Processing / Products No. 32

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- *GCV for ash and Sitka spruce are within the range quoted in EN 14961–1: 2010 Solid Biofuels- fuel specifications and classes whereas hybrid larch was slightly higher than the range quoted.*
- *The NCV (db) of hybrid larch and ash were within the range quoted in EN 14961–1: 2010 whereas the NCV (db) of Sitka spruce was slightly lower than the quoted range.*
- *Across all species, equations estimating the NCV (ar) produced NCV (ar) values higher than the experimentally determined NCV (ar), irrespective of whether the default % hydrogen value or an experimentally determined value was used*

Calorific value of Irish woodfuels

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Introduction

Wood is one of the most important renewable energy sources in Ireland [1]. The estimated 2011 total demand for wood energy, excluding post consumer recovered work (PCRW), is 1.59 million m^3 (ROI 0.95 million m^3), and it is estimated to increase to 3.08 million m^3 (ROI 1.67 million m^3) by 2028 [2]. As well as being a renewable fuel, wood, on complete combustion it is virtually smoke-free, with low levels of sulphur emitted.

Box 1: Definition of calorific value.

Gross Calorific Value (GCV) or Higher Heating Value (HHV) is a characteristic of all fuel and is the amount of heat released during combustion, measured in Mega Joules per kilogram (MJ/kg).

The quantity known as higher heating value (HHV) (*or gross energy or upper heating value or gross calorific value or higher calorific value* HCV) is determined by bringing all the products of combustion back to the original pre-combustion temperature, and in particular condensing any vapour produced. Such measurements often use a temperature of 25°C.

The higher heating value takes into account the latent heat of vaporisation of water in the combustion products, and is useful in calculating heating values for fuels where condensation of the reaction products is practical (e.g., in a gas-fired boiler used for space heat). In other words, HHV assumes all the water component is in liquid state at the end of combustion (in product of combustion).

The quantity known as lower heating value (LHV) (*net calorific value or lower calorific value* - LCV) is determined by subtracting the heat of vaporisation of the water vapour from the higher heating value. This treats any H_2O formed as a vapour. The energy required to vaporise the water therefore is not realised as heat.

LHV calculations assume that the water component of a combustion process is in the vapour state at the end of combustion, as opposed to the higher heating value (HHV) (also known as *gross calorific value* or *gross CV*) which assumes all of the water in a combustion process is in a liquid state after a combustion process.

The LHV assumes that the latent heat of vaporisation of water in the fuel and the reaction products is not recovered. It is useful in comparing fuels where condensation of the combustion products is impractical, or heat at a temperature below 150 °C cannot be put to use.

GCV and NCV values are initially expressed on dry basis, and then on an "as received" basis which takes into account moisture content.

GCV(db) for a number of species, wood assortments, seasoning duration and harvesting time are presented in this note. Selected data have been converted to NCV (db) using the equation in EN 14918: 2009: *Solid biofuels – determination of calorific value*.

$$NCV\ (db) = GCV\ (db) - 0.206*wH_d \qquad \text{equation 1}$$

where:
0.206 is the MJ/kg for 1% (m/m) of hydrogen in the fuel sample and $w(H)_d$ is the hydrogen content, in percentage by mass, of the moisture-free fuel. Typical default hydrogen values as well as experimentally-determined hydrogen values were used as a comparison.

To determine the NCV (as received) of a sample with a required moisture content (e.g. total moisture content as received (M(ar)), then the following conversion equation is used:

$$NCV(ar) = [GCV(db) - 0.206*w(H)_d]*(1 - 0.01*M) - 0.02305*M \qquad \text{equation 2}$$

where:
0.02305 MJ/kg represents the evaporation heat needed for 1% (m/m) moisture and M is the moisture content of the fuel.

In transacting woodfuels, particularly in Scandinavia, the following equation is used to estimate the NCV(ar) for conifers (equation 3) and broadleaved species (equation 4)

$$NCV(ar)\ conifers = 19.2 - (0.2164*M) \qquad \text{equation 3}$$

$$NCV(ar)\ broadleaves = 19.0 - (0.2144*M) \qquad \text{equation 4}$$

In this note, the NCV as experimentally determined is compared with the NCV as estimated by equations 3 and 4.

