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BIOENERGY IN GERMANY FACTS AND FIGURES 2020

SOLID FUELS
BIOFUELS
BIOGAS

With support from

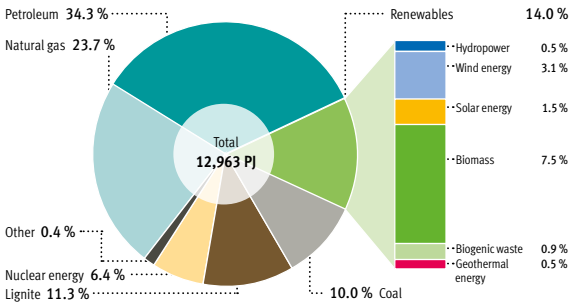
Federal Ministry
of Food
and Agriculture

by decision of the
German Bundestag

FNR
Fachagentur Nachwachsende Rohstoffe e.V.

RENEWABLE ENERGIES (BIOENERGY)

Primary energy consumption 2018



Source: FNR based on ZSW/AGEB (March 2019)

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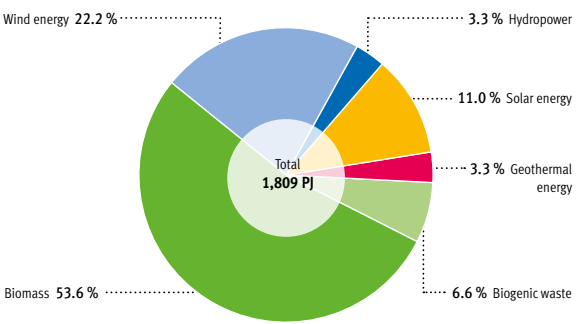
Primary energy consumption of renewables 2018



Source: FNR based on ZSW/AGEB (March 2019)

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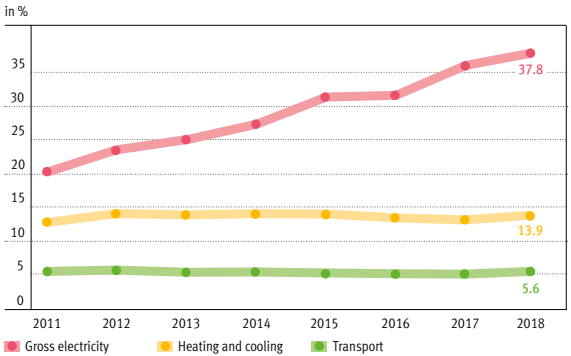
Growth of renewable energies in relation to final energy consumption



Source: BMWi, AGEE-Stat (February 2019)

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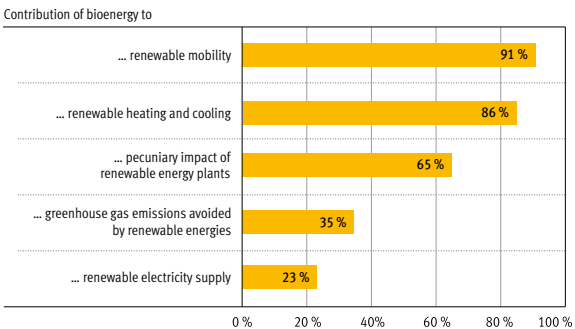
Bioenergy – An essential pillar of climate protection and energy transition (“Energiewende”)



Data for Germany 2018

Source: BMWi, AGEE-Stat (February 2019)

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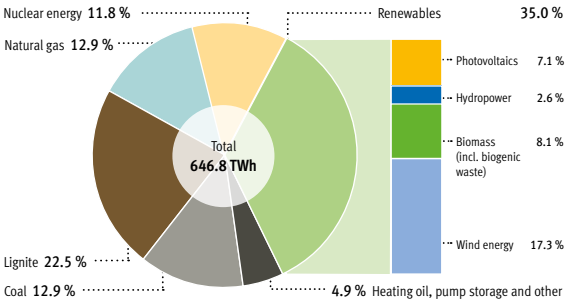
Gross electricity generation 2018

Gross electricity generation: 646.8 TWh – Renewables: 35 %
Gross electricity consumption: 595.6 TWh – Renewables: 37.8 %
(Difference: 51.2 TWh electricity export balance in 2018)



Source: FNR based on AGEB (March 2019)

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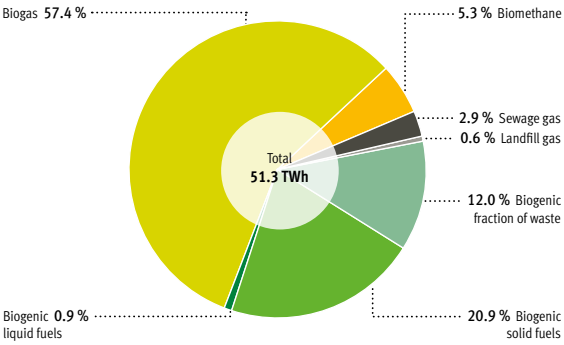
Electricity generation from biomass 2018



Source: BMWi, AGEE-Stat (February 2019)

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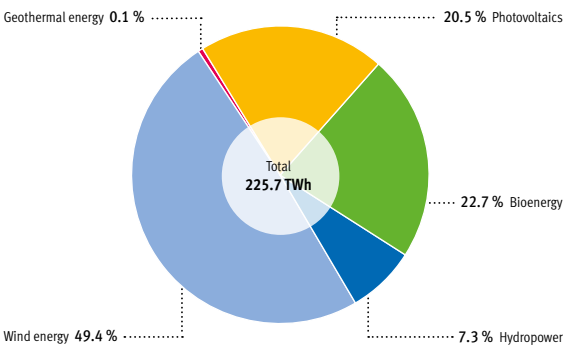
Electricity generation from renewable energies 2018



Source: BMWi, AGEE-Stat (February 2019)

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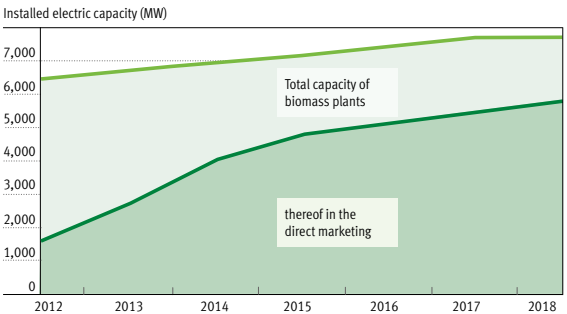
Direct marketing of electricity from biomass



Source: Fraunhofer IWES, www.netztransparenz.de, AGEE-Stat (2018)

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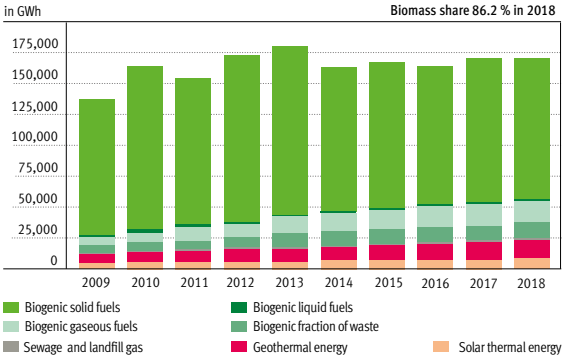
Heat from renewable energies: Development

171 TWh in 2018 – thereof 86.2 % or 147 TWh from Biomass



Source: BMWi, AGEE-Stat (February 2019)

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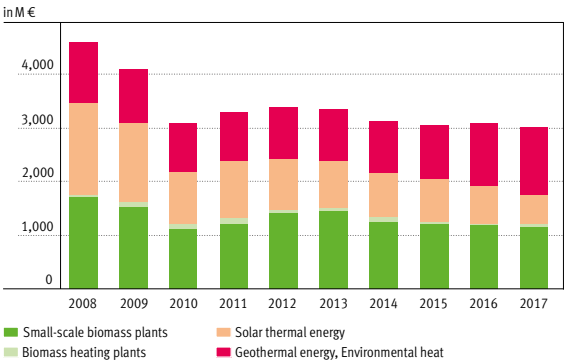
Investments in plants for renewable heat



Source: BMWI (2019)

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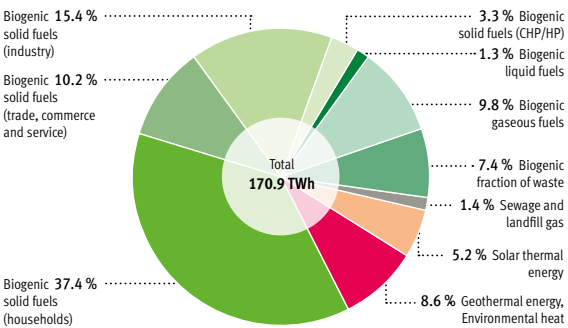
Heat from renewable energies 2018



Source: BMWi, AGEE-Stat (February 2019)

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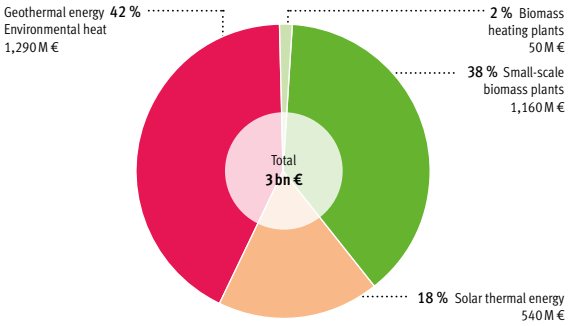
Investments 2017 in plants for renewable heat



