

Research to support the review of the Renewable Obligation Scotland and impact of the Renewable Heat Incentive

Part 2: Biomass thresholds for electricity, CHP and heat generation

Appendices





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APPENDIX A: Parameters for Biomass Energy Technologies

Type of Biomass Feedstock	Specification of Biomass Feedstock: Moisture	Use of Conversion Technology	Scale of Plant: Input Rate (t/h)		Scale of Plant: Output Rate (MW)		Specification of Plant: Net Thermal Efficiency (%)		Specification of Plant: Heat to Power Ratio
	Content (%)		Lower Range	Higher Range	Lower Range	Higher Range	Lower Range	Higher Range	(CHP only)
Wood Logs	20	Individual Domestic Heating	0.00368	0.0245	0.015 thermal	0.1 thermal	80	91	
Round Wood	53	Power only	64	64	44 electricity	44 electricity	32	32	
Wood Briquettes	8	Individual Domestic Heating	0.00306	0.0653	0.015 thermal	0.32 thermal	80	93	
Clean Wood Chips	35	Group Domestic Heating, Commercial and Industrial Heating	0.0157	6.26	0.05 thermal	20 thermal	90	90.4	
	35	Commercial and Industrial Combined Heat and Power Generation	0.689	54.79	0.4 electricity 1.8 thermal	50 electicity 125 thermal	16 electrical 86.5 overall (elec + heat)	24.7 electrical 29.4 heat 54 overall (electricity + heat)	1.2 - 4.4
	35	Power generation with flue gas heat recovery	17.84	135	50 electricity 7 thermal	100 electricity 13.7 thermal	33 net electrical 3.58 thermal	33 net electrical 3.58 thermal	0.137
	35	Power generation Only	15.65	109.58	50 electricity	350 electricity	33 net electrical	33 net electrical	



Type of Biomass Feedstock	Specification of Biomass Feedstock: Moisture	Use of Conversion Technology	Scale of Plant: Input Rate (t/h)		Scale of Plant: Output Rate (MW)		Specification of Plant: Net Thermal Efficiency (%)		Specification of Plant: Heat to Power Ratio
	Content (%)		Lower Range	Higher Range	Lower Range	Higher Range	Lower Range	Higher Range	(CHP only)
Unclean Wood Chips	5-55	Commercial and Industrial Heating	0.069	6.26	0.1 thermal	20 thermal	88.9 net	90.4 net	
	5-55	Commercial and Industrial Combined Heat and Power Generation	0.689	54.79	0.4 electricity 1.8 thermal	50 electricity 125 thermal	16 electrical 86.5 overall (elec + heat)	24.7 electrical 29.4 heat 54 overall (electricity + heat)	1.2 - 4.4
	5-55	Power Only Generation	15.65	109.58	50 electricity	350 electricity	33 net electrical		
Wood Pellets	10	Individual Domestic Heating	0.00426	0.011	0.02 thermal	0.05 thermal	90	94	
	10	Domestic, Commercial and Industrial Heating	0.00426	0.04	0.02 thermal	0.180 thermal	93	94	



APPENDIX B: Summary of Typical Results

Biomass Chain	Scale: net	End Use	Transport in	Transport to	Transport to		Results	
	output rating (MW)	Thermal Efficiency (%)	Forest	Processing	End User	Primary Energy: fossil fuels (MWh/MWh)	Primary Energy: biomass (odt/MWh)	Total Greenhouse Gas Emissions (kg eq. CO ₂ /MWh)
Individual Domestic Heating by Combustion of Roundwood Logs (DRWL)	0.015 - 0.100	91.0	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 80 km	0.119	0.228	39.3
Individual Domestic Heating by Combustion of Roundwood Logs (DRWL)	0.015 - 0.100	80.0	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 80 km	0.134	0.259	43.1
Individual Domestic Heating by Combustion of Wood Briquettes from Roundwood (DRWB)	0.015 - 0.320	93.0	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 80 km	0.193	0.237	53.6
Individual Domestic Heating by Combustion of Wood Briquettes from Roundwood (DRWB)	0.015 - 0.320	80.0	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 80 km	0.224	0.276	60.4



Biomass Chain	Scale: net	End Use	Transport in	Transport	Transport		Results	NORTH ENERGY
	output rating	Thermal	Forest	to	to End	Primary	Primary	Total
	(MW)	Efficiency		Processing	User	Energy:	Energy:	Greenhouse
		(%)				fossil fuels	biomass	Gas Emissions
						(MWh/MWh)	(odt/MWh)	(kg eq.
								CO ₂ /MWh)
Individual	0.020 - 0.050	94.0	Typical	Typical	Typical	0.177	0.242	39.5
Domestic Heating			road round	road round	local road			
by Combustion of			trip	trip	round trip			
Wood Pellets from			distance:	distance:	distance:			
Roundwood			16 km	66 km	80 km			
(DRWP)	0.020 0.050	00.0	T · ·	- · ·	T	0.402	0.252	40.0
Individual	0.020 - 0.050	90.0	Typical	Typical	Typical	0.183	0.253	40.8
Domestic Heating			road round	road round	local road			
by Combustion of Wood Pellets from			trip distance:	trip distance:	round trip distance:			
Roundwood			16 km	66 km	80 km			
(DRWP)			IO KIII	OU KIII	OU KIII			
Individual	0.020 - 0.050	94.0	Typical	Typical	Maximum	0.198	0.242	45.2
Domestic Heating	0.020 0.030	74.0	road round	road round	national	0.170	0.272	73.2
by Combustion of			trip	trip	road round			
Wood Pellets from			distance:	distance:	trip			
Roundwood			16 km	66 km	distance:			
(DRWP)					600 km			
Individual	0.020 - 0.050	90.0	Typical	Typical	Maximum	0.205	0.253	46.8
Domestic Heating			road round	road round	national			
by Combustion of			trip	trip	road round			
Wood Pellets from			distance:	distance:	trip			
Roundwood			16 km	66 km	distance:			
(DRWP)					600 km			



Biomass Chain	Scale: net	End Use	Transport in	Transport	Transport		Results	
	output rating	Thermal	Forest	to	to End	Primary	Primary	Total
	(MW)	Efficiency		Processing	User	Energy:	Energy:	Greenhouse
		(%)				fossil fuels	biomass	Gas Emissions
						(MWh/MWh)	(odt/MWh)	(kg eq.
								CO ₂ /MWh)
Individual	0.020 - 0.050	94.0	Typical	Typical	Typical	0.102	0.242	22.1
Domestic Heating			road round	road round	local road			
by Combustion of			trip	trip	round trip			
Wood Pellets			distance:	distance:	distance:			
from Forest			16 km	66 km	80 km			
Residues (DFRP)					_			
Individual	0.020 - 0.050	90.0	Typical	Typical	Typical	0.105	0.253	22.6
Domestic Heating			road round	road round	local road			
by Combustion of			trip	trip	round trip			
Wood Pellets			distance:	distance:	distance:			
from Forest			16 km	66 km	80 km			
Residues (DFRP)								
Individual	0.020 - 0.050	94.0	Typical	Typical	Maximum	0.124	0.242	27.8
Domestic Heating			road round	road round	national			
by Combustion of			trip	trip	road round			
Wood Pellets			distance:	distance:	trip			
from Forest			16 km	66 km	distance:			
Residues (DFRP)	0.000 0.050	22.2			600 km	0.40=	2.252	20. (
Individual	0.020 - 0.050	90.0	Typical	Typical	Maximum	0.127	0.253	28.6
Domestic Heating			road round	road round	national			
by Combustion of			trip	trip	road round			
Wood Pellets			distance:	distance:	trip			
from Forest			16 km	66 km	distance:			
Residues (DFRP)					600 km			