Methods
Woodfuel samples were taken from different species, wood assortments and harvesting and seasoning times from ForestEnergy 2006-08 sites. Unless otherwise specified, samples were taken from first thinning sites as outlined in COFORD Connects Note Harvesting/Transportation Nos. 26 and 27 [3, 4].

In the ForestEnergy programme, four assortments were harvested:
1. wholetree, including top and branches, chipped after a seasoning period, where the chips contain wood, bark, twigs, and some needles,
2. shortwood, 3 m, cleanly delimbed pulpwood, where the chip contains only wood and bark,
3. energy wood, 3m crudely delimbed logs, with some branch stubs, where the chips contain wood, bark, some twigs and some needles and
4. firewood, cut and split into 30 cm lengths, which consists of wood and bark.

Samples were taken at the time of felling (green samples) and after one or two summers' seasoning (brown samples). The green samples contained all the needles, while the brown samples of the wholetree and energy wood assortment had lost most of their needles. Most of the broadleaves were harvested in the dormant period, when there are no leaves on the trees, but some of the 'green' samples still contained some leaves. In the 'brown' samples all the leaves had disappeared.

Gross calorific value (GCV) was determined using a 6300 Parr bomb calorimeter, in accordance with European Standard (EN) 14918: 2009: [5]. Determination of GCV was carried out at constant volume in the calorimeter, which was calibrated using combustion of certified benzoic acid. All samples were allowed to reach equilibrium moisture content with the laboratory atmosphere before analysis. Moisture content was determined at the same time as calorific value, and subsequently used to calculate GCV on a dry basis (db) [6]. NCV was calculated from the GCV (db). GCV averages were estimated based on three or five replicate determinations, calculated on a dry basis. The standard deviation (SD of replicate samples was also determined (the standard deviation shows how much variation there is between samples).

Results
In Table 1, GCVs for Sitka spruce (wholetree, shortwood, energy wood and firewood assortments) from eight of the ForestEnergy programme sites, and one further site (Lismore) are presented. At 7 of the 9 locations, trees or logs were seasoned for one summer or for two summers in some locations. CV did not vary significantly across the geographical location or assortments (Table 1). However, it appears that on seasoning (one summer), the GCV of all assortments, irrespective of locations, decreased slightly over the first summer. This may be explained by assortments drying out, and needles and bark falling off during seasoning (these contain aromatic oils and other combustible, high calorific value compounds). However, for locations where seasoning took place over two summers (Abbeyfeale and Croaghrimcarra) an increase in GCV to one similar to the green sample GCV was observed. This result cannot be explained and will require further analysis.

GCV of freshly-felled Sitka spruce was in the range of 18.46–20.03 MJ/kg, with an average of 19.63 MJ/kg. Values for seasoned (one summer) Sitka spruce were in the range 17.85-19.81MJ/kg, with an average of 18.85 MJ/kg.

Table 1: GCV (db) of Sitka spruce assortments, with varying seasoning duration and at different locations.

Site	Assortment	Condition (and storage duration)	GCVMJ/Kg Mean	Standard
Abbeyfeale	WT	Green	19.83	0.24
		Brown (5 months)	17.85	0.40
		Brown (16 months)	20.18	0.12
	SW	Green	19.79	0.24
		Brown (5 months)	18.07	0.26
		Brown (16 months)	19.85	0.11
	EW	Green	19.54	0.12
		Brown (5 months)	18.01	0.16
	FW	Green	19.78	0.08
Ballybofey	WT	Green	19.96	0.07
		Brown (5 months)	18.96	0.13
	SW	Green	19.95	0.04
		Brown (5 months)	19.52	0.07
	EW	Green	19.94	0.02
		Brown (5 months)	19.75	0.04
	FW	Green	19.86	0.06
Bweeng	WT	Green	19.86	0.03
		Brown (5 months)	18.49	0.21
	SW	Green	19.58	0.07
		Brown (5 months)	18.07	0.05
	EW	Green	19.46	0.02
		Brown (5 months)	18.07	0.12
	FW	Green	19.55	0.03
Swan	WT	Green	20.00	0.18
		Brown (6 months)	18.64	0.26
	SW	Green	18.64	0.41
		Brown (6 months)	19.42	0.15
	EW	Green	19.80	0.16
		Brown (6months)	18.64	0.04
	FW	Green	19.53	0.08
		Brown (6 months)	18.64	0.24
Croaghrimcarra	WT	Green	19.48	0.07
		Brown (6 months)	19.22	0.10
		Brown (14 months)	20.18	0.04
	SW	Green	19.55	0.04
		Brown (6 months)	19.25	0.02
		Brown (14 months)	19.38	0.17
	EW	Green	19.47	0.07
		Brown (6 months)	19.10	0.05
	FW	Green	19.68	0.04

