

Net energy ratio = net energy output/ energy input

4

Fossil energy ratio = net energy output/ fossil energy used

5

Total greenhouse gas footprint (CO_2 equivalent)

Heating Oil

Most Efficient Life-Cycle

		1	2	3	4	5	6			7	8	9
	Energy Input	Extraction From Oil Reservoir	Refining and Distillation of Diesel	Pipeline Transport (750 miles)	Jobber Transport (58 miles)	Retail Transport (20 miles)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	980,000	877,100	875,521	874,033	865,992	822,692		822,881	0.82	6.0	191.6
Total BTU Required	0	20,000	102,900	1,579	1,471	8,041	43,300	177,290				
Fossil BTU Required	0	20,000	102,900	1,579	1,471	8,041	0	133,991				
Process Efficiency (%)	100%	98.00%	89.50%	99.82%	99.83%	99.08%	95.00%	82.27%				
Process Cost	0	$0.16	$1.32	$0.03	$0.03	$0.15	$0.68	$2.37				
Carbon Dioxide (lbs)	0.0	8.1	19.9	1.1	0.3	1.5	160.8	191.6				

Least Efficient Life-Cycle

		10		11								
	Energy Input	In-situ Extraction from Oil Sands	Refining and Distillation of Diesel	Pipeline Transport (750 miles)	Jobber Transport (58 miles)	Retail Transport (20 miles)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	843,000	754,485	753,127	751,997	745,079	581,162		653,766	0.65	4.0	215.3
Total BTU Required	0	157,000	88,515	1,358	1,130	6,918	163,917	418,838				
Fossil BTU Required	0	157,000	88,515	1,358	1,130	6,918	0	254,921				
Process Efficiency (%)	100%	84.30%	89.50%	99.82%	99.85%	99.08%	78.00%	58.12%				
Process Cost	0	$1.16	$1.14	$0.03	$0.02	$0.13	$2.87	$5.35				
Carbon Dioxide (lbs)	0.0	30.1	19.9	2.8	0.2	1.5	160.8	215.3				

Sources:

1,2,10,11

Energy Data - Argonne GREET 1.7 Model

Process cost Data - California Energy Commission

2

Process energy and cost Data - Personal interview with Murphy Oil Refinery

3

Transport energy Data - Embridge Energy Limited Partnership

4,5

Energy Data - Personal interviews with fuel transporters in Wisconsin

Notes:

7

Net energy ratio = net energy output/ energy input

8

Fossil energy ratio = net energy output/ fossil energy used

9

Total greenhouse gas footprint (CO_2 equivalent)

Natural Gas

Most Efficient Life-Cycle

	Energy Input	Extraction From Oil Reservoir (1)	Refining and Distillation (2)	Pipeline Transport (750 miles) (3)	Combustion (4)	Totals	Net Energy Output	Net Energy Ratio (5)	Fossil Energy Ratio (6)	Total GHG emissions (lbs CO_2 eq.) (7)
Total BTU Remaining	1,000,000	980,000	952,560	945,511	917,146		917,146	0.92	16.8	134.1
Total BTU Required	0	20,000	27,440	7,049	28,365	82,854				
Fossil BTU Required	0	20,000	27,440	7,049	0	54,489				
Process Efficiency (%)	100%	98.00%	97.20%	99.26%	97.00%	91.71%				
Process Cost	0	$0.16	$0.17	$0.05	$0.36	$0.74				
Carbon Dioxide (lbs)	0.0	8.1	5.9	2.5	117.6	134.1				

Least Efficient Life-Cycle

	Energy Input	Extraction from Gas Reservoir (8)	Refining and Distillation	Pipeline Transport (750 miles)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	972,000	944,784	937,793	731,478		731,478	0.73	11.8	133.7
Total BTU Required	0	28,000	27,216	6,991	206,314	268,522				
Fossil BTU Required	0	28,000	27,216	6,991	0	62,207				
Process Efficiency (%)	100%	97.20%	97.20%	99.26%	78.00%	73.15%				
Process Cost	0	$0.19	$0.17	$0.05	$2.59	$3.00				
Carbon Dioxide (lbs)	0.0	7.6	5.9	2.5	117.6	133.7				

Sources:

1,2,3,7,8

Extraction, transport, and refining Data - Argonne GREET Model 1.7

Process cost Data - Department of Energy

* Crude oil price ($50.28/bbl)

* N.G. wellhead price ($6.33/MMbtu)

4

Furnace efficiency Data - Department of Energy

Process cost Data - Department of Energy ($12.54/MMBtu)

