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Biomass boiler conversion potential in the eastern United States

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ABSTRACT

The U.S. is the world's leading consumer of primary energy. A large fraction of this energy is used in boiler installations to generate steam and hot water for heating applications. It is estimated there are total 163,000 industrial and commercial boilers in use in the United States of all sizes.

This paper characterizes the commercial and industrial boilers in the 37 states of the Midwest, Northeast, and Southern regions of the U.S. in term of number of units, unit capacity, aggregate capacity, and fuel type. A methodology is developed for evaluating and ranking the potential for converting from existing fossil-fuel boilers to biomass boilers in these states.

In total, 3495 oil and coal boiler units in industrial and commercial buildings, and 1067 major wood energy facilities in the 37 eastern states were identified. These represent a subset of existing and potential conversions from fossil fuels to woody biomass. Based on this sample and energy consumption data from the Energy Information Administration (EIA), we estimate that there are currently 31,776 oil, coal, and propane boiler units over 0.5 MMBtus/hour capacity in these 37 states, representing a total energy consumption of 1.7 quadrillion Btus, or roughly the equivalent of 287 million barrels of oil. Were these units all converted to woody biomass fuel, they would consume a total of 121 million dry tons of wood per year, about three times the most recent US DOE estimates of woody biomass availability in those regions. Since only the most economical conversions typically occur, the reality of woody biomass market availability combined with thermal fossil-fuel consumption patterns suggests that roughly one-third of all potential projects could be achieved under sustainable utilization of existing biomass feedstocks in the three regions.

Analysis of the results indicates that a targeted response to wood-conversion initiatives will yield the most successful program of fossil-fuel replacement in thermal applications. A ranking index developed in this study through analysis of existing boiler installations and availability of wood feedstocks suggests that the top ten states in the eastern United States on which to focus future messaging, feasibility studies, and policy development for potential woody biomass conversions are:

1. Maine, 2. Texas, 3. New York, 4. Florida, 5. Georgia, 6. Alabama, 7. South Carolina, 8. North Carolina, 9. Arkansas, 10. Pennsylvania.

1. Introduction

Renewable energy sources are the focal point of major federal and state initiatives to move closer toward energy self-sufficiency in the United States (Table 1). While wind, solar, and hydroelectric power projects have garnered most of the attention in the renewable energy dialogue, the contribution and growth of commercial and industrial wood-based thermal heating projects is helping policy makers to focus attention on the largely-overlooked biomass energy potential in North America. Even as that industry grows and evolves, technological breakthroughs and a history of successful bioenergy products from woody biomass promise to bring more focus on the country's forest resource.

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Data from the U.S. Energy Information Administration illustrate the potential for energy conversion in the country. Fig. 1 below shows the relative amount of energy by fuel type consumed in each of the three regions covered by this study: the Midwest, the Northeast, and the South. While natural gas has inherent advantages in the marketplace that are expected to remain in place for a decade or more, coal and petroleum applications are seen by many as target markets for conversion to woody biomass.

2. Methods

The project began with meetings of the research team to frame the scope of the investigation and identify specific issues within each area of the investigation that required definition and attention. The agency sponsoring the project required the analysis to be limited to the eastern hardwood region of the Eastern United States, which comprises thirty-seven states. These states are differentiated from the remaining, western, states in three primary forest cover characteristics: mostly mixed hardwood/softwood resource, mostly private ownership, and different availability, infrastructure, and demand characteristics. The project sponsors specifically were interested in: how much traditional fossil fuel boiler capacity in these states could potentially be replaced by wood-fired boilers; which fossil fuel boilers were the best targets for replacement; and which states, according to their wood availability, social and political environments, and industrial density would be the best targets for focused promotion of wood-fired boiler potential.

Working from this initial framework, an extensive review of the bioenergy literature was conducted, including all verifiable projects and information found on the Internet and other public sources. This compiled information was combined with a large accumulation of woody biomass energy knowledge previously surveyed and compiled in database format.

Eventually, the project team turned to public (Internet) sources of information and data of all known woody biomass-utilizing operations. All new relevant information was appended to a database that had been established under a previous USFS[5]-sponsored woody biomass energy study. All data sources were included as part of the database. As new records were found for the database, each existing record in the database was re-checked for current status as a validation exercise.

Finally, the resulting database was mined for all records of boiler operations, and combined with the all records of commercial and industrial portions of an EPA [2] database, which can be found independently at http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/html/sum_btu_com.html and http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/html/sum_btu_ind.html.

$$\text{Boiler Energy}_{\text{State.Fuel.CI}} = \begin{bmatrix} \text{Alabama} \\ \text{Arkansas} \\ \vdots \\ \text{West Virginia} \end{bmatrix} \times \begin{bmatrix} \text{Energy}_{\text{commercial}} & \text{Energy}_{\text{Industrial}} \end{bmatrix} \times \begin{bmatrix} \text{Coal}_c & \text{Gas}_c & \text{Oil}_c & \text{Propane}_c & \text{Biomass}_c & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \text{Coal}_I & \text{Gas}_I & \text{Oil}_I & \text{Propane}_I & \text{Biomass}_I \end{bmatrix} \times \begin{bmatrix} 33\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 33\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 33\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 33\% & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 33\% & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 43\% & 0 & 0 & 00 & 00 \\ 0 & 0 & 0 & 0 & 0 & 0 & 43\% & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 43\% & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 43\% & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 43\% \end{bmatrix}$$

3. Theory/calculation

3.1. Identifying wood energy facilities

The project team identified three types of wood energy facilities of interest: wood heating, wood pellets and wood-fired power plants. The information for each type of facility is sourcing from different public databases, including:

- Emission Database for Boiler and Process Heaters, EPA [2].
- North America's Wood Pellet Sector, USDA Forest Service [3].
- Existing and Proposed Wood Biomass Energy Facilities in the Northeastern United States and Nearby Canada, the Wilderness Society [4].
- Bioenergy Markets, Public Policy Developments, and Outlook, the Montgomery Institute [5].
- And various databases found on relevant state public websites.

3.2. Total estimated fuel input

The total fuel input for each type of boiler in each state was estimated using primarily the EIA database [1], and process assumptions found in relevant literature as referenced below. The calculation procedure is simplified by using the following formula.

where:

- Boiler $\text{Energy}_{\text{State.Fuel.CI}}$: e.g. "$\boldsymbol{BoilerEnergy_{PA.Coal,C}}$" is presenting the amount of coal energy (vs. gas, oil propane, biomass) consumed in commercial boilers (vs. I = industrial) in the state of Pennsylvania (PA), expressed in units of "trillion Btu".

[5] USDA Forest Service, Northern Research Station, NRS-01 agreement #07-JV-11242300-150.

- The matrix $[\text{Energy}_{\text{commercial}} \quad \text{Energy}_{\text{Industrial}}]$ represents all energy (excluding electricity) consumed at commercial and industrial facilities.
- The matrix $[\text{Coal}_c \quad \text{Gas}_c \quad \text{Oil}_c \quad \text{Propane}_c \quad \text{Biomass}\ _c00000\ 00000\text{Coal}_I\text{Gas}_I\text{Oil}_I\text{Propane}_I\text{Biomass}_I]$ represents all energy consumed in commercial and industrial facilities by fuel type (data is from referenced EIA websites).
- The matrix $[\text{Coal}_c \quad \text{Gas}_c \quad \text{Oil}_c \quad \text{Propane}_c \quad \text{Biomass}_c\ 00000\ 00000\text{Coal}_I\text{Gas}_I\text{Oil}_I\text{Propane}_I\text{Biomass}_I]$ represents all energy consumed in commercial facility and industrial facility by fuel types, the data is acquired from EIA.
- The matrix

$$\begin{bmatrix} 33\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 33\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 33\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 33\% & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 33\% & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 43\% & 0 & 0 & 00 & 00 \\ 0 & 0 & 0 & 0 & 0 & 0 & 43\% & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 43\% & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 43\% & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 43\% \end{bmatrix}$$

$$\text{Number of boiler}_{\text{state.fuel.CI}} = \frac{\text{Boiler Energy}_{\text{State.Fuel.CI}} \times 1,000,000}{\text{Average Capacity}_{\text{fuel.CI}} \times 365 \times 24 \times \text{Capacity factor}_{\text{CI}}}$$

where:

$$\text{Average Capacity}_{\text{fuel.CI}} = \begin{bmatrix} \text{Coal}_C & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \text{Gas}_C & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \text{Oil}_C & 0 & 0 & 0 & 0 & 0 & 0 & 00 \\ 0 & 0 & 0 & \text{Propane}_C & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \text{Biomass}_C & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \text{Coal}_I & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \text{Gas}_I & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \text{Oil}_I & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \text{Propane}_I & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \text{Biomass}_I \end{bmatrix}$$

$$= \begin{bmatrix} 36.4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 10.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 5.2 & 0 & 0 & 0 & 0 & 0 & 0 & 00 \\ 0 & 0 & 0 & 9.5 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 10.3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 198.0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 27.0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 30.9 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 27.0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 127.3 \end{bmatrix}$$

- indicates 33% of all energy (excluding electricity) is consumed by boilers at commercial facilities and 43% of all energy (excluding electricity) is consumed by boilers at industrial facilities. These two assumptions are made and based on a published report of the Energy and Environmental Analysis Group [6]. These two assumptions are applied to all 37 states with one exception, Texas, where only 10% (not 43%) of propane consumed is attributed to boiler consumption at industrial facilities. The reason is that Texas is the nation's largest consumer of LPG, accounting for nearly three-quarters (71.2 percent) of all industrial LPG used in the nation (WSG [7]). Ninety percent of propane in Texas is used as chemical feedstock, with nearly all of the remaining 10% used to produce energy (WSG [7]). Therefore the 10% assumption number is a better estimate for Texas than the 43% assumption used for the other states.
- The primary data is collected from EIA commercial and industrial energy consumption estimates [1] (excluding electricity) as summarized in Table 2.

