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Task 37 Energy from Biogas
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Coláiste na hOllscoile Corcaigh, Éire
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BIOGAS FROM ENERGY CROP DIGESTION

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Methane production per unit of feedstock

- 1 t of Volatile Solid has an energy value of ca. 19 GJ.

- 1 m_n^3 of methane (CH_4) has an energy value of ca. 38 MJ
- 1 m_n^3 CH_4 is equivalent to 1 L of diesel

- Thus for conservation of energy the maximum production of methane is 500 $m^3 .t^{-1}$ VS.

- Silage may contain alcohols and acids that allow higher levels of methane to be produced

Methane yields from digestion of energy crops

Methane yield (m^3 per t volatile solids added)			
Maize (whole crop)	205-450	Barley	353-658
Wheat (grain)	384-426	Triticale	337-555
Oats (grain)	250-295	Sorghum	295-372
(grain)	283-492		
Grass	298-467	Alfalfa	340-500
Clover grass	290-390	Sudan grass	213-303
Red clover	300-350	Red Canary Grass	340-430
Clover	345-350	Ryegrass	390-410
Hemp	355-409	Nettle	120-420
Flax	212	Miscanthus	179-218
Sunflower	154-400	Rhubarb	320-490
Oilseed rape	240-340	Turnip	314
Jerusalem artichoke	300-370	Kale	240-334
Peas	390		
Potatoes	276-400	Chaff	270-316
Sugar beet	236-381	Straw	242-324
Fodder beet	420-500	Leaves	417-453

Maize

The most frequently used energy crop

- yields of 9 to 30 tDM per hectare
- 205 – 450 m^3 CH_4 $.t^{-1}$ VS_{added}
- 1600 – 12,000 m^3 CH_4 .ha

Grass

- yields of 12 to 15 tDM per hectare
- 298 – 467 m^3 CH_4 $.t^{-1}$ VS_{added}
- 3220 – 6300 m^3 CH_4 .ha

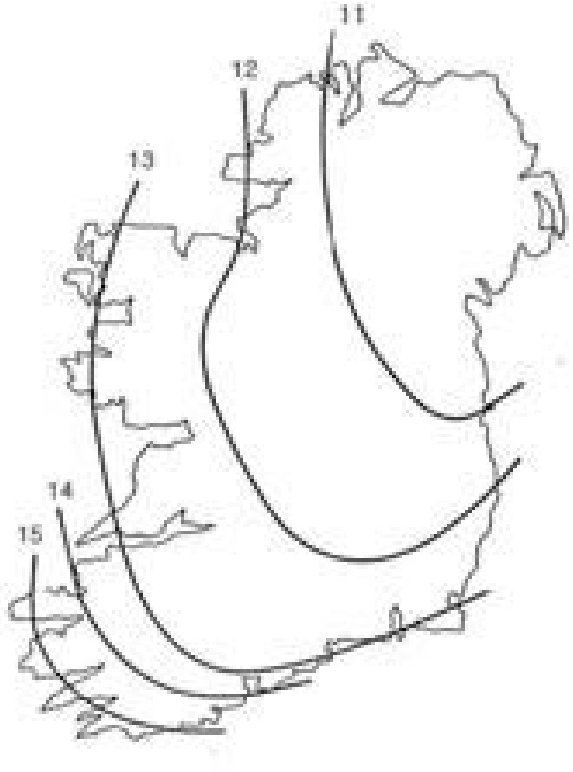
Sugar Beet

- ca. 12 tDM per hectare
- 236 – 381 m^3 CH_4 $.t^{-1}$ VS_{added}
- 2500 – 4000 m^3 CH_4 .ha

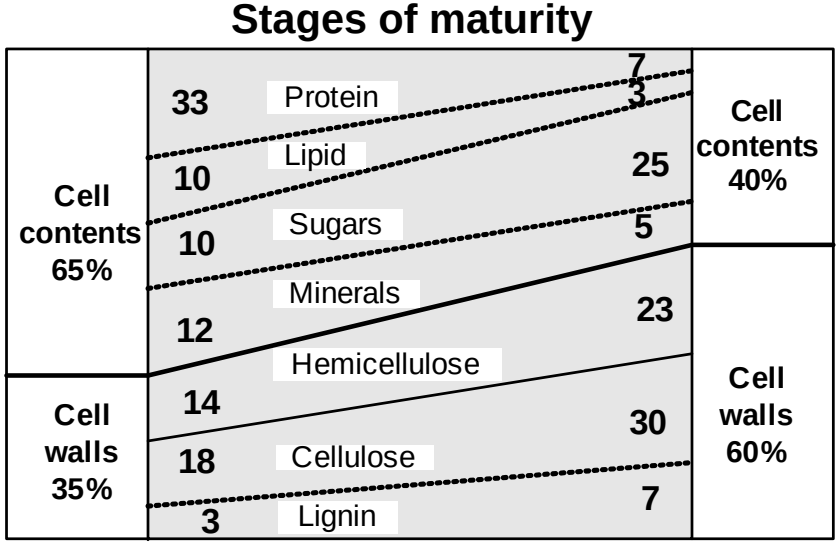
Sun Flower

- yields of 6 to 8 tDM per hectare
- 154 – 400 m^3 CH_4 $.t^{-1}$ VS_{added}
- 800 – 3000 m^3 CH_4 .ha