Site	Assortment	Condition (and storage duration)	GCVMJ/Kg Mean	Standard
Woodberry	WT	Green	19.58	0.03
		Brown (6 months)	19.56	0.23
	SW	Green	19.79	0.14
		Brown (6 months)	19.51	0.18
	EW	Green	19.64	0.07
		Brown (6 months)	19.32	0.17
	FW	Green	19.76	0.10
Kilbrin	WT	Green	20.03	0.18
		Brown(6 months)	19.81	0.08
	SW	Green	19.98	0.49
		Brown (6 months)	19.54	0.57
	EW	Green	18.46	0.98
		Brown (6months)	18.64	0.16
	FW	Green	19.31	0.08
		Brown (6months)	18.64	0.26
Stradbally	WT	Green	19.54	0.17
Lismore	WT	Green	20.03	0.14

The Swan and Kilbrin sites were harvested and seasoned during 2006, whereas the remaining sites were harvested and seasoned from 2007 to 2008.

Hybrid larch, with a mean GCV of 20.57 MJ/kg and 20.27 MJ/kg for freshly-felled and seasoned material, respectively, had a slightly higher GCV than Sitka spruce over all assortments and seasoning durations. Interestingly, from the limited number of samples studied, hybrid larch did not appear to have experienced the same decrease in GCV on seasoning.

Table 2: GCV (db) of hybrid larch assortments seasoned over one summer at four sites.

Site	Assortment	Condition (and storage duration)	GCVMJ/Kg Mean	Standard
Ballybofey	Wholetree	Green	20.67	0.09
		Brown (6 months)	20.84	0.16
	Shortwood	Green	20.49	0.05
		Brown (5 months)	20.02	0.02
	Energy wood	Green	20.35	0.03
		Brown (5 months)	20.20	0.23
	Firewood	Green	20.63	0.08
Bweeng	Wholetree	Green	20.79	0.04
Lismore	Wholetree	Green	20.20	0.07
Croaghrimcarra	Wholetree	Green	20.24	0.04

The mean GCV for ash wholetree assortment was 18.99 MJ/kg (Table 3). A comparison of GCVs (Tables 1-3) shows that the mean for ash was slightly lower than Sitka spruce, which in turn was lower than hybrid larch.

Table 3: GCV (db) of ash green wholetree chips from a number of sites.

Site	GCVMJ/Kg	
	Mean	*Standard deviation*
Ballybofey	18.73	0.21
Dovea	19.13	0.15
Greenae	19.03	0.03
Mullinavat	19.02	0.20
Portlaw	19.10	0.15
Stradbally	18.89	0.16
Woodberry	19.02	0.08

A limited seasoning trial of ash wholetree and firewood assortments was undertaken at a number of sites. Seasoning seemed to have had little effect on GCV (Table 4).

Table 4: Impact of seasoning of ash wholetree and firewood assortments on GCV at Dovea and Greenane.

Site	Assortment	Condition	GCVMJ/Kg	
			Mean	*Standard*
Dovea	WT	Green (July)	19.13	0.15
		Brown (2 months seasoning)	19.31	0.03
Greenane	WT	Green (February)	19.03	0.03
		Brown (7 months seasoning)	18.80	0.33
	FW	Green (February)	18.94	0.11
		Brown (7 months seasoning)	19.18	0.10
		Brown (10 months seasoning)	18.26	0.03

FW: firewood; WT: wholetree

Samples of ash, hybrid larch and Sitka spruce were taken from the Ballybofey site from May 2007 through to February 2008. GCV was determined for the freshly-felled material. The data indicate that the GCV was not duly affected by harvesting time (Table 5).

Table 5: GCV (db) of Ballybofey ash, hybrid larch and Sitka spruce in relation to harvesting month.