Notes:

5

Net energy ratio = net energy output/ energy input

6

Fossil energy ratio = net energy output/ fossil energy used

7

Total greenhouse gas footprint (CO_2 eqivalent)

LPG

Most Efficient Life-Cycle

	0 Energy Input	1 Extraction from Gas Reservoir	2 Refining and Processing	3 Pipeline Transport (750 miles)	4 Combustion	Totals	Net Energy Output	5 Net Energy Ratio	6 Fossil Energy Ratio	7 Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	972,000	937,980	932,634	904,655		904,655	0.90	13.4	150.3
Total BTU Required	0	28,000	34,020	5,346	27,979	96,345				
Fossil BTU Required	0	28,000	34,020	5,346	0	67,366				
Process Efficiency(%)	100%	97.20%	96.50%	99.43%	97.00%	90.47%				
Process Cost	0	$0.19	$0.21	$0.08	$0.65	$1.13				
Carbon Dioxide (lbs)	0.0	7.6	5.8	1.0	135.9	150.3				

Least Efficient Life-Cycle

	Energy Input	7 Extraction From Oil Reservoir	8 Refining and Processing	Rail Transport (750 miles)	Combustion	Totals	Net Energy Output	Net Energy Ratio	Fossil Energy Ratio	Total GHG emissions (lbs CO_2 eq.)
Total BTU Remaining	1,000,000	980,000	916,300	908,878	708,925		708,925	0.71	7.8	157.3
Total BTU Required	0	20,000	63,700	7,422	199,953	291,075				
Fossil BTU Required	0	20,000	63,700	7,422	0	91,122				
Process Efficiency(%)	100%	98.00%	93.50%	99.19%	78.00%	70.89%				
Process Cost	0	$0.16	$0.17	$0.14	$4.67	$5.15				
Carbon Dioxide (lbs)	0.0	8.1	11.9	1.5	135.9	157.3				

Sources:

1,2,3,7,8

Extraction, transportation, and refining energy Data - Argonne GREET Model 1.7

Process cost Data - Department of Energy

* Crude oil price ($50.28/bbl)

* Electricity ($0.0578/kW-hr)

* N.G. wellhead price ($6.33/MMbtu)

4

Furnace efficiency Data - Department of Energy

Fuel Cost Data - Department of Energy (LPG at $2.15/gallon)

Notes:

