

**EUROPEAN WOOD-HEATING TECHNOLOGY SURVEY:
AN OVERVIEW OF COMBUSTION PRINCIPLES AND THE ENERGY AND EMISSIONS
PERFORMANCE CHARACTERISTICS OF COMMERCIALY AVAILABLE SYSTEMS IN
AUSTRIA, GERMANY, DENMARK, NORWAY, AND SWEDEN**

PREPARED FOR:

**THE NEW YORK STATE
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Introduction

The New York State Energy Research and Development Authority (NYSERDA) is supporting R&D efforts to promote the development of a high-efficiency biomass heating market in New York State. High-efficiency biomass equipment has significantly lower emissions than their low-efficiency counterparts. This is particularly important, considering the United States Environmental Protection Agency (EPA) is currently updating the emissions performance requirements of all residential wood heating technologies. These New Source Performance Standards (NSPS) revisions will require that all newly manufactured heating systems meet emission levels representative of the current best demonstrated technology based on a survey.

The Europeans, more specifically Austria, Germany, and Scandinavian countries Denmark, Norway, and Sweden, are considered leaders in the development of this technology. BIOENERGY 2020+ prepared this report for NYSERDA to provide a comprehensive overview of biomass technologies in these countries. The report provides critical information to assist NYSERDA with the development of a high-efficiency biomass heating market and to help EPA assess the current best demonstrated technology on which to base revisions to the residential wood heater NSPS.

A key aspect of this study is the description of the European methodology for determining thermal efficiency using the net calorific value (lower heating value) of the wood fuel and the conversion of this value to the gross calorific value (upper heating value) used to determine thermal efficiencies by the U.S. heating industry. Throughout this report thermal efficiency values are converted to the American convention using gross calorific value. The emissions for “dust” or Total Suspended Particulates are converted to pounds per million British thermal unit (lb/MMBtu), the common unit used in the United States. Other emissions are normalized to values at standard conditions at 12% O₂ levels in the flue gas.

Legislative regulations and incentives on national and European levels are used in the European Union to continuously improve the performance of biomass appliances. In the European Standard EN 303-5, which regulates performance requirements for solid fuel boilers, three classes (class 1 to 3) for efficiency requirements and emission limits are defined in order to embrace the diverse technology stages of the EU member states. In the revision of EN 303-5, which is currently under discussion, more stringent classes (class 3 to 5) will be introduced, thereby resulting in the steady increase of the performance of installed biomass appliances. In addition to the EN 303-5, national regulations and eco-labels may request even higher efficiencies and lower emissions. Regional and national financial incentives for the installation of biomass appliances are often linked to eco-label requirements.

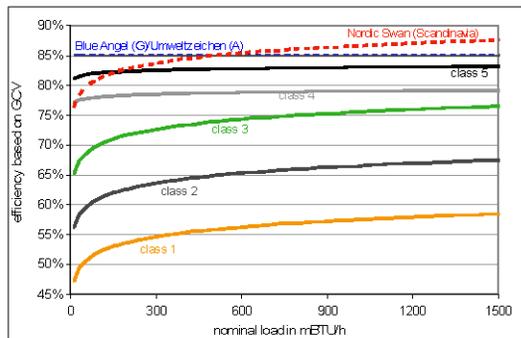


Figure ES-1. efficiency requirements for boilers from EN 303-5 (class 1 to class 5) and efficiency requirements from Austrian, German and Scandinavian eco-labels; efficiencies based on GCV were converted for pellets fuel

Austrian biomass boiler technology is a perfect example of how the improvements in combustion technology can be driven by legislative requirements and incentives. Figure ES-2 shows the technological improvement of boilers for solid wood, wood chips and pellets (starting in 1998) through test data from FJ-BLT. Over the last 30 years average efficiencies of biomass boilers have increased from approximately 55% to more than 90% based on the NCV (net calorific value) and the average CO-emissions have decreased from 15,000 to less than 50 mg/m³ at 13% O₂ in Austria.

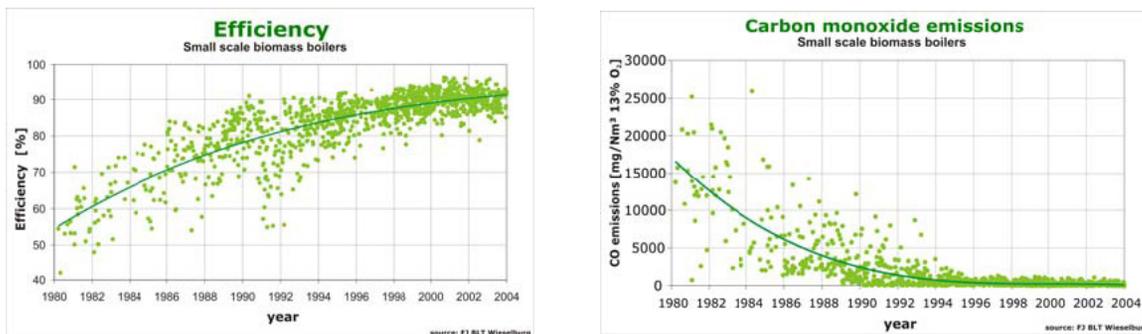


Figure ES-2. Small scale wood combustion systems: Efficiencies and CO emissions measured at the test bench through certification tests since 1980 - data according to (FJ BLT 2005), compilation in (Voglauer 2005)