Harvesting month	Assortment	Species					
		Ash		Hybrid larch		Sitka spruce	
		GCVMJ/Kg					
		Mean	*Standard Deviation*	*Mean*	*Standard Deviation*	*Mean*	*Standard Deviation*
May 2007	WT	19.26	0.04	ns		20.05	0.01
	FW	ns		ns		ns	
July 2007	WT	19.20	0.11	20.22	0.04	20.06	0.08
	FW	19.25	0.11	ns		ns	
August 2007	WT	19.28	0.04	19.67	0.10	19.81	0.09
	FW	19.19	0.04	ns		ns	
September 2007	WT	19.25	0.03	20.40	0.02	ns	
	FW	18.86	0.07	ns		ns	
November 2007	WT	19.31	0.09	19.93	0.16	19.84	0.03
	FW	19.36	0.03	ns		ns	
February 2008	WT	18.99	0.14	19.92	0.19	19.8	0.14
	FW	18.84	0.02	ns		ns	

FW: firewood; WT: wholetree
ns: not sampled

According to EN 14961-1:2010 *Solid biofuels – fuel specifications and classes*, the typical GCV for virgin coniferous and broadleaved wood in Europe is 20.4 MJ/kg and 20.1 MJ/kg respectively, with typical variation of 20.1–20.8 MJ/kg and 19.4–20.4 MJ/kg, on a dry basis.[7].
The values found in this analysis fall within the range indicated.

GCV of a number of species, harvested during the ForestEnergy programme are provided in Table 6. Samples were taken from trees outside the thinning trials. Typically, the trees were smaller than those taken from the trial plots, and as such the bark to wood ratio would be greater. However, the typical GCV of bark and virgin wood are similar. According to EN 14961-1:2010, the typical GCV of bark in Europe, for coniferous and broadleaved species, respectively, is 20.2 MJ/kg and 20.0 MJ/kg [7].

Table 6: GCV of assortments and species from different sites.

Site	Assortment	Species	GCVMJ/Kg Mean	Standard
Ballybofey	WT	Alder	20.24	0.05
		Beech	19.65	0.04
		Douglas fir	20.51	0.05
		Japanese larch	20.21	0.07
		Norway spruce	20.39	0.07
		Oak	21.75	0.11
		Red oak	19.55	0.16
		Red alder	19.91	0.09
		Sycamore	19.56	0.05
		Western red cedar	20.30	0.17
Bweeng	WT	Birch	20.11	0.02
		Lodgepole pine	20.79	0.05
Croaghrimcarra	WT	Japanese larch	20.40	0.2
		Lodgepole pine	20.12	0.10
Dovea	WT	Beech	19.49	0.16
		Sycamore	19.28	0.08
	SW	Oak	19.07	0.06
	WT	Sycamore	19.22	0.05
Greenane		Oak	18.88	0.10
	FW	Sycamore	19.07	0.13
		Oak	19.11	0.02
Lismore	WT	Douglas fir	19.93	0.09
		Japanese larch	20.18	0.03
Portlaw	WT	Oak	19.21	0.05
		Sycamore	19.30	0.06
Stradbally	WT	Douglas fir	20.22	0.21
	WT	Oak	19.18	0.04
	FW	Oak	19.06	0.07

FW: firewood, SW: shortwood, WT: wholetree

Converting Gross Calorific Value to Net Calorific Value
From equations 1 and 2, the hydrogen content (%) is required when converting GCV to NCV. During the ForestEnergy programme 2006 -2008, the hydrogen content (%) was determined for over 100 samples. Samples included different species, assortments and seasoning times. EN 14961-1: 2010: *Solid Biofuels –Fuels specifications and classes – Part 1: General requirements*, lists typical values of 6.3% (range 5.6–7.0%) and 6.2% (range 5.9–6.5%) for coniferous and broadleaved biofuels from virgin wood, with or without insignificant amounts of bark, leaves and needles, respectively. The hydrogen content (%) of the samples was within the range in the EN. For convenience, a default hydrogen value of 6.2% is typically used when converting GCV to NCV [7].

Table 7 shows typical NCV(db) as described in EN 14961-1: 2010: *Solid Biofuels –Fuels specifications and classes – Part 1: General requirements* [7].

Table 7: Typical NCV (db) of broadleaves and conifers.