5

Net energy ratio = net energy output/ energy input

6

Fossil energy ratio = net energy output/ fossil energy used

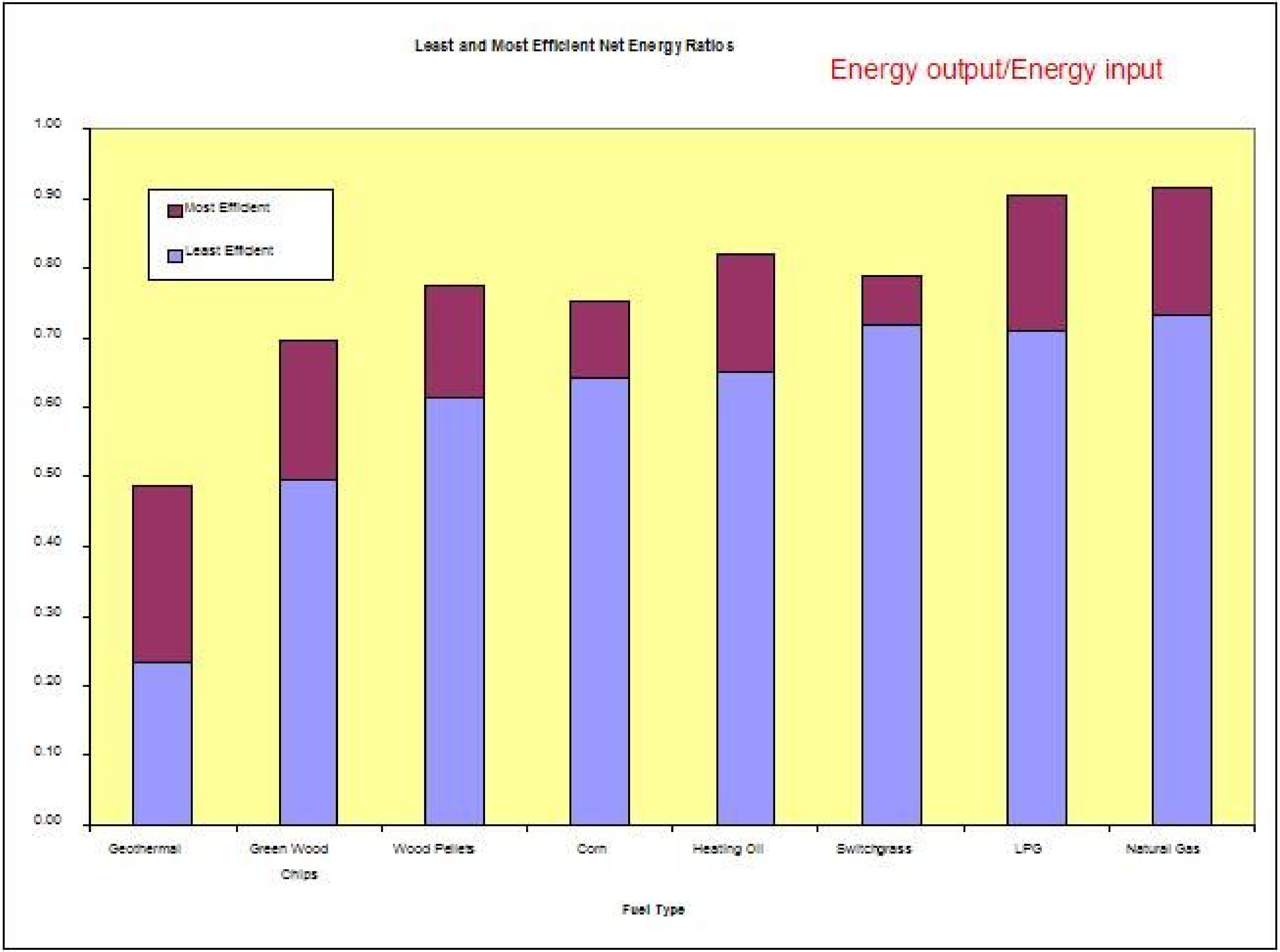
7

Total greenhouse gas footprint (CO_2 eqivalent)

Outcomes

Net Energy Ratios for Wisconsin Space Heating Fuels

Fuel Type	Most Efficient Net Energy Ratio	Least Efficient Net Energy Ratio	Average Net Energy Ratio
Geothermal	0.49	0.23	0.36
Green Wood Chips	0.70	0.50	0.60
Wood Pellets	**0.76**	**0.61**	**0.69**
Corn	0.75	0.64	0.70
Heating Oil	0.82	0.65	0.74
Switchgrass	0.79	0.72	0.75
LPG	0.90	0.71	0.81
Natural Gas	0.92	0.73	0.82
AVERAGES	**0.77**	**0.60**	**0.68**