Variability of crop yields and digestibility



Grass yields tDS.ha^{-1}.a^{-1}



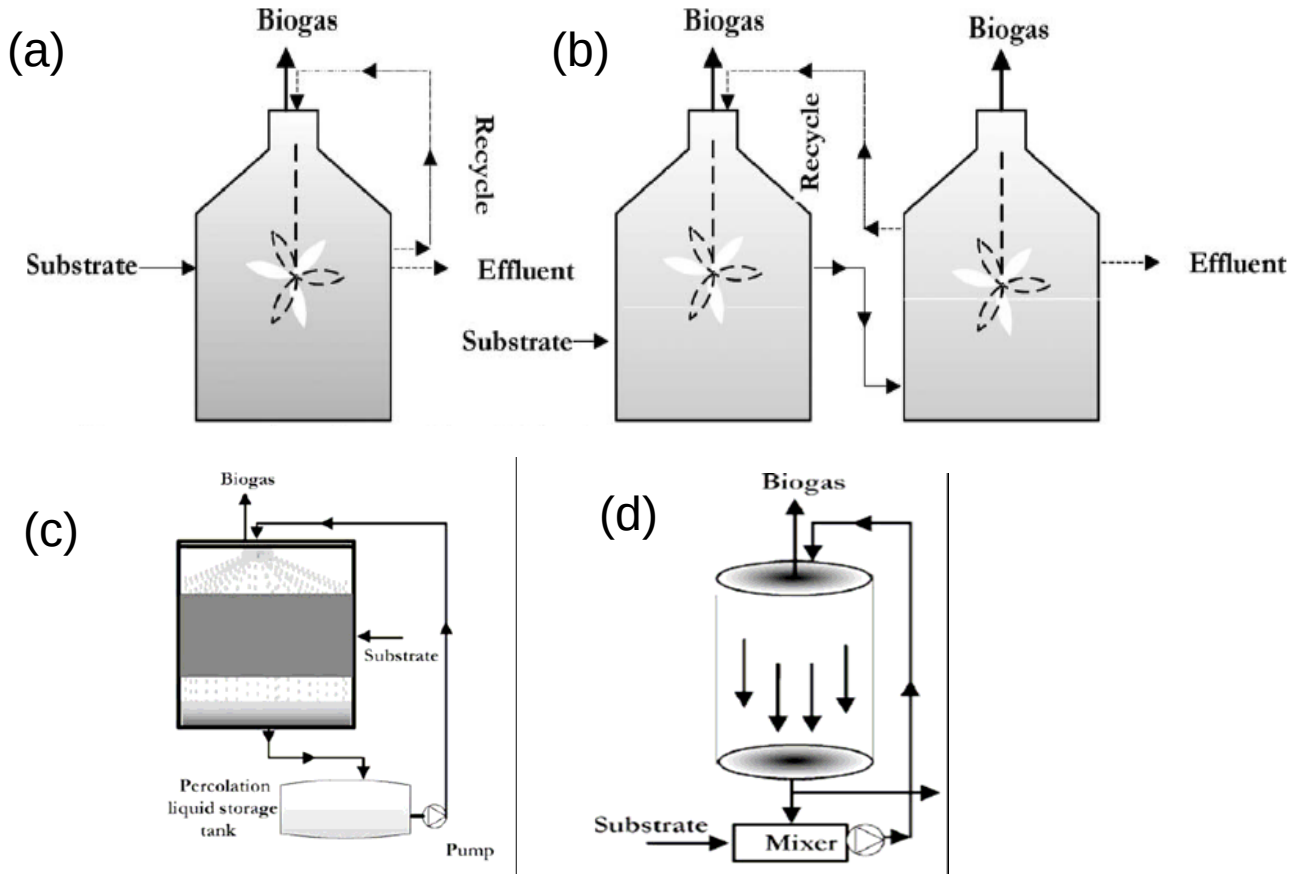
Reduced methane yield with age of grass

Harvest, pre-processing and storage of energy crops

Typical maize harvesting, using a standard combine harvester

Ensiling of whole crop chopped maize, using a front loader

Anaerobic process configuration



(a) one stage wet digestion (b) two stage wet digestion (c) dry batch system (d) dry continuous system

Feeding digesters

Silage dosing unit (back)
with spiral elevator (front).

Solid substrate grinder (right) used for preparation of dry substrates (maize) in anaerobic digestion of energy crops

Treatment, storage and usage of digestate

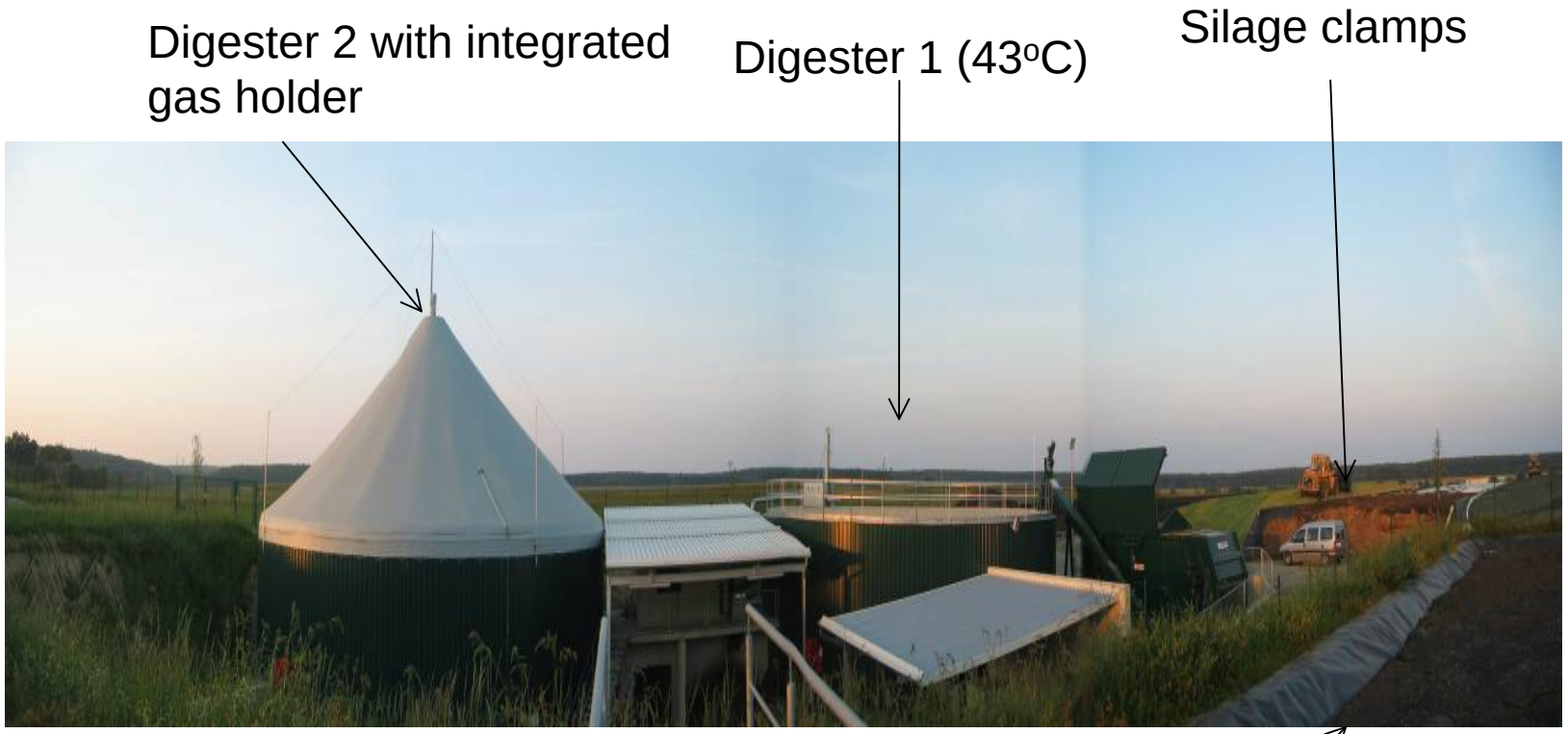
Gas tight coverage of a post storage tank for digestate. Residual biogas is collected for energy use, while greenhouse gas and ammonia emissions are prevented.