3.3. Estimated boilers-of-interest population

Given the "Total Estimated Fuel Input" as described in Section 3.2, the average capacity and capacity factor for each type of boiler fuel are assumed to estimate the number of boilers.

This matrix represents different average capacities for different types of boiler fuel in commercial and industrial facilities. The numbers are assumed based EEA [6] report and adjusted to reduce data discrepancy between year 2005 and 2010. The footnotes "C" and "I" indicate "Commercial" and "Industrial". The numbers are expressed in units of "MMBtu/hr".

$$\text{Capacity factor}_{\text{CI}} = \begin{bmatrix} C & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & C & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & C & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & C & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & C & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & I & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & I & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & I & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & I \end{bmatrix}$$

$$= \begin{bmatrix} 14\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 14\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 14\% & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 14\% & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 14\% & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 47\% & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 47\% & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 47\% & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 47\% & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 47\% \end{bmatrix}$$

Table 1
Comparison between 2007 and 2010 in the proportion of total energy generation derived from renewable sources for the 37 states (adapted from the Energy Information Administration [1]).

State	2007		2010	
	Renewable proportion (Percentage)	Wood proportion	Renewable proportion (Percentage)	Wood proportion
Alabama	10.86	8.89	12.54↑[a]	7.47↓
Arkansas	10.56	7.69	11.14↑	7.08↓
Connecticut	4.29	2.30	5.21↑	2.63↔
Delaware	1.64	0.40	2.38↑	0.94↑
Florida	4.64	3.58	6.92↑	4.02↔
Georgia	6.61	5.71	7.57↑	5.09↓
Iowa	12.90	1.69	22.69↑	1.77↔
Illinois	3.04	0.67	4.85↑	0.76↔
Indiana	2.23	0.91	4.92↑	1.15↔
Kansas	3.04	0.43	6.46↑	0.50↔
Kentucky	3.11	1.56	3.90↑	1.50↔
Louisiana	3.48	3.25	3.02↔	2.29↓
Massachusetts	4.05	2.00	4.50↔	2.11↔
Maryland	3.81	1.57	4.08↔	1.61↔
Maine	34.84	26.15	37.15↑	25.26↓
Michigan	4.57	2.94	5.94↑	3.29↑
Minnesota	7.97	3.33	11.44↑	3.83↑
Missouri	3.03	1.28	4.44↑	1.38↔
Mississippi	5.16	5.08	5.76↑	4.54↓
North Carolina	4.32	3.03	6.93↑	3.83↑
North Dakota	7.18	0.45	17.89↑	0.42↔
Nebraska	8.39	0.93	15.37↑	0.91↔
New Hampshire	12.35	7.12	14.72↑	7.82↑
New Jersey	1.96	0.65	2.42↔	0.76↔
New York	9.86	2.59	11.73↑	2.85↔
Ohio	2.01	1.21	3.29↑	1.43↔
Oklahoma	5.11	1.61	6.62↑	1.63↔
Pennsylvania	2.98	1.91	4.61↑	2.17↔
Rhode Island	3.16	1.36	3.65↔	1.27↔
South Carolina	5.79	4.69	7.84↑	5.10↔
South Dakota	20.89	0.45	34.43↑	0.40↔
Tennessee	5.37	2.39	8.09↑	2.83↔
Texas	2.08	0.71	3.95↑	0.76↔
Virginia	5.10	3.87	5.59↔	3.53↔
Vermont	12.16	7.72	19.72↑	8.54↑
Wisconsin	7.37	4.79	9.96↑	5.41↑
West Virginia	3.35	1.46	5.59↑	1.62↔
U.S. Total	6.39	2.45	8.24↑	2.51↔

[a] Arrows indicate whether the percentage have increased, decreased, or remained within 0.5% range from 2007 to 2010.

This matrix represents the capacity factors for different types of boilers in commercial and industrial facilities. Capacity factors for commercial and industrial boilers are assumed based on the EEA [6] report. Limited by insufficient data on capacity factors, we assume that the capacity factor for various types of boilers are equal, while the differences in capacity between commercial and industrial boilers are more significant than the differences among various types of boilers.

3.4. Conversion potential to wood

This calculation is based on the assumption that one oven-dry short ton of wood is equal to 13.8 MMBtu (Lower Heating Value) of energy input. If the wood used for conversion calculations has a higher average moisture content of wood, more wood on dry ton basis will be needed to provide an equal amount of energy input.

$\text{Wood}_{\text{State.Fuel.CI}} = \frac{\text{Boiler Energy}_{\text{State.Fuel.CI}}}{13.8}$, expressed in unit of million dry ton.

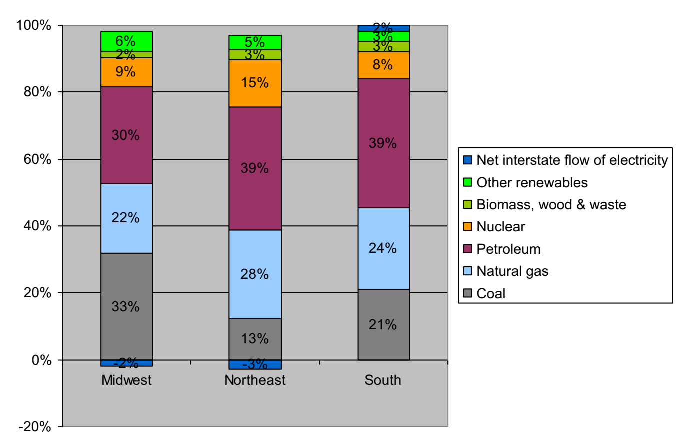

Fig. 1. Sources of energy consumed in 37 states by regions, 2010 (EIA [1]).

Table 2
Commercial and industrial sector energy consumption estimates for 37 midwestern, northeastern, and southern states, EIA [1].