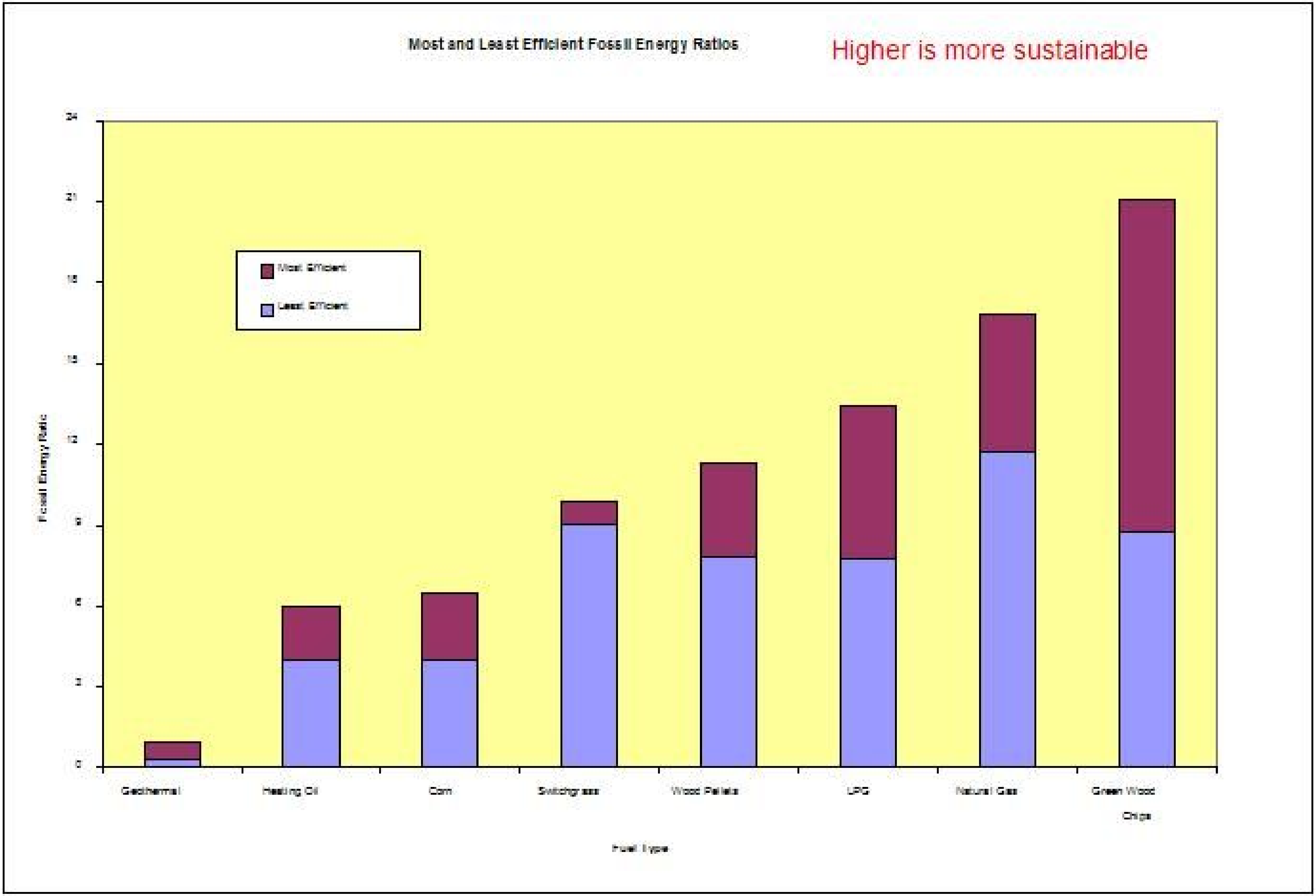


Least and Most Efficient Net Energy Ratios
Energy output/Energy input
Most Efficient
Least Efficient
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Geothermal
Green Wood Chips
Wood Pellets
Corn
Heating Oil
Switchgrass
LPG
Natural Gas
Fuel Type

Outcomes

Fossil Energy Ratios for Wisconsin Space Heating Fuels

Fuel Type	Most Efficient Fossil Energy Ratio	Least Efficient Fossil Energy Ratio	Average Fossil Energy Ratio
Geothermal	1.0	0.3	0.6
Heating Oil	6.0	4.0	5.0
Corn	6.5	4.0	5.3
Switchgrass	9.9	9.1	9.5
Wood Pellets	**11.3**	**7.8**	**9.6**
LPG	13.4	7.8	10.6
Natural Gas	16.8	11.8	14.3
Green Wood Chips	21.1	8.8	14.9
AVERAGES	**10.7**	**6.7**	**8.7**