Open lagoon storage for completely digested maize and grass silage;

Four Examples:

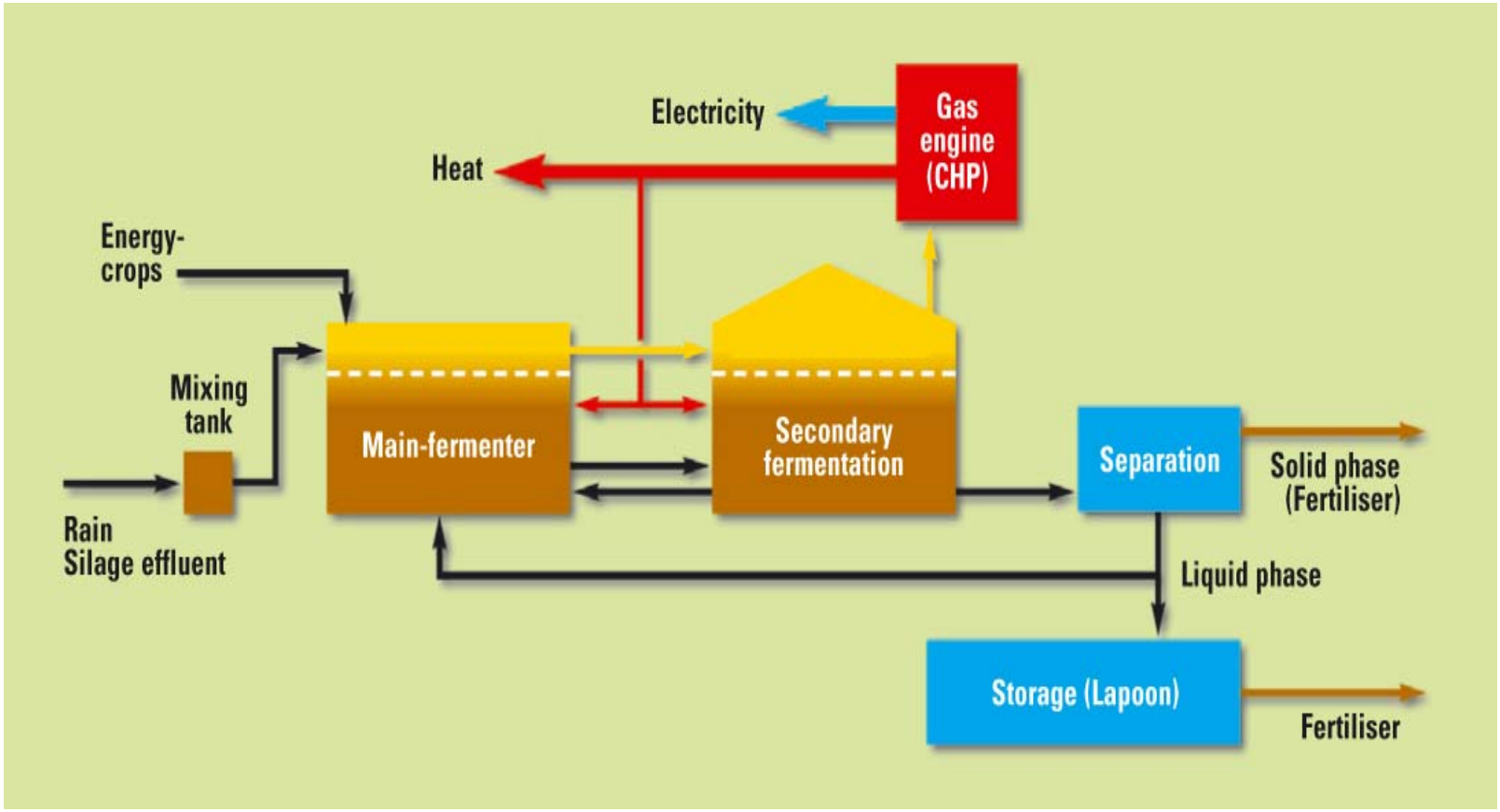
(1) 500 kWe energy crop digestion plant
(2) Co-digestion of energy crops at 1 MWe scale
(3) Continuous dry digestion energy crop plant
(4) Grass to transport fuel

500 $kW_{e.}$ energy crop digestion plant



300 ha of agricultural land
15,000 m^3 silage capacity (50m^3 of silage capacity per hectare).
2 tanks of 1500 m^3 each (10m^3 of digestion capacity per hectare)

500 $kW_{e.}$ energy crop digestion plant



500 $kW_{e.}$ energy crop digestion plant

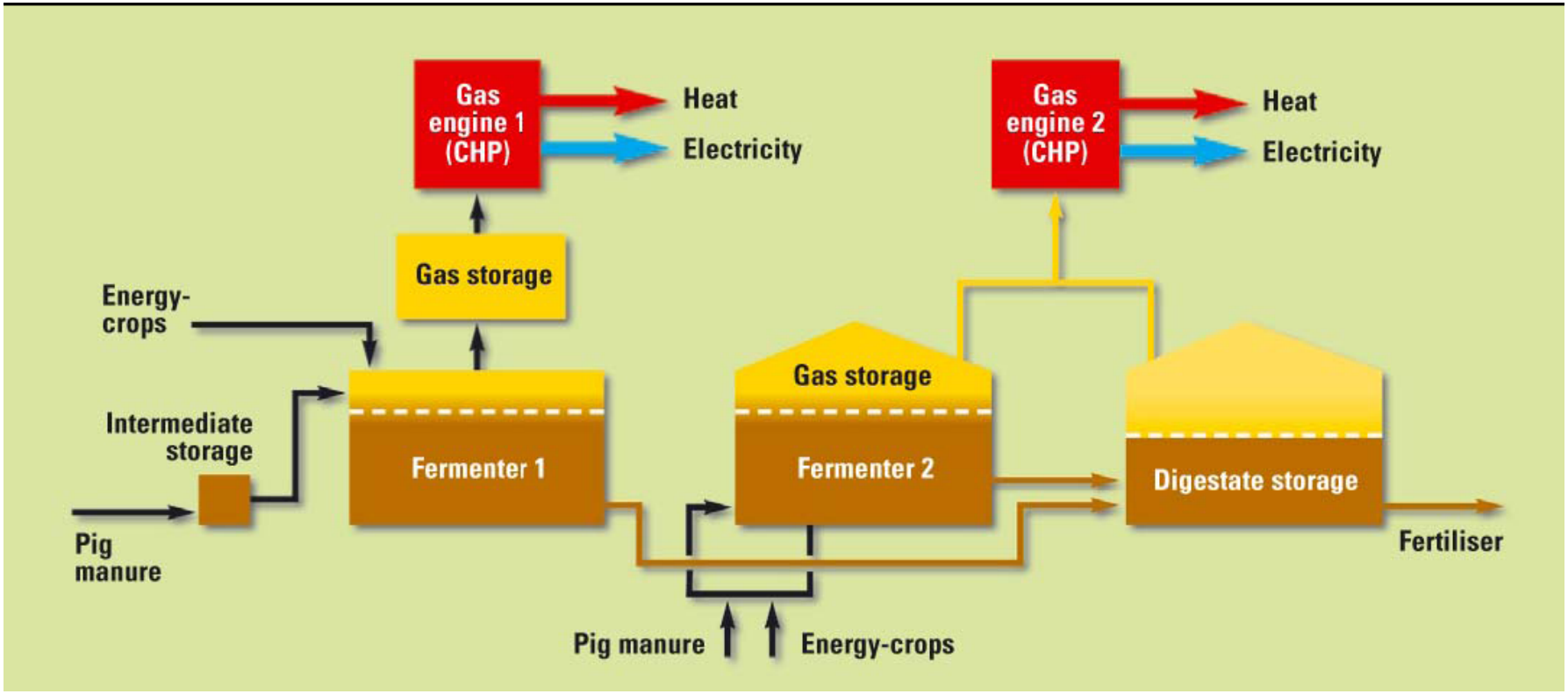
Input of maize whole crop silage	5,940 t. $year^{-1}$
Input of grass silage	2,181 t. $year^{-1}$
Input of clover silage	1,374 t. $year^{-1}$
Total feedstock	9,495 t. $year^{-1}$
Biogas production	1.88 Mio m^3. $year^{-1}$ (198 $m^3.t^{-1}$)
Production of electrical energy	4,153 MWh. $year^{-1}$ (38%η_e)
Production of thermal energy	4,220 MWh. $year^{-1}$ (39%η_t)
Own electrical consumption	161 MWh. $year^{-1}$ (4% parasitic demand)
Own thermal consumption	701 MWh. $year^{-1}$ (17% parasitic demand)
Sale of electricity	3,992 MWh. $year^{-1}$
Sale of thermal energy	1,697 MWh. $year^{-1}$ (48% of available)