State	Abb.	C/I	Fuel consumption in commercial[a] and industrial[b] sectors (trillion Btu)				
			Coal	Natural gas	Fuel oil	Propane	Biomass
Alabama	AL	Commercial	0	26.9	6.85	2.5	0.8
		Industrial	68.9	167.7	23.7	3.7	135.9
Arkansas	AR	Commercial	0	40.5	4	1.1	1
		Industrial	7.3	89.6	31.95	2.6	72.2
Connecticut	CT	Commercial	0	41.7	13.2	3	0.4
		Industrial	0	24.7	4.2	2.6	3.7
Dist. of Col.	DC	Commercial	0.1	18.8	1.1	0.05	0.05
		Industrial	0	0	0.1	0.05	0
Delaware	DE	Commercial	0	12.5	1.3	1.1	0.1
		Industrial	0	8.2	4.4	0.4	0.05
Florida	FL	Commercial	0	55.4	17.6	8	0.9
		Industrial	21.7	83	60.9	2.8	119.9
Georgia	GA	Commercial	0.2	61.4	6.9	3.7	1.3
		Industrial	31.8	149.7	32.7	5.4	149.5
Iowa	IA	Commercial	5.3	52	2.85	2.5	1.3
		Industrial	66	168.4	34.5	34.8	19.4
Illinois	IL	Commercial	3.4	199.3	5.9	3	1
		Industrial	96.2	261.6	36.35	42	13.2
Indiana	IN	Commercial	6.9	76.2	4.4	2.3	6.7
		Industrial	267.7	281.9	24.3	5.2	10.6
Kansas	KS	Commercial	0	33.8	1.55	1.9	0.6
		Industrial	2.9	126.4	30.8	51.6	0.7
Kentucky	KY	Commercial	1.1	38	2	1.2	1.7
		Industrial	50.2	111.2	35.5	22.1	17.5
Louisiana	LA	Commercial	0	27	5.7	1	0.2
		Industrial	0.5	1069.9	90.8	195.1	90
Massachusetts	MA	Commercial	0	73.5	36.8	2.2	0.6
		Industrial	1.8	44.4	8.3	1.3	4.5
Maryland	MD	Commercial	0.4	69.3	13.75	3.3	2.7
		Industrial	22.6	23.7	7.8	1.6	9.1
Maine	ME	Commercial	0	6.1	15.2	4.6	3
		Industrial	0.9	29.5	15.1	0.2	61.7
Michigan	MI	Commercial	4.4	154.8	7.4	2.6	9
		Industrial	66.8	154.1	20.4	3.2	36.2
Minnesota	MN	Commercial	0.7	90.9	6.2	2.6	2.4
		Industrial	24.8	160	41.1	7.9	34.4
Missouri	MO	Commercial	3.3	61.5	3.15	3.6	3
		Industrial	17.4	65.9	25.4	9.8	4.9
Mississippi	MS	Commercial	0	21.6	3.5	2.1	0.8
		Industrial	2.8	122.7	14.6	2.5	48.5
North Carolina	NC	Commercial	4.5	57.2	11.85	8	2.5
		Industrial	23.1	93.9	31.5	10.6	72.5
North Dakota	ND	Commercial	1.3	10.9	2.55	1.1	0.1
		Industrial	95.7	33.6	37.2	2.5	1.6
Nebraska	NE	Commercial	0	32.3	1.55	0.7	0.5
		Industrial	12.7	85.7	25.1	2.9	4.2
New Hampshire	NH	Commercial	0	8.7	7.8	3.3	0.5
		Industrial	0	6.2	4.7	0.4	1.8
New Jersey	NJ	Commercial	0	186.2	12.8	1.8	3.2
		Industrial	0	49.5	10.8	0.9	4.2
New York	NY	Commercial	0.1	294.1	119.5	6.6	10.6
		Industrial	25.5	77.8	18.6	1.7	15
Ohio	OH	Commercial	5.3	161.8	14.65	3.9	3.4
		Industrial	119	278.1	38.7	5.4	26.7
Oklahoma	OK	Commercial	0	43.1	3.9	1.8	0.5
		Industrial	12.4	256.2	18.8	1.4	21.7
Pennsylvania	PA	Commercial	4.2	146.9	25.2	6.9	4.6
		Industrial	186.5	208.7	39.6	27	31.8
Rhode Island	RI	Commercial	0	10.7	4.6	0.3	0.1
		Industrial	0	8.2	1.6	0.3	0.1
South Carolina	SC	Commercial	0	24.6	3.6	2.7	0.6
		Industrial	23.9	74.9	13.8	1.9	71.6
South Dakota	SD	Commercial	0.2	11.1	1.25	1.4	0.2
		Industrial	2.7	40.5	10.4	1.2	0.2
Tennessee	TN	Commercial	2	57.5	7.1	1.7	1.9
		Industrial	69.5	93.6	12.3	1	50.2
Texas	TX	Commercial	0.3	195.8	15.1	9	3.5
		Industrial	54.4	1568.9	141.5	160.7	62.4
Virginia	VA	Commercial	2	70.7	9	5.8	7.3
		Industrial	72.2	70.1	25	2.2	49.9
Vermont	VT	Commercial	0	2.4	4.4	2.8	0.6
		Industrial	0	2.9	4	0.2	1.7

(*continued on next page*)

Table 2 (*continued*)

State	Abb.	C/I	Fuel consumption in commercial[a] and industrial[b] sectors (trillion Btu)				
			Coal	Natural gas	Fuel oil	Propane	Biomass
Wisconsin	WI	Commercial	2.7	83	4	3.4	4.6
		Industrial	35.1	122.6	22.5	4	57.6
West Virginia	WV	Commercial	0	26.8	1.3	0.8	1.5
		Industrial	63.2	41.1	30.2	0.5	1.4

[a] Data available at: http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/html/sum_btu_com.html.
[b] Data available at: http://www.eia.gov/state/seds/hf.jsp?incfile=sep_sum/html/sum_btu_ind.html.

4. Results

4.1. Composite eastern region overview

Table 3 summarizes the number of boiler installations specifically identified in this study, and the estimated entire population of facilities based upon 1) distribution of known number of boilers in the U.S. to the individual states according to each state's population, and 2) application of the known percentage usage of boiler fuels for commercial and industrial boilers by state to the estimated number of boilers per state calculated by the formula described in Section 3.3. Finally, Table 3 shows the amount of wood necessary to replace all of the boilers in each category.

Fig. 2 illustrates the relative proportion of woody biomass-based heating, power, and pellet production operations by region of the study, based on identification of the major wood consuming energy producers in each state. Fig. 3 shows the relative weight-based proportion of wood each biomass energy sector consumes. While the Midwest and South display similar allocation to energy conversion of woody biomass, the Northeast displays a much higher allocation of wood to electricity production. Most of these wood-to-electricity production facilities are combined heat and power (CHP) facilities and most are near or part of an industrial operation where the heat is being utilized as part of the industrial process. The exception to this is New Hampshire, where eleven dedicated wood power facilities have been in operation since the 1980's.

In researching the uses of different feedstocks with their application category, we identify a target sector for potential conversion projects to biomass thermal. Fig. 4 illustrates the relative percentage of the commercial/industrial thermal sector that calls for further investigation. In it we see that although biomass is currently utilized in 12% of all industrial heating applications and less than 3% of all commercial applications, coal, oil, and propane (an oil-derived gas) account for 31% of industrial and over 17% of commercial applications. By our estimates, this represents a total of 31,776 oil, coal, and propane boilers of interest across the thirty-seven states, with a total energy consumption of 1.665 quadrillion Btu's, or the equivalent of roughly 287 million barrels of oil. When comparing these calculated wood demand requirements to the estimated total available woody biomass in these states (U.S. DOE [8]), it is seen that only about 1/3 of this heating potential can be converted to woody biomass feedstocks under the constraints of feasible and sustainable supply.

Fig. 5 shows the total energy consumption of boilers in commercial and industrial buildings in trillion Btus, and demonstrates the fact that although the number of boilers is much larger in commercial buildings, the energy consumption of the industrial boilers, in aggregate, is nearly five times larger. This reflects the relatively smaller size of boilers in commercial buildings.

Table 3
Summary of thermal energy database compilation and estimations for 37 midwestern, northeastern, and southern states.

Identified wood energy facilities	**Heat** 754	**Electricity** 229	**Pellets** 84	**Total** 1067
Currently identified boilers of interest	**Oil** 2900	**Coal** 595	**Propane** 0	**Total** 3495
Estimated boilers of interest population	**Oil**	**Coal**	**Propane**	**Total**
Commercial	20713	347	3155	24215
Industrial	3510	822	3229	7561
Total estimated fuel input (Trillion Btu)	**Oil**	**Coal**	**Propane**	**Total**
Commercial	135	16	38	189
Industrial	446	670	360	1476
Conversion potential to wood (Million dry tons)	**Oil**	**Coal**	**Propane**	**Total**
Commercial	10	1	3	14
Industrial	32	49	26	107

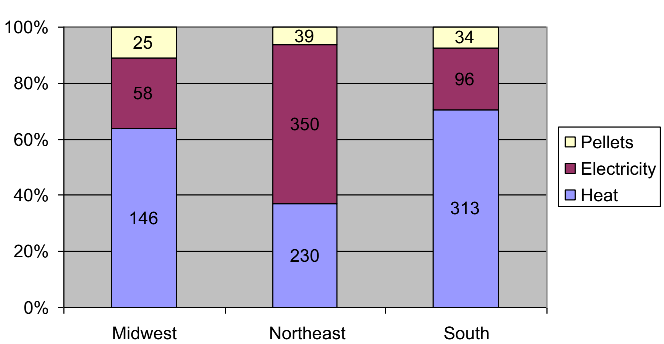

Fig. 2. Major woody biomass energy conversion operations in 37 states – number and percentage of total in region.