Biomass Chain	Scale: net	End Use	Transport	Transport	Transport		Results	
	output rating	Thermal	in Forest	to	to End	Primary	Primary	Total
	(MW)	Efficiency		Processing	User	Energy:	Energy:	Greenhouse
		(%)				fossil fuels	biomass	Gas
						(MWh/MWh)	(odt/MWh)	Emissions
								(kg eq.
								$CO_2/MWh)$
Individual Domestic Heating by Combustion of Wood Briquettes from Clean Waste Wood (DCWB)	0.015 - 0.320	93.0	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.098	n.a.	19.5
Individual Domestic Heating by Combustion of Wood Briquettes from Clean Waste Wood (DCWB)	0.015 - 0.320	80.0	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.102	n.a.	20.2



Biomass Chain	Scale: net	End Use	Transport	Transport	Transport		Results	
	output rating	Thermal	in Forest	to	to End	Primary	Primary	Total
	(MW)	Efficiency		Processing	User	Energy:	Energy:	Greenhouse
		(%)				fossil fuels	biomass	Gas
						(MWh/MWh)	(odt/MWh)	Emissions
								(kg eq.
<u> </u>	0.05020.000	00.0	- · ·	T	- · ·	0.477	0.330	CO ₂ /MWh)
Commercial or Industrial	0.050 - 20.000	90.0	Typical	Typical road round	Typical local road	0.177	0.338	42.8
Heating by			road round trip		round trip			
Combustion of			distance:	trip distance:	distance:			
Wood Chips from			16 km	66 km	80 km			
Roundwood			10 Kill	OO KIII	OO KIII			
(IRWC)								
Commercial or	0.050 - 20.000	90.0	Typical	Typical	Maximum	0.239	0.338	59.6
Industrial			road	road round	national			
Heating by			round trip	trip	road round			
Combustion of			distance:	distance:	trip			
Wood Chips from			16 km	66 km	distance:			
Roundwood					600 km			
(IRWC)								



Biomass Chain	Scale: net	End Use	Transport in	Transport	Transport		Results	
	output rating	Thermal	Forest	to	to End	Primary	Primary	Total
	(MW)	Efficiency		Processing	User	Energy:	Energy:	Greenhouse
		(%)				fossil fuels	biomass	Gas Emissions
						(MWh/MWh)	(odt/MWh)	(kg eq.
								CO ₂ /MWh)
Commercial or	0.050 - 20.000	90.0	Typical	Typical	Typical	0.074	0.338	18.9
Industrial Heating			road round	road	local road			
by Combustion of			trip	round trip	round trip			
Wood Chips from			distance:	distance:	distance:			
Forest Residues (IFRC)			16 km	66 km	80 km			
Commercial or	0.050 - 20.000	90.0	Typical	Typical	Maximum	0.137	0.338	35.8
Industrial Heating			road round	road	national			
by Combustion of			trip	round trip	road round			
Wood Chips from			distance:	distance:	trip			
Forest Residues			16 km	66 km	distance:			
(IFRC)	0.050.000	00.0	N1 /		600 km	0.040		40.0
Commercial or	0.050 - 20.000	90.0	Not	Processed	Typical	0.042	n.a.	10.8
Industrial Heating			applicable	on site of	local road			
by Combustion of				waste	round trip distance:			
Wood Chips from Clean Waste Wood				generation	80 km			
(ICWC)					OU KIII			
Commercial or	0.050 - 20.000	90.0	Not	Processed	Maximum	0.077	n.a.	20.2
Industrial Heating	2.030 20.000	70.0	applicable	on site of	national	0.077	π.α.	20.2
by Combustion of			applicable	waste	road round			
Wood Chips from				generation	trip			
Clean Waste Wood				J === == === == = = = = = = = = = = = =	distance:			
(ICWC)					600 km			



Biomass Chain	Scale: net	End Use	Transport	Transport	Transport		Results		
	output rating	Thermal	in Forest	to	to End	Primary	Primary	Total	
	(MW)	Efficiency		Processing	User	Energy:	Energy:	Greenhouse	
		(%)				fossil fuels	biomass	Gas Emissions	
						(MWh/MWh)	(odt/MWh)	(kg eq.	
	0.400.000	00.0				0.111		CO ₂ /MWh)	
Commercial or	0.100 - 20.000	90.0	Not	Processed	Typical	0.141	n.a.	29.4	
Industrial Heating			applicable	on site of	local road				
by Combustion of Wood Chips from				waste generation	round trip distance:				
Unclean Waste				generation	80 km				
Wood (IUWC)					OO KIII				
Commercial or	0.100 - 20.000	89.0	Not	Processed	Typical	0.142	n.a.	29.7	
Industrial Heating			applicable	on site of	local road				
by Combustion of				waste	round trip				
Wood Chips from				generation	distance:				
Unclean Waste					80 km				
Wood (IUWC)				_					
Commercial or	0.100 - 20.000	90.0	Not	Processed	Maximum	0.176	n.a.	38.9	
Industrial Heating			applicable	on site of	national				
by Combustion of				waste	road round				
Wood Chips from Unclean Waste				generation	trip distance:				
Wood (IUWC)					600 km				
Commercial or	0.100 - 20.000	89.0	Not	Processed	Maximum	0.177	n.a.	39.2	
Industrial Heating	20.000	67.6	applicable	on site of	national	0.177	11.4.	37.2	
by Combustion of				waste	road round				
Wood Chips from				generation	trip				
Unclean Waste					distance:				
Wood (IUWC)					600 km				



Biomass Chain	Scale: net	End Use	Heat	Transport	Transport	Transport		Results ^(a)	
	output rating (MW)	Thermal Efficiency (%)	to Power Ratio	in Forest	to Processing	to End User	Primary Energy: fossil fuels (MWh/MWh)	Primary Energy: biomass (odt/MWh)	Total Greenhouse Gas Emissions (kg eq. CO ₂ /MWh)
Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Roundwood (CRWC)	1.800 - 125.000 heat	86.5	4.4	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 80 km	0.126	0.297	30.0
Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Roundwood (CRWC)	1.800 - 125.000 heat	54.0	1.2	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 600 km	0.236	0.387	58.5



Biomass Chain	Scale: net	End Use	Heat	Transport	Transport	Transport		Results ^(a)	
	output	Thermal	to	in Forest	to	to End	Primary	Primary	Total
	rating	Efficiency	Power		Processing	User	Energy: fossil	Energy:	Greenhouse
	(MW)	(%)	Ratio				fuels	biomass	Gas
							(MWh/MWh)	(odt/MWh)	Emissions
									(kg eq.
									CO ₂ /MWh)
Commercial or	1.800 -	86.5	4.4	Typical	Typical	Typical	0.036	0.297	9.1
Industrial	125.000			road	road round	local			
Heating from	heat			round trip	trip	road			
Combined Heat and Power				distance: 16 km	distance: 66 km	round			
Generation by				10 KIII	OO KIII	trip distance:			
Combustion of						80 km			
Wood Chips						OO KIII			
from Forest									
Residue (CFRC)									
Commercial or	1.800 -	54.0	1.2	Typical	Typical	Typical	0.118	0.387	31.2
Industrial	125.000			road	road round	local			
Heating from	heat			round trip	trip	road			
Combined Heat				distance:	distance:	round			
and Power				16 km	66 km	trip			
Generation by						distance:			
Combustion of						600 km			
Wood Chips									
from Forest									
Residue (CFRC)									



Biomass Chain	Scale:	End Use	Heat	Transport	Transport	Transport		Results ^(a)	
	net	Thermal	to	in Forest	to	to End	Primary	Primary	Total
	output	Efficiency	Power		Processing	User	Energy:	Energy:	Greenhouse
	rating	(%)	Ratio				fossil fuels	biomass	Gas Emissions
	(MW)						(MWh/MWh)	(odt/MWh)	(kg eq. CO ₂ /MWh)
Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Clean Waste Wood (CCWC)	1.800 - 125.000 heat	86.5	4.4	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.008	n.a.	2.0
Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Clean Waste Wood (CCWC)	1.800 - 125.000 heat	54.0	1.2	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 600 km	0.050	n.a.	13.4



