An Analysis of the Projected Energy Use of Future Dry Mill Corn Ethanol Plants (2010-2030)

Prepared for:
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Introduction

The Illinois Corn Marketing Board and the ProExporter Network have retained the University of Illinois at Chicago to conduct an analysis of the energy use of future dry mill corn ethanol plants operating between the years 2010 through 2030. This report details the results of this effort. This analysis, combined with data on agricultural efficiency improvements compiled by the ProExporter Network will form the basis to study changes in the global warming intensity of corn ethanol resulting from future production practices.

Several sources provide a good indication of current ethanol plant energy conversion efficiencies. ICM, Inc. a major ethanol plant process developer currently provides process guarantees for new natural gas fired ethanol plants in the range of 32,000-34,000 Btu/gal (thermal energy) and 0.75 kWh/gal (electricity) with 100% DDGS drying and 22,000 to 24,000 Btu/gal without DDGS drying.[1] Mueller and Cuttica (2006) as well as Energy and Environmental Analysis Inc. (2006) expect the current coal fired ethanol plant conversion efficiency to be around 40,000 Btu/gal (thermal) and 0.9 kWh/gal (electricity). Data by Life Cycle Associates (2007) expects certain biomass conversion technologies to be in the same range as coal fired ethanol plants.[2] Looking at the time frame of this study (2010-2030), these conversion efficiencies will experience an adjustment based on ethanol plants choosing different primary energy feedstocks (coal, natural gas, biomass), different energy system configurations (adoption of combined heat and power technologies), improvements to energy equipment (boilers, motors, etc.), and adjustments to the dry mill processes. The various adjustments to ethanol plant conversion efficiencies will be discussed followed by an analysis of their impact on the currently prevailing thermal and electricity requirements at ethanol plants.

Projected Fuel Feedstocks and Plant Energy System Configurations

Based on projected cost reductions for biomass based energy systems as well as a likely valuation of carbon in the fuel, more ethanol plants are expected to switch to this energy source. Biomass-based fuel is either provided as solid fuel for boilers or gasifiers or converted to biogas in integrated biogas energy systems using wet cake or manure from animal feedlots as a biomass source. For example, E3 BioFuels in Nebraska produces biomethane from digested manure and thin stillage. Panda Ethanol Inc. plans to gasify cattle manure for process heat at its Hereford, Texas, facility that is currently under construction. Existing producers are retrofitting their plants to gasify wood waste or combust syrup, like Central Minnesota Ethanol Co-op and Corn Plus, respectively. Some

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[1] A by-product of the ethanol process, distillers wet grain (DWG) or distillers wet grain with solubles (DWGS, thin stillage left from the centrifugation process is added back in) may be used as animal feed. In order to increase the shelf life of DWG(S), many ethanol plants currently elect to dry DWG(S) to produce an animal feed called distillers dried grain with solubles (DDGS).

[2] Certain biomass plants use similar equipment as coal fired plants (use of fluidized bed boilers, solid fuel handling systems, etc.)

of these companies are already replicating these biomass technologies in plants under development.

In addition to the type of primary feedstock used at the ethanol plant, energy systems can also differ by configuration. The majority of plants currently employ natural gas boiler technologies. However, several plants utilize combined heat and power technologies (chp). These technologies allow ethanol plants to generate a significant part of the plant's electricity needs onsite and utilize the otherwise wasted heat from electricity generation to meet process (thermal) energy requirements.

Table 1 shows the projected changes to the primary energy feedstock and energy system configuration at ethanol plants over time. The base year (2007) numbers are taken from an industry survey conducted by Ethanol Producers Magazine (June 2006) adjusted by ethanol plant construction data provided by the Renewable Fuels Association and a study by Mueller and Cuttica (2006).[3,4,5] For example, while currently 88% of ethanol plants utilize natural gas fired boiler technologies, the relative use of natural gas boiler technology is expected to decline by 2030 and natural gas boiler plants will constitute only 31% of the total stock of plants. The decline in natural gas boilers is expected to be due to increased use of biomass (combustion, gasification, integrated biogas systems) as well as increased deployment of natural gas chp plants. The diffusion rates over time are largely estimated from the rates at which projects get announced in each category. For example, Panda Energy announced this year that it is in development of four manure fueled ethanol plants, which, together with another company's (Prime BioSolutions) indication of future joint ventures (www.e3biofuels.com) in this field resulted in a relatively high diffusion rate of integrated biogas energy systems.