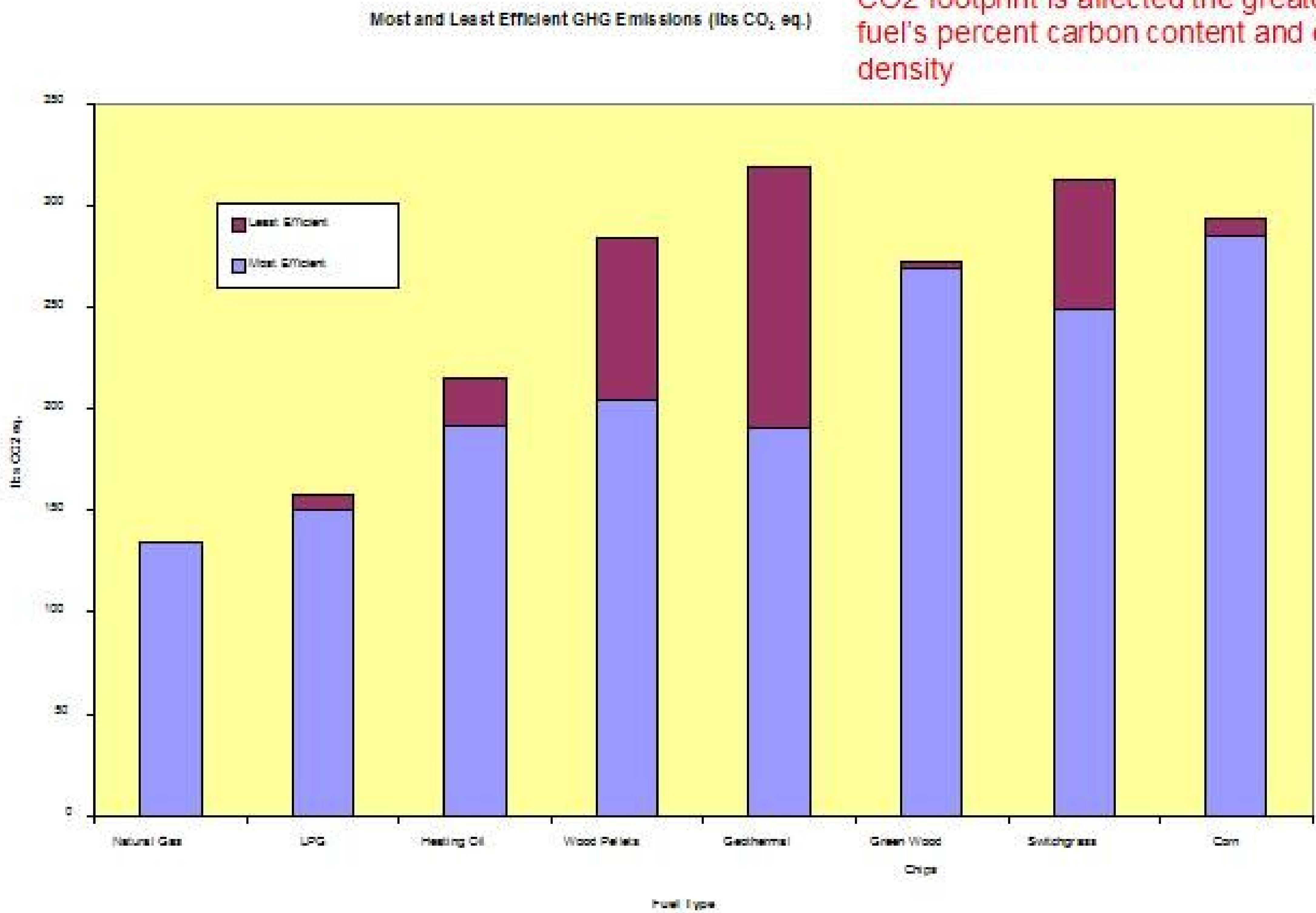
Most and Least Efficient Fossil Energy Ratios
Higher is more sustainable
Most Efficient
Least Efficient
Fossil Energy Ratio
Geothermal
Heating Oil
Corn
Switchgrass
Wood Pellets
LPG
Natural Gas
Green Wood Chips
Fuel Type

Outcomes

Total Life Cycle GHG Emissions for Wisconsin Space Heating Fuels

Fuel Type	Most Efficient GHG Emissions (lbs CO_2 eq.)	Least Efficient GHG Emissions (lbs CO2 eq.)	Average GHG Emissions (lbs CO2 eq.)
Natural Gas	134.1	133.7	133.9
LPG	150.3	157.3	153.8
Heating Oil	191.6	215.3	203.5
Wood Pellets	204.6	283.6	244.1
Geothermal	190.2	315.4	252.8
Green Wood Chips	268.9	272.8	270.8
Switchgrass	249.5	313.0	281.3
Corn	285.1	293.3	289.2
AVERAGES	209.3	248.0	228.7

CO2 footprint is affected the greatest by the fuel's percent carbon content and energy density