Biomass Chain	Scale:	End Use	Heat	Transport	Transport	Transport		Results ^(a)	
	net output rating (MW)	Thermal Efficiency (%)	to Power Ratio	in Forest	to Processing	to End User	Primary Energy: fossil fuels (MWh/MWh)	Primary Energy: biomass (odt/MWh)	Total Greenhouse Gas Emissions (kg eq. CO ₂ /MWh)
Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Unclean Waste Wood (CUWC)	1.800 - 125.000 heat	86.5	1.2	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.094	n.a.	18.4
Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Unclean Waste Wood (CUWC)	1.800 - 125.000 heat	54.0	1.2	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 600 km	0.163	n.a.	34.8



Biomass Chain	Scale: net	End Use	Heat	Transport	Transport	Transport		Results ^(a)		
	output rating (MW)	Thermal Efficiency (%)	to Power Ratio	in Forest	to Processing	to End User	Primary Energy: fossil fuels (MWh/MWh)	Primary Energy: biomass (odt/MWh)	Total Greenhouse Gas Emissions (kg eq.	
Commercial or Industrial Electricity from Combined Heat and Power Generation by Combustion of Wood Chips from Roundwood (CRWC)	0.400 - 50.000 electricity	86.5	4.4	Typical road round trip distance: 16 km	Typical road round trip distance: 66 km	Typical local road round trip distance: 80 km	0.251	0.366	CO ₂ /MWh) 60.0	
Commercial or Industrial Electricity from Combined Heat and Power Generation by Combustion of Wood Chips from Roundwood (CRWC)	0.400 - 50.000 electricity	54.0	1.2	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 600 km	0.471	0.478	117.0	



Biomass Chain	Scale: net	End Use	Heat	Transport	Transport	Transport		Results ^(a)	
	output	Thermal	to	in Forest	to	to End	Primary	Primary	Total
	rating	Efficiency	Power		Processing	User	Energy:	Energy:	Greenhouse Gas
	(MW)	(%)	Ratio				fossil fuels	biomass	Emissions
							(MWh/MWh)	(odt/MWh)	(kg eq.
	0.400	0/ 5	4 4	- · ·	- · ·	- · ·	0.074	0.503	CO ₂ /MWh)
Commercial or	0.400 - 50.000	86.5	4.4	Typical	Typical	Typical	0.071	0.593	18.2
Industrial Electricity from	electricity			road round trip	road round trip	local road round trip			
Combined Heat	electricity			distance:	distance:	distance:			
and Power				16 km	66 km	80 km			
Generation by									
Combustion of									
Wood Chips									
from Forest									
Residue (CFRC)									(0.0
Commercial or	0.400 -	54.0	1.2	Not	Processed	Typical	0.236	0.774	62.3
Industrial	50.000			applicable	on site of	local road			
Electricity from Combined Heat	electricity				waste generation	round trip distance:			
and Power					generation	600 km			
Generation by						000 1111			
Combustion of									
Wood Chips									
from Forest									
Residue (CFRC)									



Biomass Chain	Scale: net	End Use	Heat	Transport	Transport	Transport		Results ^{(a})
	output	Thermal	to	in Forest	to	to End	Primary	Primary	Total Greenhouse
	rating	Efficiency	Power		Processing	User	Energy:	Energy:	Gas Emissions
	(MW)	(%)	Ratio				fossil fuels	biomass	(kg eq.
							(MWh/MWh)	(odt/MWh)	CO ₂ /MWh)
Commercial or	0.400 -	86.5	4.4	Not	Processed	Typical	0.015	n.a.	4.0
Industrial	50.000			applicable	on site of	local			
Electricity from	electricity				waste	road			
Combined Heat					generation	round			
and Power						trip			
Generation by						distance:			
Combustion of						80 km			
Wood Chips from									
Clean Waste Wood									
(CCWC)	0.100		4.0				0.000		0.4 =
Commercial or	0.400 -	54.0	1.2	Not	Processed	Typical	0.099	n.a.	26.7
Industrial	50.000			applicable	on site of	local			
Electricity from	electricity				waste	road			
Combined Heat					generation				
and Power						trip			
Generation by						distance:			
Combustion of						600 km			
Wood Chips from									
Clean Waste Wood									
(CCWC)									



Biomass Chain	Scale: net	End Use	Heat	Transport	Transport	Transport		Results ^(a)	
	output	Thermal	to	in Forest	to	to End	Primary	Primary	Total
	rating	Efficiency	Power		Processing	User	Energy:	Energy:	Greenhouse Gas
	(MW)	(%)	Ratio				fossil fuels	biomass	Emissions
							(MWh/MWh)	(odt/MWh)	(kg eq. CO₂/MWh)
Commercial or Industrial Electricity from Combined Heat and Power Generation by Combustion of Wood Chips from Unclean Waste Wood (CUWC)	0.400 - 50.000 electricity	86.5	4.4	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.188	n.a.	36.8
Commercial or Industrial Electricity from Combined Heat and Power Generation by Combustion of Wood Chips from Unclean Waste Wood (CUWC)	0.400 - 50.000 electricity	54.0	1.2	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 600 km	0.325	n.a.	69.5



Biomass Chain	Scale: net	End Use	Transport	Transport	Transport to		Results	
	output	Thermal	in Forest	to	End User	Primary	Primary	Total
	rating	Efficiency		Processing		Energy:	Energy:	Greenhouse
	(MW)	(%)				fossil fuels	biomass	Gas Emissions
						(MWh/MWh)	(odt/MWh)	(kg eq.
		,,,						CO ₂ /MWh)
Power Only	5 - 350	30.0 ^(b)	Typical	Not	Typical local	0.283	0.706	84.1
Generation by	electricity		road round	applicable	road round			
Combustion of			trip		trip distance:			
Roundwood (PRWC)			distance:		80 km			
		a a a(b)	16 km					
Power Only	5 - 350	30.0 ^(b)	Typical	Not	Typical	0.441	0.706	126.7
Generation by	electricity		road round	applicable	international			
Combustion of			trip		ship round trip			
Roundwood (PRWC)			distance:		distance: 4000			
	5 350	20 0(b)	200 km		km	2.24=	2 724	22.0
Power Only	5 - 350	30.0 ^(b)	Typical	Not	Typical local	0.067	0.706	33.9
Generation by	electricity		road round	applicable	road round			
Combustion of Wood			trip		trip distance:			
Chips from Forest			distance:		80 km			
Residues (PFRC)	F 250	20. O(b)	16 km	NI-4	T ! !	0.225	0.70/	77 /
Power Only	5 - 350	30.0 ^(b)	Typical	Not	Typical	0.225	0.706	77.6
Generation by	electricity		road round	applicable	international			
Combustion of Wood			trip		ship round trip			
Chips from Forest			distance:		distance: 4000			
Residues (PFRC)			200 km		km			

Note (b) Assuming an initial average net thermal efficiency of 33% reduced to 32% for chipping/milling at the power plants and adjusted for 5.7% transmission and distribution losses to 30%.



Biomass Chain	Scale: net	End Use	Transport	Transport	Transport to		Results	
	output	Thermal	in Forest	to	End User	Primary	Primary	Total
	rating	Efficiency		Processing		Energy:	Energy:	Greenhouse
	(MW)	(%)				fossil fuels	biomass	Gas
						(MWh/MWh)	(odt/MWh)	Emissions
								(kg eq.
								CO ₂ /MWh)
Power Only	5 - 350	31.0 ^(c)	Typical	Typical	Typical local	0.160	0.706	53.3
Generation by	electricity		road round	local road	road round			
Combustion of			trip	round trip	trip distance:			
Wood Pellets			distance:	distance:	80 km			
from Forest			16 km	80 km				
Residues (PFRP)								
Power Only	5 - 350	31.0 ^(c)	Typical	Typical	Typical	0.248	0.706	76.5
Generation by	electricity		road round	local road	international			
Combustion of			trip	round trip	ship round			
Wood Pellets			distance:	distance:	trip distance:			
from Forest			200 km	80 km	4000 km			
Residues (PFRP)								

Note (c) Assuming an initial average net thermal efficiency of 33% adjusted for 5.7% transmission and distribution losses to 31%.