Source: BMWI (2019)

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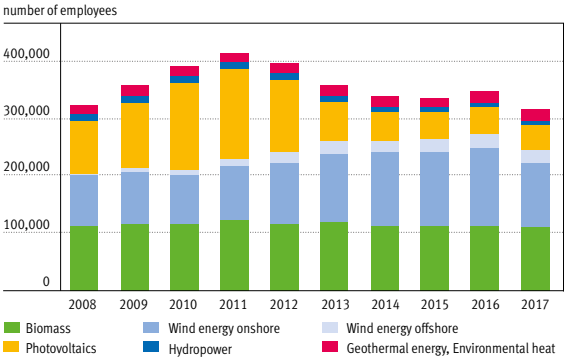
Trend of gross employment in the renewable energy sector



Source: DIW/DLR (2019)

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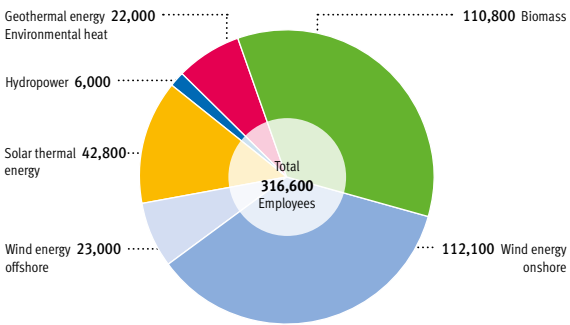
Gross employment in the renewable energy sector 2017



Source: DIW/DLR (2019)

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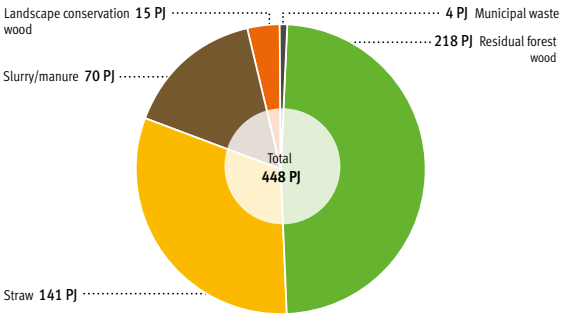
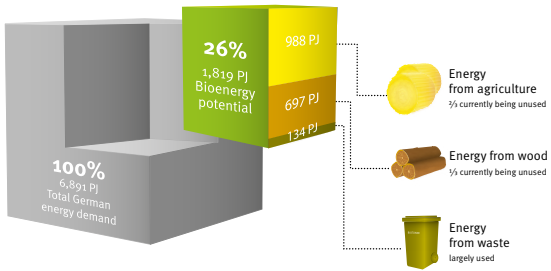
Unused potentials from biogenic residual and waste materials



Source: DBFZ (2015)

© FNR 2015

Domestic bioenergy: Potential 2050



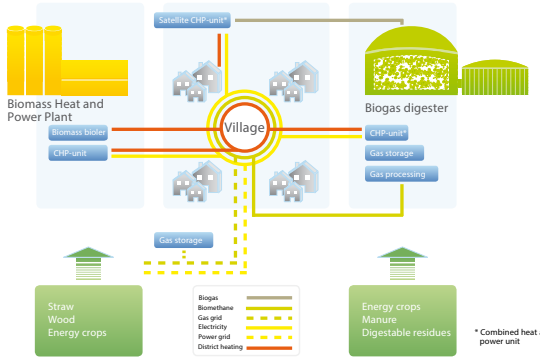
Rounded figures

Source: FNR

© FNR 2016

Domestic biomass will contribute substantially to the energy supply in Germany. It can cover up to 26 % of the need for heat, electricity and fuels in 2050. Energy from agriculture, from wood and from waste offers the potential to generate energy to a large extent sustainably.

Material flows in a bioenergy village



Source: FNR (2012)

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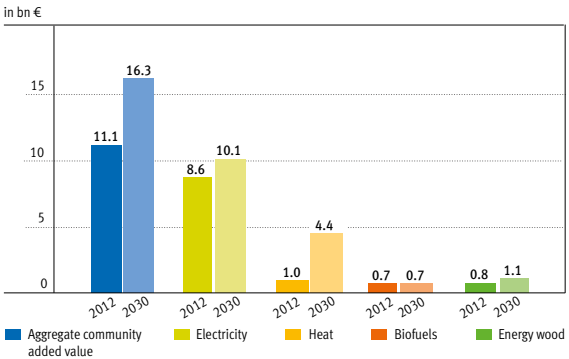
Community added value by renewable energies 2012–2030



Source: IÖW (September 2014)

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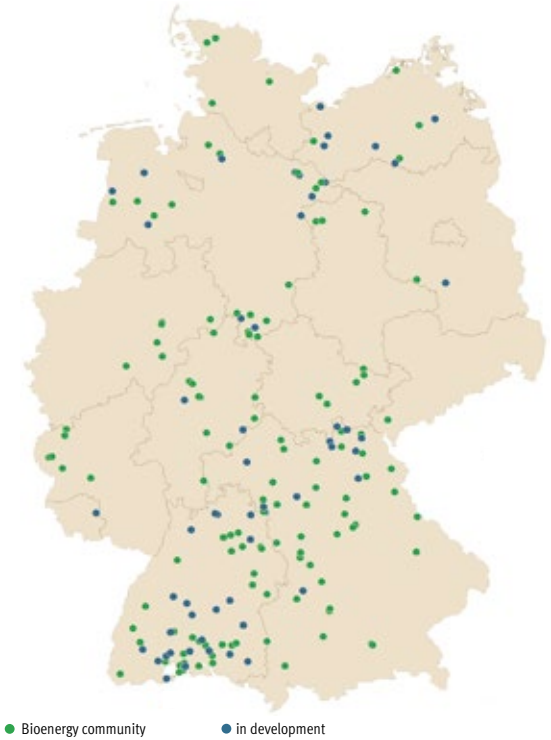
Bioenergy communities in Germany 2017

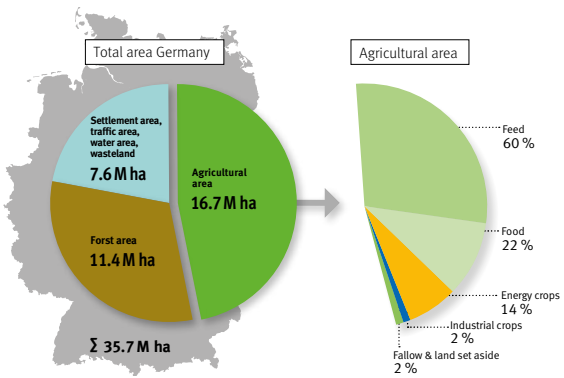


Source: GeoBasis-DE/BKG 2013, FNR 2018

© FNR 2018

CULTIVATION OF RENEWABLE RESOURCES

Land use in Germany 2017



Source: FNR based on Statistisches Bundesamt, BMEL (2017)

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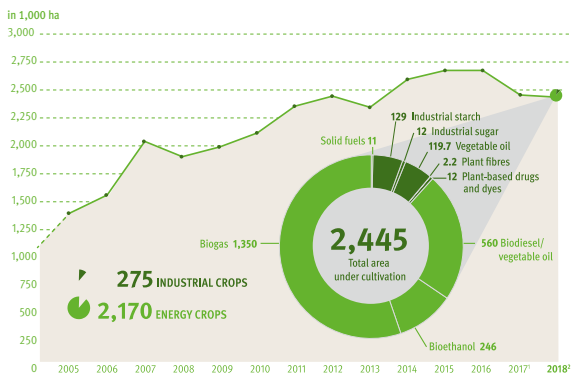
Cultivation of renewable resources in Germany



Source: FNR, BMEL (2019)

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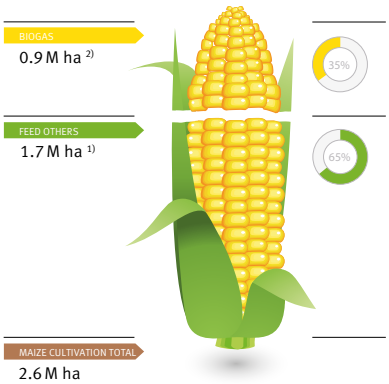
Cultivation of renewable resources in Germany 2016–2018 (in ha)

Plants	Feedstock	2016	2017*	2018**
Industrial crops	Industrial starch	128,000	132,000	129,000
	Industrial sugar	12,800	11,600	12,000
	Technical rapeseed oil	132,000	117,000	109,000
	Technical sunflower oil	7,740	7,210	7,210
	Technical linseed oil	3,500	3,500	3,500
	Plant fibres	1,520	2,200	2,200
	Plant-based drugs and dyes	12,000	12,000	12,000
	Industrial crops total	**298,000**	**286,000**	**275,000**
Energy crops	Rapeseed oil for biodiesel/ vegetable oil	720,000	598,000	560,000
	Crops for bioethanol	259,000	248,000	246,000
	Crops for biogas	1,390,000	1,320,000	1,350,000
	Crops for solid fuels e.g. farmed wood, miscanthus	11,000	11,000	11,000
	Energy crops total	**2,380,000**	**2,180,000**	**2,170,000**
Total acreage of renewable resources		**2,678,000**	**2,466,000**	**2,445,000**

Source: FNR, BMEL (2019)

**preliminary values; **estimated values Values rounded to significant digits, deviations in the sums result from rounding of the numbers*

Cultivation of maize (crop year 2018)



Source: 1) Statistisches Bundesamt (2019), 2) FNR e. V.