Modern combustion technology for biomass is based on staged combustion in order to enable maximum burnout rates. In the primary zone located on the grate, drying, devolatilization and solid combustion take place. In the secondary combustion zone, which is situated in the combustion chamber, the volatile gases are burnt with secondary air. In order to minimize emissions, combustion must be as complete as possible in the secondary zone. In Figure ES-3, Figure ES-4 Figure ES-5 and Figure ES-6, the function principles of a solid wood boiler, an underfeed pellet boiler with condensing technology, a pellet boiler with top feed technology, and a pellet boiler with an underfeed burner are illustrated.



Figure ES-3. Under-burning solid wood boiler (Froeling 2005)

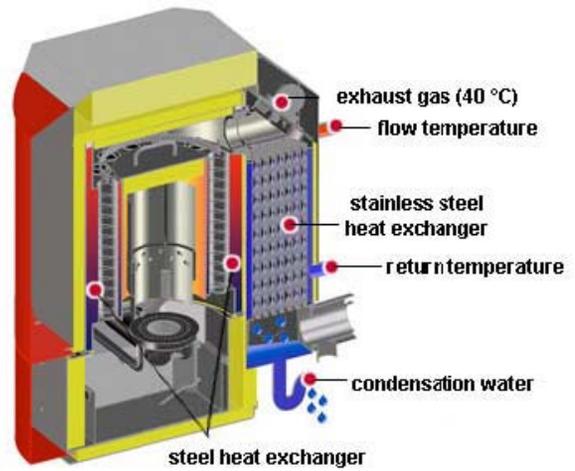


Figure ES-4. Condensing boiler for wood pellets with underfeed burner (Oekofen 2007)

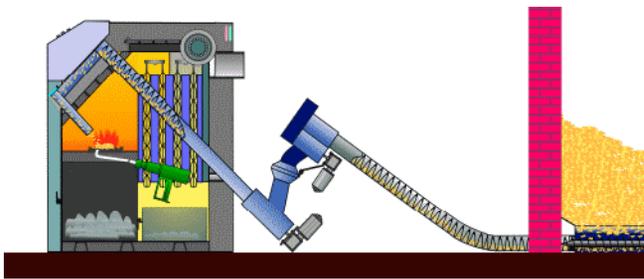


Figure ES-5. Top feed pellets boiler (Evotherm 2010)



Figure ES-6. Underfeed burner for wood chips and pellets (KWB 2007)

The complete combustion of fuel in an optimized 2-stage combustion design results in very low dust (TSP) emissions because it prevents particle formation from unburned hydrocarbons that are absent in the exhaust gas. Figure ES-7 contrasts the chemical composition in an optimized heating appliance and a poorly operated woodstove. The dust from the optimized system is primarily inorganic, while the poorly operated stove emissions are mostly unburned organics and will be a multiple higher in mass than the emissions from the optimized appliance.

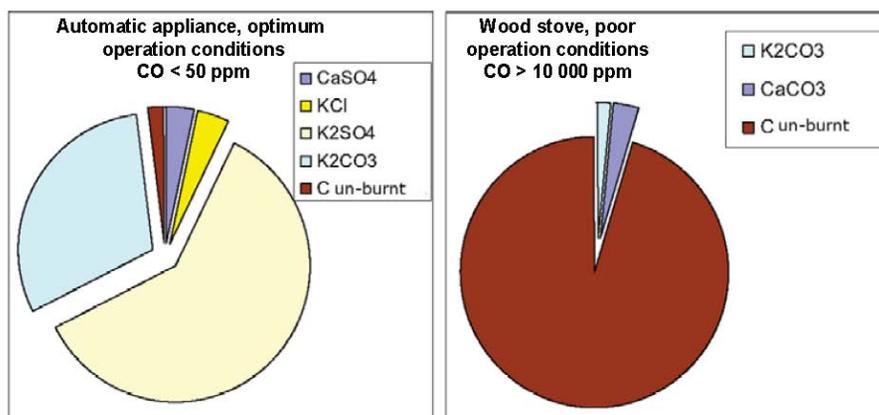


Figure ES-7. chemical composition of dust samples from different biomass appliances and operation conditions (Klippel 2007)

The development of solid bio-fuel standards in Europe is linked to the beginning of wood pellet production. In order to gain a common understanding between the manufacturers and the users, codes of good practice, quality guidelines and later national standards have been developed. For the development of high performing combustion appliances, harmonized fuel properties are advantageous because the optimization of operating conditions is only possible if the fuel properties are known.