Biomass Chain	Scale: net	End Use	Transport in	Transport	Transport to		Results	
	output rating (MW)	Thermal Efficiency (%)	Forest	to Processing	End User	Primary Energy: fossil fuels (MWh/MWh)	Primary Energy: biomass (odt/MWh)	Total Greenhouse Gas Emissions (kg eq. CO ₂ /MWh)
Power Only Generation by Combustion of Wood Chips from Clean Waste Wood (PCWC)	5 - 350 electricity	31.0 ^(c)	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.025	n.a.	23.7
Power Only Generation by Combustion of Wood Chips from Clean Waste Wood (PCWC)	5 - 350 electricity	31.0 ^(c)	Not applicable	Processed on site of waste generation	Typical international ship round trip distance: 4000 km	0.115	n.a.	48.5
Power Only Generation by Combustion of Wood Pellets from Clean Waste Wood (PCWP)	5 - 350 electricity	31.0 ^(c)	Not applicable	Processed on site of waste generation	Typical local road round trip distance: 80 km	0.108	n.a.	38.7
Power Only Generation by Combustion of Wood Pellets from Clean Waste Wood (PCWP)	5 - 350 electricity	31.0 ^(c)	Not applicable	Processed on site of waste generation	Typical international ship round trip distance: 4000 km	0.154	n.a.	51.4

Note (c) Assuming an initial average net thermal efficiency of 33% adjusted for 5.7% transmission and distribution losses to 31%.



Biomass Chain	Scale: net	End Use	Transport	Transport	Transport to	Results		
	output	Thermal	in Forest	to	End User	Primary	Primary	Total
	rating	Efficiency		Processing		Energy:	Energy:	Greenhouse
	(MW)	(%)				fossil fuels	biomass	Gas Emissions
						(MWh/MWh)	(odt/MWh)	(kg eq.
								CO ₂ /MWh)
Power Only	5 - 350	31.0 ^(c)	Not	Processed	Typical local	0.310	n.a.	60.4
Generation by	electricity		applicable	on site of	road round			
Combustion of Wood				waste	trip distance:			
Chips from Unclean				generation	80 km			
Waste Wood (PUWC)		- (8)						
Power Only	5 - 350	31.0 ^(c)	Not	Processed	Typical	0.399	n.a.	85.3
Generation by	electricity		applicable	on site of	international			
Combustion of Wood				waste	ship round trip			
Chips from Unclean				generation	distance: 4000			
Waste Wood (PUWC)		2 (2(5)			km			
Power Only	5 - 350	31.0 ^(c)	Not	Processed	Typical local	0.393	n.a.	75.5
Generation by	electricity		applicable	on site of	road round			
Combustion of Wood				waste	trip distance:			
Pellets from Unclean				generation	80 km			
Waste Wood (PUWP)	F 350	24 O(C)	N1 4		+ · ·	0.420		00.0
Power Only	5 - 350	31.0 ^(c)	Not	Processed	Typical	0.439	n.a.	88.2
Generation by	electricity		applicable	on site of	international			
Combustion of Wood				waste	ship round trip			
Pellets from Unclean				generation	distance: 4000			
Waste Wood (PUWP)					km			

Note (c) Assuming an initial average net thermal efficiency of 33% adjusted for 5.7% transmission and distribution losses to 31%.



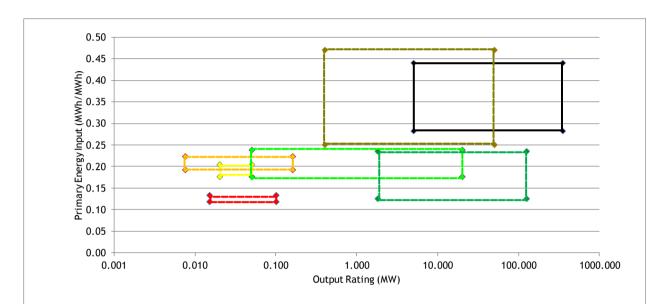
APPENDIX C: Comparison of Total Primary Energy (fossil fuel) Inputs for Providing Heat and/or Electricity from Wood and Fossil Fuels

Option	Total Primary Energy (fossil fuel)
·	Input
	(MWh/MWh)
Domestic Heating:	
- coal-fired	1.457 - 2.040
- oil-fired	1.311 - 1.748
- natural gas-fired	1.188 - 1.527
- wood-fired (roundwood logs)	0.119 - 0.134
- wood-fired (roundwood briquettes)	0.193 - 0.224
- wood-fired (roundwood pellets)	0.177 - 0.205
- wood-fired (forest residue pellets)	0.102 - 0.127
- wood-fired (clean waste wood briquettes)	0.098 - 0.102
Commercial or Industrial Heating from Heat Only Plant:	
- coal-fired	1.275 - 1.457
- oil-fired	1.166 - 1.499
- natural gas-fired	1.188 - 1.311
- wood-fired (roundwood chips)	0.081 - 0.143
- wood-fired (forest residue chips)	0.074 - 0.137
- wood-fired (clean waste wood chips)	0.042 - 0.077
- wood-fired (unclean waste wood chips)	0.141 - 0.177
Commercial or Industrial Heat from CHP Plant:	00000
- coal-fired	0.445 - 1.299
- oil-fired	0.457 - 1.336
- natural gas-fired	0.466 - 1.361
- wood-fired (roundwood chips)	0.126 - 0.236
- wood-fired (forest residue chips)	0.036 - 0.118
- wood-fired (clean waste wood chips)	0.008 - 0.050
- wood-fired (unclean waste wood chips)	0.094 - 0.163
Commercial or Industrial Electricity from CHP Plant:	0.071 0.103
- coal-fired	0.590 - 0.743
- oil-fired	0.607 - 0.762
- natural gas-fired	0.619 - 0.777
- wood-fired (roundwood chips)	0.251 - 0.471
- wood-fired (forest residue chips)	0.071 - 0.236
- wood-fired (clean waste wood chips)	0.015 - 0.099
- wood-fired (clean waste wood chips)	0.188 - 0.235
Electricity from Power Only Plant:	0.100 - 0.255
- coal-fired	2.914 - 4.080
- coal-fired	2.914 - 4.080
	2.376 - 3.563
- natural gas-fired	0.283 - 0.441
- wood-fired (roundwood)	
- wood-fired (forest residue chips)	0.067 - 0.225
- wood-fired (forest residue pellets)	0.160 - 0.248
- wood fired (clean waste wood chips)	0.025 - 0.115
- wood-fired (clean waste wood pellets)	0.108 - 0.154
- wood-fired (unclean waste wood chips)	0.310 - 0.399
- wood-fired (unclean waste wood chips)	0.393 - 0.439



APPENDIX D: Typical Primary Energy [fossil fuel] Inputs for Energy Generation from Wood

Figure D1 Range of Typical Results for Total Primary Energy [fossil fuel] Inputs for the Use of Roundwood



- $\bullet \ \, \text{Individual Domestic Heating by Combustion of Roundwood Logs}$
- lacktriangle Individual Domestic Heating by Combustion of Wood Briquettes from Roundwood
- Individual Domestic Heating by Combustion of Wood Pellets from Roundwood
- ◆ Commercial or Industrial Heating by Combustion of Wood Chips from Roundwood
- ◆ Commercial or Industrial Heating from Combined Heat and Power Generation by Combustion of Wood Chips from Roundwood
- ◆ Commercial or Industrial Electricity from Combined Heat and Power Generation by Combustion of Wood Chips from Roundwood
- ◆ Power Only Generation by Combustion of Roundwood (chipped/milled at power plant)



Figure D2 Range of Typical Results for Total Primary Energy [fossil fuel] Inputs for the Use of Forest Residues