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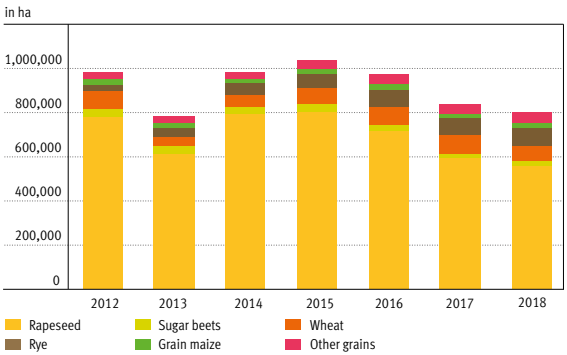
Development of energy crop cultivation for biofuels



Source: FNR, BMEL (2019)

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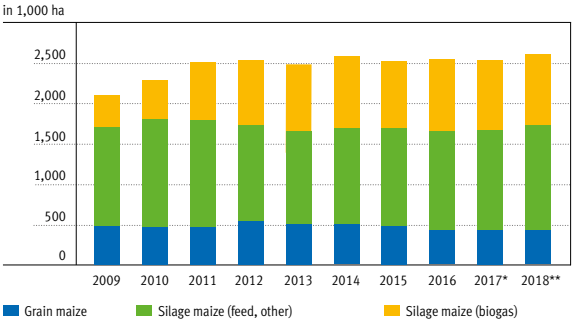
Development of the cultivation area of maize



** Temporarily, ** Outlook*

Source: FNR based on Stat. Bundesamt, DMK, BDBe, BLE, VDGS

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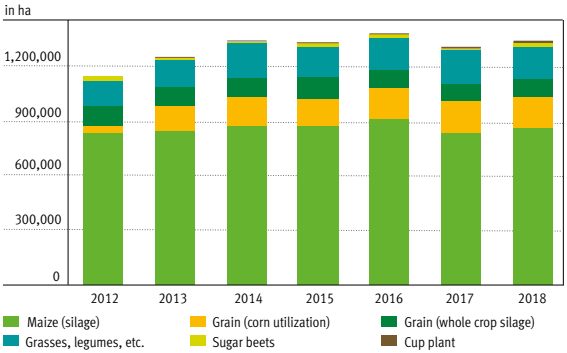
Development of energy crop cultivation for biogas



Source: FNR, BMEL (2019)

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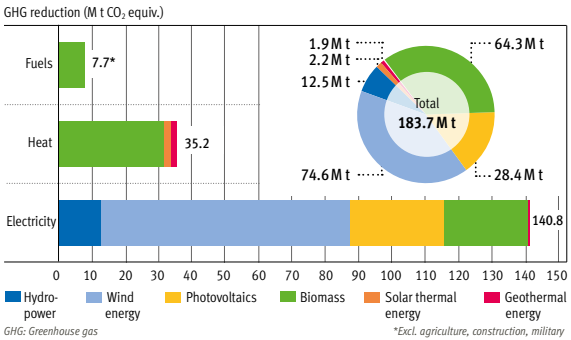
CLIMATE PROTECTION

GHG savings by renewable energies 2018



Source: BMWi, AGEE-Stat (February 2019)

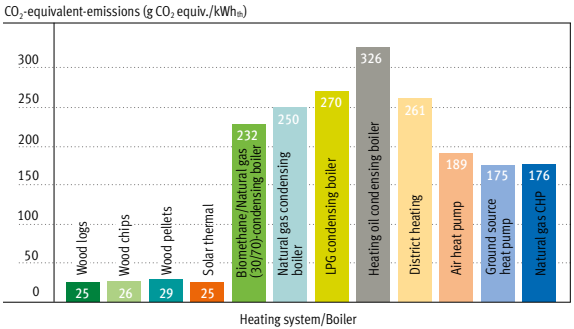
© FNR 2019

GHG savings by bioenergy 2018

	GHG savings in 1,000 t CO_2 equiv.			
	Electricity	**Heat**	**Fuels**	**Total**
Solid biofuels	12,064	27,726	n/a	39,790
Liquid biofuels	245	510	7,628	8,383
Biogas	13,002	3,044	89	16,135
Total	**25,311**	**31,280**	**7,717**	**64,308**

Source: FNR based on AGEE-Stat (February 2019)

Greenhouse gas emissions of heat supply



Source: IER Universität Stuttgart 2018 (based on GEMIS, Version 4.95, IFEU)

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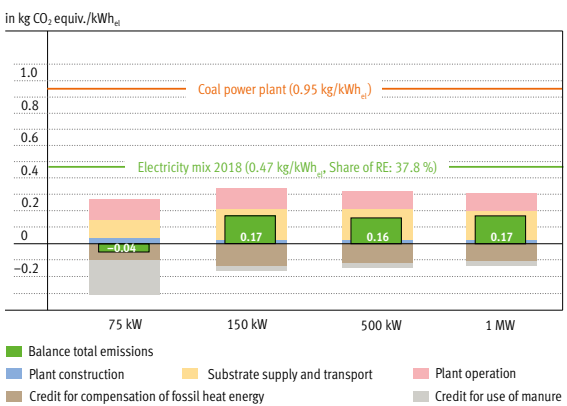
Greenhouse gas emissions of biogas plants in comparison to the German electricity mix



Source: KTBL (2011), UBA, AGEE-Stat (2019)

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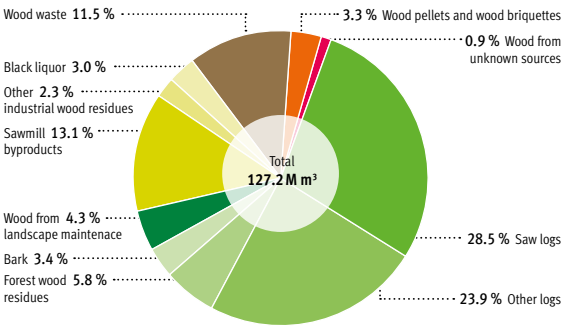
For further information visit "Grafiken Biogas" at mediathek.fnr.de

SOLID FUELS

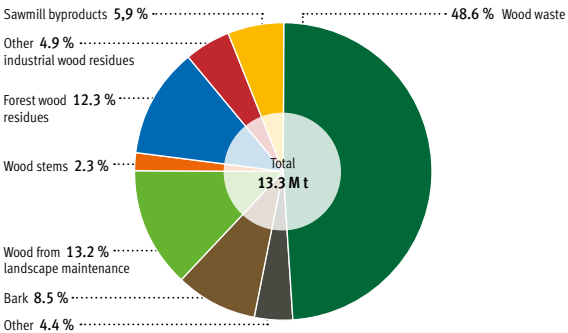
Classification of wood raw materials 2016



Source: INFRO e.K. (2018)

© FNR 2018

Use of wood in large biomass combustion plants*

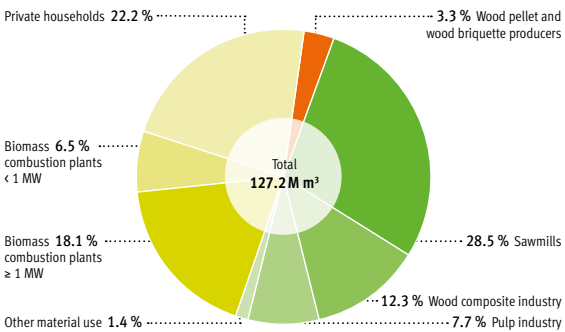


› 1 MW

Source: INFRO e.K. (2018)

© FNR 2018

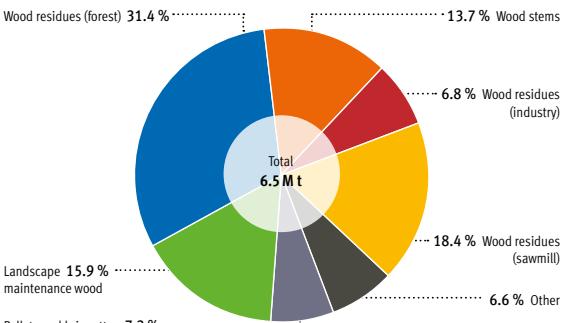
Use of wood raw materials according to user groups 2016



Source: INFRO e.K. (2018)

© FNR 2018

Use of wood in small biomass combustion plants*



** 16 to 999 kW, Without biomass boilers in private households*

Source: INFRO e.K. (2018)