Co-digestion of energy crops at 1MW$_e$ scale

Two parallel digesters (left background) with gas storage integrated in digester 2 . Operated at 39^{o}C and a 77 day retention time

Covered final digestate storage tank (center foreground) with gas storage

Co-digestion of energy crops at 1MW$_e$ scale



Co-digestion of energy crops at 1MW$_e$ scale

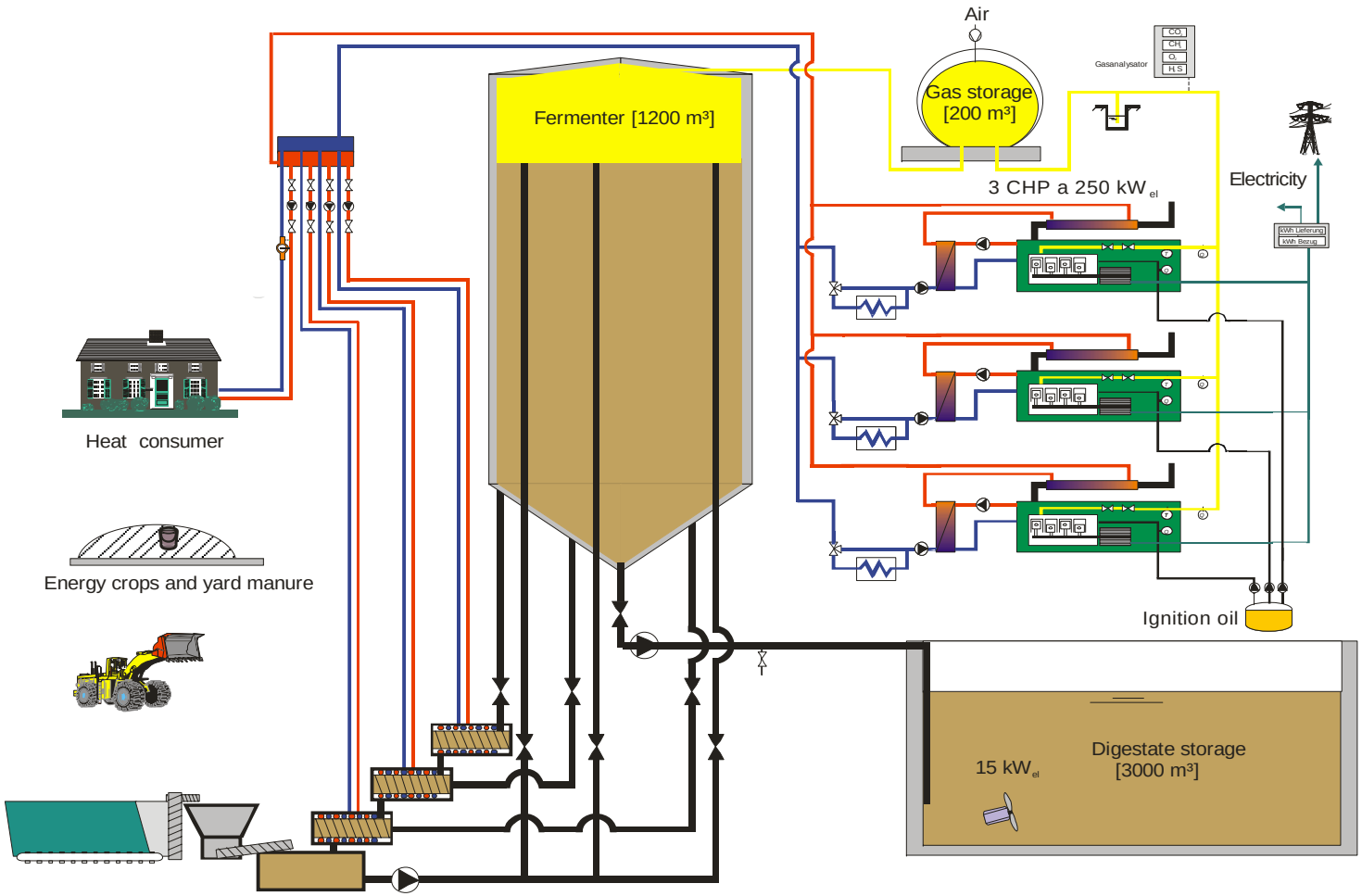
Input energy crops	11,000 t. year^{-1}
Input manure + leachate from silage	7,300 t. year^{-1}
Total feedstock	18,300 t. year^{-1}
Silage clamp capacity	9,000 m^3 (0.82 m^3.t^{-1})
Total volume of digesters	3,850 m^3 (0.21 m^3.t^{-1}.year^{-1})
Biogas production	4.02 Mio m^3 . year^{-1} (220m^3.t^{-1})
Production of electrical energy	8,030 MWh . year^{-1}
Production of thermal energy	8,223 MWh . year^{-1}
Total digestate storage	5,800 m^3 (0.32 m^3.t^{-1}.year^{-1})

Continuous Dry Digestion energy crop plant

Digester 1,200 m^3 (height of 25 m, diameter 8.5 m).
Ensiled crops mixed with digestate and mixture pumped to the top.
Upper zone intense fermentation with constant recycle of digestate, lower zone post fermentation.
750kW_e but limited to 500kW_e for tariff purposes

355 ha arable land and 25 ha pasture land
54 °C at a 29 day residence time,
Volumetric loading rate of 9.7 kg $VS.m^{-3}.d^{-1}$
Substrate 30 % DS; digestate 16 % DS.
Specific biogas productivity is 5.8 m^3 per m^3 reactor volume per day^{-1}.

