JRC GHG calculations for solid and gaseous biomass

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European Commission

Agenda

- JRC
- Default Values process
- Datasets and pathways definition for solid and gaseous biomass
- Example: Pellets from forest residues
- Critical points in the methodology

Panorama of the European Union

European Court of Auditors

European Parliament

The Council of the European Union

The Committee of the Regions

Court of Justice

European Commission (27 Commission members)

Economic and Social Committee

Commissioner

Commissioner

Commissioner

Máire Geoghegan-Quinn

Commissioner

SG

RELEX

ENTR

MOVE

ENER

RTD

JRC

CLIMA

IRMM

IES

IPSC

IPTS

IET

IHCP

ITU

Institute for Energy and Transport

Ispra, Italy

Petten, The Netherlands

Extended experience on GHG calculations and Carbon footprint of transportation biofuels:

- Well-to-Wheels report (JEC consortium + E3 Database)
- Default values for Directive 2009/28/EC
- Default values for COM(2010) 11

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1. Request from stakeholders / Initiative from JRC / request from DG ENER

The definition / update of a new default value is initiated either by the needs of stakeholders or by JRC / DG ENER initiative based on significant technical developments in the field.

2. Definition of the pathway and transport schemes

The pathway needs to be defined in all of its processes, from cradle to the final biofuel. This includes the definition of typical import routes to EU and typical transport means. Interaction with external consultants and stakeholders is a valuable contribution to this step.

3. Data collection for each process

For each process involved, data are collected from several sources: peer reviewed publications, published handbooks, LCA databases, consultation with stakeholders and external consultants etc…The data are chosen (whenever possible) to be representative of the European situation. Critical evaluation of the data is done by JRC experts. Large database available (E3 database)

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4. Data conversion to common energy basis

The data collected need to be converted to a common energy basis based on the dry LHV of the materials. A common set of fuel properties is used.

5. GHG emissions calculations

The data acquired and converted, are inserted into a LCA calculation tool that, applying a set of emission factors, produces the final “typical value”.

6. Definition of the DEFAULT VALUE

The “default value” is finally obtained by increasing specific sections of the typical value (to be defined).

Feedstocks

- Harvest residues
- Short rotation forestry
- Wood industry residues
- Roundwood
- Agricultural residues
- Straw
- Sugar Cane Bagasse
- Palm kernel meal

Biomass Form

- Chips
- Bales
- Pellets

Process utilities

- Natural Gas Boiler + Grid Electricity
- Wood Pellets Boiler + Grid Electricity
- Wood Pellets CHP

Transport

- 1 - 500 km by truck
- 500 – 2500 km by truck and bulk carrier
- 2500 – 10000 km by truck and bulk carrier
- > 10000 km by train and bulk carrier

1. Woodchips from forest residues;
2. Woodchips from SRF;
3. Woodchips from wood industry residues;
4. Woodchips from roundwood;
5. Wood pellets from forest residues;
6. Wood pellets from SRF;
7. Wood pellets from wood industry residues;
8. Wood pellets from roundwood;
9. Agricultural residues with bulk density < 0.2 t/m^3;
10. Agricultural residues with bulk density > 0.2 t/m^3;
11. Straw pellets;
12. Bagasse pellets;
13. Palm kernel meal;