Table 1: Projected Diffusion of Primary Energy Feedstocks and Energy System Configurations

	2007	**2010**	**2015**	**2020**	**2025**	**2030**
Natural Gas Boiler	88%	77%	65%	54%	42%	31%
Natural Gas CHP	4%	6%	8%	11%	13%	15%
Coal Boiler	0%	0%	0%	0%	0%	0%
Coal CHP	4%	4%	4%	4%	4%	4%
Biomass Boiler*	2%	5%	7%	10%	12%	15%
Biomass CHP*	1%	4%	7%	9%	12%	15%
Integ. Biogas Energy System	1%	5%	9%	12%	16%	20%
Sum:	100%	100%	100%	100%	100%	100%

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[3] "Process Heat and Steam Alternatives Rising"; Dave Nilles, Ethanol Producer Magazine, June 2006.

[4] Renewable Fuels Association. Ethanol Industry Overview. http://www.ethanolrfa.org/industry/statistics/#EIO

[5] "Research Investigation for the Potential Use of Illinois Coal in Dry Mill Ethanol Plants"; Report to the Illinois Clean Coal Institute, Mueller and Cuttica, October 2006.

Projected Energy Equipment Technologies

Technologies that are currently in various stages of the commercialization process will increase the efficiency of currently utilized energy generating and conversion equipment such as natural gas and coal boilers, combustion turbines, motors, fans, and pumps. For example, significant boiler improvements may come from technology programs such as the US DOE Super Boiler Program and the development of new combustion control technologies (tunable diode laser sensors, new high efficiency burners, and others), whereas efficiency improvements of motors will come from increased deployment of technologies like NEMA Premium efficient motors and advanced motor monitoring and diagnostic systems (i.e. sensors that measure current and voltage and integrate with advanced energy management systems).[6]

Table 2 below shows the expected improvement of current energy equipment technologies. Data for boilers are based on an assessment of the success of DOE's Super Boiler program, which is expected to produce a "family of future generation Super Boilers" with 94% efficiency by 2020.[7] The data in the table takes the expected diffusion and commercialization of this technology into account. Expected efficiency improvements to electrical equipment used at ethanol plants is expected to track the diffusion of NEMA Premium Efficiency motors. Ethanol plants utilize a significant amount of high horsepower motors (in excess of 100 hp) for induced draft fans, dryer motors etc. and NEMA Premium Efficiency motors are expected to be adopted widely and thus reduce electricity consumption of ethanol plants.[8] The efficiency of distributed electricity generating equipment (10 MW Industrial Turbine, the size that would be installed in a 100 mgpy plant) is taken from US DOE projections available through 2020 and held conservatively constant during the outer years.[9] Central power plant efficiencies are taken from EPA eGrid data and efficiency improvements are expected to track improvements projected for the 10 MW turbine.

Table 2: Projected Energy Equipment Efficiencies

	2007	2010	2015	2020	2025	2030
Boiler, Efficiency (HHV)	82.0%	83.0%	86.0%	90.0%	94.0%	94.0%
Energy Savings rel. to Base Year		1.2%	4.7%	8.9%	12.8%	12.8%
Motor, Efficiency	90.0%	91.0%	92.0%	93.0%	95.0%	95.0%
Energy Savings rel. to Base Year		1.1%	2.2%	3.2%	5.3%	5.3%
10 MW Industrial Turbine, Efficiency (HHV)	31.0%	32.0%	33.0%	34.0%	34.0%	34.0%
Energy Savings rel. to Base Year		3.1%	6.1%	8.8%	8.8%	8.8%
Central Power Plant, Efficiency (HHV)	30.5%	31.5%	32.5%	33.5%	33.5%	33.5%
Energy Savings rel. to Base Year		3.1%	6.1%	8.8%	8.8%	8.8%

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[6] US Department of Energy Industrial Technologies Program. "US DOE Energy Technology Solutions: Public Private Partnerships Transforming Industries"; June 2006

[7] US Department of Energy Industrial Technologies Program. "Super Boiler – First Generation, Ultra-High Efficiency Firetube Boiler"; June 2007.