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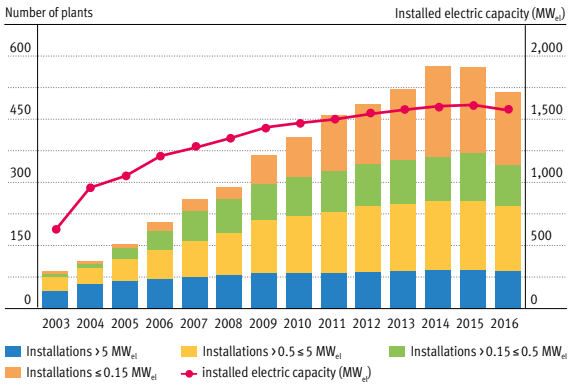
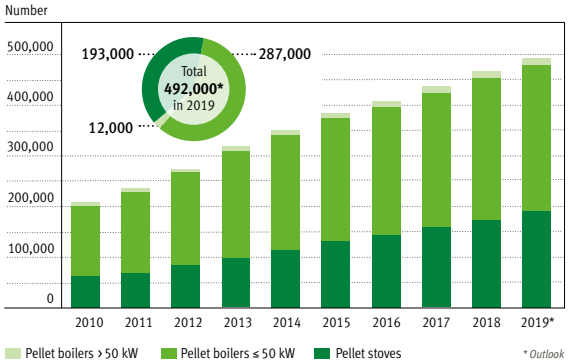
Quantity and electric capacity of wood power plants



Source: DBFZ (2017) based on EEG monitoring

© FNR 2018

Installed pellet boilers



Source: Deutsches Pelletinstitut (February 2019)

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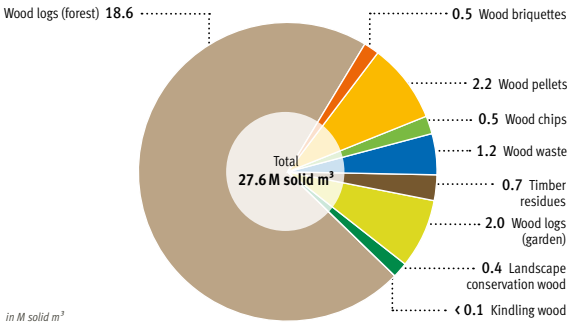
Use of energy wood in private households



Source: Thünen-Institut für Internationale Waldwirtschaft und Forstökonomie (2019)

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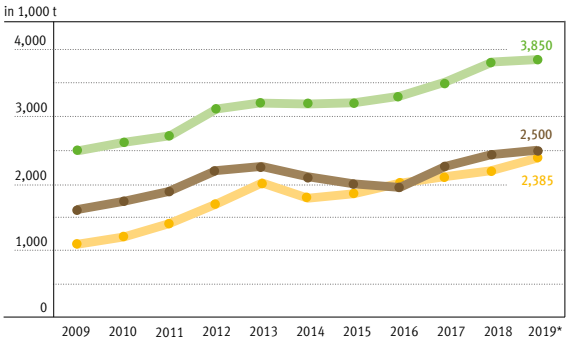
Wood pellets – Production and consumption



Source: Deutsches Pelletinstitut (2019)

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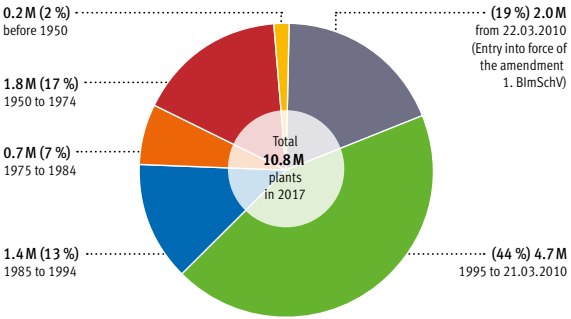
Single room heating units – percentage by construction period



Source: ZIV Bundesverband des Schornsteinfegerhandwerks (2018)

© FNR 2019

Retrofitting of dust filters or decommissioning of single room heating units for solid fuels (as per transitional regulation §26, 1. BImSchV)

Date on type plate	Date of retrofitting or decommissioning
1 January 1985 to 31 December 1994	31 December 2020
1 January 1995 to 21 March 2010	31 December 2024

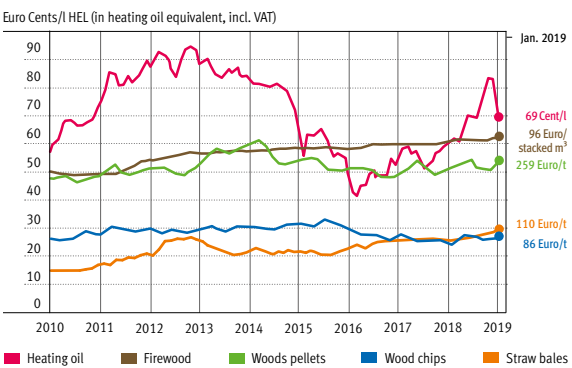
Equivalent prices of wood fuels with regard to the heating value

Heating oil in €/litre	Wood pellets (w < 10 %) in €/t	Beech logs (w = 15 %) in €/stacked m³	Spruce chips (w = 30 %) in €/loose m³
0.4	200	76	30
0.5	250	95	37
0.6	300	114	45
0.7	350	133	52
0.8	400	152	60
0.9	450	172	67
1.0	500	191	75
1.1	550	210	82
1.2	600	229	89

Source: FNR (2016)

Fuel prices are compared with regard to the lower heating value.

Development of fuel prices



Source: FNR based on TFZ, AMI (2019)

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General conversion factors for wood quantities

	$t_{abs\ dry}$	Solid m^3	Stacked m^3	Loose m^3
1 $t_{abs\ dry}$	1.0	1.3–2.5	2.9	4.9
1 Solid m^3	0.4–0.7	1.0	1.4	2.5
1 Stacked m^3	0.3	0.7	1.0	1.8
1 Loose m^3	0.2	0.4	0.5	1.0

Note

The undimensioned edge length amounts to 1 m each.

Abbreviations

abs dry: Absolutely dry (0 % water content)

Solid m^3: Common measure in the forestry and timber industry for one cubic metre of solid wood without gaps.

Stacked m^3: Common measure in the forestry and timber industry for one cubic metre of stacked wood including air spaces.

Loose m^3: Common measure in the forestry and timber industry for one cubic metre of poured wood parts (e. g. wood chips, bulk material).

Source: Handbuch Bioenergie Kleinanlagen, FNR (2013) and own calculations

Wood pellets storage volume calculation for a new residential building (150 m²)

Ultimate energy demand space heating:	100 kWh/m²/a
Ultimate energy demand domestic hot water:	50 kWh/m²/a
Heat demand in kWh/year:	(100 + 50) • 150 = 22,500
Wood pellets demand in kg:	22,500 : 4 = 5,625 (= 5.625 t)
Storage volume in m^3:	5.625 • 2 = 11.25

Source: DEPI (2015)

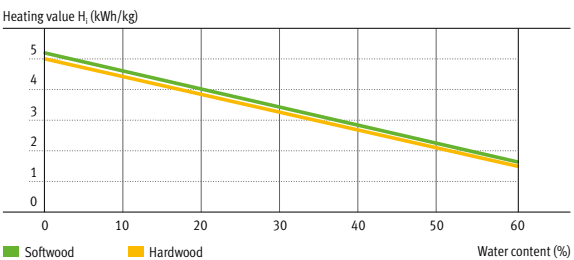
Water content and wood moisture

$$\text{Water content w [\%]} = \frac{\text{Weight of water [kg]}}{\text{Weight of moist wood [kg]}} \cdot 100$$

$$\text{Wood moisture u [\%]} = \frac{\text{Weight of water [kg]}}{\text{Weight of dry wood [kg]}} \cdot 100$$

Water content in %	10	15	20	25	30	40	50
Wood moisture in %	11	18	25	33	43	67	100

Heating value of wood depending on the water content



Source: Bayerisches Landesanstalt für Forstwirtschaft (Merkblatt 12)

© FNR 2013

Typical mass and energy yields in agriculture and forestry

	Mass yield (w = 15 %) in t/(ha • a)	Average heating value H_i (w = 15 %) in MJ/kg	Gross annual fuel yield in GJ/(ha • a)	Heating oil equivalent in l/(ha • a)
Residual materials				
Residual forest wood	1.0	15.6	15.6	433
Grain straw	6.0	14.3	85.8	2,383
Rapeseed straw	4.5	14.2	63.9	1,775
Hay from landscape conservation	4.5	14.4	64.8	1,800
Energy crops				
Short rotation plantations	12.0	15.4	185.0	5,133
Cereal whole plants	13.0	14.1	183.0	5,092
Forage grasses	8.0	13.6	109.0	3,022
Miscanthus	15.0	14.6	219.0	6,083

Source: Leitfaden Feste Biobrennstoffe, FNR (2014)

Biofuels in comparison with heating oil

Heating values and densities of selected fuels in comparison

Fuel	Density	Energy content in		Oil equivalent in	
		kWh/kg	kWh/l	l/l_{OE}	kg/kg_{OE}
Heating oil	0.85 kg/l	11.83	10.06	1.00	0.98
Rapeseed oil	0.92 kg/l	10.44	9.61	1.04	1.14
Ethanol	0.79 kg/l	7.41	5.85	1.70	1.35
Wood pellets (w = 10 %)	664 kg/m³	5.00	3.32	3.00	1.99
Straw pellets (w = 10 %)	603 kg/m³	4.90	2.95	3.37	2.03
Beech logs 33 cm (w = 15 %)	445 kg/ stacked m³	4.15	1.85	5.40	2.40
Spruce logs 33 cm (w = 15 %)	304 kg/ stacked m³	4.33	1.32	7.56	2.30
Pine chips (w = 15 %)	203 kg/m³	4.33	0.88	11.33	2.30
Spruce sawdust (w = 15 %)	160 kg/m³	4.33	0.69	14.37	2.30
Cerale whole plants (w = 15 %)	150 kg/m³	3.92	0.59	16.96	2.54
Cereal straw, big bales (w = 15 %)	140 kg/m³	3.96	0.55	17.98	2.52
Miscanthus, chopped (w = 15 %)	130 kg/m³	4.07	0.53	18.85	2.45