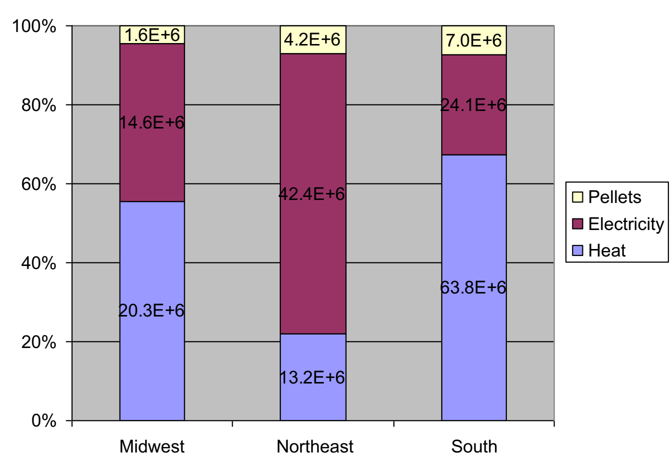

Fig. 3. Percentage and amount of woody biomass (in green tons 50% MC) consumed in the regions by facility type.

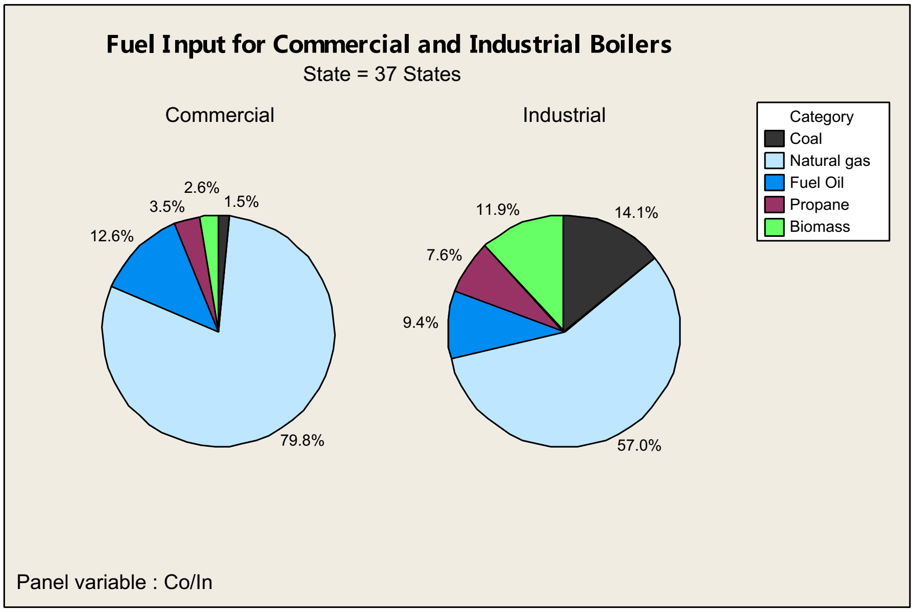

Fig. 4. Fuel consumption percentage, by feedstock, in the commercial and industrial sectors (excluding transportation and electric power) for the 37 easternmost states. Source: EIA [1].

4.2. State-by-state results and analysis

The next stage of this analysis was to disaggregate our 37-state composite analysis into the individual states. While the composite data shows us the potential impact of boiler conversions on a national scale, breaking the data down into the individual states and making side-by-side comparisons allows us to think about the value of messaging, feasibility studies, and policy on a more local scale.

In doing so, we found that different metrics and comparisons can result in different conclusions. For example, Figs. 6 and 7 provide two different ways of ranking the boiler impact of the states. In Fig. 6, which compares the states on the number of boilers in service, we see that Texas and New York stand far above the rest. Also, we observe that the two states are very different in one significant respect; most of New York's 14,000 + boilers are employed in commercial buildings, while more than half of Texas' boilers are utilized in industrial settings. As we know from the previous section, this means that Texas' boilers are much larger, on average, than New York's, and would therefore require a much larger wood resource if converted to woody biomass-based units.

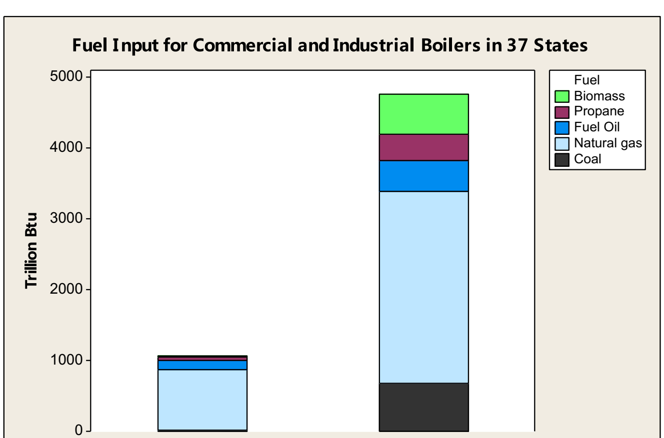

Fig. 5. Fuel consumption, in trillion Btus, by feedstock, in the commercial and industrial sectors (excluding transportation and electric power) for the 37 easternmost states. Source: EIA [1].

However, the figures above include both natural gas and wood in their calculations. We believe that the tremendous surge in natural gas exploration and production, both in the U.S. and other parts of the world, guarantees that the price of natural gas will remain the lowest per Btu of all boiler feedstocks, except coal, for the foreseeable future. At currently prevailing prices, the results of dozens of feasibility studies in various parts of the country show that when natural gas is available to a facility, conversion or implementation of a wood-fired boiler is typically not economically feasible.

Therefore, it is important to analyze the states' boiler capacities not only on a basis of commercial or industrial application, but by feedstock of existing boilers. Fig. 8 shows the relative percentage of each type of boiler feedstock for each state, with the order based on the proportion of wood-fired boilers in each state. The first thing noticeable is the very high percentage of natural gas usage in each state, indicated by the light blue portion of each bar. Generally speaking, more natural gas is used to fire boilers than any other feedstock in the U.S. And, as mentioned above, the continued availability and low price of natural gas is likely to increase that percentage over time.

We used the wood percentages, or green portion of the bars in Fig. 8, to rank the states because it reveals another important aspect of wood conversion feasibility – existing wood markets and acceptability. In those states where existing wood usage for energy is highest, potential projects are more likely to be greeted with a positive response where feasibility comparisons show wood to be competitive, than in those states where wood use is relatively unknown. So one way to interpret Fig. 8 is that, all other operational aspects of a potential project being equal, conversion to wood is most likely to be undertaken in Maine, and least likely to be undertaken in the District of Columbia, and states like Kansas, Delaware, and South Dakota.

The wood-based ranking of states does not necessarily mean that the states will continue to convert to wood at the relative rates indicated by Fig. 8. It simply provides us a strong indication of