Continuous Dry Digestion energy crop plant



Continuous Dry Digestion energy crop plant

Input of whole crop maize silage	5,700 t . year^{-1}
Input of total plant cereal silage	2,760 t . year^{-1}
Input of sunflower silage	1,490 t . year^{-1}
Input of grass silage	720 t . year^{-1}
Input of yard manure	830 t . year^{-1}
Total feedstock	11,500 t . year^{-1}
Potential biogas production	2.54 Mio m^3 . year^{-1} (221m^3.t^{-1})
Production of electrical energy	4,140 MWh.year^{-1}
Production of thermal energy	4,340 MWh .year^{-1}
Own electrical consumption	350 MWh .year^{-1} (8.5% parasitic demand)
Own thermal consumption	275 MWh .year^{-1} (6.3% parasitic demand)

Grass to transport fuel

harvest →

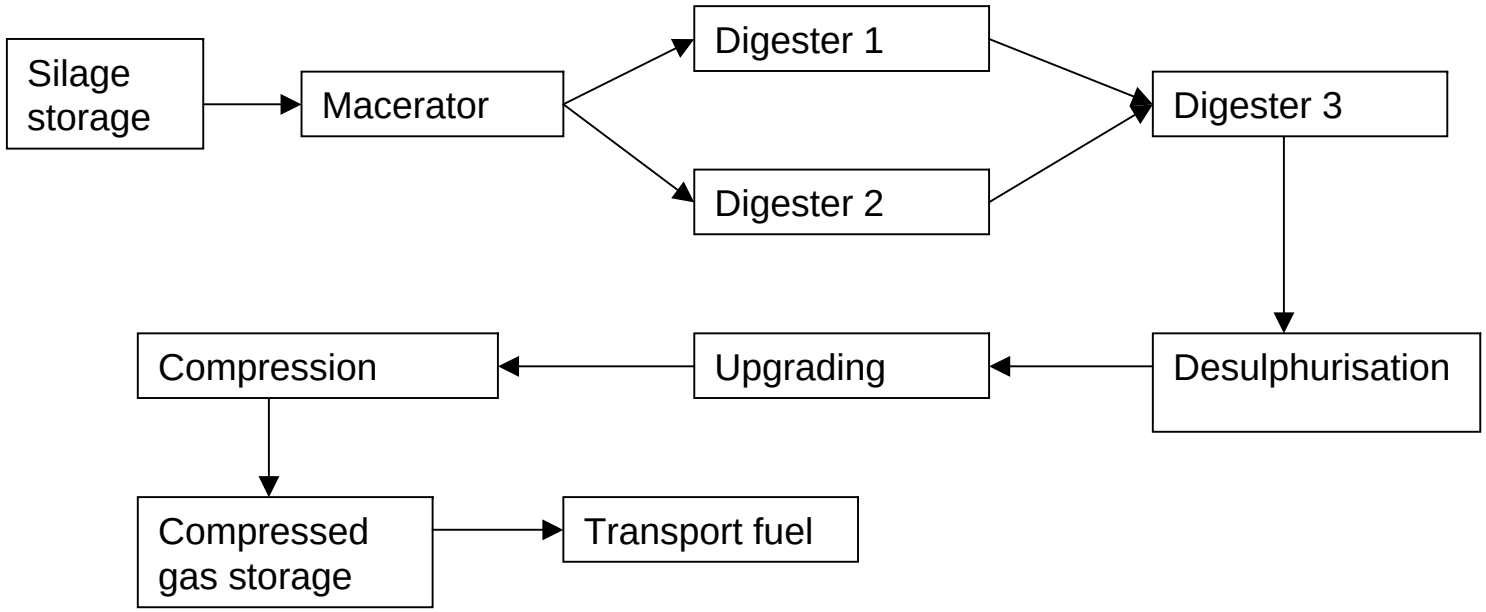
→ weigh bridge →

silage storage ↓

macerator ← anaerobic digester ← Scrubbing & storage ← Biogas service station ←

Source: energiewerkstatt, IEA and personal photos

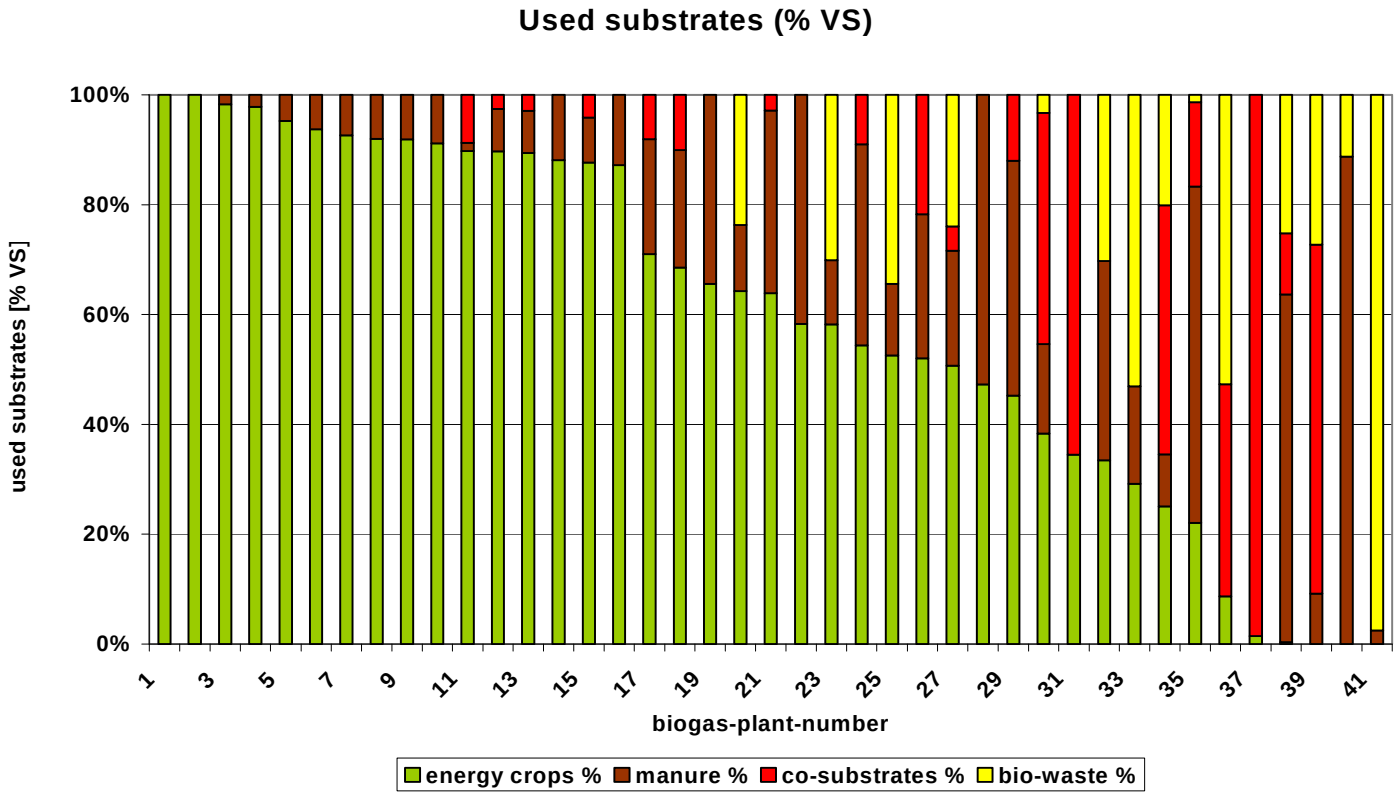
Grass to transport fuel



Grass to transport fuel

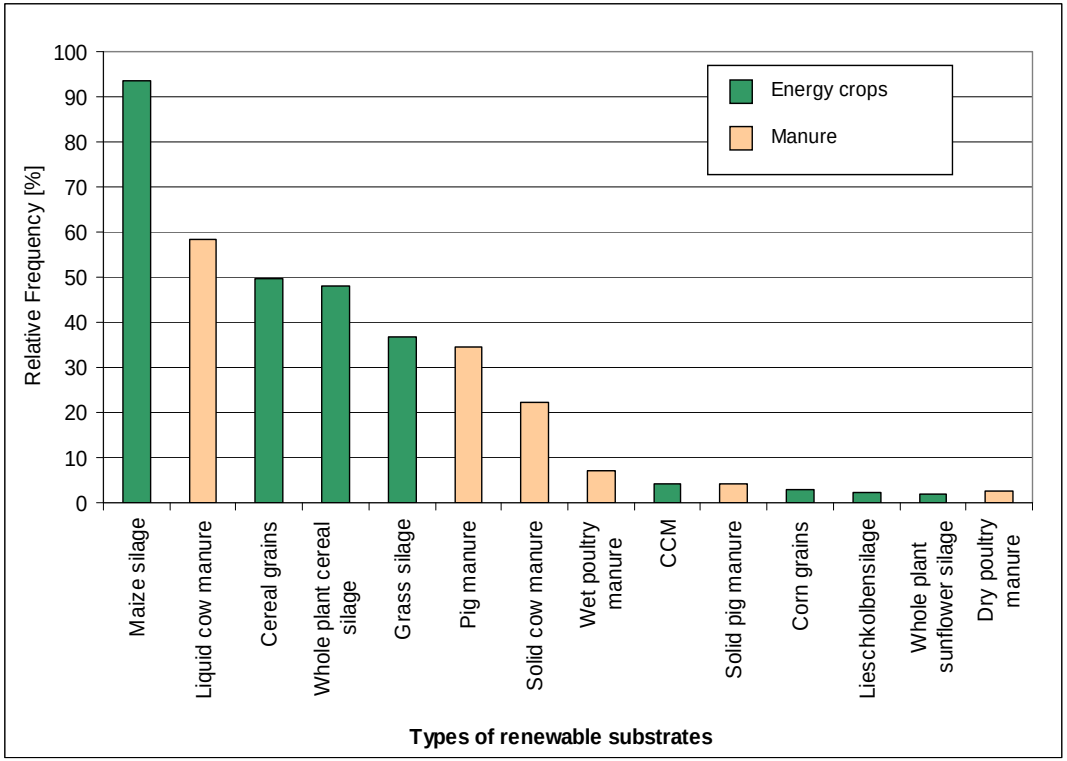
Grass silage yield (150 ha @ 11 tDS.ha^{-1}.year^{-1})	1650 t DS. year^{-1}
Mass of silage per annum (@40% dry solids)	4125 t. year^{-1}
Capacity of silage clamps	3000 m^3 (20m^3.ha^{-1}.year^{-1})