Source: FNR

w: Water content; l: Litre; OE: Oil equivalent

Combustion data for solid, liquid and gaseous biofuels

Fuel	Quantity/ Unit	Water content w in %	Mass (incl. water) in kg	Heating value (at w) in MJ/kg	Quantity of fuel in		
					MJ	kWh	Heating oil equivalent (l)
Firewood logs (stacked)*							
Beech 33 cm, air-dry	1 stacked m³	15	445	15.3	6,797	1,888	189
Beech 33 cm, surface dry	1 stacked m³	30	495	12.1	6,018	1,672	167
Spruce 33 cm, air-dry	1 stacked m³	15	304	15.6	4,753	1,320	132
Spruce 33 cm, surface dry	1 stacked m³	30	349	12.4	4,339	1,205	121
Wood chips*							
Beech, dry	m³	15	295	15.3	4,503	1,251	125
Beech, limitedly storable	m³	30	328	12.1	3,987	1,107	111
Spruce, dry	m³	15	194	15.6	3,032	842	84
Spruce, limitedly storable	m³	30	223	12.4	2,768	769	77
Wood pellets							
Wood pellets, by volume	m³	8	650	17.1	11,115	3,088	309
Wood pellets, by weight	1 t	8	1,000	17.1	17,101	4,750	475
Solid biofuels by weight							
Beech, air-dry	1 t	15	1,000	15.3	15,274	4,243	424
Beech, surface dry	1 t	30	1,000	12.1	12,148	3,374	337
Spruce, air-dry	1 t	15	1,000	15.6	15,614	4,337	434
Spruce, surface dry	1 t	30	1,000	12.4	12,428	3,452	345
Stalk-type biomass (e. g. straw)	1 t	15	1,000	14.3	14,254	3,959	396
Liquid and gaseous biofuels							
Rapeseed oil	m³	< 0.1	920	37.6	34,590	9,609	961
Biodiesel (Rapeseed oil methyl ester)	m³	< 0.03	880	37.1	32,650	9,093	909
Bioethanol	m³	< 0.3	789	26.8	21,140	5,870	588.9
Biogas	m³	2–7	1.2	15–22.5	18–27	5–7.5	0.6
Biomethane	m³	0	0.72	50	38.9	10.8	1

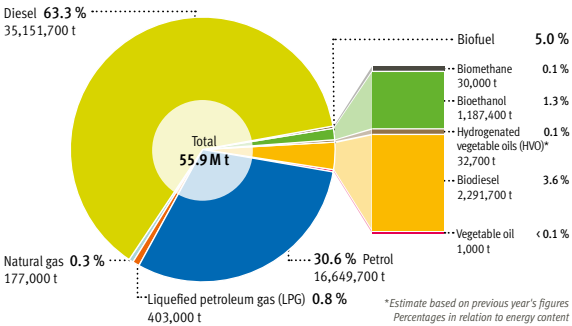
Source: KTBL (2013), FNR (2013) and own calculations

** The occurring change of volume below 25 % water content was considered.*

BIOFUELS

Fuel consumption in the transport sector 2018

Biofuel share 5.0 % (by energy)



Source: FNR based on BAFA, Destatis, DVFG, BDEW, BLE (2019)

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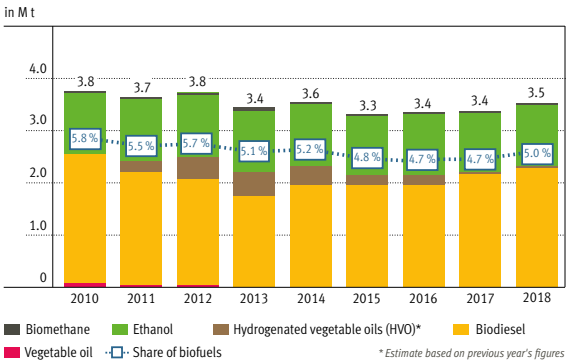
Development of biofuel consumption



Source: BAFA, BMF, AGEE-Stat, FNR (2019)

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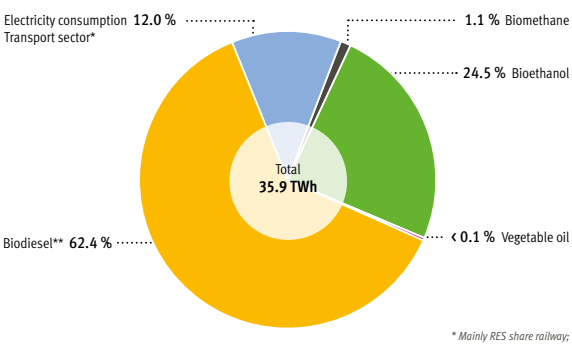
Renewable energies in the transport sector 2018

Share of renewable energies 5.6 % (energetically)



Source: FNR based on AGEE-Stat (February 2019)

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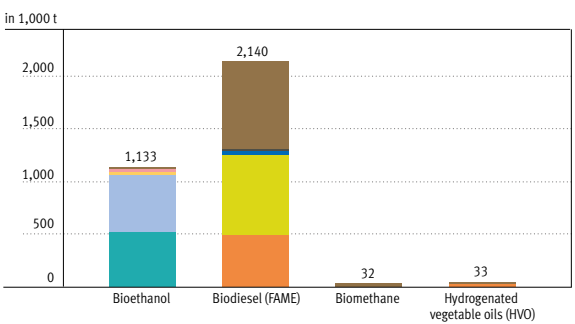
Biofuel production 2017: raw materials



Source: BLE (2018)

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Biodiesel (raw materials for production)

Raw materials	Biomass yield (FM) [t/ha]	Biodiesel yield [l/t BM]	Biodiesel yield [l/ha]	Required biomass per litre of fuel [kg/l]
Rapeseed	3.9	455	1,775	2.2
Palm oil	20.0	222	4,440	4.5
Soy	2.9	222	644	4.5
Jatropha	2.5	244	610	4.1

Source: Meo, FNR

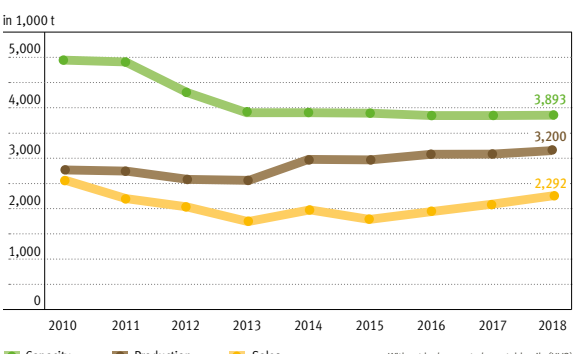
FM: Fresh matter; BM: Biomass

Sales of biodiesel

Sales (in 1,000 t)	2013	2014	2015	2016	2017	2018
Admixture	1,741	1,970	1,978	1,987	2,183	2,292
Pure biofuels	30	5	3	‹ 1	‹ 1	‹ 1
Total sales	**1,772**	**1,975**	**1,981**	**1,987**	**2,183**	**2,292**

Source: BAFA, BMF, FNR (2019)

Biodiesel production and sales



Without hydrogenated vegetable oils (HVO)

Source: FNR, BLE, BAFA, UFOP, AGQM, VDB (2019)

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Bioethanol (raw materials for production)

Raw materials	Biomass yield (FM) [t/ha]	Bioethanol yield [l/t BM]	Bioethanol yield [l/ha]	Required biomass per litre of fuel [kg/l]
Grain maize	9.9	400	3,960	2.5
Wheat	7.7	380	2,926	2.6
Rye	5.4	420	2,268	2.4
Sugar beets	70.0	110	7,700	9.1
Sugar cane	73.0	88	6,424	11.4
Straw	7.0	342	2,394	2.9

Source: Meo, FNR, BDBe

FM: Fresh matter; BM: Biomass

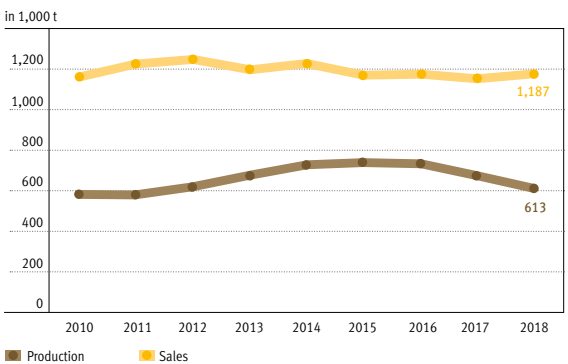
Sales of bioethanol

Sales (in 1,000 t)	2013	2014	2015	2016	2017	2018
E 85 (ethanol share)	14 (11)	10 (8)	7 (6)	n/a	n/a	n/a
Ethanol*	1,041	1,082	1,054	1,047	1,045	1,077
ETBE**	154	139	119	129	111	110
Total sales	**1,206**	**1,229**	**1,179**	**1,175**	**1,157**	**1,187**