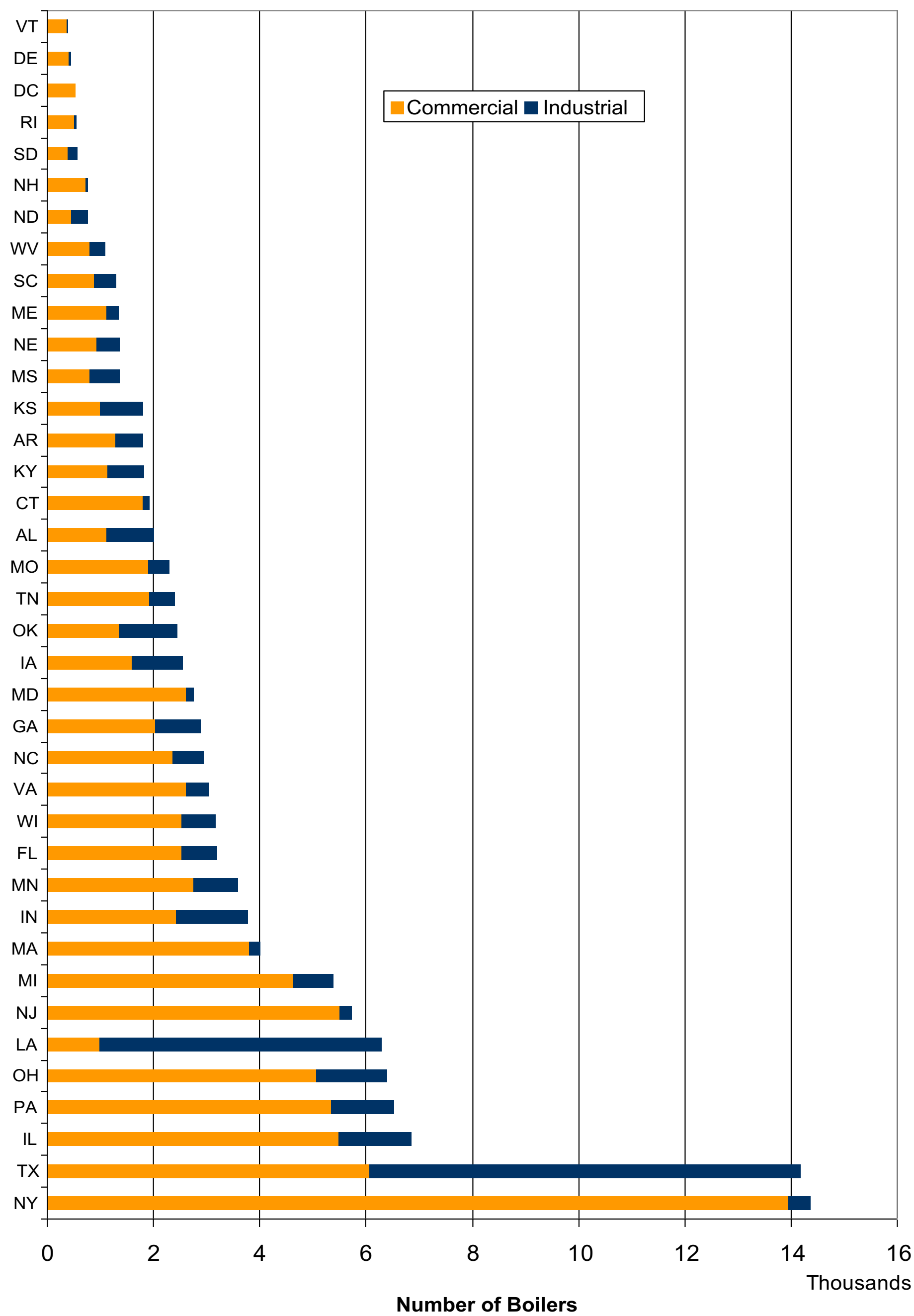

Fig. 6. Total number of commercial and industrial boilers, all feedstocks, for 37 states of the eastern U.S.

where wood-conversion projects are most likely to be successful. An additional step in that type of analysis would be to compare the existing wood consumption in each state to the potential sustainable wood harvest in each state. This type of analysis is complicated by the role of non-energy industrial consumers of wood, and wood supply across state lines, and is beyond the scope of this study.

However, once the relative strength of wood energy markets by state, as shown in Fig. 8, is considered, then we can once again return to the current consumption of boiler feedstock and begin to make some comparisons.

In the following four figures, natural gas boiler capacity is excluded for market reasons, and wood boiler capacity is excluded as already wood. This leaves us with three target feedstocks of interest: oil, coal, and propane. Wood has been shown to be competitive to each in specific case studies. It is on these three target feedstocks that we will then focus our remaining analysis.

First, in Fig. 9, we order the states based on their combined consumption of the three target feedstocks. Once again, Texas appears to be a prime candidate state for more wood conversion. However, in Fig. 8 above we see that Texas ranks very low on percentage of installations fired by wood. This in spite of the fact that Texas has a huge timber resource in the state that is being less consumed now than at any time in the last hundred years, and that non-energy industrial consumption of wood is likely to decline.

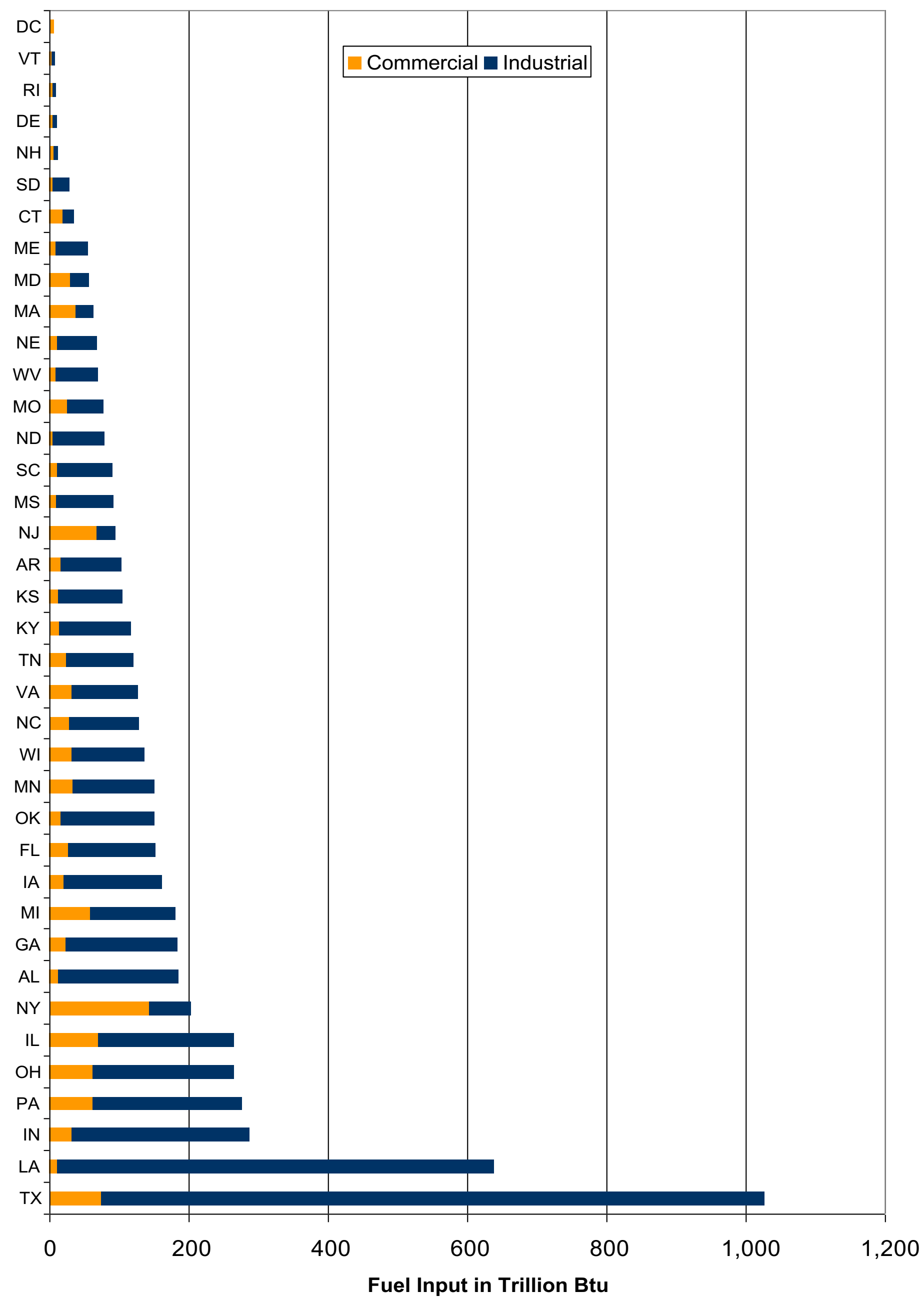

Fig. 7. Total fuel consumption of commercial and industrial boilers, all feedstocks, for 37 states of the eastern U.S.

Most of this apparent market contradiction is explained by the fact that the primary industrial centers of Texas lay a considerable distance from the forest resource. The sprawling Dallas-Fort Worth area is, at its closest point, more than an hour from the edge of the forest resources of East Texas, as is the Houston metropolis and the heavily-industrialized oil refining centers of the Gulf Coast. And, since Texas has been historically, and continues to be, a leading producer of oil and natural gas, and natural gas pipelines are dense in the industrial centers, wood will continue to remain a minor player in Texas industrial operations. However, referring again to Fig. 6 in the earlier section of this report, we see that Texas is the second largest eastern state in terms of the number of boilers in commercial building installations. Unfortunately, none of the major population centers of Texas lie in the forests of East Texas, with the exception of the northeastern fringes of Houston.

Finally, most of the wood energy interest in Texas has been centered around investments in wood-fired power. Although less efficient than wood-fired thermal energy, wood-fired power generation makes more sense in Texas (and Louisiana) than the other eastern states simply because of the long distance of the huge forest resource from large population centers. Without significant local heat demand, and in the face of declining consumption of wood by the existing timber and pulp and paper industries, wood-based power may yield a return simply as the best use of a large, underutilized natural resource.