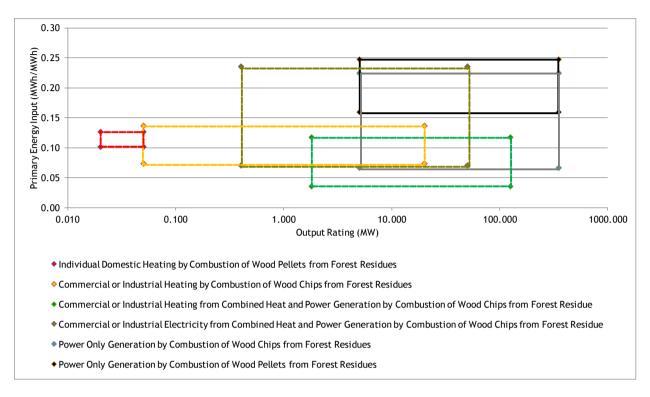


Figure D3 Range of Typical Results for Total Primary Energy [fossil fuel]
Inputs for the Use of Clean Waste Wood

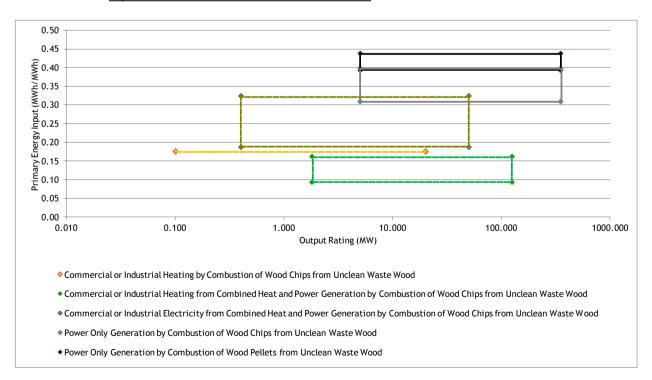
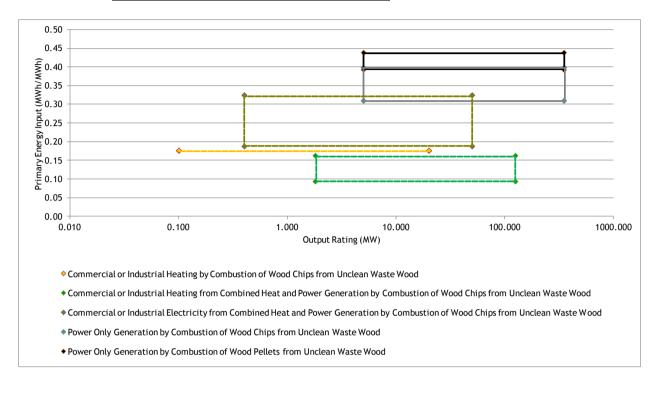




Figure D4 Range of Typical Results for Total Primary Energy [fossil fuel]
Inputs for the Use of Unclean Waste Wood





APPENDIX E: Typical Primary Energy [biomass] Requirements for Energy Generation from Wood

Figure E1 Range of Typical Results for Total Primary Energy [biomass]
Requirements for the Use of Roundwood

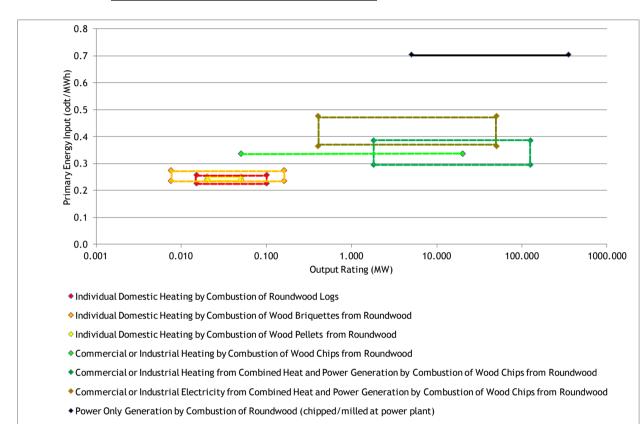
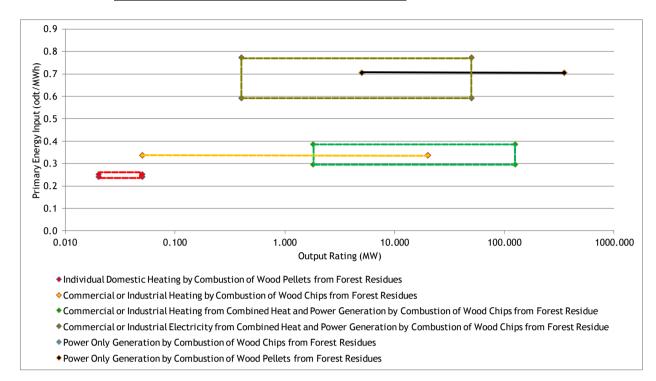




Figure E2 Range of Typical Results for Total Primary Energy [biomass]
Requirements for the Use of Forest Residues





APPENDIX F: Results of Idealised Modelling: Total Greenhouse Gas Emissions

Figure F1

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Roundwood Logs for Domestic Heating Plants and Roundwood for a Power Only Plant

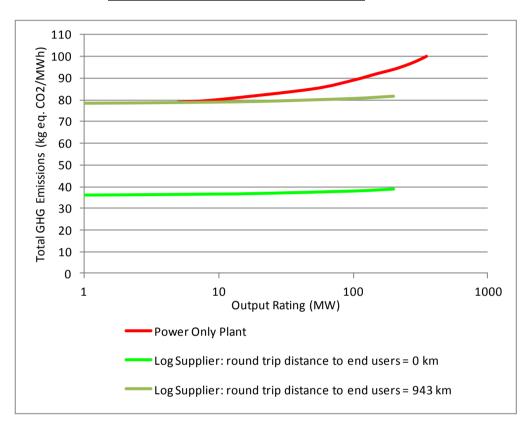




Figure F2

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Roundwood Briquettes for Domestic Heating Plants and Roundwood for a Power Only Plant

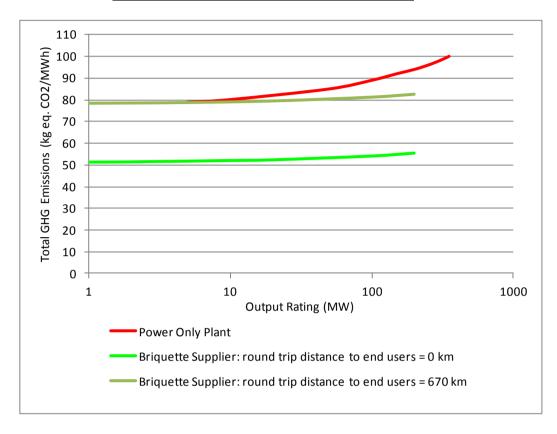




Figure F3

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Roundwood Pellets for Domestic Heating Plants and Roundwood for a Power Only Plant

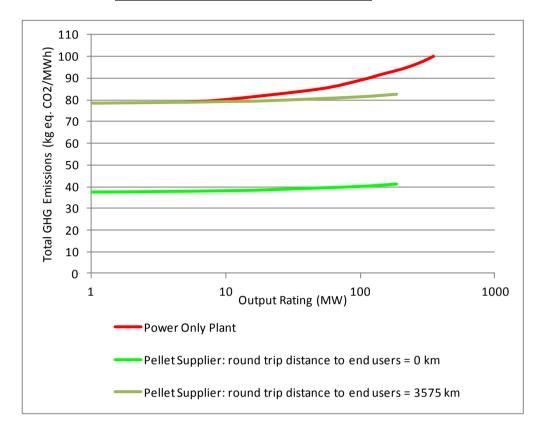




Figure F4

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Roundwood Chips for a Commercial and Industrial Heat Only Plant and Roundwood for a Power Only Plant