Source: FNR nach BAFA (2019)

** as admixture in gasoline; ** ETBE: Ethyl tert-butyl ether; Bioethanol share by volume of ETBE = 47 %*

Bioethanol production and sales



Source: BAFA, BDBe (2019)

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Fuel comparison: Characteristics of biofuels

Fuel	Density [kg/l]	Heating value [MJ/kg]	Heating value [MJ/l]	Viscosity at 20 °C [mm²/s]	Cetane number	Octane number (RON)	Flash point [°C]	Fuel equivalence[h] [l]
Diesel	**0.83**	**43.1**	**35.87**	**5.0**	**50**	**–**	**80**	**1**
Rapeseed oil fuel	0.92	37.6	34.59	74.0	40	–	317	0.96
Biodiesel	0.88	37.1	32.65	7.5	56	–	120	0.91
Hydrogenated vegetable oils (HVO)[f]	0.78	44.1	34.30	› 3.5[g]	› 70	–	60	–
Biomass-to-Liquid (BtL)[a]	0.76	43.9	33.45	4.0	› 70	–	88	0.97
Petrol	**0.74**	**43.9**	**32.48**	**0.6**	**–**	**92**	**‹ 21**	**1**
Bioethanol	0.79	26.7	21.06	1.5	8	› 100	‹ 21	0.65
Ethyl tert-butyl ether (ETBE)	0.74	36.4	26.93	1.5	–	102	‹ 22	0.83
Biomethanol	0.79	19.7	15.56	–	3	› 110	–	0.48
Methyl tert-butyl ether (MTBE)	0.74	35.0	25.90	0.7	–	102	–28	0.80
Dimetyl ether (DME)	0.67[b]	28.4	19.03	–	60	–	–	0.59
Biomethane	0.72[e]	50.0	36.00[c]	–	–	130	–	1.5[d]
Biohydrogen	0.09[e]	120.0	10.80[c]	–	–	‹ 88	–	3.6[d]

Source: FNR

[a] Basis Fischer-Tropsch-Fuels; [b] at 20 °C; [c] [MJ/m³]; [d] [kg]; [e] [kg/m³]; [f] Source: VTT; [g] at 40 °C;
[h] Example: 1 l Biodiesel corresponds to 0.91 l Diesel • 1 kg Biohydrogen corresponds to 3.6 l petrol (when used by fuel cell 7 l)

Vegetable oils (fuel characteristics)

Vegetable oil	Density (15 °C) in kg/l	Heating value in MJ/kg	Kinetic viscosity (40 °C) in mm²/s	Pour point in °C	Flash point in °C	Iodine value
Requirements DIN 51605 (rapeseed oil fuel)	0.910–0.925	min. 36.0	max. 36.0	n/a	min. 101	max. 125
Requirements DIN 51623 (vegetable oil fuel)	0.900–0.930	min. 36.0	max. 35.0*	n/a	min. 101	max. 140
Rapeseed oil	0.92	37.6	34.0	–2 to –10	› 220	94 to 113
Sunflower oil	0.92	37.1	29.5	–16 to –18	› 220	118 to 144
Soya oil	0.92	37.1	30.8	–8 to –18	› 220	114 to 138
Jatropha oil	0.92	36.8	30.5	2 to –3	› 220	102
Palm oil	0.92	37.0	26.9	27 to 43	› 220	34 to 61
Palm kernel oil	0.93	35.5	n/a	20 to 24	› 220	14 to 22

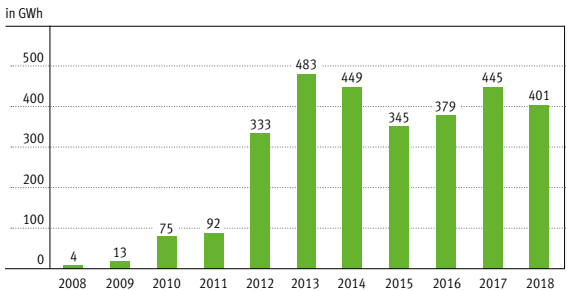
Source: TFZ, ASG, FNR (2015)

*Kinematical viscosity at 50 °C

Biomethane as biofuel in German transport sector

- 100,000 CNG (compressed natural gas) fueled vehicles
- 900 CNG fuel stations
- of which ~ 150 fuel stations offer 100 % biomethane as Bio-CNG and more than 300 fuel stations offer a mixture of biomethane and natural gas

Sales of biomethane as fuel



Source: AGEE-Stat (February 2019)

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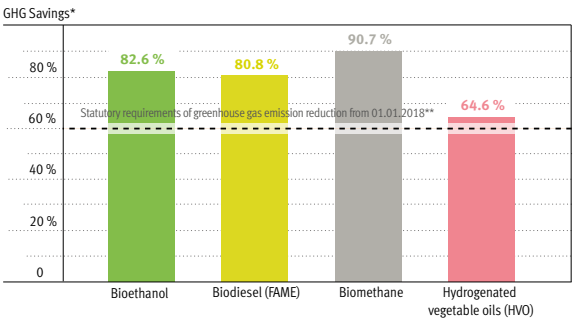
Greenhouse gas emission savings of biofuels



** Average greenhouse gas emission reduction compared to reference of fossil fuels (83.8 g CO_2 equiv./MJ).*
*** Applies to biofuel plants that started operation after 5 October 2015 (50 % for previously implemented plants).*

Source: BLE (2018)

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GHG savings in transport sector – EU-requirements

Options for implementation according Directive 2009/28/EC and 2015/1513[a]	Share to count towards the targets (in terms of energy content)
Biofuels from cultivated biomass (from grain, starch, sugar or oil plants)	Limitation to max. 7 %
"propspective biofuel options"	0.5 % (non-binding target)
Electromobility	– rail transport: 2.5-fold counting – road transport: 5-fold counting

EU target 2020

The European directive on the promotion of the use of energy from renewable sources (Directive 2009/28/EC)[a] defines binding targets for biofuels and regulates their sustainability.

- 10 % renewable energies in final energy consumption

The "Fuel Quality Directive" (98/70/EC)[b] defines binding targets for GHG savings of fuels as well as sustainability criteria.

- 6 % GHG savings of marketed fuels

Germany – Target 2020

6 % GHG savings in transport sector in 2020 to reference value with introduced biofuels und other compliance options (§37a BImSchG, 38. BImSchV)[c].

GHG: Greenhouse gas;
[a] Directive 2009/28/EG on the promotion of the use of energy from renewable sources from 23 April 2009 and Directive 2015/1513/EU from 9 September 2015;
[b] Directive 98/70/EG relating to the quality of petrol and diesel fuels and Directive 2015/1513/EU from 9 September 2015;
[c] 38. Bundes-Immissionsschutz-Verordnung (BImSchV) from 8 December 2017: Directive on the Definition of further provisions on GHG savings for fuels

Sustainability of biofuels

Since 2011, sustainability requirements apply for biofuels and electricity from liquid biomass. The criteria are defined in the

- Ordinance on the requirements for sustainable production of liquid biomass for electricity production (Biomass-electricity-sustainability ordinance – BioSt-NachV) and the
- Ordinance on the requirements for sustainable production of biofuels (Biofuel-sustainability ordinance – Biokraft-NachV).

Biofuels must meet sustainability criteria along the entire manufacturing and supply chain. For plants producing biofuels, a GHG saving towards fossil fuels applies:

- 50 % from 2018 for plants with first operation before 5 October 2015
- 60 % for plants with first operation after 5 October 2015

Directive EU 2015/1513 with amendments to Directives 98/70/EG and 2009/28/EG

Energy tax for transport fuels 2019

Fuel	Energy tax
Diesel (incl. Biodiesel)	47.04 Cent/l
Gasoline	65.45 Cent/l
Ethanol/E85	65.45 Cent/l
Natural gas/biomethane (CNG: Compressed Natural Gas, LNG: Liquified Natural Gas)	13.90 Euro/MWh or 17.79 Cent/kg
Autogas (LPG: Liquified Petroleum Gas)	22.6 Cent/kg

Tax relief for companies of agriculture and forestry (agricultural diesel)

Fuel	Rate of exemption
Diesel	21.48 Cent/l
Vegetable oil	45.03 Cent/l
Biodiesel	45.00 Cent/l

Fuel standardisation

The quality of fuels and its labelling is defined in the Regulation of the Condition and the Labelling of the Quality of Fuels and Combustibles (10. BImSchV).