[8] Personal conversation with the US DOE Industrial Assessment Center at University of Illinois at Chicago.

[9] US Department of Energy, Office of Energy Efficiency and Renewable Energy Programs. "Projected Benefits of Federal Energy Efficiency and Renewable Energy Programs FY 2005 – FY 2050"; Prepared by the National Renewable Energy Laboratory, May 2004, Chapter 5, p. 5-9

Projected Dry Mill Corn Ethanol Processes

The traditional dry mill ethanol process consists of the following steps: Corn is ground and slurried with water and enzymes (alpha amylase), followed by cooking of the slurry to gelatinize and liquefy the starch (liquefaction). After liquefaction, the mash is cooled, and another enzyme is added (gluco amylase) to convert the liquefied starch into fermentable sugars. The yeast is added to ferment the sugars to ethanol and carbon dioxide, followed by distillation and dehydration.[10] As mentioned above, a by-product of the ethanol process, distillers wet grain is often dried to produce distillers dried grain with solubles (DDGS). Expected process improvements will enhance both the ethanol as well as the by product production process. The following process adjustments have been identified and considered in this study.

Corn Oil Extraction (after ethanol distillation):

In an adjustment to the traditional dry mill ethanol process, corn oil is removed after the ethanol distillation process from the syrup using centrifuges. With this adjustment a 100 mgpy plant can produce an additional 7 million gallons of corn oil (biodiesel) and thus increase a plant's fuel production by 7 %. Since the corn oil is removed after the distillation process, the extraction process has no impact on the ethanol yield. Furthermore, the deoiled DDGS is believed to be of higher value as a feed particularly for cattle operations and have lower energy requirements and VOC emissions during the drying process. GS Cleantech Corp. is currently implementing the process in 4 ethanol plants.[11]

According to GS Cleantech Corp. the process increases dryer efficiency by about 20% (2000-2500 Btu/gal) resulting in overall savings of about 8% (2,500/32,000 Btu/gal). The National Corn to Ethanol Research Center (NCERC) estimates the energy savings to be slightly lower. NCERC assumes that the reduction in the dryer load is proportional to the reduction in the mass of the oil content in the whole stillage, which is approximately 10% resulting in overall savings of about 1,200/32,000 Btu/gal or 4%. The more conservative assumptions by NCERC were assumed for this study. However, electricity needs will increase by about 9% to operate the centrifuges for oil extraction.[12]

Raw Starch Hydrolysis, also known as cold cooking or cold hydrolysis:

Raw starch hydrolysis allows producers to eliminate the cooking step. The cold cook process (which occurs at 86 to 104 degrees F) skips the liquefaction and saccharification steps. The ground corn is slurried with water and both gluco amylase and alpha amylase are added, followed directly by fermentation. Skipping the cooking process reduces both water and energy consumption. Nine Poet managed companies have implemented the BPX cold cook process. Critics argue that the process needs significantly more enzymes (20% more) and reduces yield in fermentation.[13] In a personal conversation with an industry insider, the energy savings from cold cooking were estimated to be about 5,000

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[10] Ethanol Producer Magazine. "Break it Down."; January 2006.

[11] Distillers Grains Quarterly. "GS Cleantech to install corn oil extraction for four ethanol producers." Third Quarter 2007, BBI International.

[12] Personal conversation with Chris Kennedy from GS Cleantech Corp.

[13] Ethanol Producer Magazine. "Break it Down", January 2006.

btu/gal (5,000/32,000 Btu/gal) or 16%. Electricity consumption is likely similar to current dry mill ethanol plants; no increase or decrease in electricity consumption was assumed.