The TOP 25% performing biomass appliances that were identified within this study reach high efficiencies and low emissions.

Table ES-1. summary of average efficiency and emission data for TOP 25% performing biomass technologies

technology	fuel	load range (MBtu/h)	data at nominal load			
			$\eta_{GCV}^{(1)}$ (%)	CO (mg/m ³ % ₀₂)	TSP ⁽¹⁾ (lb/MMBtu)	NOx (mg/m ³ % ₀₂)
boiler	pellets	< 55	87	43	0.022	140
		55 - 100	86	39	0.024	136
		100 - 170	87	38	0.023	132
		170 - 340	86	24	0.036	154
		> 340	86	17	0.031	133
	solid wood	< 85	83	174	0.039	139
		85 - 120	83	220	0.044	126
		120 - 170	83	152	0.066	115
	wood chips	> 170	82	97	0.033	119
		< 100	76	60	0.046	157
100 - 200		79	39	0.027	134	
200 - 340		78	30	0.038	138	
combined boiler	pellets	340 - 680	80	22	0.042	125
		> 680	78	34	0.092	131
		50 - 150	82	34	0.027	145
stove with hot water	pellets	50 - 150	79	252	0.027	120
		25 - 50	85	117	0.019	143
stove	pellets	< 30	88	164	0.045	88
		> 30	87	180	0.043	110
	solid wood	20 - 130	73	1069	0.050	126

Figure ES-8 clearly exhibits that efficiencies of the TOP 25% performing pellet boilers far exceed the future requirements of EN 303-5, class 5. The same is true for wood chip and solid wood boilers.

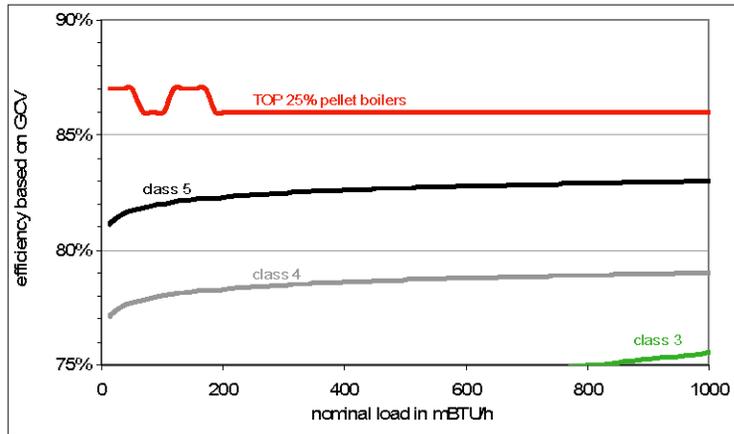


Figure ES-8. average efficiency performance of TOP 25% pellet boilers in comparison to efficiency requirements of EN 303-5, class 3 and future efficiency requirements of EN 303-5, class 4 and 5

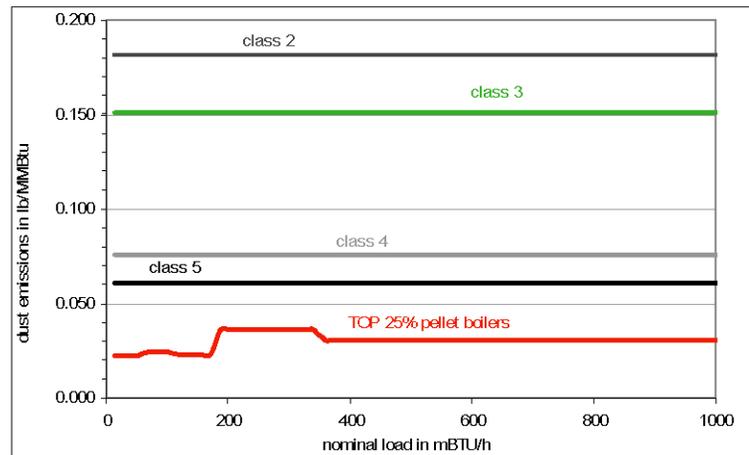
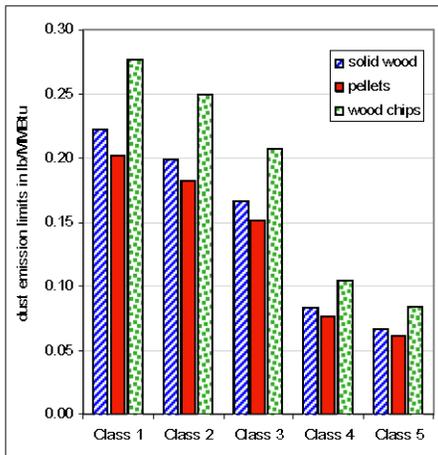


Figure ES-9. dust emission limits for solid wood, wood chips and pellet boilers of EN 303-5, classes 1 to 5 and average dust emissions of the TOP 25% performing pellet boilers.