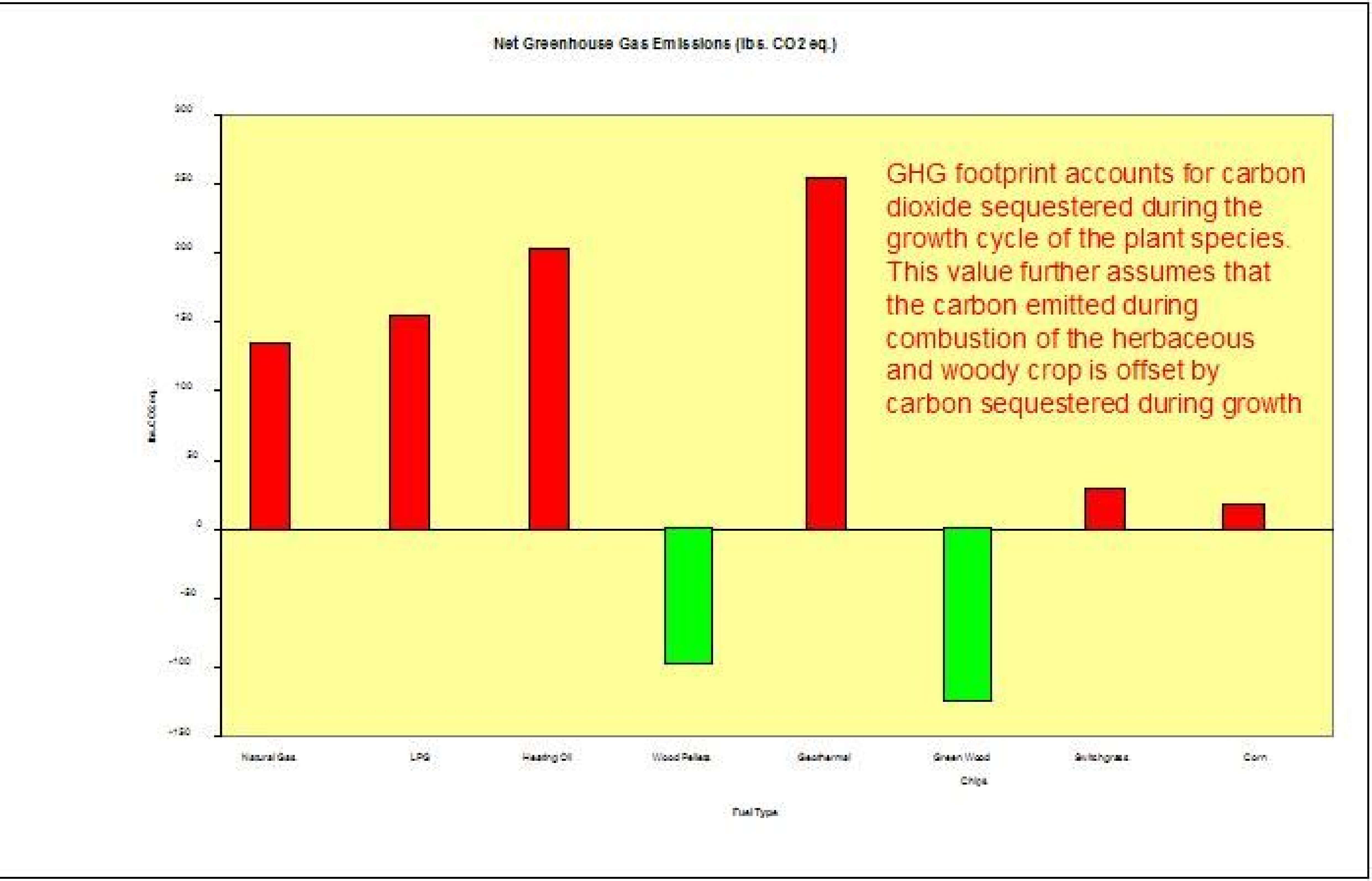


Outcomes

Total LCA Greenhouse Gas Emissions w/o Combustion +

Net Greenhouse Gas Emissions with Combustion

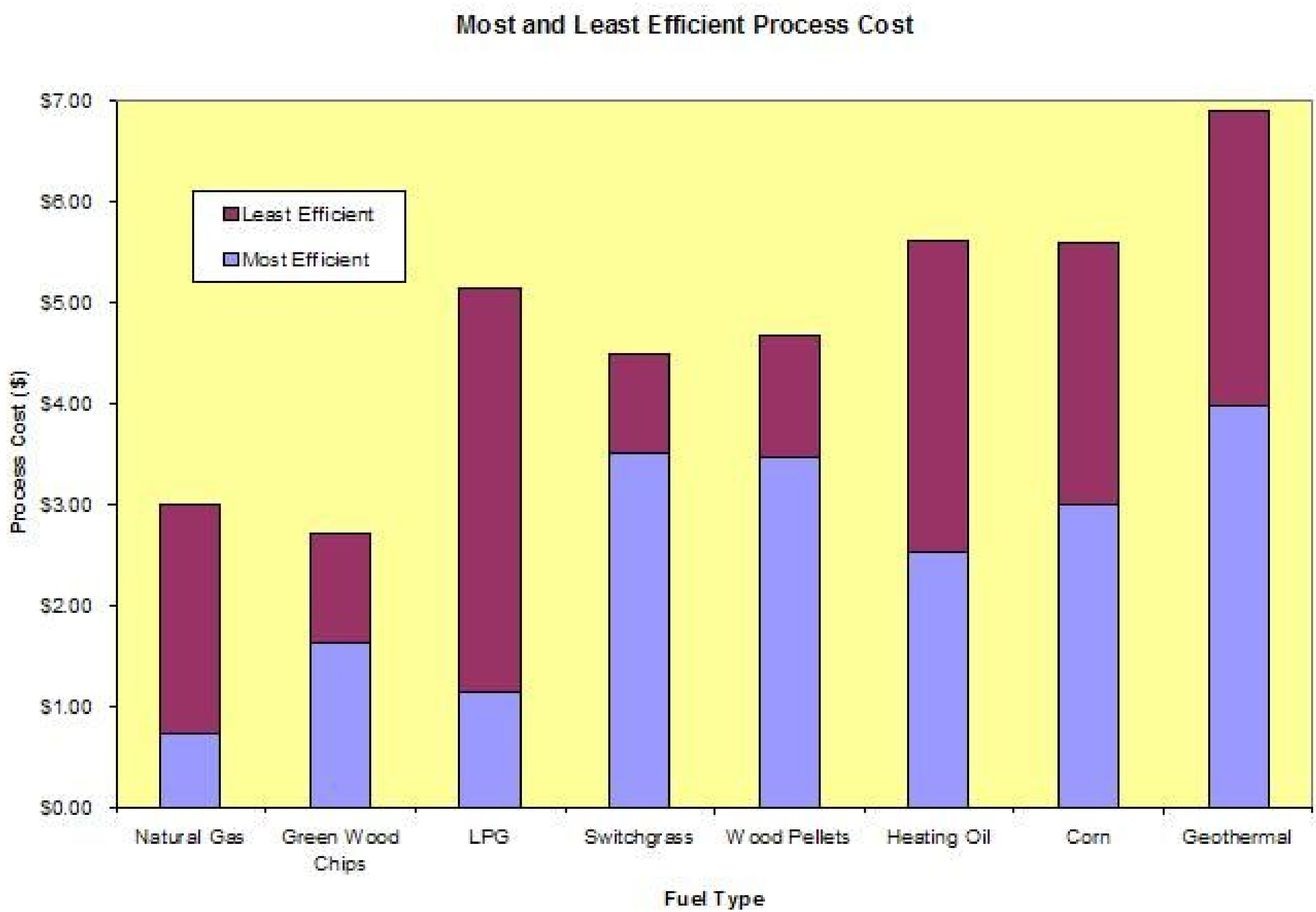
Fuel Type	Most Efficient GHG Emissions (lbs CO_2 eq.)	Least Efficient GHG Emissions (lbs CO_2 eq.)	Average GHG Emissions (lbs CO_2 eq.)	Net GHG Emissions (lbs CO_2 eq.)	
Green Wood Chips	5.3	9.2	7.3	-120.6	
Natural Gas	16.5	16.0	16.2	133.9	
Corn	14.0	22.2	18.1	18.1	-8.1
LPG	14.5	21.4	17.9	153.8	
Switchgrass	26.7	35.9	31.3	29.3	
Wood Pellets	18.0	51.6	34.8	-93.0	
Heating Oil	30.8	54.5	42.7	203.5	
Geothermal	117.6	202.0	159.8	252.8	
AVERAGES	30.4	51.6	41.0		


Net Greenhouse Gas Emissions (lbs. CO2 eq.)
GHG footprint accounts for carbon dioxide sequestered during the growth cycle of the plant species. This value further assumes that the carbon emitted during combustion of the herbaceous and woody crop is offset by carbon sequestered during growth
Natural Gas
LPG
Heating Oil
Wood Pellets
Geothermal
Green Wood Chips
Switchgrass
Corn
Fuel Type