Dry Mill Corn Fractionation (germ/oil is removed at the front end):

The objective of this process adjustment is to remove the fermentable components from the non fermentable components as a first step in the ethanol production process. Fractionation separates the endosperm from the kernel. The endosperm contains 98% of the starch (the germ, another part of the kernel, in contrast contains the oil, protein and enzymes that start the germination process). By removing non fermentable components at the front end, the percentage of starch in the slurry is higher, requiring less enzymes. Also, the removal of non-fermentable compounds reduces the drying load and thus the energy requirements. Furthermore, the removed germ (with the oil) can be more easily processed into corn oil. Similar to corn oil extraction, about 7-8% by volume of additional corn oil (convertible to biodiesel) can be produced with this process. Critics argue that fractionation results in a loss of starch and reduced ethanol yields.[14] Fractionation is expected to be often adopted in conjunction with the corn kernel fiber to ethanol process (see below).

The energy savings from dry mill fractionation/corn kernel fiber to ethanol are around 10,000 Btu/gal or (10,000/32,000) 31%. About 2/3rd of the savings are from reduced drying requirements, 1/3rd of the savings from reduced process energy needs. The process does require about 10% more electricity.[15]

Corn Kernel Fiber to Ethanol (adopted with fractionation):

Corn kernel fiber to ethanol is another often cited near term possible technology improvement for dry grind ethanol plants. The technology utilizes specific enzymes which can convert corn kernel fibers into fermentable sugars. The technology can increase the ethanol yield from a bushel of corn by 10-20%.[16] The challenges are to develop affordable enzymes, and create process streams which are concentrated enough for ethanol recovery. According to NCERC, this technology will likely be adopted with corn fractionation. While the technology increases yield, the energy conversion efficiency is expected to remain constant.

Table 3 below details the expected adoption rate for each process adjustment as a percentage of the total ethanol plant stock in that year. For example, in year 2030 it is expected that 30% of all operating ethanol plants will utilize raw starch hydrolysis. Please note the use of the corn oil extraction process and dry mill corn fractionation is mutually exclusive, since both processes remove oil from the corn. In contrast, combined adoption of an oil extraction process and raw starch hydrolysis could be possible. For the purpose of this study it is assumed that almost every ethanol plants built in 2030 will make use of one process improvement, hence a total of 90% combined diffusion rate.

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[14] Ethanol Producer Magazine. "Corn Fractionation for the Ethanol Industry"; November 2005 Issue.

[15] Personal conversation with Ehanex Energy Inc. representative.

[16] Rodney J. Bothast. "New Technologies in Biofuels Production"; Presented at the Agricultural Outlook Forum, February 2005, available at www.ethanolresearch.com, and Illinois Department of Commerce and Economic Opportunity.

Table 3 also details the expected thermal energy and electricity reductions that can be expected from each process relative to current production practices. As a conservative assumption, only slight additional gains for each process improvement are assumed over time.

Table 3: Projected Adoption Rates and Energy Savings from Ethanol Process Improvements

Percent of all Plants Adopting Process						
Process Improvement	**2007**	**2010**	**2015**	**2020**	**2025**	**2030**
Corn Oil Extraction	5%	10%	15%	20%	25%	30%
Raw Starch Hydrolysis	5%	10%	15%	20%	25%	30%
Dry Mill Corn Fractionation	1%	7%	13%	18%	24%	30%
Energy Reduction from Base Process (Thermal)						
	Btu/gal	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**
Corn Oil Extraction	4%	4%	4%	4%	5%	5%
Raw Starch Hydrolysis	16%	16%	16%	16%	17%	17%
Dry Mill Corn Fractionation	31%	31%	31%	31%	31%	32%
Weighted Average Savings from Process Adjustments (Thermal)	1.3%	4.1%	6.9%	9.7%	13.1%	16.2%
Energy Reduction from Base Process (Electric)						
	kWh/gal	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**
Corn Oil Extraction	-9%	-9%	-9%	-9%	-8%	-8%
Raw Starch Hydrolysis	0%	0%	0%	0%	0%	0%
Dry Mill Corn Fractionation	-10%	-10%	-9%	-9%	-8%	-8%
Weighted Average Savings from Process Adjustments (Electric)	-0.6%	-1.6%	-2.5%	-3.5%	-3.9%	-4.8%

