Supplementary material

Table S1. Specification of combustion appliance (REKA HKRST 10N FSK 500) according to the manufacturer technical document.

Nominal output	14.9 kW
Fuel consumption	approx. 3.45 kg/h
Minimum output	4.08 kW
Difference temperature between flow and return water	10 to 15 °C
Return water minimum temperature	60 °C

Table S2. The quantification limit (LOQ) of ICP-MS analysis.

Element	LOQ (µg mg^{-1} of PM_1 sample)
Na	0.07049
Mg	0.04910
Al	0.20809
P	0.36527
K	0.43702
Ca	3.16373
Ti	0.03964
Fe	0.03624
V	0.00031
Cr	0.00039
Mn	0.00109
Co	0.00005
Ni	0.00316
Cu	0.00244
Zn	0.00538
As	0.01496
Sr	0.00047
Mo	0.00116
Cd	0.00001
Sn	0.00090
Sb	0.00043
Ba	0.00054
Tl	0.00002
Pb	0.00089
Bi	0.00024

Table S3. Chemicals used in solution preparations.

Solution	Chemical	Cas number	Supplier
Potassium Phosphate buffer	Potassium phosphate dibasic	7758-11-4	Riedel-de Haen
	Potassium phosphate monobasic	7778-77-0	Sigma-Aldrich
AA solution	Ascorbic acid	50-81-7	Fisher Chemical™
DTT solution	Dithiothreitol	3483-12-3	Thermo Scientific™
DTNB solution	DTNB (5,5-dithio-bis-(2-nitrobenzoic acid)	69-78-3	Thermo Scientific™