Storage of silage (density of silage 500 kg . m^{-3})	4.4 months
Volatile solids (92% of DS)	1518 t VS. year^{-1}
Combined Fermenter volume	4000 m^3 (0.96m^3.t^{-1}.year^{-1})
Loading Rate	1.04 kg VS.m^{-3}.day^{-1}
Methane production (340 m^3 CH_4. t^{-1} VS)	516,120 m_n^3. year^{-1}
Biogas production (@55% CH_4)	938,400 m_n^3. year^{-1}(227 m_n^3.t^{-1})
Biomethane production (@98% CH_4; 5% to off gas)	500,350 m_n^3. year^{-1}
Biomethane production	57 m_n^3. hour^{-1}
Biomethane storage (1920 L @ 300 bar = 576 m_n^3)	10 hours

Survey of 41 Austrian Digesters



- The mean methane yield was 0.362 $m_n^3\,kg^{-1}$ VS;
- Mean electrical efficiency was 31.3%;
- The VS degradation efficiency had a mean value of 82.8%;
- Lack of thermal markets yielded an overall mean efficiency of biogas use at 47.3%.

Energy Crop Digestion plants in Germany



Frequency of different substrates in German biogas plants (FNR, 2009)

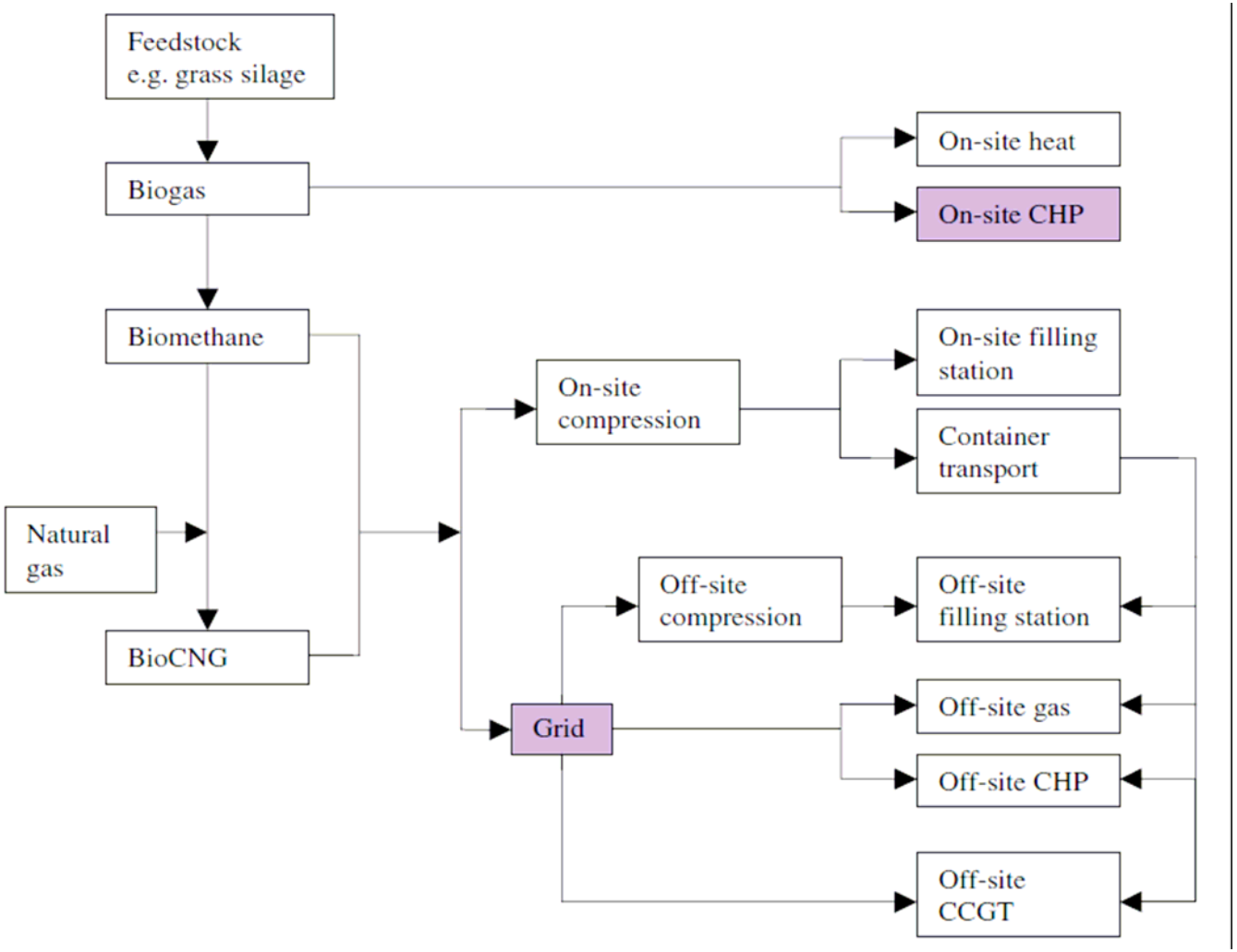
	Maize silage	Cereal Grains	Grass silage	Whole crop cereal silage	Early rye Silage
Average mass percentage of total substrate	50.0	3.1	10.5	10.7	9.8
Minimum (%)	7.0	0.25	0.53	0.29	0.36
Maximum (%)	98.3	23.5	51.5	29.3	53.5