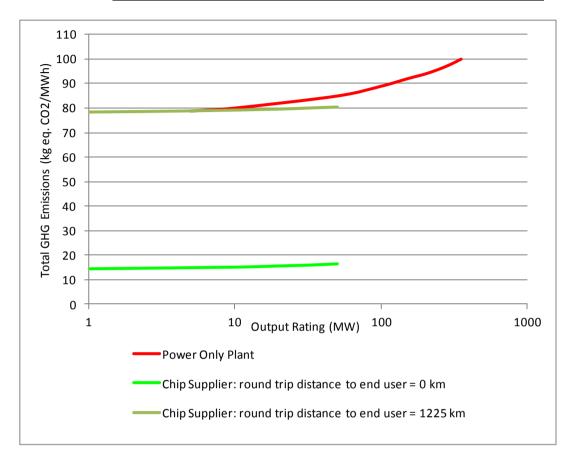




Figure F5
Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Roundwood Chips for Commercial and Industrial Heating with a Combined Heat and Power Plant and Roundwood for a Power Only Plant

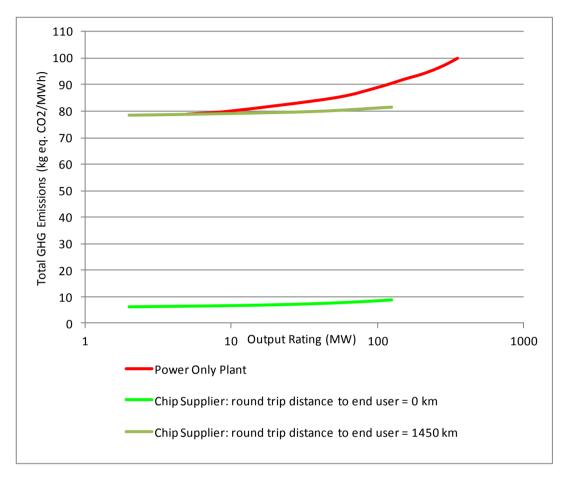




Figure F6

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Forest Residue Pellets for Domestic Heating Plants and Forest Residues for a Power Only Plant

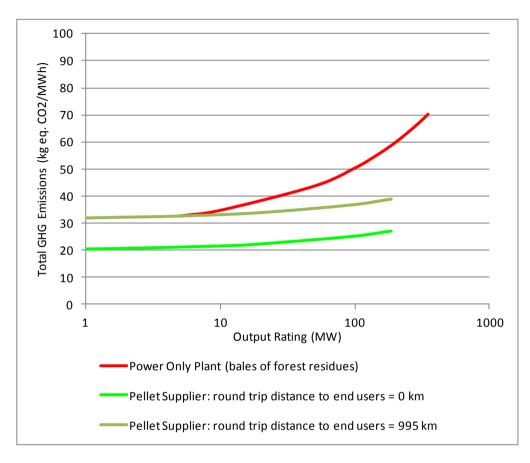




Figure F7

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Forest Residue Chips for a Commercial or Industrial Heat Only Plant and Forest Residues for a Power Only Plant

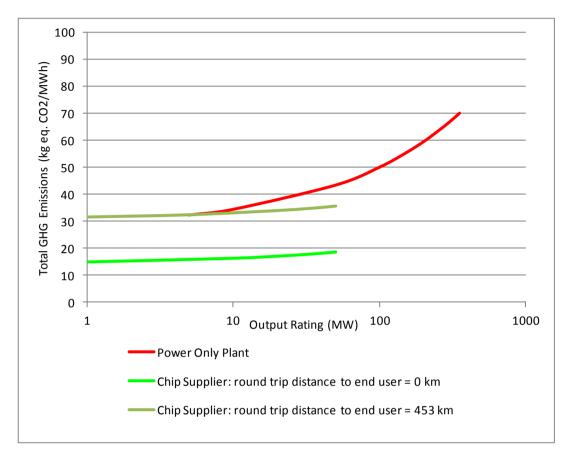
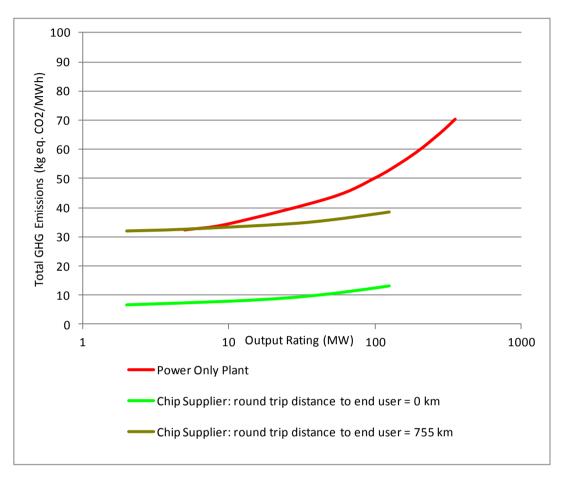




Figure F8

Variation of Total Greenhouse Gas Emission with Scale from an Idealised Model; Forest Residue Chips for Commercial or Industrial Heating with a Combined Heat and Power Plant and Forest Residues for a Power Only Plant





APPENDIX G:Effect of Weighting on Total Greenhouse Gas Emissions for Electricity and Heat from Wood-fired Combined Heat and Power Plants

Figure G1

Effect of Weighting of Value of Electricity to Value of Heat on
Total Greenhouse Gas Emissions for Electricity and Heat from a
Typical Combined Heat and Power Plant Using Roundwood Chips

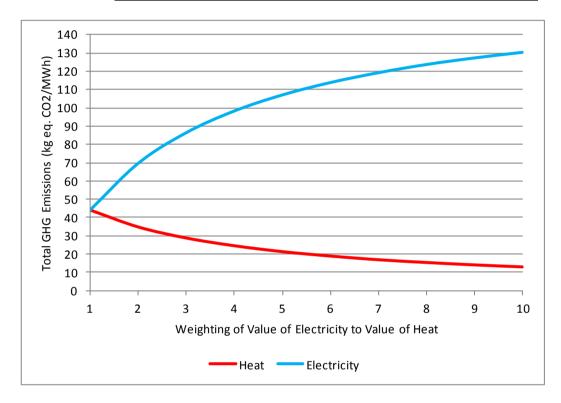




Figure G2 Effect of Weighting of Value of Electricity to Value of Heat on Total Greenhouse Gas Emissions for Electricity and Heat from a Typical Combined Heat and Power Plant Using Forest Residue Chips

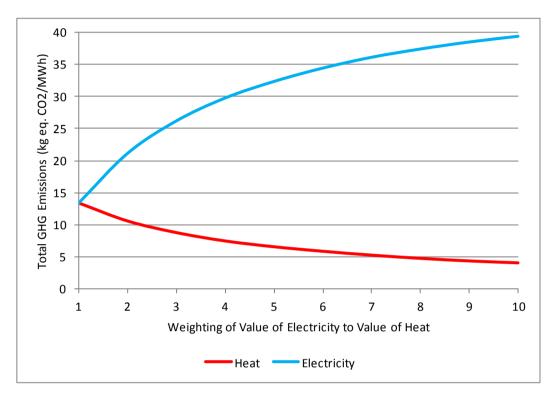




Figure G3

Effect of Weighting of Value of Electricity to Value of Heat on
Total Greenhouse Gas Emissions for Electricity and Heat from a
Typical Combined Heat and Power Plant Using Clean Waste Wood
Chips

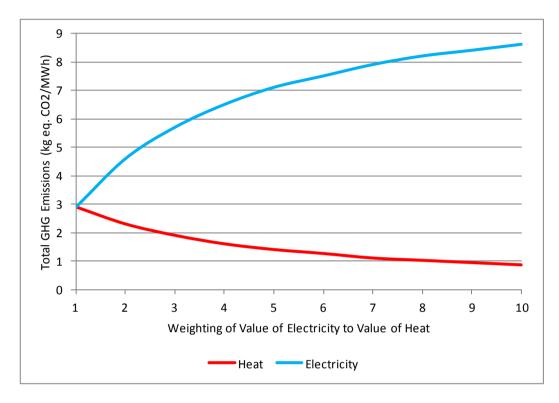
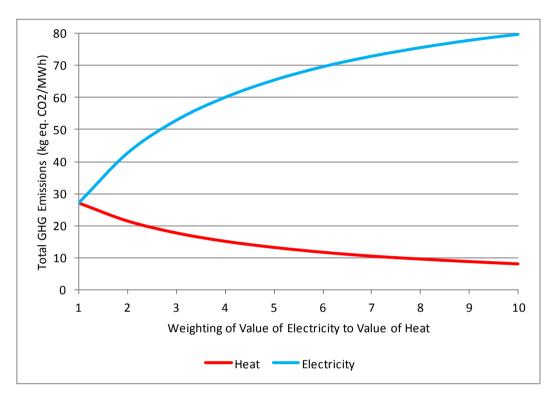