Note: Negative numbers indicate increased energy consumption

Summary of Projected Dry Mill Ethanol Plant Conversion Efficiencies

Table 4 below shows the currently prevailing ethanol plant conversion efficiencies. As discussed above, these numbers are based on current process guarantees from ethanol process developers (ICM), a study by Mueller and Cuttica (2006), Energy and Environmental Analysis Inc (2006), data provided by NCERC, and data summarized in the BEACCON model developed by Life Cycle Associates.[17] [,18,19] [,20,21] The weighted average in Table 4 is the sum of the product of the currently prevailing energy consumption for each energy technology and configuration multiplied by the diffusion rates listed in Table 1.

Table 4: Current Dry Mill Ethanol Plant Energy Conversion Efficiencies

Thermal	**2007**
	Btu/gal
Natural Gas Boiler	32,000
Natural Gas CHP	34,500
Coal Boiler	40,000
Coal CHP	44,000
Biomass Boiler	40,000
Biomass CHP	44,000
Integ. Biogas Energy System	14,500
Weighted Average Efficiency	32,685
Electric	**kWh/gal**
Natural Gas Boiler	0.75
Natural Gas CHP	0.17
Coal Boiler	0.90
Coal CHP	0.06
Biomass Boiler	0.90
Biomass CHP	0.06
Integ. Biogas Energy System	0.06
Weighted Average Efficiency	0.69

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[17] ICM, Inc. “ICM Performance Guarantees – We Put Them in Writing”; Revision 6/01/06, www.icminc.com

[18] Mueller and Cuttica. “Research Investigation for the Potential Use of Illinois Coal in Dry Mill Ethanol Plants”; Report to the Illinois Clean Coal Institute, October 2006.

[19] Energy and Environmental Analysis, Inc. “An Assessment of the Potential for Energy Savings in Dry Mill Ethanol Plants from the Use of Combined Heat and Power (CHP)”; prepared for the US Environmental Protection Agency Combined Heat and Power Partnership, July 2006.

[20] Life Cycle Associates. “Biofuels Emissions and Cost Connection (BEACCON) model”; www.lifecycleassociates.com

[21] NCERC provided comments on the energy consumption of an integrated biogas energy system. For example, a 100 mgpy plant which anaerobically digests wet cake can produce 20,000 Btu/gal of biogas, and thus reduce the energy needs of chp based ethanol plant from 34,500 Btu/gal to 14,500 Btu/gal. Other sources show that integrated biogas energy systems can be almost self sufficient, see “Bioconversion of Thin Stillage – A business case for ethanol plants”; New Bio E Systems, Inc., 2007, available at www.newbio.com

Table 5 shows the expected decrease of ethanol plant energy consumption due to expected improvements to current energy equipment. Efficiency improvements to the thermal energy equipment are approximated by efficiency improvements to boiler systems.[22] For example, in year 2030 the average natural gas boiler plant is expected to utilize only 27,915 Btu/gal of thermal energy (as opposed to the current 32,000 Btu/gal) due to the expected 12.8% boiler efficiency improvements listed in Table 2. Weighted by the diffusion rate of the various plant energy system primary fuel uses and configurations in Table 1, the average ethanol plant will consume 28,225 Btu/gal.

On the electricity side, energy consumption for boiler based ethanol plants are expected to decrease by the product of efficiency improvements for electric equipment (largely improvements to large motors, see Table 1) and efficiency improvements to central power stations (see Table 1) since boiler plants purchase all of their electricity from central power plants. Electricity consumption for chp-based ethanol plants is expected to decrease by the product of efficiency improvements in electric equipment (again, largely improvements to large motors, see Table 1) and projected efficiency improvements approximated by small combustion turbines (see Table 1), a common equipment type utilized by chp plants to produce onsite electricity.