Net energy yield per hectare of crops

	Maize	Potatoes	Fodder beet	Grass	Oilseed rape	Rye
Methane yield $m^3 . ha^{-1}$	5,748	9,235	8,515	4,303	1,344	732
$GJ . ha^{-1}$	217	349	322	163	51	28
Process energy demand for digestion $GJ. ha^{-1}$	33	52	48	24	8	4
Energy requirement in cropping $GJ. ha^{-1}$	17	24	20	17	17	17
Total energy requirement $GJ. ha^{-1}$	50	76	68	41	25	21
Net energy yield $GJ.ha^{-1}$	167	273	254	122	26	7
$\frac{\text{Output } (GJ.ha^{-1})}{\text{Input (tot. Energy)}}$	4.3	4.6	4.7	4.0	2.0	1.3

Compare to liquid biofuels: e.g. sugarcane ethanol net energy ca. 120 $GJ.ha^{-1}.year^{-1}$

Pathways for use of biogas



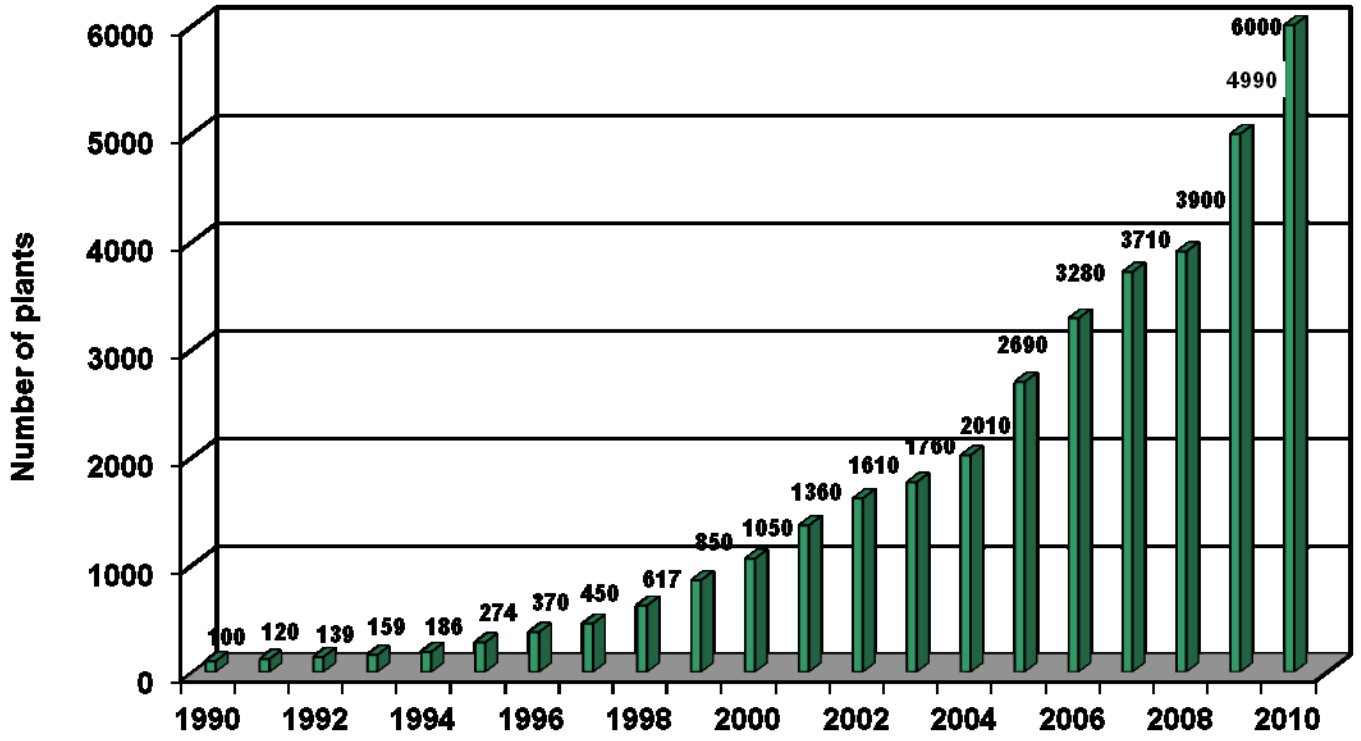
Economic viability of biogas from energy crops

Grass silage:
Costs approximately €25 t^{-1} for pit silage (22% DS)
Produces about 140m_n^3 of biogas (3.00 GJ; 325 kW_e @ 40% η_e)
Feedstock cost is of the order of € c 7.7 kW_eh^{-1}.

Table 5. Potential tariffs with German tariff structure (simplified).

Tariff	On-site CHP (€c kWh_e^{-1})	Off-site CHP (€c kWh_e^{-1})
Basic compensation	9.18	9.18
Emission minimization bonus	1	–
Grass as a feedstock	7	7
Upgrading	–	2
Total	17.18	18.18