Species group	Virgin wood materials, with or without insignificant amounts of bark, leaves and needles	Virgin wood materials logging residues
	NCV (db) MJ/Kg	
Broadleaves	18.9 (range 18.4-19.2)	18.7 (range 17.8-18.9)
Conifers	19.1 (range 18.7-19.8)	19.6 (range 18.7-19.8)

Tables 8, 9 and 10 shows the average GCV and hydrogen content for Sitka spruce, hybrid larch and ash; freshly-felled and seasoned. These values were used to convert GCV to NCV using the default H content (6.2 %) and the experimentally determined H content, for comparison. The resultant values for the NCV are similar and would generally support the use of the default H% value. Typically, the NCV using the experimentally determined H value produced NCV values which were approximately 1 % higher than when the default H value was used.

Table 8: GCV (db) and NCV (db) of freshly-felled and seasoned Sitka spruce using default and experimentally determined H values (% H).

Assortment	Condition	GCV (db)	H % (db)	NCV (default H%)	NCV (exper H%)
		MJ/Kg		MJ/Kg	MJ/Kg
Wholetree	Green	19.81	5.20	18.53	18.74
Wholetree	Seasoned	19.21	5.17	17.93	18.14
Shortwood	Green	19.61	5.30	18.33	18.52
Shortwood	Seasoned	19.18	5.19	17.90	18.11
Energy wood	Green	19.47	5.16	18.19	18.41
Energy wood	Seasoned	18.96	5.17	17.68	17.89
Firewood	Green	19.64	5.13	18.36	18.80
Firewood	Seasoned	18.64	5.06	17.36	17.60

nd: not determined

Table 9: GCV (db) and NCV (db) of freshly-felled and seasoned hybrid larch using default and experimentally determined H values (% H).

Assortment	Condition	GCV (db)	H % (db)	NCV (default H%)	NCV (exper H%)
		MJ/Kg		MJ/Kg	MJ/Kg
WT	Green	20.36	5.07	19.08	19.32
	Seasoned	20.84	nd	19.56	
SW	Green	20.49	nd	19.21	
	Seasoned	20.02	nd	18.74	
EW	Green	20.35	5.07	19.07	19.31
	Seasoned	20.20	5.07	18.92	19.16
FW	Green	20.63	nd	19.35	

EW: energy wood, FW: firewood, SW: shortwood, WT: wholetree
nd: not determined

Table 10: GCV(db) and NCV(db) of freshly-felled and seasoned ash using default and experimentally determined H values (% H).

Assortment	Condition	GCV (db)	H % (db)	NCV (default H%)	NCV (exper H%)
		MJ/Kg		MJ/Kg	MJ/Kg
Wholetree	Green	18.99	5.21	17.71	17.92
	Seasoned	19.04	nd	17.76	
Firewood	Green	18.94	5.16	17.66	17.88
	Seasoned	18.80	nd	17.52	

nd: not determined

From a commercial perspective, NVC as received (ar), is the most informative calorific value. It describes the energy content of biomass with the moisture content as received. Tables 11, 12 and 13 show the relationship between GCV and NCV (ar) for freshly-felled and seasoned Sitka spruce, hybrid larch and ash, respectively, over a range of moisture contents.

Table 11: GCV(db) and NCV(ar) of freshly-felled and seasoned Sitka spruce using default and experimentally determined hydrogen values (% H).

Assortment	Condition	GCV	NCV (Moisture content 25%)		NCV (Moisture content 35%)		NCV (Moisture content 45%)	
			Default H%	Exper H%	Default H%	Exper H%	Default H%	Exper H%
			MJ/Kg					
WT	Green	19.81	13.00	13.21	10.79	11.00	8.58	8.79
	Seasoned	19.21	12.55	12.77	10.40	10.61	8.25	8.46
SW	Green	19.61	12.85	13.04	10.66	10.85	8.47	8.66
	Seasoned	19.18	12.53	12.74	10.38	10.59	8.23	8.44
EW	Green	19.47	12.75	12.96	10.57	10.79	8.39	8.61
	Seasoned	18.96	12.37	12.58	10.24	10.45	8.11	8.33
FW	Green	19.64	12.88	13.10	10.68	10.90	8.49	8.71
	Seasoned	18.64	12.13	12.36	10.03	10.27	7.94	8.17

EW: energy wood, FW: firewood, SW: shortwood, WT: wholetree

Table 12: GCV(db) and NCV(ar) for freshly-felled and seasoned hybrid larch using default and experimentally determined hydrogen values (% H).