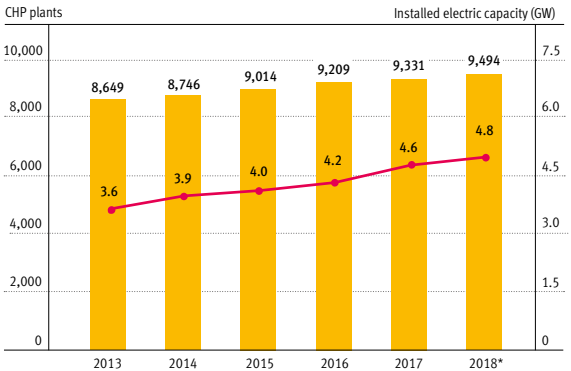
Fuel	Standard	Notes
Diesel (B 7)	DIN EN 590	Diesel with up to 7 vol% Biodiesel (Status: 10/2017)
Biodiesel (B 100)	DIN EN 14214	Fatty acid methyl esters (FAME) for diesel engines (Status: 05/2019)
Rapeseed oil fuel	DIN 51605	Rapeseed oil fuel for engines suitable for vegetable oils (Status: 01/2016)
Vegetable oil fuel	DIN 51623	Fuels for engines suitable for vegetable oils "Vegetable oil fuel" Requirements and test methods (Status: 12/2015)
Petrol (E 5)	DIN EN 228	Unleaded petrol with up to 5 vol% ethanol or rather 15 vol% ETBE (Status: 08/2017)
Petrol (E 10)	DIN EN 228	Petrol E 10 – with up to 10 vol% ethanol (Status: 08/2017)
Ethanol	DIN EN 15376	Ethanol as blend component in petrol (Status: 12/2014)
Ethanol (E 85)	DIN 51625	– min. 75 to max. 86 vol% ethanol – class A (summer) – min. 70 to 80 vol% ethanol – class B (winter) (Status: 08/2008)
Natural gas & Biomethane	DIN EN 16723-2	Biomethane must fulfill the standard for natural gas as fuel – a mixture of biomethane and natural gas is possible in any proportion (Status: 10/2017)

Source: FNR (July 2019)

vol%: Percentage by volume

BIOGAS

Development of biogas CHP plants



Source: FNR based on DBFZ, Fachverband Biogas e.V. (2018)

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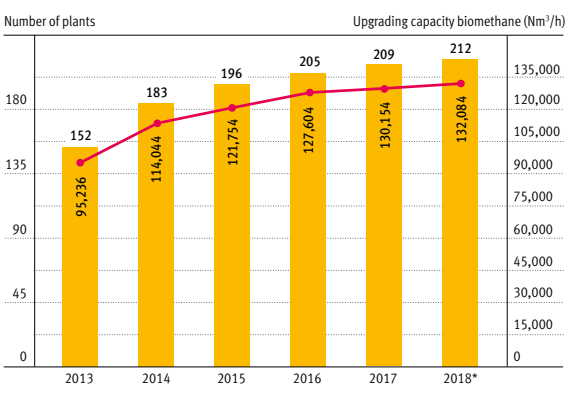
Plants for biomethane production



Source: FNR based on dena (2018)

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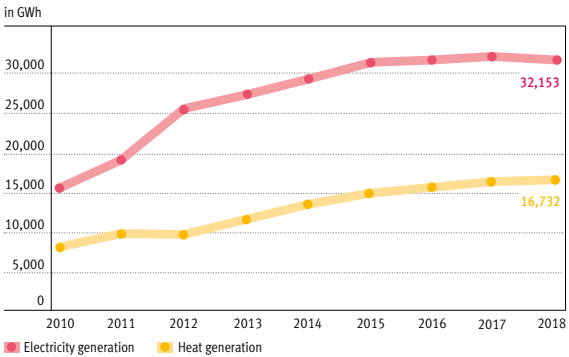
Energy supply from biogas



Source: BMWi, AGEE-Stat (February 2019)

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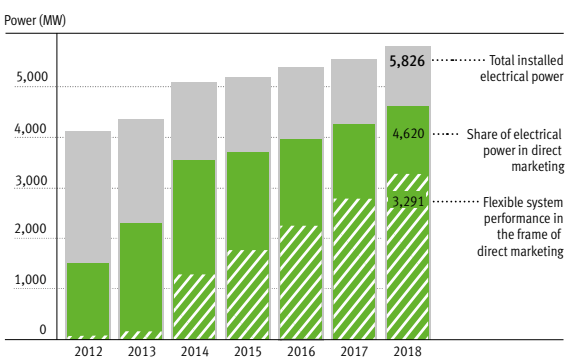
Direct marketing and flexible electricity generation



Source: Fraunhofer IEE based on BNetzA and www.netztransparenz.de (2019)

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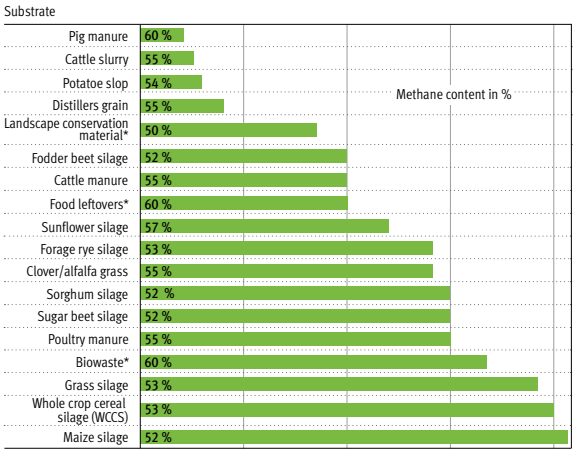
Biogas yields of selected substrates



** Varies widely*

Source: KTBL (2015)

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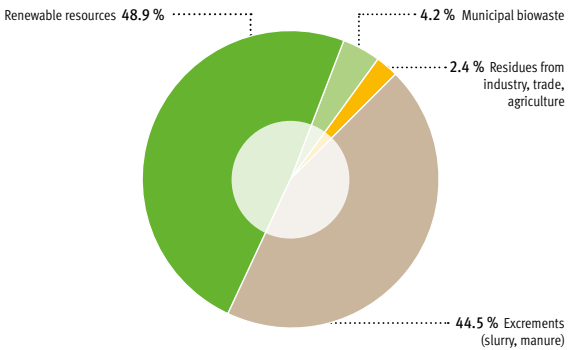
Substrate input in biogas plants 2016 (mass related)



Source: DBFZ Betreiberbefragung Biogas (2017)

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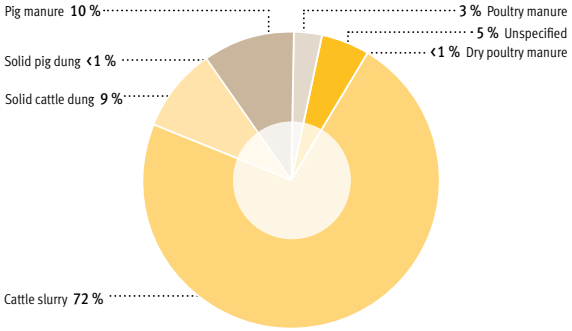
Farm manure in biogas plants – mass related substrate input 2016



Source: DBFZ Betreiberbefragung Biogas (2017)

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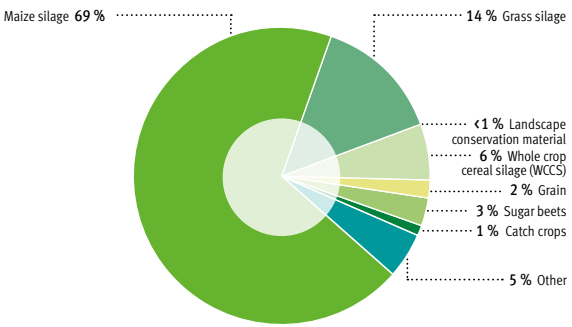
Renewable resource in biogas plants – mass related substrate input 2016



Source: DBFZ Betreiberbefragung Biogas (2017)

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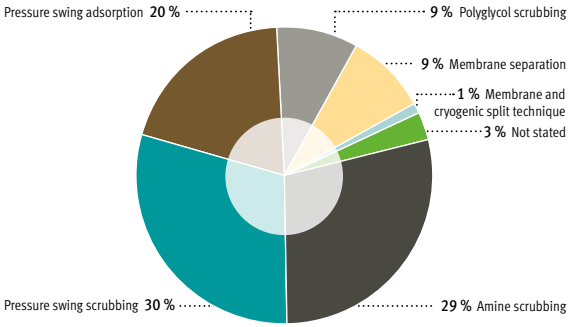
Types of biomethane upgrading processes in Germany



Source: FNR based on DBFZ (2017)

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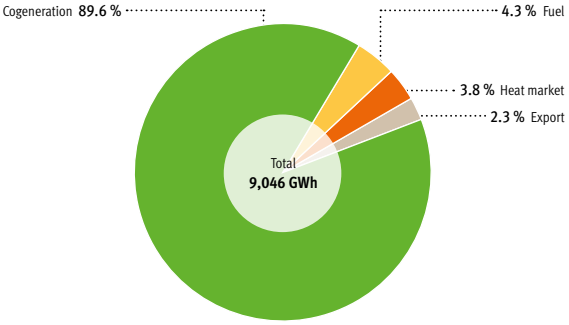
Marketing of biomethane 2015



Source: DBFZ Report Nr 30 (2017)

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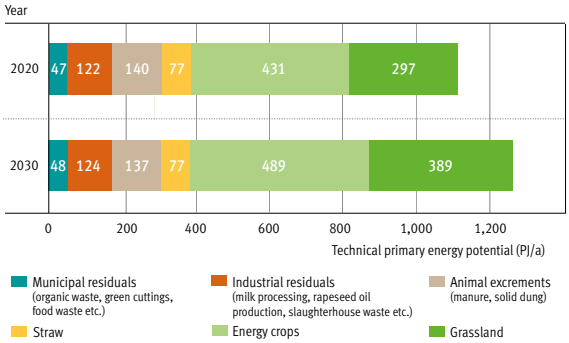
Characteristic values of different biogas treatment processes