Feedstocks

- Fresh Manure
- Maize whole crop

Processing alternatives

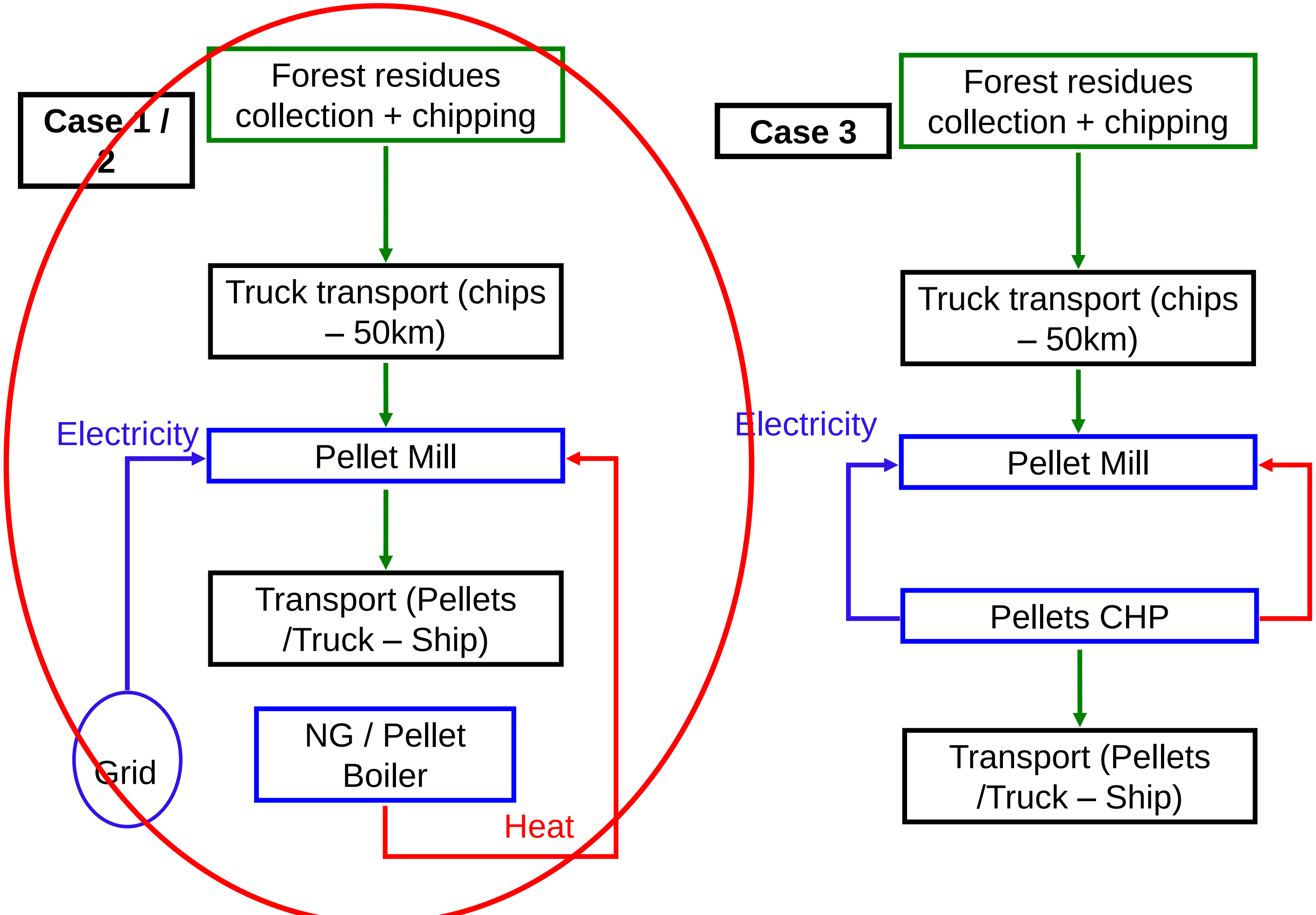
- Open/closed storage of digestate
- Off-gas combustion / release

End-use

- CHP
- Upgrading to biomethane

1. Biogas for electricity from Manure;
2. Biogas for electricity from Maize whole crop;
3. Biomethane from Manure;
4. Biomethane from Maize whole crop.

Example 1: Pellets from forest residues



Forest residues collection + chipping

- Includes: Forwarding, Bundling/Lifting, Oil use, Machine Transport, Load/Unload, Chipping;
- Includes case of loose residues, bundled residues and stump lifting;
- It uses an average between central electrical chipping and roadside chipping (diesel);

Input	***Consumption***	***Unit***
Wood	**1.025**	$MJ/MJ_{wood\ chips}$
Diesel	**0.0154**	$MJ/MJ_{wood\ chips}$

LHV Wood:

19 MJ/kg dry

Moisture (chips):

30%

Source: E.-L. Lindholm, S. Berg, P.-A. Hansson, Eur. J. Forest Res. (2010), 129, 1223-1235