Figure G4

Effect of Weighting of Value of Electricity to Value of Heat on
Total Greenhouse Gas Emissions for Electricity and Heat from a
Typical Combined Heat and Power Plant Using Unclean Waste
Wood Chips





APPENDIX H: Variations in Proportional Price Differentials

Figure H1 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Roundwood Logs for Domestic
Heating

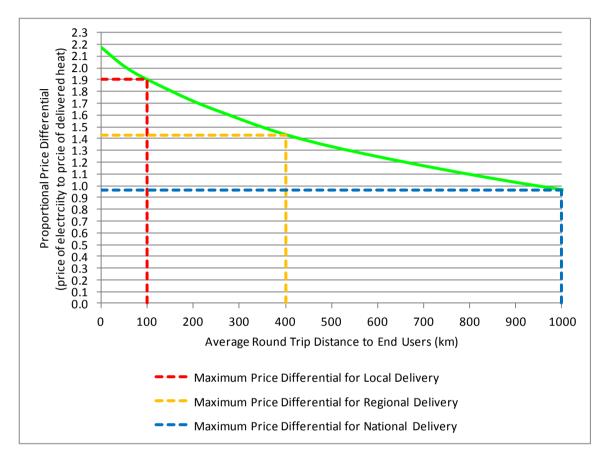




Figure H2 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Roundwood Briquettes for
Domestic Heating

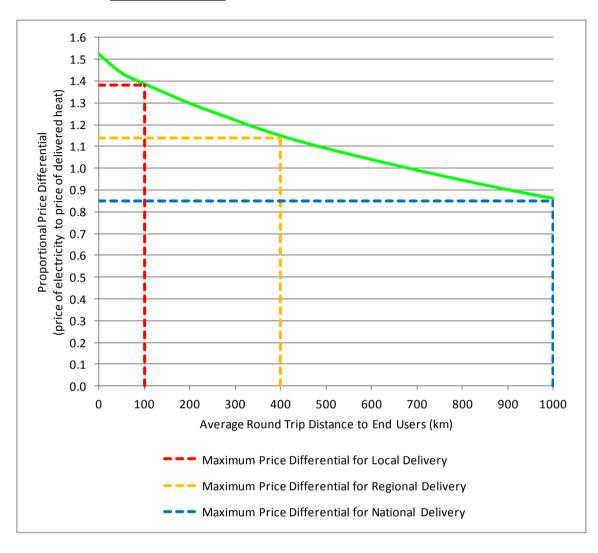




Figure H3 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Roundwood Pellets for Domestic
Heating

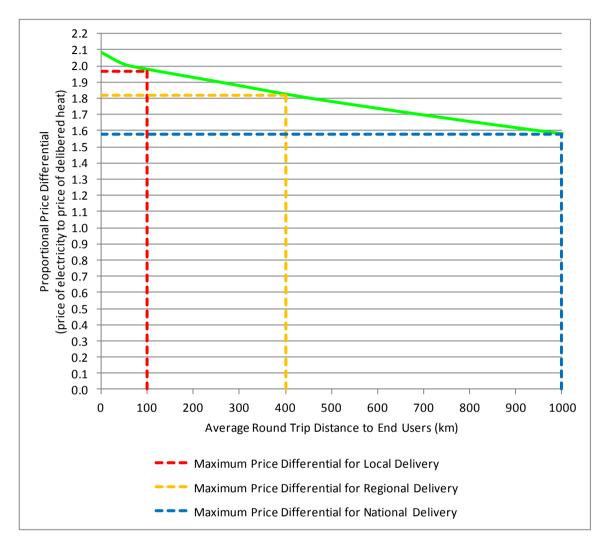




Figure H4 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Roundwood Chips for
Commercial and Industrial Heating

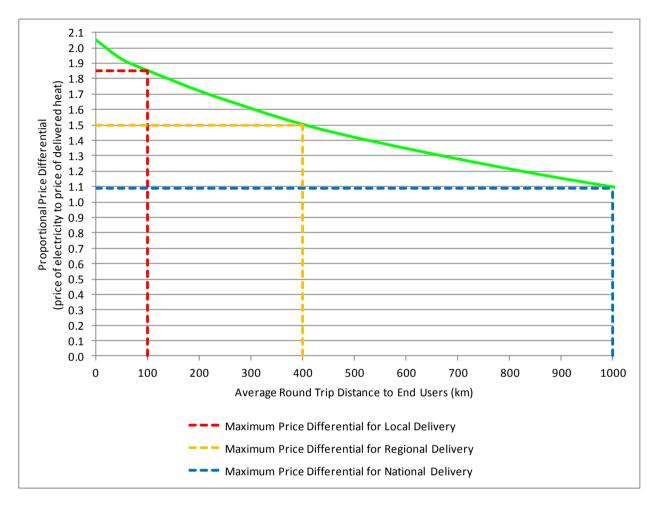




Figure H5

Variation of Proportional Price Differential with Round Trip

Transport Distance to End Users: Roundwood Chips for

Commercial and Industrial Combined Heat and Power Generation

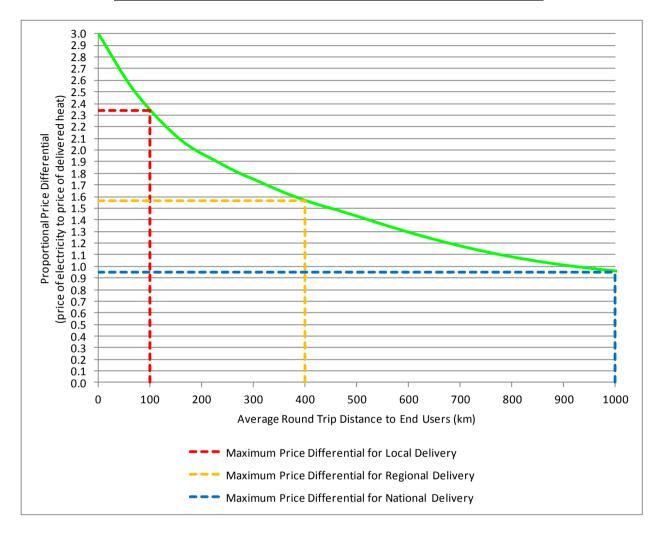




Figure H6

Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Forest Residue Pellets for
Domestic Heating

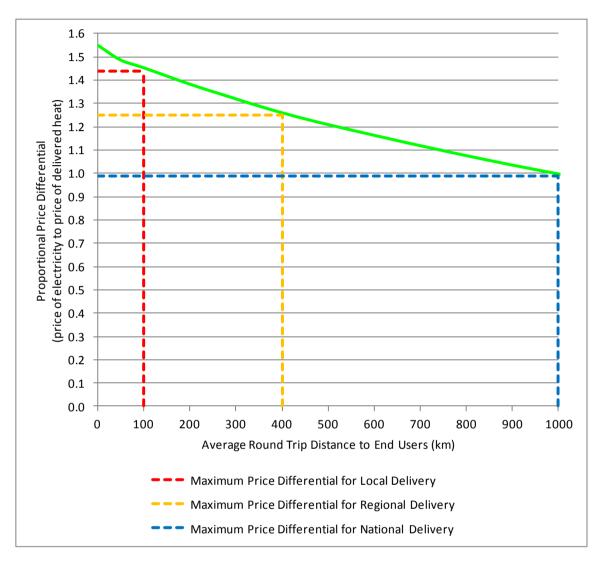




Figure H7

Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Forest Residue Chips for
Commercial and Industrial Heating