Relationship between tariffs and biogas industry



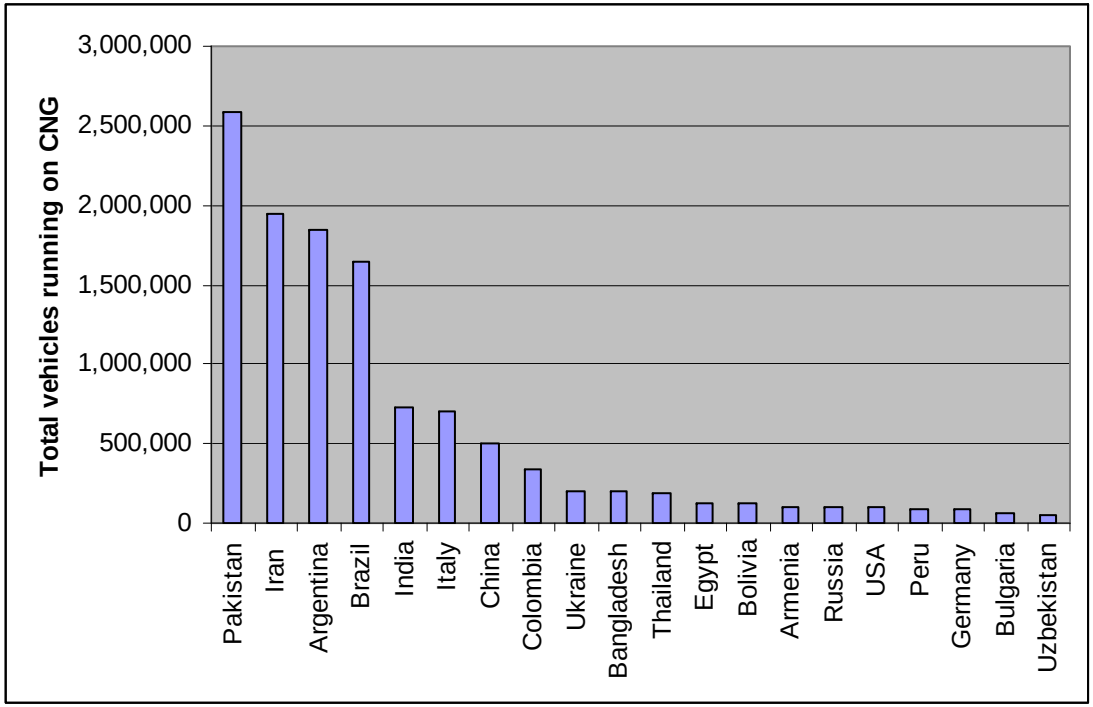
Number of Biogas plants in Germany

Economic viability of biogas as a transport fuel

Fuel	Unit cost	Energy value	Cost per unit energy (€c MJ^{-1})
Petrol	€1.40 L^{-1}	30 MJ. L^{-1}	4.7
Diesel	€1.40 L^{-1}	37.4 MJ. L^{-1}	3.7
Biomethane from grass	€1.06 m_n^{-3}	37 MJ. m_n^{-3}	2.9
CNG – UK	€0.71 m_n^{-3}	37 MJ. m_n^{-3}	1.9
Bio-CNG [a]	€0.75 m^{-3}	37 MJ. m_n^{-3}	2.0

[a] Bio-CNG price calculated using UK CNG prices and a blend of 10% biomethane, 90% CNG. No excise on gas as a propellant; VAT charged at 21%

Number of vehicles running on GNG worldwide

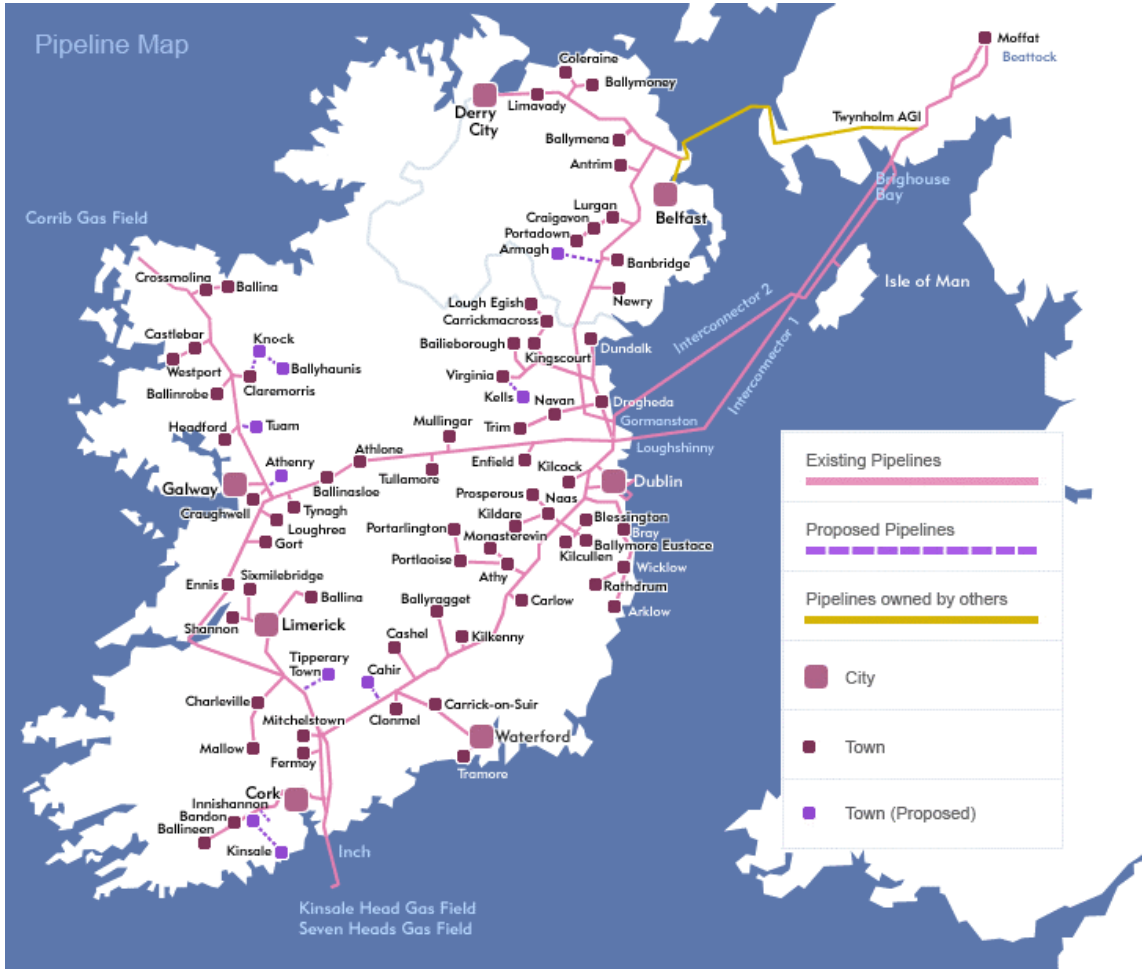


Potential for Biomethane in Ireland: RES-T and RES-H

Feed stock	Potential 2020 (PJ)	Practical 2020 (PJ)	Factor for RES-T	Contribution to RES-T	% energy in transport 2020 (240 PJ)	% residential gas demand (34 PJ)
Slurry	15.53	1.88	X2	3.76	1.57	5.5
OFMSW	2.26	0.57	X2	1.14	0.48	1.7
Slaughter	1.37	0.68	X2	1.36	0.57	2.0
Grass	47.58	11.93	X2	23.86	9.94	35.1
Total	66.74	15.03		30.06	12.53	44.3

Irish Gas Grid

Serves:
153 towns
19 counties
619,000 houses
24,000 industrial and commercial



Recommendations

- **Recommendation 1: Tariffs for anaerobic digestion.**
- **Recommendation 2: Align renewable energy and agricultural policy**
- **Recommendation 3: Set targets for gas demand to be met with biomethane.**
- **Recommendation 4: Use of biomethane in transport**
- **Recommendation 5: Research and development**