Emission Factors

Input	*Factor*	*Unit*
Diesel	**88.73**	$gCO_{2eq.}/MJ$
N fertilizer	**6172.1**	$gCO_{2eq.}/kg_N$
K_2O fertilizer	**590.0**	$gCO_{2eq.}/kg_{K2O}$
P_2O_5 fertilizer	**1029.9**	$gCO_{2eq.}/kg_{P2O5}$
$CaCO_3$ fertilizer	**118.6**	$gCO_{2eq.}/kg_{CaCO3}$
Pesticides	**11372.2**	$gCO_{2eq.}/kg$
Electricity (0.4kV)	**144.1**	$gCO_{2eq.}/MJ$
Natural Gas	**67.8**	$gCO_{2eq.}/MJ$
Heavy Fuel Oil	**87.2**	$gCO_{2eq.}/MJ$

Source: JRC

Note: Values could be updated further before final publication

Forest residues collection + chipping

Input	*Consumption*	*Unit*	Emission	
Wood	**1.025**	$MJ/MJ_{wood\ chips}$	**-**	
Diesel	**0.0154**	$MJ/MJ_{wood\ chips}$	**1.37**	$gCO_{2eq.}/MJ_{wood\ chips}$

Specific emissions from diesel forestry engines:

Emission	*Consumption*	*Unit*	*Emissions*	*Unit*
CH_4	1.79E-03	$g\ /MJ_{diesel}$	**6.9E-04**	$gCO_{2eq.}/MJ_{wood\ chips}$
N_2O	1.79E-03	$g\ /MJ_{diesel}$	**0.008**	$gCO_{2eq.}/MJ_{wood\ chips}$

Source: GEMIS, 4.7.1, 2012, "dieselmotor-EU-agriculture-2010"

Transport of Wood chips

- *Distance: 50 km*
- *Truck 40 t (payload 26 t + 1 t tank)*
- *Fuel: Diesel*
- *Two components: Distance + Fuel Consumption*
- *19 MJ/kg dry – 30% moisture*

Input	***Consumption***	***Unit***
Distance	**0.0039**	ton km/$MJ_{wood\ chips}$
Fuel Consumption	**0.94**	MJ_{diesel} /ton km

Input	***Consumption***	***Unit***	***Emissions***	***Unit***
Total Diesel	0.00365	MJ_{diesel} /MJ_{chips}	**0.324**	$gCO_{2eq.}$/$MJ_{wood\ chips}$

Pellet mill (wood chips)

Input	*Consumption*	*Unit*
Wood chips	**1.01**	MJ / MJ_{pellet}
Electricity	**0.05**	MJ / MJ_{pellet}
Heat	**0.185**	MJ / MJ_{pellet}
Diesel	**0.002**	MJ / MJ_{pellet}

Sources:

1. Hagberg et al., LCA calculation on Swedish wood pellet production chain, IVL Swedish Environmental Research Institute, 2009.
2. Obernberger, I. and Thek, G., The Pellet Handbook, 2010.
3. Mani, S., A System Analysis of Biomass Densification Process, PhD Thesis at The University of British Columbia, 2005.
4. Yves Ryckmans, LABORELEC, personal communication, 05/12/2011
5. Sikkema, R., Junginger, M., Pichler, W., Hayes, S., Faaij, A.P.C., Biofuels Bioproducts & Biorefininig (2010), 4, 132 - 153

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Pellet mill (wood chips)

Input	*Consumption*	*Unit*	Emissions	
Wood chips	1.01	MJ / MJ_{pellet}	-	
Electricity	0.05	MJ / MJ_{pellet}	**7.21**	$gCO_{2eq.}/MJ_{pellet}$
Heat	0.185	MJ / MJ_{pellet}		
Diesel	0.002	MJ / MJ_{pellet}	**0.177**	$gCO_{2eq.}/MJ_{pellet}$

Sources:

1. Hagberg et al., LCA calculation on Swedish wood pellet production chain, IVL Swedish Environmental Research Institute, 2009.
2. Obernberger, I. and Thek, G., The Pellet Handbook, 2010.
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4. Yves Ryckmans, LABORELEC, personal communication, 05/12/2011
5. Sikkema, R., Junginger, M., Pichler, W., Hayes, S., Faaij, A.P.C., Biofuels Bioproducts & Biorefininig (2010), 4, 132 - 153