Figure ES-9 demonstrates that the TOP 25% performing boilers have lower emissions than future EN 303-5, class 5 requirements.

Figure ES-10 shows the average efficiencies at nominal and partial load for the TOP 25% performing pellet, solid wood and wood chip appliances. For solid wood boilers partial load equals 50% of nominal load, for pellets and wood chip boilers the partial load is 30% of the nominal load.

Efficiencies for nominal and partial load are almost identical. Solid wood and wood chip boilers sometimes even reach higher efficiencies at partial load operation.

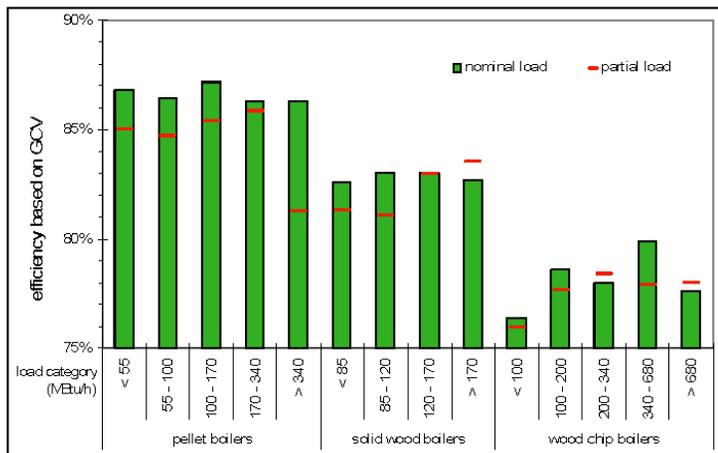


Figure ES-10. average efficiencies based on GCV at nominal and partial heat load for the TOP 25% performing boilers

Although modern solid wood boilers are able to modulate their operation load from 100 to 50%, the use of heat storage is strongly recommended in order to reach high efficiencies and keep emissions low by preventing short cycling. Even though pellet and wood chip boilers can modulate their operation load from 100 to 30%, some studies also recommend the integration of accumulator tanks in these heating systems in order to increase the annual efficiencies of the heating systems. In addition to improved performance, the design of heat storage systems also influences the need for maintenance and the durability of boilers.

Due to their high availability, non-wood biomasses such as grasses and agriculture products are very attractive fuels. They may however have certain general physical and chemical properties that cause problems during combustion. In addition to the possible increase of NO_x , HCl, SO_2 , and other emissions in comparison to wood biomass, higher ash contents combined with lower ash melting temperatures and corrosive effects negatively influence the failure rate and durability of the boilers.

Summary

By making careful conversions of conventional methodology and units, the energy efficiency and emissions performance of the European heating systems can be more easily summarized in the context of the American nomenclature. After conversions, differences in evaluation duty-cycle and the emissions sampling and analysis protocols still exist in the regulatory test methods between the European Commission and the U.S. For example, the European Commission evaluation duty cycles do not include operation for the very low burn rates (low heat demand rates) that U.S. evaluations typically require. The U.S. evaluation duty cycles include these low burn rates because many U.S. designs do not always automatically minimize or eliminate idle modes that have poor combustion characteristics. There is considerable interest in the U.S. in this opportunity for much improved performance. Also, the U.S. sampling and analysis typically include condensable particulate matter, which by and large is organic. Such testing is not required in European tests because the high-efficiency designs combust

virtually all of the organic precursors to condensable aerosol particles. Instead, the European test measures any residual organic gases in the exhaust stream. Thus one must be careful in comparing results and recognize that not all results are directly comparable. In the case of the Top 25% performing wood boilers in the size range of 120,000 - 170,000 Btu, converting all of the organic gases to particulate matter would result in an increase of approximately 4% of the mass or an output based emission rate of 0.068 lb/mmBtu.

Even considering the differences described above, it is clear that by using improved staged combustion design, fuels with lower water content; only 22.5% for wood chips and 14.5% for solid (cord) wood, requirements for minimum thermal efficiency, and sophisticated controls that optimize combustion and minimize or eliminate idle modes, the top 25% performing commercially available European technologies greatly exceed performance requirements of not only the current classes (1, 2, and 3) of boilers but also the proposed classes (4 and 5) for thermal efficiency and emissions. Technology-forcing policies, regulations, and Eco-labeling efforts have clearly resulted in greatly improved technology now available in Europe, which is expanding into the American wood heating market as well.

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FINAL REPORT

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