Fig. 10 provides us with a different perspective of wood-boiler conversion potential. Here we have ordered the states

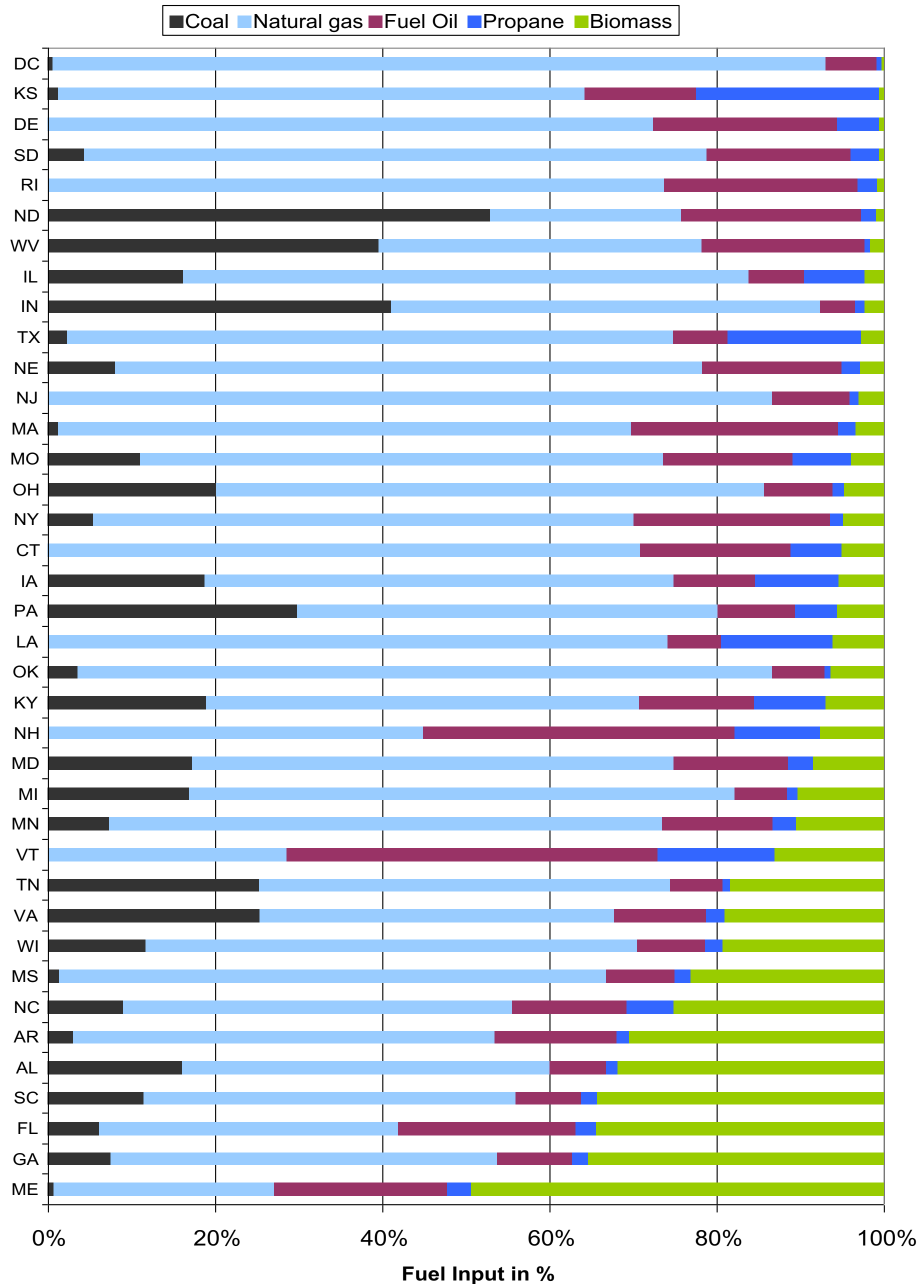

Fig. 8. Estimated relative proportion of fuel feedstocks for commercial and industrial heating applications, by state.

not by fuel consumption, but by total number of boilers in each state. When viewed in this perspective, New York once again becomes a focus because of the huge number of commercial boilers in the state.

Unlike Texas, New York urban centers, where these commercial boilers function, are relatively close to wood resources, as most of New York is partially forested in mixed hardwoods. New York has a different set of problems, though, as far as boiler conversions to wood go. It has perhaps the second most stringent set of air emissions regulations in the country next to California for commercial and industrial point sources of emissions. Further, it has perhaps the most stringent set of harvesting regulations in the eastern states, with multiple overlapping sets of regulations at the state and local levels. The net effect of this is perhaps the highest wood prices in the U.S. Nevertheless, wood boilers are popular in the more rural regions of New York, and the potential of converting New York commercial buildings to “green building showcases” based in part on high-efficiency and clean wood-fired boilers remains high.

Massachusetts is a surprising third on the list of Fig. 10. The population-dense eastern half of the state has historically been a place where oil boilers have been popular. This popularity was tested by the oil embargos of the 1970’s and more recently, by the oil price spikes of the first decade of this century. When we reference Fig. 9, we see that Massachusetts ranks low in total fuel consumption for this high number of boilers, meaning they have a relatively small average size, also meaning that they could very well be strong candidates for conversion. However, the low existing percentage of wood as a

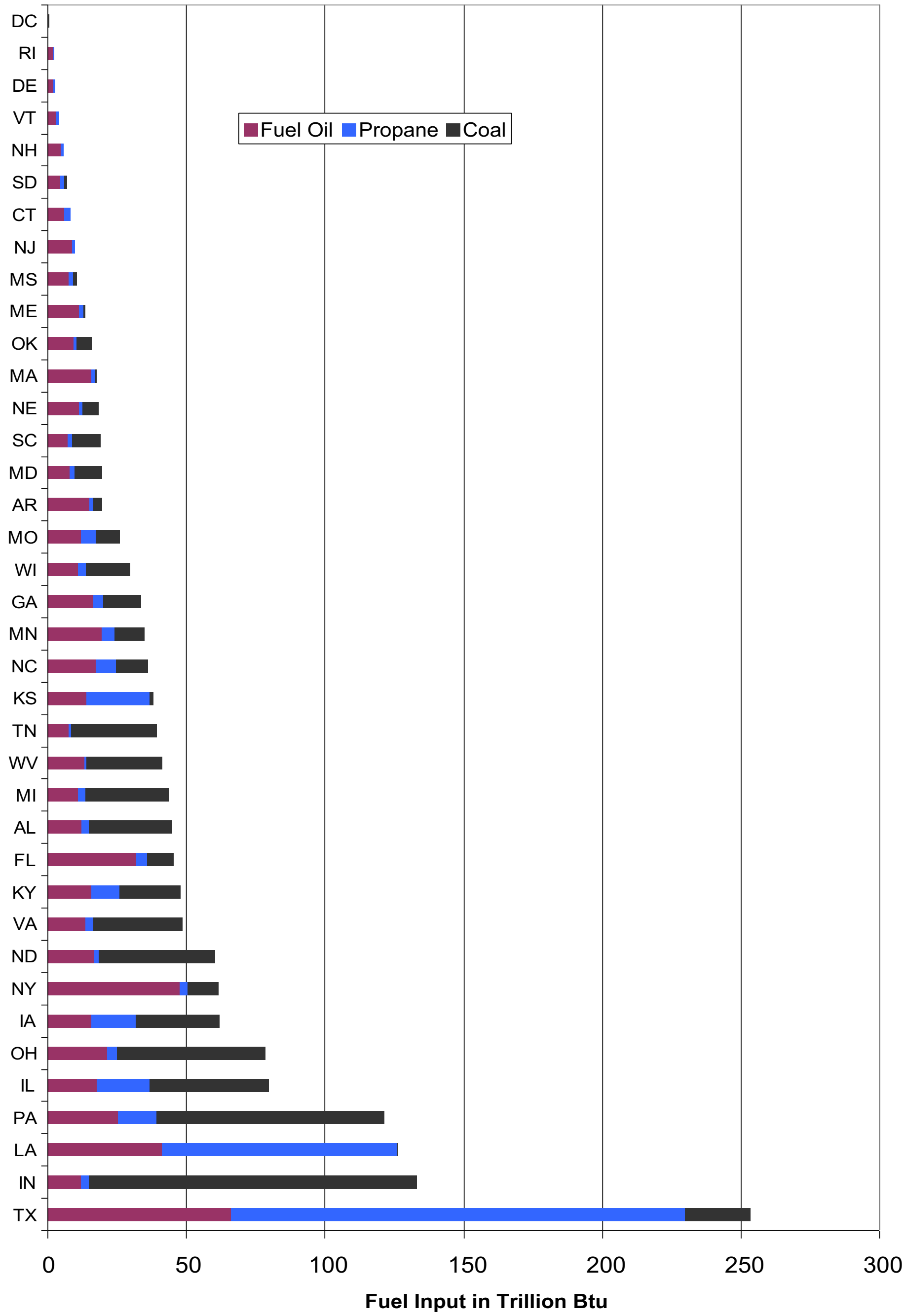

Fig. 9. Total fuel consumption of commercial and industrial boilers, oil, propane, and coal, for 37 states of the eastern U.S. (Penn State Wood Operations Laboratory, based on statistics from the EIA, 2010).

boiler fuel as shown in Fig. 8 points again to a strong regulatory environment that tends to work against wood installations in the state. Nevertheless, Massachusetts renewable energy targets, in combination with recent state efficiency requirements that essentially eliminate biomass power production from consideration in the state, means that high-efficiency boiler installations should increase as a percentage of thermal applications in the future.