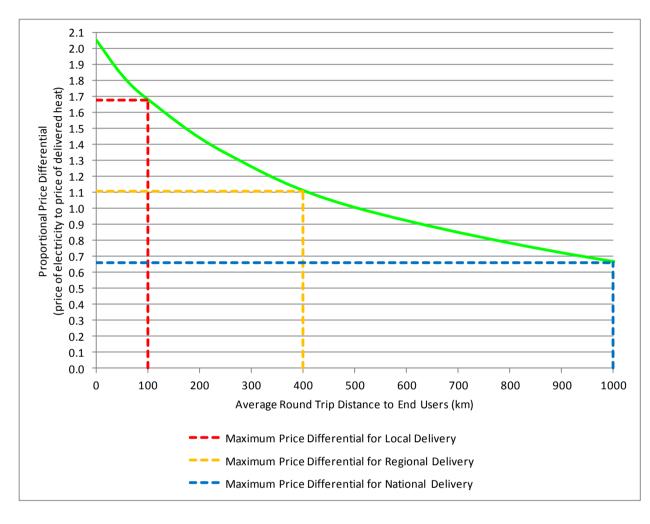




Figure H8

Variation of Proportional Price Differential with Round Trip

Transport Distance to End Users: Forest Residue Chips for

Commercial and Industrial Combined Heat and Power Generation

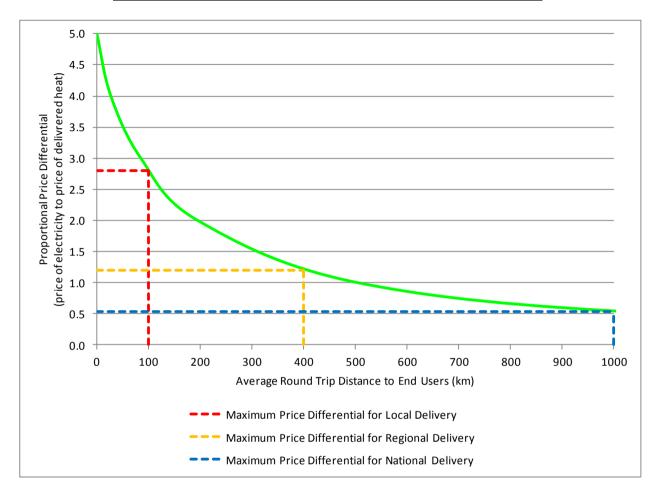




Figure H9

Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Clean Waste Wood Briquettes
for Domestic Heating

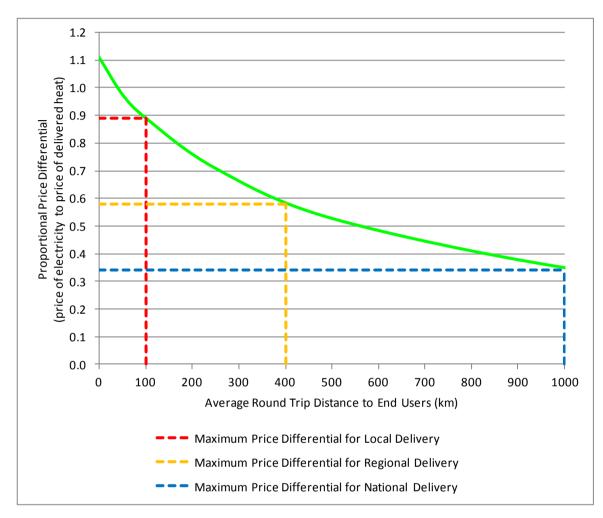




Figure H10 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Clean Waste Wood Pellets for
Domestic Heating

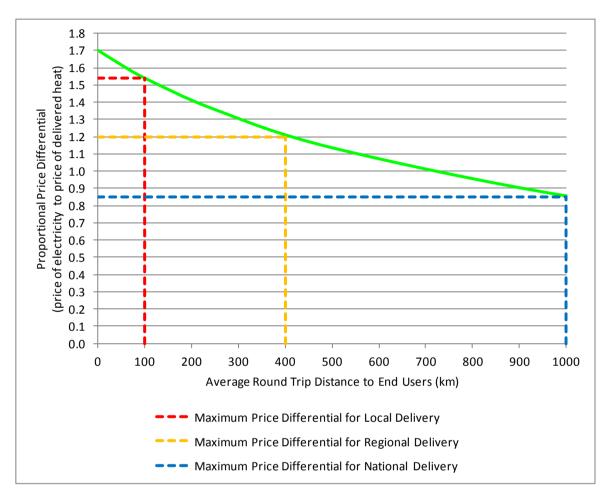




Figure H11 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Clean Waste Wood Chips for
Commercial and Industrial Heating

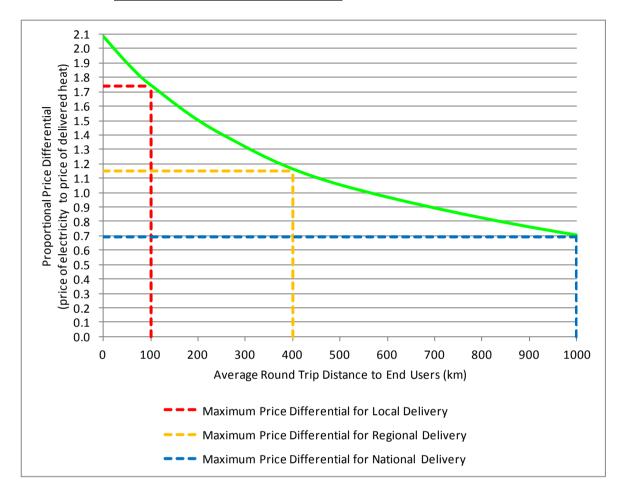




Figure H12 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Clean Waste Wood Chips for
Commercial and Industrial Combined Heat and Power Generation

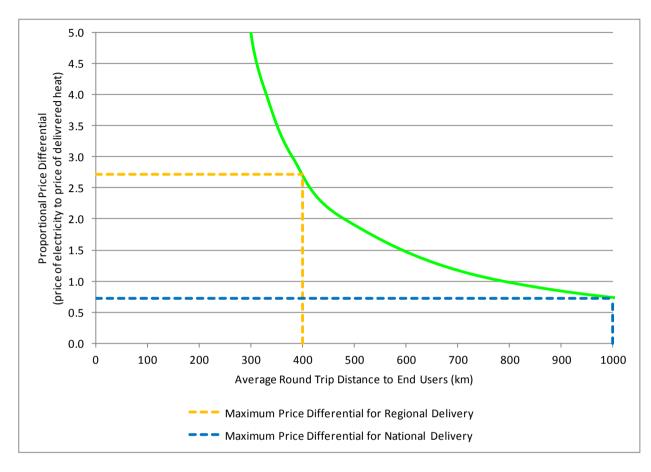




Figure H13 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Unclean Waste Wood Chips for
Commercial and Industrial Heating

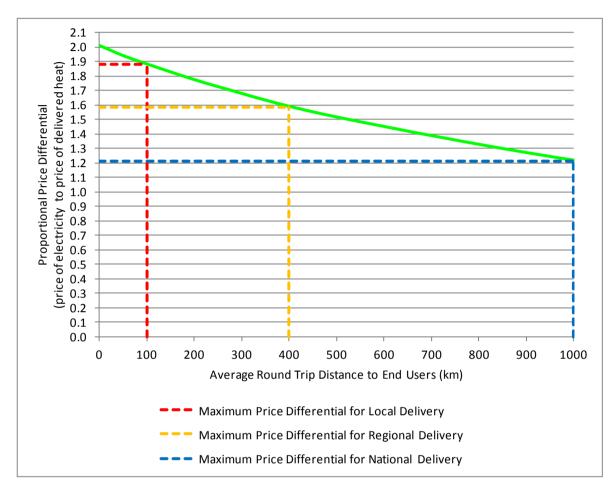




Figure H14 Variation of Proportional Price Differential with Round Trip
Transport Distance to End Users: Unclean Waste Wood Chips for
Commercial and Industrial Combined Heat and Power Generation