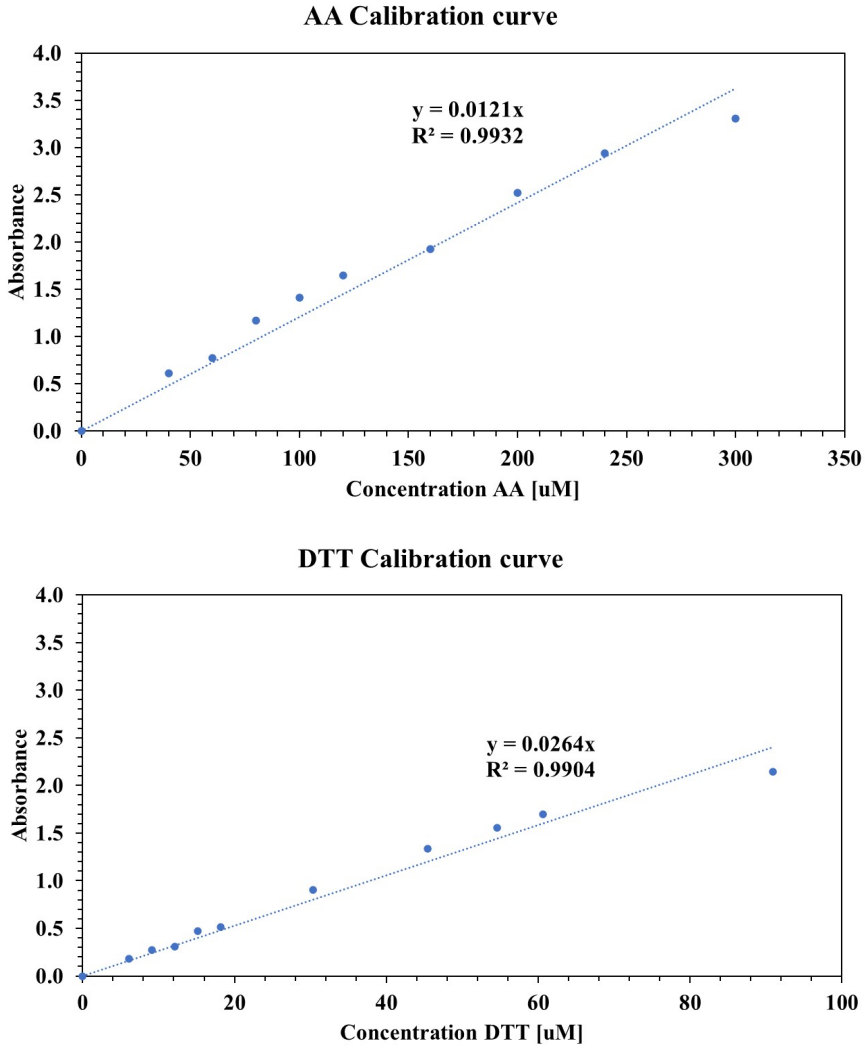

Figure S1. Calibration curves of AA and DTT absorbance measurement

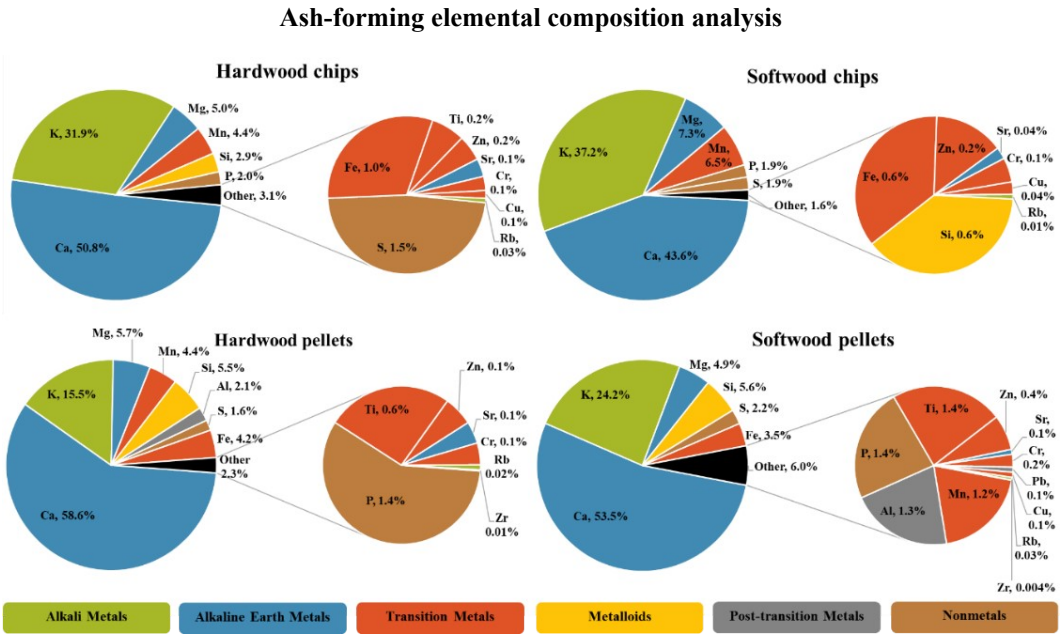

Figure S2. The proportion of elemental compositions (%) in the ashes from each biomass fuel.

Table S4. The elemental composition of ashes from each biomass fuel (unit: mg kg^{-1} biomass dry basis).

Ash elemental Composition	Wood chips		Wood pellets	
	Hardwood	Softwood	Hardwood	Softwood
Ca	3822.60	715.58	1799.82	3580.55
K	2402.37	609.46	476.59	1620.38
Mg	373.41	119.36	175.08	330.75
Mn	329.36	106.42	135.45	77.87
Si	218.37	10.17	167.68	374.24
Al	ND	ND	64.75	83.96
P	148.64	30.95	41.48	93.39
S	112.35	31.91	49.15	149.92
Fe	72.89	9.53	129.83	232.81
Ti	16.26	ND	18.48	92.12
Zn	12.42	3.77	4.33	28.90
Sr	8.66	0.64	3.22	4.01
Cr	6.78	1.31	3.19	10.44
Pb	ND	ND	ND	4.01
Cu	3.77	0.67	ND	4.28
Rb	2.03	0.25	0.74	2.07
Zr	ND	ND	0.15	0.27

Note: "ND" is non-detected. The results of Table S4 were calculated by using the proportion of each element presented in Figure S2 and the ash content (%) of each biomass.