Fig. 11 shows the states ranked by combined oil and propane consumption, and Fig. 12 shows them ranked by coal consumption. From a material handling standpoint, coal installations may be more easily convertible to wood than oil and propane installations. Also, coal is more heavily regulated by state and federal air emission departments and operators of coal boilers may be more open to the idea of boiler conversion to a "green" fuel. However, from an economic standpoint, oil and propane boilers are the better target for conversion to wood, as the cost of these fuels is higher per Btu than wood and will probably remain so. In this case, the ranking of Fig. 11 may be a better indicator of where successful conversions to wood may succeed.

4.3. A potential composite ranking system of wood energy conversion potential

Given the many different ways boiler conversion potential may be viewed, we have produced Table 4, which reflects a weighted

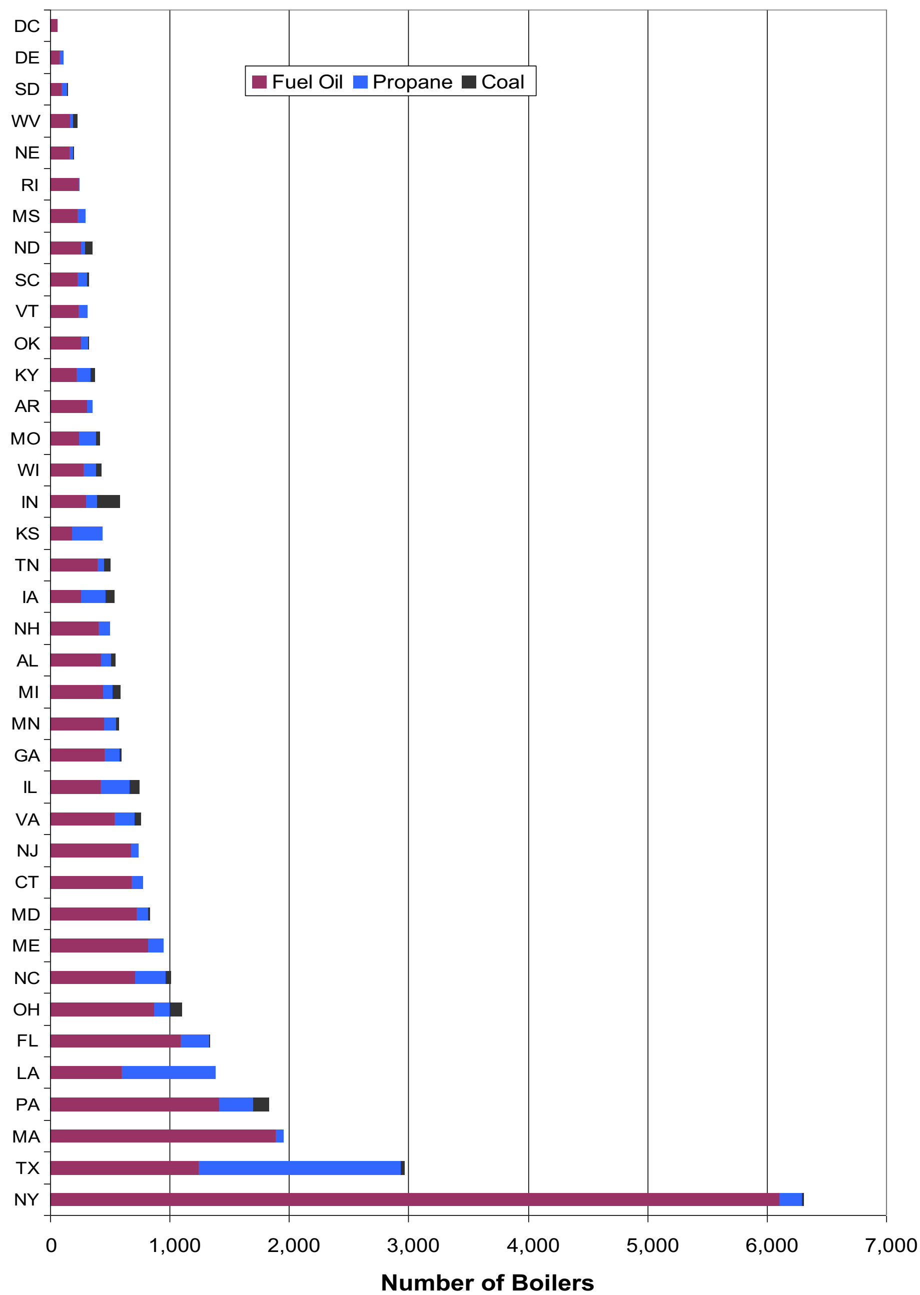

Fig. 10. Total number of commercial and industrial boilers, oil, propane, and coal, for 37 states of the eastern U.S.

index ranking based 25% on the number of boiler, 25% on fuel input requirements, and 50% on percentage of current boiler capacity fueled by wood, which is used as a general wood market indicator. The result is one view of boiler conversion potential to woody biomass, as evaluated and ranked according to the methodology presented in this paper.

5. Conclusions

The New England states have been more inclined to utilize wood for electricity, wood pellet production has been more focused in the Mid-Atlantic and Gulf regions, and wood combustion for heat is common throughout the entire Northeast, South, and Lake States regions. In total, this study identified 1067 wood-based energy facilities in the eastern United States. These 1067 facilities together consume roughly 86.2 million dry tons of wood per year.

The focus of this study was to estimate the population of oil, coal, and propane-fired commercial and industrial boilers in the eastern 37 states as potential targets for conversion to wood. Using data compiled from EIA sources, we found that coal, oil, and propane (an oil-derived gas) still account for 25% of all boiler installations. By our estimates, this represents a total of 31,776 oil, coal, and propane boilers of interest across the thirty-seven states, with a total energy consumption of 1.665 quadrillion Btu's, or the equivalent of roughly 287 million barrels of oil.

Conversion of all of these installations to wood would require approximately 121 million dry tons of wood. However, since the most recent estimate of available woody biomass for energy by the

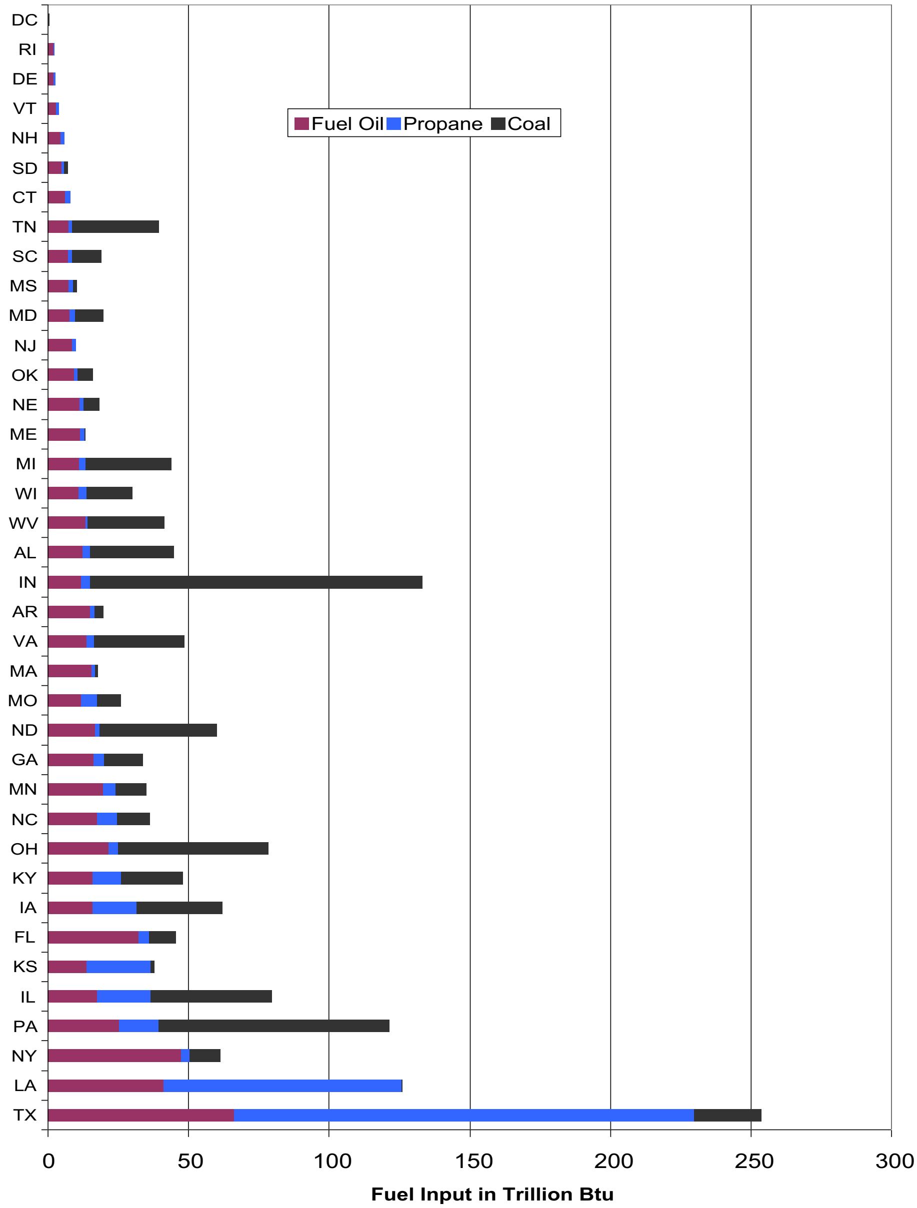

Fig. 11. Total fuel consumption of commercial and industrial boilers, oil, propane, and coal, for 37 states of the eastern U.S, ranked by combined oil and propane consumption.