Assortment	Condition	GCV	NCV (Moisture content 25%)		NCV (Moisture content 35%)		NCV (Moisture content 45%)	
			Default H%	Exper H%	Default H%	Exper H%	Default H%	Exper H%
			MJ/Kg					
WT	Green	20.36	13.42	13.65	11.15	11.38	8.88	
	Seasoned	20.84	13.78		11.46		9.15	
SW	Green	20.49	13.51		11.23		8.96	
	Seasoned	20.02	13.16		10.93		8.70	
EW	Green	20.35	13.41	13.64	11.14	11.38	8.88	
	Seasoned	20.2	13.30	13.53	11.05	11.28	8.80	
FW	Green	20.63	13.62		11.33		9.03	

EW: energy wood, FW: firewood, SW: shortwood, WT: wholetree

Table 13: GCV(db) and NCV(ar) for freshly-felled and seasoned ash using default and experimentally determined hydrogen values (% H).

Assortment	Condition	GCV	NCV (Moisture content 25%)		NCV (Moisture content 35%)		NCV (Moisture content 45%)	
			Default H%	Exper H%	Default H%	Exper H%	Default H%	Exper H%
			MJ/Kg					
FW	Green	18.94	12.35	12.57	10.23	10.44	8.10	8.32
	Seasoned	18.8	12.25		10.14		8.03	
WT	Green	18.99	12.39	12.59	10.26	10.46	8.13	8.35
	Seasoned	19.04	12.43		10.29		8.16	

FW: firewood, WT: wholetree

Equations 3 and 4, presented in the introduction, are typically used in transacting woodfuels to estimate the NCV of a biomass fuel for any moisture content. Table 14 shows the estimated NCV over the moisture content range described in Tables 11, 12 and 13.

Table 14: Estimated NCV (ar) using equations 3 and 4.

Species group	Moisture content %		
	25	35	45
	NCV (MJ/Kg)		
Broadleaves	13.59	11.5	9.35
Conifers	13.79	11.63	9.46

The energy contents NCV(ar) as calculated by the standard formula differ substantially from the energy contents NCV(ar) calculated using experimentally determined or assumed hydrogen content of the fuel. As the moisture content increases the difference in the NCV(ar) from tables 11, 12 and 13 and those estimated in table also increases. The values calculated by the formula are between 4 and 16% higher for Sitka spruce, 1 and 8% higher for larch and 7 and 14% higher for ash.

To date, suppliers of wood fuel have been paid according to equations 3 or 4 or something very similar. Often payment has been per tonne, depending on moisture content. A wood fuel price calculated on the basis of the energy content outlined here would need to be in the region of 10-12% higher than heretofore paid, in order that the price per tonne at a given moisture content remains the same.

Conclusions

• GCV of hybrid larch is greater than Sitka spruce, which is greater than ash.
• GCV does not appear to be significantly influenced by location or seasoning, except in Sitka spruce which showed a lowering of GCV on initial seasoning.
• GCVs for ash and Sitka spruce (Table 15 were within the range quoted in EN 14961–1: 2010 *Solid Biofuels- fuel specifications and classes*.
• The GCV for hybrid larch (Table 15) was slightly higher than the range quoted in EN 14961–1.

Table 15: Average GCV of ash, hybrid larch and Sitka spruce assortments, green and seasoned.

Assortment	Condition	Species		
		Ash	Hybrid Larch	Sitka spruce
		GCV MJ/Kg		
Energy wood	Green	ns	20.35	19.47
	Seasoned	ns	20.20	18.96
Shortwood	Green	ns	20.49	19.61
	Seasoned	ns	20.02	19.18
Wholetree	Green	18.99	20.36	19.81
	Seasoned	19.04	20.84	19.21
Firewood	Green			19.64
	Seasoned			18.64

ns: not sampled

• NCV determined from GCV, using the default value for the % hydrogen was always slightly lower than when using the experimentally determined % hydrogen (approximately 1%).
• The NCV (db) of hybrid larch and ash were within the range quoted in EN 14961–1: 2010 whereas the NCV (db) of Sitka spruce was slightly lower than the quoted range.
• Across all species the estimated NCV (ar) using equations 3 and 4 are higher than the experimentally determined NCV (ar), irrespective of whether the default % hydrogen value or an experimentally determined value was used.
• If the more correct measured value of NCV is to be used in contracts, the price per energy unit should be increased, so that the price per tonne of fuel remains the same for the supplier.

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