Pellet mill (wood chips) – Case 1

Input	*Consumption*	*Unit*	Emissions	
Wood chips	1.01	MJ / MJ_{pellet}	-	
Electricity	0.05	MJ / MJ_{pellet}	**7.21**	$gCO_{2eq.}/MJ_{pellet}$
Heat	0.185	MJ / MJ_{pellet}		
Diesel	0.002	MJ / MJ_{pellet}	**0.177**	$gCO_{2eq.}/MJ_{pellet}$

Input	*Consumption*	*Unit*
Natural Gas	**1.111**	MJ / MJ_{heat}
Electricity	**0.02**	MJ / MJ_{heat}
CH_4	**0.056**	g / MJ_{heat}
N_2O	**0.00112**	g / MJ_{heat}

Pellet mill (wood chips) – Case 1

Input	*Consumption*	*Unit*	Emissions	
Wood chips	1.01	MJ / MJ_{pellet}	-	
Electricity	0.05	MJ / MJ_{pellet}	**7.21**	$gCO_{2eq.}/MJ_{pellet}$
Heat	0.185	MJ / MJ_{pellet}		
Diesel	0.002	MJ / MJ_{pellet}	**0.177**	$gCO_{2eq.}/MJ_{pellet}$

Input	*Consumption*	*Unit*	*Emissions*	*Unit*
Natural Gas	1.111	MJ / MJ_{heat}	**13.93**	$gCO_{2eq.}/MJ_{pellet}$
Electricity	0.02	MJ / MJ_{heat}	**0.53**	$gCO_{2eq.}/MJ_{pellet}$
CH_4	0.056	g / MJ_{heat}	**0.026**	$gCO_{2eq.}/MJ_{pellet}$
N_2O	0.00112	g / MJ_{heat}	**0.062**	$gCO_{2eq.}/MJ_{pellet}$

Pellet mill (wood chips) – Case 1

Input	*Consumption*	*Unit*	**Emissions**	
Wood chips	1.01	MJ / MJ_{pellet}	**-**	
Electricity	0.05	MJ / MJ_{pellet}	**7.21**	$gCO_{2eq.}/MJ_{pellet}$
Heat	0.185	MJ / MJ_{pellet}	**14.55**	$gCO_{2eq.}/MJ_{pellet}$
Diesel	0.002	MJ / MJ_{pellet}	**0.177**	$gCO_{2eq.}/MJ_{pellet}$

Input	*Consumption*	*Unit*	*Emissions*	*Unit*
Natural Gas	1.111	MJ / MJ_{heat}	**13.93**	$gCO_{2eq.}/MJ_{pellet}$
Electricity	0.02	MJ / MJ_{heat}	**0.53**	$gCO_{2eq.}/MJ_{pellet}$
CH_4	0.056	g / MJ_{heat}	**0.026**	$gCO_{2eq.}/MJ_{pellet}$
N_2O	0.00112	g / MJ_{heat}	**0.062**	$gCO_{2eq.}/MJ_{pellet}$

Transport of Wood pellets (Truck)

- *Distance: 200 km*
- *Truck 40 t (payload 25 t + 2 t tank)*
- *Fuel: Diesel*
- *Two components: Distance + Fuel Consumption*
- *19 MJ/kg – 10% moisture*

Input	***Consumption***	***Unit***
Distance	**0.0126**	ton km/MJ_{pellet}
Fuel Consumption	**0.94**	MJ_{diesel} /ton km

Input	***Consumption***	***Unit***	***Emissions***	***Unit***
Total Diesel	0.0118	MJ_{diesel} /MJ_{pellet}	**1.05**	$gCO_{2eq.}$/MJ_{pellet}

Transport of Wood pellets (Bulk Carrier)

- *Distance: 8000 km*
- *Handysize carrier (payload 40000 t)*
- *Fuel: Heavy fuel oil*
- *Two components: Distance + Fuel Consumption*
- *19 MJ/kg dry – 10% moisture*

Input	***Consumption***	***Unit***
Distance	**0.468**	ton km/MJ_{pellet}
Fuel Consumption	**0.12**	MJ_{HFO} /ton km

Input	***Consumption***	***Unit***	***Emissions***	***Unit***
Total HFO	0.056	MJ_{HFO} /MJ_{pellet}	**4.89**	$gCO_{2eq.}$/MJ_{pellet}