Department of Energy in the 2011 Billion-Ton Update [8] is only roughly 80-100 million tons per year (assuming a mix of 50% logging residue and 50% forest thinnings)[6] for the entire United States. When available logging residue amounts and simulated forest thinning volume estimates for the 37 eastern states included here are separated out, the Billion-Ton Update suggests we can convert only about one-third of these targeted boiler systems (requiring roughly 40 million dry tons) at sustainable levels of biomass harvesting.

Traditionally, the conversion of oil, coal, and propane thermal heating systems to wood-fired systems has been undertaken in rural, forested areas of the country where availability of woody biomass is high and inexpensive. However, when the entire population of oil, coal, and propane-fired commercial and industrial boilers is surveyed, it becomes apparent that the best opportunity for further conversion projects may be in highly-populated areas that have an abundance of commercial and industrial development and are fairly near to abundant sources of woody biomass.

The toughest constraint against the development of an economical biomass supply chain is the low density of customers in an area attempting to procure wood. Were biomass project opportunities approached in clusters where commercial and industrial coal, oil, and propane boilers are plentiful and dense, potential suppliers would be able to optimize delivery economics and potential customers would be able to acquire a less costly non-fossil fuel for their thermal heating applications. The data accumulated and analyzed in this study support the notion that perhaps wood biomass conversion projects have the greatest potential impact in high-density population centers, not the traditional rural locations where wood bioenergy is normally utilized. However, we expect to

[6] The full set of assumptions used to estimate forest residue sustainable levels of forest residue utilization in the 2011 U.S. Billion Ton Update can be found in Table 3. 1 of that report and include the assumptions that 30 percent of logging residue is left onsite to provide for ecological sustainability and that no stumpage costs will be associated with residual biomass removal on federal lands.

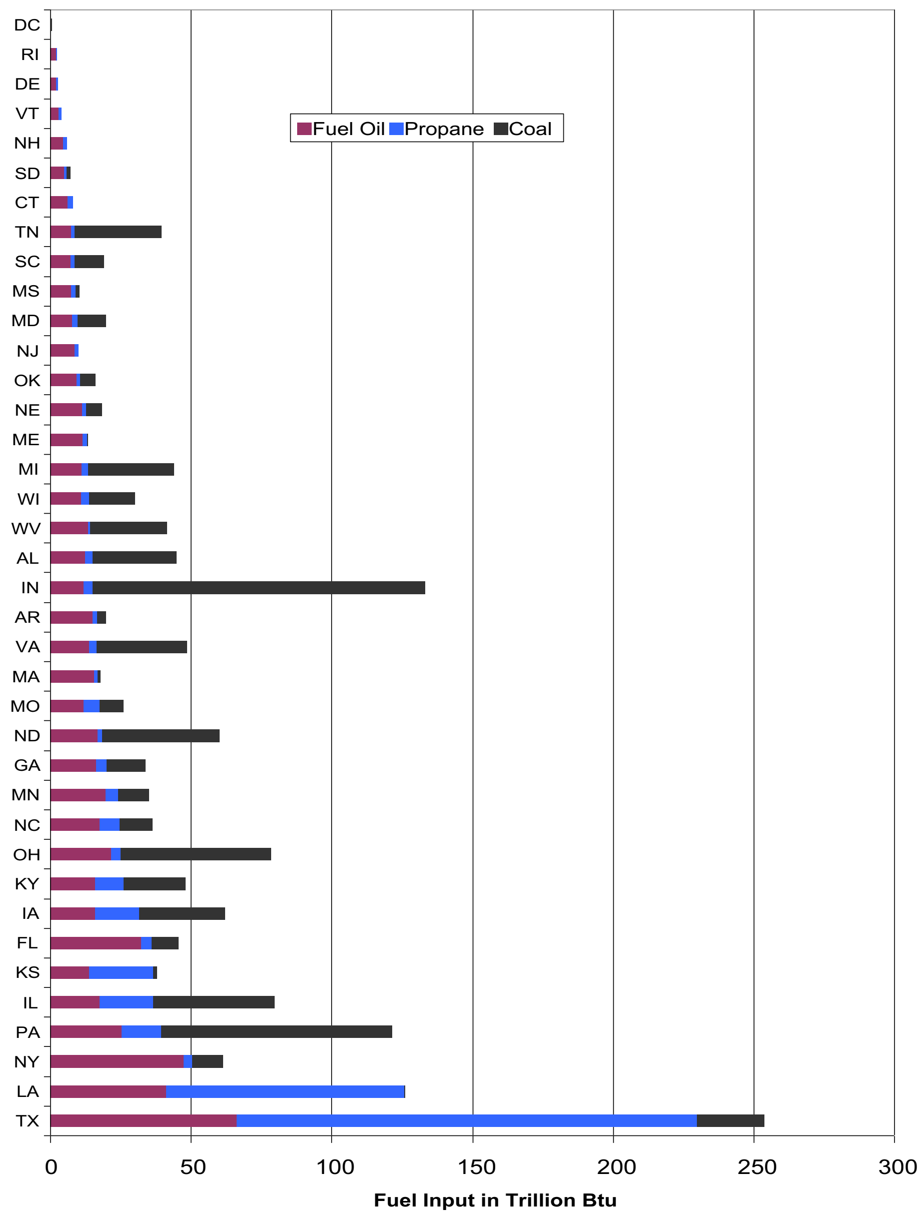

Fig. 12. Estimated relative proportion of fuel feedstocks for commercial and industrial heating applications, by state, ranked by coal consumption.

Table 4
Boiler conversion potential to wood of each state, listed by overall weighted rank.

State	Rank by # of boiler[a]	Rank by fuel input[b]	Rank by % of biomass[c]	Weighted overall rank[d]
Maine	9	29	1	1
Texas	2	1	29	2
New York	1	8	23	3
Florida	6	12	3	4
Georgia	15	20	2	5
Alabama	19	13	5	6
South Carolina	29	25	4	7
North Carolina	8	18	7	8
Arkansas	28	23	6	9
Pennsylvania	4	4	20	10
Louisiana	5	3	19	11
Virginia	12	10	10	12
Tennessee	22	16	11	13
Mississippi	32	30	8	14
Wisconsin	24	21	9	15
Indiana	17	2	30	16

Table 4 (*continued*)

State	Rank by # of boiler[a]	Rank by fuel input[b]	Rank by % of biomass[c]	Weighted overall rank[d]
Ohio	7	6	24	17
Michigan	16	14	14	18
Massachusetts	3	27	26	19
Minnesota	18	19	13	20
Illinois	13	5	31	21
Iowa	20	7	21	22
Maryland	10	24	15	23
Kentucky	26	11	17	24
Vermont	31	35	12	25
New Hampshire	21	34	16	26
Connecticut	11	32	22	27
North Dakota	27	9	33	28
Oklahoma	30	28	18	29
Missouri	25	22	25	30
New Jersey	14	31	27	31
West Virginia	34	15	32	32
Kansas	23	17	37	33
Nebraska	35	26	28	34
Rhode Island	33	37	34	35
South Dakota	36	33	35	36
Delaware	37	36	36	37
Dist. of Col.	38	38	38	38

[a] Rank by the number of boilers fueled with coal, oil and propane in commercial and industrial sectors.
[b] Rank by the corresponding fuel inputs of the boilers specified above.
[c] Rank by the percentage of biomass energy consumed among all energy (excluding electricity) at commercial and industrial facilities.
[d] Rank by the weighting of boiler number (25%), fuel input (25%) and biomass percentage (50%).

see rural operations continue to lead the way in conversion to wood-firing.

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