	Pressure swing adsorption (PSA)	Pressure water scrubbing (PWS)*	Physical absorption** (with organic solvents)	Chemical absorption*** (with organic solvents)	Membrane processes***	Cryogenic processes
Electricity requirement (kWh/Nm³)	0.20–0.25	0.18–0.21	0.15–0.24	0.06–0.15	0.18–0.29	0.18–0.33
Heat requirement (kWh/Nm³)	0	0	0	0.5–0.7	0	0
Temperature process heat (°C)	–	–	55–80	110–140	0	–
Process pressure (bar)	4–7	5–10	4–6	0.1–0.25	9.5–16	–
Methane loss (%)	1–5	1	0.5–1.5	0.1	0.5–1	–
After-treatment of exhaust gases required? (legislation: EEG & GasNZV)	yes	yes	yes	no	yes	yes
Fine desulphurisation of the raw gas required?	yes	no	yes	yes	yes	yes
Water demand	no	yes	no	yes	no	no
Demand for chemicals	no	no	yes	yes	no	no

Source: Fraunhofer-IWES based on DWA (2011), Manufacturer specifications (2018)

*Manufacturer information from * Malmberg Bioerdgastech GmbH, ** BMF Haase Energietechnik GmbH, *** Hitachi Zosen Inova Biomethan GmbH*

Technical primary energy potential for biogas



Source: FNR based on DBFZ (2019)

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Theoretical electricity potential of different energy crops (in ha)

Energy crop	Harvest yield [t FM]	Methane yield [Nm³]	Electricity yield [kWh]	Number of households supplied
Maize	50	4,945	18,731	5.2
Sugar beets	65	4,163	15,769	4.4
Whole crop cereal silage (WCCS)	40	3,846	14,568	4.0
Cup plant	55	3,509	13,291	3.7
Grassland	29	2,521	9,549	2.7

Source: FNR based on KTBL (2014)

Assumptions: average yields, 12 % storage losses, for sugar beets 15 % (lagoon); CHP efficiency rate 38 %; Electricity consumption 3,600 kWh/a • household

Rules of thumb

The following figures can be used as guide values for general calculations of agricultural biogas plants.

General conversion biogas and biomethane	
1 m³ biogas	5.0–7.5 kWh energy content
1 m³ biogas	50–75 % methane content
1 m³ biogas	approx. 0.6 l heating oil equivalent
1 m³ methane	9.97 kWh energy content
1 m³ methane	heating value 36 MJ/m³ or 50 MJ/kg
1 m³ methane	1 l heating oil equivalent

Average composition of biogas	
Component	**Concentration**
Methane (CH_4)	50–75 vol%
Carbon dioxide (CO_2)	25–45 vol%
Water vapour (H_2O)	2–7 vol%
Hydrogen sulphide (H_2S)	20–20,000 ppm
Oxygen (O_2)	< 2 vol%
Nitrogen (N_2)	< 2 vol%
Ammonia (NH_3)	< 1 vol%
Hydrogen (H_2)	< 1 vol%
Trace gases	< 2 vol%

Biogas yield of	
Dairy cow (17 m^3 manure/ space per animal • a)	289 Nm^3 methane ≙ 1,095 kWh_{el}/space per animal • a*
Fattening pig (1.6 m^3 manure/ space per animal • a)	19 Nm^3 methane ≙ 73 kWh_{el}/space per animal • a*
Fattening cattle (2.8 t solid manure/ space per animal • a)	185 Nm^3 methane ≙ 562 kWh_{el}/space per animal • a*
Riding horse (11.1 t solid manure/ space per animal • a)	388 Nm^3 methane ≙ 1,472 kWh_{el}/space per animal • a*
Chicken (2.0 m^3 rotting manure/ 100 animal spaces • a)	164 Nm^3 methane ≙ 621 kWh_{el}/100 animal spaces • a*
1 ha silage maize (40–60 t FM**)	3,956–5,934 Nm^3 methane ≙ 14,985–22,477 kWh_{el}/ha*
1 ha sugar beets (55–75 t FM**)	3,523–4,803 Nm^3 methane ≙ 13,343–18,195 kWh_{el}/ha*
1 ha whole crop cereal silage (WCCS) (30–50 t FM**)	2,884–4,807 Nm^3 methane ≙ 10,926–18,210 kWh_{el}/ha*
1 ha cup plant (45–60 t FM**)	2,871–3,828 Nm^3 methane ≙ 10,874–14,499 kWh_{el}/ha*
1 ha sudangrass (35–55 t FM**)	2,392–3,759 Nm^3 methane ≙ 9,061–14,238 kWh_{el}/ha*
1 ha grassland (23–43 t FM**)	2,001–3,808 Nm^3 methane ≙ 7,579–14,424 kWh_{el}/ha*
1 ha grain rye (4.3–6.8 t FM**)	1,390–2,179 Nm^3 methane ≙ 5,264–8,255 kWh_{el}/ha*

Process parameters		
Temperature	*mesophilic*	32–34 °C
	thermophilic	50–57 °C
pH value	*hydrolysis/ acidogenesis*	4.5–7
	acetogenesis/ methanogenesis	6.8–8.2
Digester load		Ø 3.2 kg ODM/(m^3 • d); (from 1.1–9.3)
Average hydraulic retention time	*single-stage*	22–88 days (Ø 58)
	multistage	37–210 days (Ø 101)
VOA/TIC value		< 0.6
Gas permeability of biogas tanks		1–5 ‰ biogas/day
Electricity demand BGP		Ø 7.6 %
Heat demand BGP		Ø 27 %
Workload BGP per year		1.15–8.5 MHr/(kW_{el} • a)
Breakdowns BGP per year		1.2 /10 kW_{el}

Key figures gas utilisation	
CHP efficiency $rate_{el}$	28–47 %
CHP efficiency $rate_{th}$	34–55 %
CHP efficiency $rate_{total}$	approx. 85–90 %
CHP extent of use	60,000 operating hours
Micro gas turbine efficiency $rate_{el}$	26–33 %
Micro gas turbine efficiency $rate_{th}$	40–55 %
Fuel cell efficiency $rate_{el}$	40–60 %
ORC system efficiency $rate_{el}$	6–16 %

Economic figures	
Specific investment costs	
BGP 75 kW_{el}	approx. 9,000 €/kW_{el}
BGP 150 kW_{el}	approx. 6,500 €/kW_{el}
BGP 250 kW_{el}	approx. 6,000 €/kW_{el}
BGP 500 kW_{el}	approx. 4,600 €/kW_{el}
BGP 750 kW_{el}	approx. 4,000 €/kW_{el}
BGP 1,000 kW_{el}	approx. 3,500 €/kW_{el}
BGP with gas upgrading 400 Nm^3/h	approx. 9,600 €/Nm^3 • h
BGP with gas upgrading 700 Nm^3/h	approx. 9,100 €/Nm^3 • h
ORC system 13–375 kW_{el}	approx. 5,000–7,700 €/kW_{el}
Electricity generation costs	
BGP 75 kW_{el}	approx. 30 ct/kWh
BGP 500 kW_{el}	approx. 17 ct/kWh
BGP 1,000 kW_{el}	approx. 15 ct/kWh
Production costs biomethane	
400 Nm^3/h	7–9 ct/kWh
700 Nm^3/h	6–8 ct/kWh

Example: annual need for substrate of a biogas plant 75 kW_{el}
3,300 t cattle slurry (194 dairy cows; with Ø 8,000 milk yield/a)
790 t maize silage (18 ha; with Ø 50 t FM/ha yield**)

Example: annual need for substrate of a biogas plant 500 kW_{el}
2,200 t cattle slurry (129 dairy cows; with Ø 8,000 l milk yield/a)
6,500 t maize silage (148 ha; with Ø 50 t FM/ha yield**)
1,100 t Whole crop cereal silage (31 ha; with Ø 40 t FM/ha yield**)
1,100 t grass silage of permanent grassland
(42 ha; with Ø 30 t FM/ha yield**)

* *CHP efficiency rate 38 %el*
** *12 % silage losses considered, for sugar beets 15 % (lagoon), for grain rye 1.4 %*

Source: Biomasse-Verordnung (2012); Faustzahlen Biogas (KTBL, 2013); Leitfaden Biogas (FNR, 2013); Leitfaden Biogasaufbereitung und -einspeisung (FNR, 2014); Stromerzeugung aus Biomasse (DBFZ, 2014) and own calculations

APPENDIX

Market reports and prices for fuels and biomass

Biodiesel	www.ufop.de
Oilseeds and vegetable oils	www.oilworld.biz
Wood chips and pellets	www.carmen-ev.de
Wood logs	www.tfz.bayern.de
Pellets	www.depi.de
Agricultural sector	www.ami-informiert.de
Federal Statistical Office	www.destatis.de

Conversion of units

	MJ	kWh	m^3 natural gas
1 MJ	1	0.278	0.032
1 kWh	3.6	1	0.113
1 m^3 natural gas	31.74	8.82	1

	m^3	l	Barrel
1 m^3	1	1,000	6.3
1 l	0.001	1	0.0063
1 barrel	0.159	159	1

Signs for units

Prefix	Sign	Factor	Numeral
Kilo	k	10^3	thousand
Mega	M	10^6	million
Giga	G	10^9	billion
Tera	T	10^{12}	trillion
Peta	P	10^{15}	quadrillion
Exa	E	10^{18}	quintillion

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