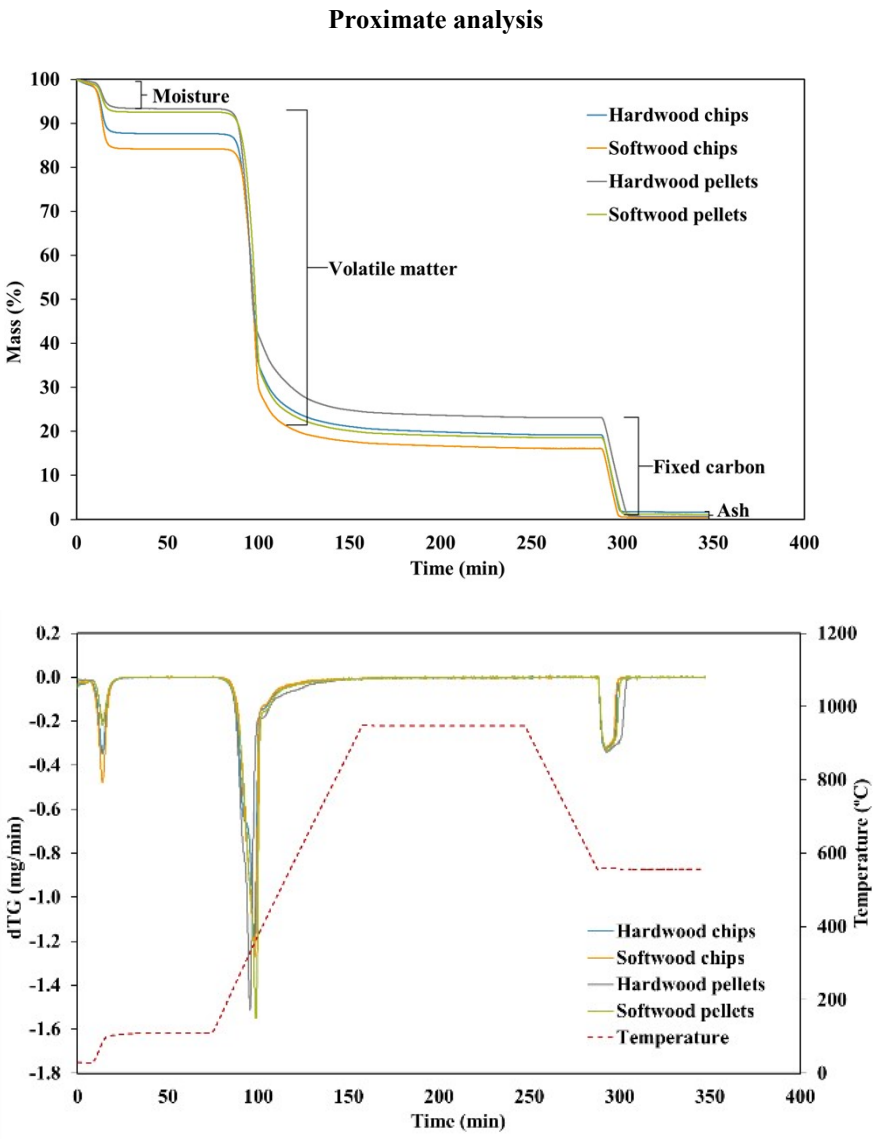

Figure S3. Thermal degradation curves of different biomass fuels with respect to time in mass loss percentage basis and derivative thermogravimetric (dTG) basis.

Figure S3 presents the mass loss and dTG curves at different times and temperatures of biomass samples. The dTG curves represent the rate of mass loss as a function of time. To provide a consistent and comparable baseline in evaluating biomass characteristics, we normalized volatile matter (VM), fixed carbon (FC), and ash content (AC) of all biomasses to dry basis. Hardwood resulted in lower volatile matter with 78.0% for chips and 75.2% for pellets. Whereas softwood chips had 80.8% and pellets had 79.9% VM. Fixed carbon was observed to be lower in softwood compared to hardwood. The FC were 20.1%, 18.7%, 24.2%, 18.9% for hardwood chips, softwood chips, hardwood pellets, and softwood pellets, respectively. The ash content for all biomasses determined with TGA ranges from 0.6 to 1.9%. Although the AC determined with TGA differed from the ash content determined at 550 °C, the relative ranking among samples remained consistent, where hardwood chips were the highest, followed by softwood pellets, hardwood pellets, and softwood chips. Therefore, the differences in AC were attributed to the methodological variations and sample sizes.

Calculation equation for total carbon (TC), organic carbon (OC), elemental carbon (EC), and organic matter (OM). Given that the OM/OC ratio implemented in this study is 1.82 average from Hartikainen et al.,2020.

$$X\ (OC, EC, TC)\left[\frac{\mu g}{cm^2}\right] \times Filter\ area\ of\ PM\ [cm^2] = X\ [\mu g]$$

$$Mass\ concentration\ of\ X\left[\frac{mg}{m^3}\right] = \frac{X\ [\mu g]}{sampled\ gas\ volume\ [m^3]} \times \frac{1\ [mg]}{1000\ [\mu g]}$$

$$TC = OC + EC$$

$$OM\left[\frac{\mu g}{cm^2}\right] = OC\left[\frac{\mu g}{cm^2}\right] \times \frac{OM}{OC} ratio$$

$$Total\ PM\ mass\ concentration\left[\frac{mg}{m^3}\right] = OM\ \left[\frac{mg}{m^3}\right] + EC\left[\frac{mg}{m^3}\right] + others\left[\frac{mg}{m^3}\right]$$

Table S5. The calculation of OM and other fractions of PM_1 from different biomass combustion.

Biomass source of PM_1	OC/TC	EC/TC	OC/EC	mg m^{-3} (at 0°C, 1 atm, 10% O_2 and dry gas)					
				TC	OC	OM	EC	Others	Total mass concentration
Hardwood chips	0.17	0.83	0.21	32.53	5.54	10.06	26.99	33.50	70.54
Softwood chips	0.15	0.85	0.18	57.59	8.64	15.68	48.96	28.71	93.34
Hardwood pellets	0.38	0.62	0.63	15.55	5.98	10.85	9.57	4.07	24.49
Softwood pellets	0.04	0.96	0.04	88.44	3.77	6.84	84.67	44.72	136.23

Note: The PM mass and mass concentration used to calculate the results here were from the same filters used in OC-EC analysis. The detection limit of the analyzer is 0.10 µg C cm^{-2}. "Others" refers to the remaining PM components not reported separately.