Outcomes

Life Cycle Process Costs for Wisconsin Space Heating Fuels

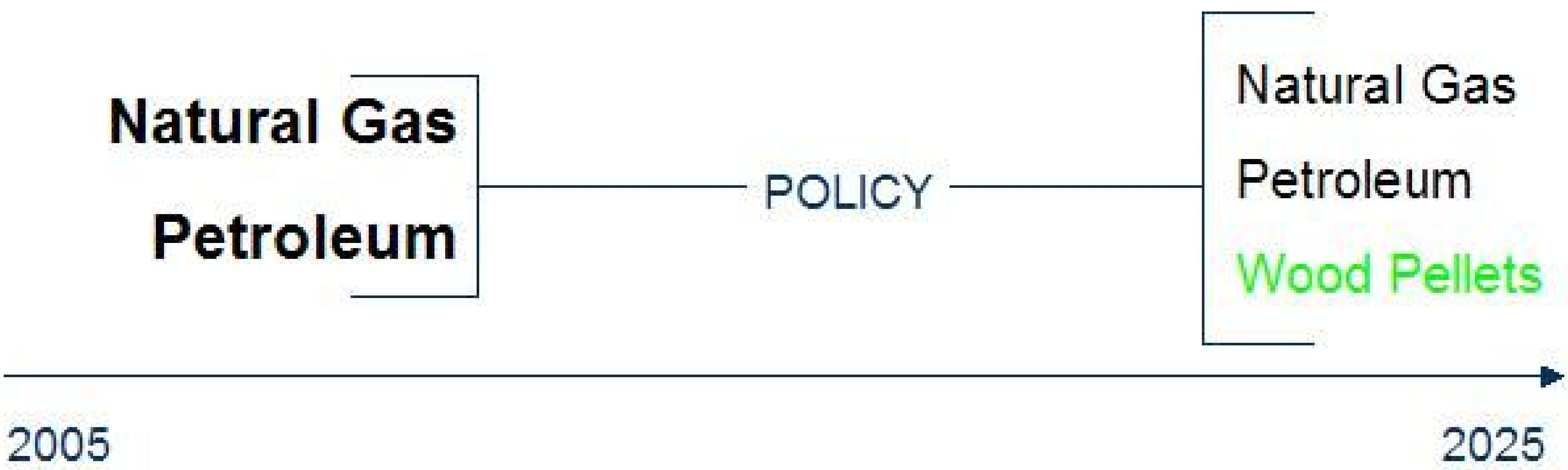
Fuel Type	Most Efficient Life-Cycle Process Cost	Least Efficient Life-Cycle Process Cost	Average Life-Cycle Process Cost
Natural Gas	$0.74	$3.00	$1.87
Green Wood Chips	$1.62	$2.71	$2.17
LPG	$1.13	$5.15	$3.14
Heating Oil	$2.37	$5.35	$3.86
Corn	$2.99	$4.93	$3.96
Switchgrass	$3.50	$4.49	$4.00
Wood Pellets	$3.51	$4.52	$4.01
Geothermal	$3.98	$6.90	$5.44
AVERAGES	$2.48	$4.63	$3.56



Most and Least Efficient Process Cost
Least Efficient
Most Efficient
$7.00
$6.00
$5.00
$4.00
$3.00
$2.00
$1.00
$0.00
Process Cost ($)
Natural Gas
Green Wood Chips
LPG
Switchgrass
Wood Pellets
Heating Oil
Corn
Geothermal
Fuel Type

Sensitivity Analysis

- What if Wisconsin policy offset 25% of all residential petroleum and natural gas used for space heating with wood pellets?



Sensitivity Analysis

Parameter Sensitivity Analysis for LCA GHG Emissions in Wisconsin

Fuel	Projected Values (2025 with current practice)		Projected Values (2025 with 25% wood pellet offset)	
	Energy Total (trillion Btu)	Net Emission Totals (tons CO_2)	Energy Total (Trillion Btu)	Net Emission Totals (tons CO_2)
Natural Gas	161.0	10,774,925	120.8	8,081,194
Petroleum	31.2	2,744,740[a]	23.4	2,058,555
Wood Pellets	0	0	48.1	-2,234,441[b]
Totals	192.2	13,519,665	192.2	7,905,307

a Assumes an average LCA emission value between heating oil and LPG
b Assumes an average emission total for most and least efficient LCA for wood fuel pellets

Sensitivity Analysis Findings

- Decrease of 5,614,357 tons of CO_2
- GHG reduction of nearly 41.5%
  - Most efficient cycle = 44.5% reduction
  - Least efficient cycle = 38.6% reduction

Conclusion

- Wood Pellet Fuels:
  - Possess an average net energy ratio
  - Possess an above average fossil energy ratio
  - Are sustainable and have a negative net CO_2 footprint
  - Have above average LCA costs (as do most renewables)
  - Provide a reasonable alternative to fossil fuel energies in Wisconsin (as they would in many other regions of the US)

Considerations for each US region

- Biomass resource availability
- Importance of combustion efficiencies
- Cost variations of each fuel due to transport
- Variance in carbon sequestration
  - Further environmental impacts (NO_x, SO_x, PM)
- Policy approaches could vary due to above

THANK YOU FOR YOUR ATTENTION!

Josh did a wonderful job and my appreciation goes out to him and the UW-GB for facilitating this project and expanding on it further.

Any further questions feel free to ask or email me at tj@marthwood.com