Summary (1)

Phase	*Emission*	*Unit*
Cultivation	**0**	$gCO_{2eq.}/MJ_{wood}$
Collection	**1.38**	$gCO_{2eq.}/MJ_{wood\ chips}$
Transport Chips	**0.324**	$gCO_{2eq.}/MJ_{wood\ chips}$
Pellet Mill	**21.94**	$gCO_{2eq.}/MJ_{pellet}$
Transport Pellets	**5.94**	$gCO_{2eq.}/MJ_{pellet}$

Wood chips to pellets: 1.01 $MJ_{wood\ chips}/MJ_{pellet}$

Summary

Phase	*Emission*	*Unit*	Emission	Unit
Cultivation	**0**	$gCO_{2eq.}/MJ_{wood}$	**0**	$gCO_{2eq.}/MJ_{pellet}$
Collection	**1.38**	$gCO_{2eq.}/MJ_{wood\ chips}$	**1.394**	$gCO_{2eq.}/MJ_{pellet}$
Transport Chips	**0.324**	$gCO_{2eq.}/MJ_{wood\ chips}$	**0.327**	$gCO_{2eq.}/MJ_{pellet}$
Pellet Mill	**21.94**	$gCO_{2eq.}/MJ_{pellet}$	**21.94**	$gCO_{2eq.}/MJ_{pellet}$
Transport Pellets	**5.94**	$gCO_{2eq.}/MJ_{pellet}$	**5.94**	$gCO_{2eq.}/MJ_{pellet}$
Total			**29.6**	$gCO_{2eq.}/MJ_{pellet}$

Summary (Final Result)

Phase	*Emission*	*Unit*
Total pathway	**29.6**	$gCO_{2eq.}/MJ_{pellet}$
Total (Electricity -> 25%)		
Total (Heat -> 85%)		

Summary (Final Result)

Phase	*Emission*	*Unit*
Total pathway	**29.6**	$gCO_{2eq.}/MJ_{pellet}$
Total (Electricity -> 25%)	**118.4**	$gCO_{2eq.}/MJ_{el.}$
Total (Heat -> 85%)	**34.8**	$gCO_{2eq.}/MJ_{heat}$

Fossil Fuel Comparator (Electricity): 184 gCO2 eq./$MJ_{el.}$

Fossil Fuel Comparator (Heat): 77 gCO2 eq./MJ_{heat}

GHG savings (Elec.): (184 – 118.4)/184 **= 35.6%**

GHG savings (Heat): (77 – 34.8)/77 **= 54.8%**

Summary (Final Result)

Phase	*Emission*	*Unit*
Total pathway	**29.6**	$gCO_{2eq.}/MJ_{pellet}$
Carnot (elec.)	**1**	-
Carnot (heat@150°C)	**0.3546**	-
Total (elec. – CHP)	**69.3**	$gCO_{2eq.}/MJ_{el.}$
Total (Heat – CHP)	**24.6**	$gCO_{2eq.}/MJ_{heat}$

GHG savings (Elec.): (184 – 69.3)/184 **= 62.3%**

GHG savings (Heat): (77 – 24.6)/77 **= 68.1%**

Critical Points:

- Material Properties (e.g. LHV, moisture etc…)
- Emission Factors (e.g. fertilizers production, fossil fuels emissions etc…)
- Upstream emissions for residues
- Non-CO_2 emissions in the life cycle (incl. biomass combustion)
- Biogenic – CO_2 emissions
- Biogas co-digestion
- Biogas Manure credits

Thank you for your attention!