Table 5: Projected Conversion Efficiencies with Efficiency Gains from Energy Equipment Improvements

	2007	**2010**	**2015**	**2020**	**2025**	**2030**
Thermal	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**
Natural Gas Boiler	32,000	31,614	30,512	29,156	27,915	27,915
Natural Gas CHP	34,500	34,084	32,895	31,433	30,096	30,096
Coal Boiler	40,000	39,518	38,140	36,444	34,894	34,894
Coal CHP	44,000	43,470	41,953	40,089	38,383	38,383
Biomass Boiler	40,000	39,518	38,140	36,444	34,894	34,894
Biomass CHP	44,000	43,470	41,953	40,089	38,383	38,383
Integ. Biogas Energy System	14,500	14,325	13,826	13,211	12,649	12,649
Weighted Average Efficiency	32,685	32,226	31,039	29,599	28,282	28,225
Electric	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**
Natural Gas Boiler	0.75	0.72	0.69	0.66	0.65	0.65
Natural Gas CHP	0.17	0.16	0.16	0.15	0.15	0.15
Coal Boiler	0.90	0.86	0.83	0.79	0.78	0.78
Coal CHP	0.06	0.06	0.06	0.06	0.05	0.05
Biomass Boiler	0.90	0.86	0.83	0.79	0.78	0.78
Biomass CHP	0.06	0.06	0.06	0.06	0.05	0.05
Integ. Biogas Energy System	0.06	0.06	0.06	0.06	0.05	0.05
Weighted Average Efficiency	0.69	0.60	0.53	0.46	0.40	0.35

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[22] Note that chp plants also benefit from boiler efficiency improvements. Coal-fired chp ethanol plants generally utilize a larger boiler and a steam turbine to produce thermal and electric energy. Natural gas fired ethanol plants generally utilize a combustion turbine with a heat recovery steam generator (essentially a boiler) for thermal and electricity generation.

Table 6 shows the expected decrease of ethanol plant energy consumption due to both improvements to current energy equipment and adjustments to the current corn dry mill process. The weighted average adjusts the conversion efficiency improvements by the diffusion rate of each plant type listed in Table 1. As can be seen by 2030, on average, an ethanol plant will consume about 23,652 Btu/gal of thermal energy and 0.37 kWh/gal of electricity taking into account:
a) adjustment based on ethanol plants choosing different primary energy feedstocks (coal, natural gas, biomass) and energy system configurations (adoption of combined heat and power technologies),
b) expected improvements to energy equipment (more efficient boilers, motors, etc.), and
c) adjustments to the current dry mill processes (adoption of corn fractionation, cold cook, etc.).

Table 6: Projected Conversion Efficiencies with Efficiency Gains from Energy Equipment Improvements and Dry Mill Process Improvements

	2007	**2010**	**2015**	**2020**	**2025**	**2030**
Thermal	**Btu/gal***	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**	**Btu/gal**
Natural Gas Boiler	31,581	30,316	28,395	26,326	24,272	23,393
Natural Gas CHP	34,048	32,684	30,614	28,383	26,168	25,220
Coal Boiler	39,476	37,895	35,494	32,908	30,340	29,241
Coal CHP	43,424	41,684	39,044	36,199	33,374	32,165
Biomass Boiler*	39,476	37,895	35,494	32,908	30,340	29,241
Biomass CHP*	43,424	41,684	39,044	36,199	33,374	32,165
Integ. Biogas Energy System	14,310	13,737	12,867	11,929	10,998	10,600
Weighted Average Efficiency	32,257	30,902	28,886	26,727	24,591	23,652
Electric	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**	**kWh/gal**
Natural Gas Boiler	0.75	0.73	0.71	0.68	0.67	0.68
Natural Gas CHP	0.17	0.17	0.16	0.16	0.15	0.15
Coal Boiler	0.90	0.88	0.85	0.82	0.81	0.81
Coal CHP	0.06	0.06	0.06	0.06	0.06	0.06
Biomass Boiler*	0.90	0.88	0.85	0.82	0.81	0.81
Biomass CHP*	0.06	0.06	0.06	0.06	0.06	0.06
Integ. Biogas Energy System	0.06	0.06	0.06	0.06	0.06	0.06
Weighted Average Efficiency	0.69	0.61	0.54	0.47	0.41	0.37

*Higher Heating Value