For further questions:
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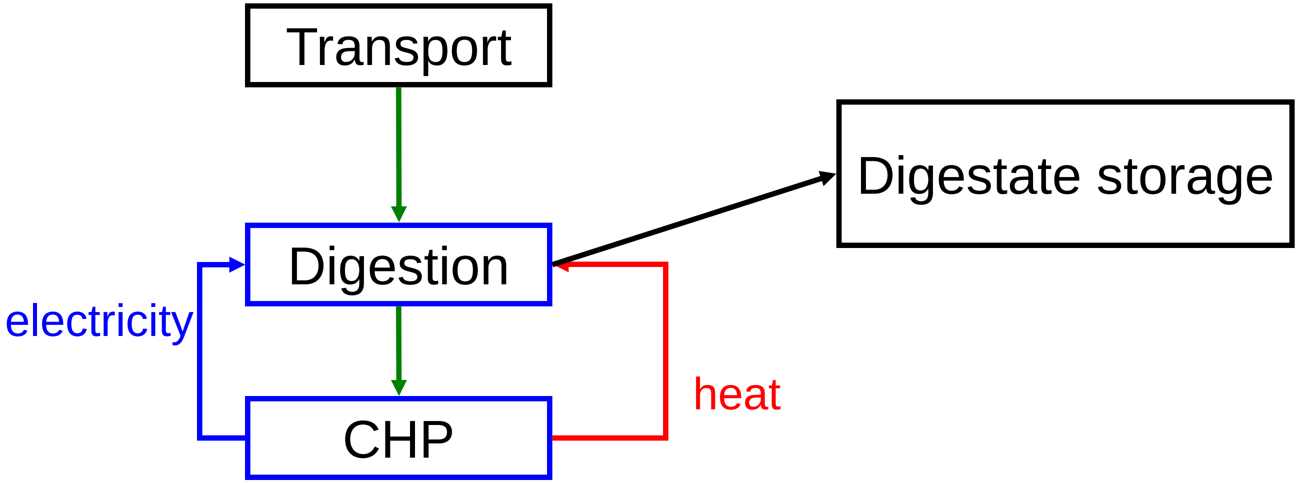
Additional slides

Pathways	Distance Tag	Representative Geographic Origin	Typical distances (km)			
			Truck (chips/raw)	Truck (pellets/ finished product)	Train (chips/ pellets)	Bulk Carrier (chips / pellets)
Woodchips	1 - 500 km	Intra EU	500	-	-	-
	500 - 2500 km	Russia	250	-	-	2000
	2500 - 10000 km	Brazil	200	-	-	8000
	> 10000 km	Western Canada	-	-	750	16500
Wood Pellets	1 - 500 km	Intra EU	50	500	-	-
	500 - 10000 km	Brazil	50	200	-	8000
	> 10000 km	Western Canada	100	-	750	16500
Agricultural Residues	1 - 500 km	Intra EU	500	-	-	-
	500 - 2500 km	Russia	250	-	-	2000
	2500 - 10000 km	Brazil	200	-	-	8000
	> 10000 km	Western Canada	-	-	750	16500
Charcoal	1 – 50 km	Intra EU	-	50	-	-
	> 10000 km	Brazil	-	700	-	10186
Straw Pellets	1 - 500 km	Intra EU	50	500	-	-
	500 - 10000 km	Brazil	50	200	-	8000
	> 10000 km	Western Canada	100	-	750	16500
Bagasse Pellets / Briquettes	500 - 10000 km	Brazil	-	200	-	8000
	> 10000 km	Brazil	-	700	-	10186

Example 2: Biogas from Manure



Manure is considered a residue -> no emissions up to the point of collection

Source:OJ 2010, 160/08, 5.2.

Transport of wet manure

- *Distance: 10 km*
- *Truck 40 t (payload 25 t + 1 t tank)*
- *LHV Manure (dry): 12 MJ/kg$_{dry}$*
- *Moisture Manure: 85%*

Input	***Consumption***	***Unit***
Distance	**0.0060**	ton km/MJ$_{manure}$
Fuel Consumption	**0.94**	MJ$_{diesel}$ /ton km

Input	***Consumption***	***Unit***	***Emissions***	***Unit***
Total Diesel	0.0056	MJ$_{diesel}$ /MJ$_{manure}$	**0.502**	gCO2eq./MJ$_{manure}$

Anaerobic Digestion

Input	*Consumption*	*Unit*
Manure	**2.5**	MJ_{manure}/MJ_{biogas}
Electricity	**0.02**	$MJ_{el.}/MJ_{biogas}$
Heat	**0.10**	MJ_{heat}/MJ_{biogas}

- Biogas yield: 300 $l_{biogas}/kg_{volatile\ solids}$
- LHV Biogas: 19.7 MJ/m^3_{biogas}

Anaerobic Digestion

Input	*Consumption*	*Unit*	*Emissions*	*Unit*
Manure	2.5	MJ_{manure}/MJ_{biogas}	-	
Electricity	0.02	$MJ_{el.}/MJ_{biogas}$	**2.88**	$gCO_{2\ eq.}/MJ_{biogas}$
Heat	0.10	MJ_{heat}/MJ_{biogas}	Internal production via CHP	

CHP Engine

Input	*Consumption*	*Unit*
Biogas	**2.78**	$MJ_{biogas}/MJ_{el.}$
Electricity (auxiliary)	**0.01**	$MJ_{el.}/MJ_{biogas}$

Output	*Production*	*Unit*
Electricity	**1.00**	$MJ_{el.}$
Heat	**1.78**	$MJ_{heat}/MJ_{el.}$

- CHP Gross El. Efficiency = 36%
- Heat is used for internal consumption in the digester; other eventual commercial uses would have to be included and emissions allocated by exergy to the electricity produced.

CHP Engine

Input	*Consumption*	*Unit*	*Emissions*	*Unit*
Biogas	2.78	$MJ_{biogas}/MJ_{el.}$	-	
Electricity (auxiliary)	0.01	$MJ_{el.}/MJ_{biogas}$	**4.0**	$gCO_{2\ eq.}/MJ_{el.}$
Output	***Production***	***Unit***	***Emissions***	***Unit***
Electricity	1.00	$MJ_{el.}$	-	
Heat	1.78	$MJ_{heat}/MJ_{el.}$	Availability of this heat varies	
Methane Slip	0.94	$gCH_4/MJ_{el.}$	**23.6**	$gCO_{2\ eq.}/MJ_{el.}$
N2O	0.004	$gN_2O/MJ_{el.}$	**1.18**	$gCO_{2\ eq.}/MJ_{el.}$

- CHP Gross El. Efficiency = 36%
- Heat is used for internal consumption in the digester; other commercial uses would have to be accounted and emissions allocated by exergy to the electricity and heat produced.

Digestate storage emissions

Open Storage Tank

Output	*Production*	*Unit*	*Emissions*	*Unit*
Methane	1.00	gCH_4/MJ_{biogas}	**69.5**	$gCO_{2\ eq.}/MJ_{el.}$

Closed Storage Tank

Output	*Production*	*Unit*	
Biogas (additional)	0.05	MJ/MJ_{biogas}	Corresponds to higher productivity from manure -> lower emissions for transport and for digester.

Summary (Open storage)

Phase	*Emission*	*Unit*
Cultivation	**-**	-
Transport Manure	**0.50**	$gCO_{2eq.}/MJ_{manure}$
Digestion	**2.88**	$gCO_{2eq.}/MJ_{biogas}$
CHP	**10.4**	$gCO_{2eq.}/MJ_{biogas}$
Storage	**25**	$gCO_{2eq.}/MJ_{biogas}$

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Summary (Open storage)

Phase	*Emission*	*Unit*	*Emission*	*Unit*
Cultivation	-	-	**-**	-
Transport Manure	0.50	$gCO_{2eq.}/MJ_{manure}$	**3.5**	$gCO_{2eq.}/MJ_{el.}$
Digestion	2.88	$gCO_{2eq.}/MJ_{biogas}$	**8.0**	$gCO_{2eq.}/MJ_{el.}$
CHP	10.4	$gCO_{2eq.}/MJ_{biogas}$	**28.9**	$gCO_{2eq.}/MJ_{el.}$
Storage	25	$gCO_{2eq.}/MJ_{biogas}$	**69.5**	$gCO_{2eq.}/MJ_{el.}$
Total pathway	**109.9**			$gCO_{2eq.}/MJ_{el.}$

Summary (Closed storage)

Phase	*Emission*	*Unit*	*Emission*	*Unit*
Cultivation	-	-	**-**	-
Transport Manure	0.50	$gCO_{2eq.}/MJ_{manure}$	**3.3**	$gCO_{2eq.}/MJ_{el.}$
Digestion	2.74	$gCO_{2eq.}/MJ_{biogas}$	**7.6**	$gCO_{2eq.}/MJ_{el.}$
CHP	10.4	$gCO_{2eq.}/MJ_{biogas}$	**28.8**	$gCO_{2eq.}/MJ_{el.}$
Storage	-	$gCO_{2eq.}/MJ_{biogas}$	**-**	$gCO_{2eq.}/MJ_{el.}$
Total pathway	**39.7**			$gCO_{2eq.}/MJ_{el.}$

Summary (GHG Savings)

Phase	*Emission*	*Unit*
Total Open Storage	**109.9**	$gCO_{2eq.}/MJ_{el.}$
Total Close Storage	**39.7**	$gCO_{2eq.}/MJ_{el.}$

Fossil Fuel Comparator Electricity: 184 gCO2 eq./$MJ_{el.}$

GHG savings (open): 40.3%

GHG savings (close): 78.4%

Eucalyptus Cultivation (Brazil)

Input	*Consumption*	*Unit*
Diesel	**1300.8**	MJ/(ha*yr)
N fertilizer	**176.5**	kg N/(ha*yr)
K_2O fertilizer	**141.2**	kg K_2O/(ha*yr)
P_2O_5 fertilizer	**67.6**	kgP_2O_5/(ha*yr)
$CaCO_3$ fertilizer	**367.5**	kg$CaCO_3$/(ha*yr)
Pesticides	**1.57**	kg/(ha*yr)

LHV Wood:

19 MJ/kg dry

Moisture:

50%

Output	*Yield*	*Unit*
Wood	**20000**	kg_{FM}/(ha*yr)

Eucalyptus Cultivation

Input	*Consumption*	*Unit*	*Consumption*	*Unit*
Diesel	1300.8	MJ/(ha*yr)	**0.0068**	MJ/MJ_{wood}
N fertilizer	176.5	kg N/(ha*yr)	**0.00093**	Kg/MJ_{wood}
K_2O fertilizer	141.2	kg K_2O/(ha*yr)	**0.00074**	Kg/MJ_{wood}
P_2O_5 fertilizer	67.6	kgP_2O_5/(ha*yr)	**0.00036**	Kg/MJ_{wood}
$CaCO_3$ fertilizer	367.5	kg$CaCO_3$/(ha*yr)	**0.00193**	Kg/MJ_{wood}
Pesticides	1.57	kg/(ha*yr)	**0.0000083**	Kg/MJ_{wood}

Output	*Yield*	*Unit*	*Yield*	*Unit*
Wood	20000	kg_{FM}/(ha*yr)	**190000**	MJ_{wood}/(ha*yr)

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Eucalyptus Cultivation: Emission factors

Input	*Consumption*	*Unit*	*Emission*	*Unit*
Diesel	0.0068	MJ/(ha*yr)	**0.61**	$gCO_{2eq.}/MJ_{wood}$
N fertilizer	0.00093	kg N/(ha*yr)	**5.73**	$gCO_{2eq.}/MJ_{wood}$
K_2O fertilizer	0.00074	kg K_2O/(ha*yr)	**0.44**	$gCO_{2eq.}/MJ_{wood}$
P_2O_5 fertilizer	0.00036	kgP_2O_5/(ha*yr)	**0.37**	$gCO_{2eq.}/MJ_{wood}$
$CaCO_3$ fertilizer	0.00193	kg$CaCO_3$/(ha*yr)	**0.23**	$gCO_{2eq.}/MJ_{wood}$
Pesticides	0.0000083	kg/(ha*yr)	**0.09**	$gCO_{2eq.}/MJ_{wood}$

Input	Emission	Unit
Diesel	**0.61**	$gCO_{2eq.}/MJ_{wood}$
N fertilizer	**5.73**	$gCO_{2eq.}/MJ_{wood}$
K_2O fertilizer	**0.44**	$gCO_{2eq.}/MJ_{wood}$
P_2O_5 fertilizer	**0.37**	$gCO_{2eq.}/MJ_{wood}$
$CaCO_3$ fertilizer	**0.23**	$gCO_{2eq.}/MJ_{wood}$
Pesticides	**0.09**	$gCO_{2eq.}/MJ_{wood}$
Field N2O	5.76	$gCO_{2eq.}/MJ_{wood}$
TOTAL	**13.23**	$gCO_{2eq.}/MJ_{wood}$