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Biomass as energy storage

THEORY

What is Biomass?

- In ecology: biological matter derived from living or recently living organisms.
- Legally (EU Directive): biodegradable fraction of products, waste and residues from agriculture, forestry and related industries, as well as biodegradable fraction of industrial and municipal waste.
- Physically: Biomass is an accumulator for solar energy stored in a process of photosynthesis.

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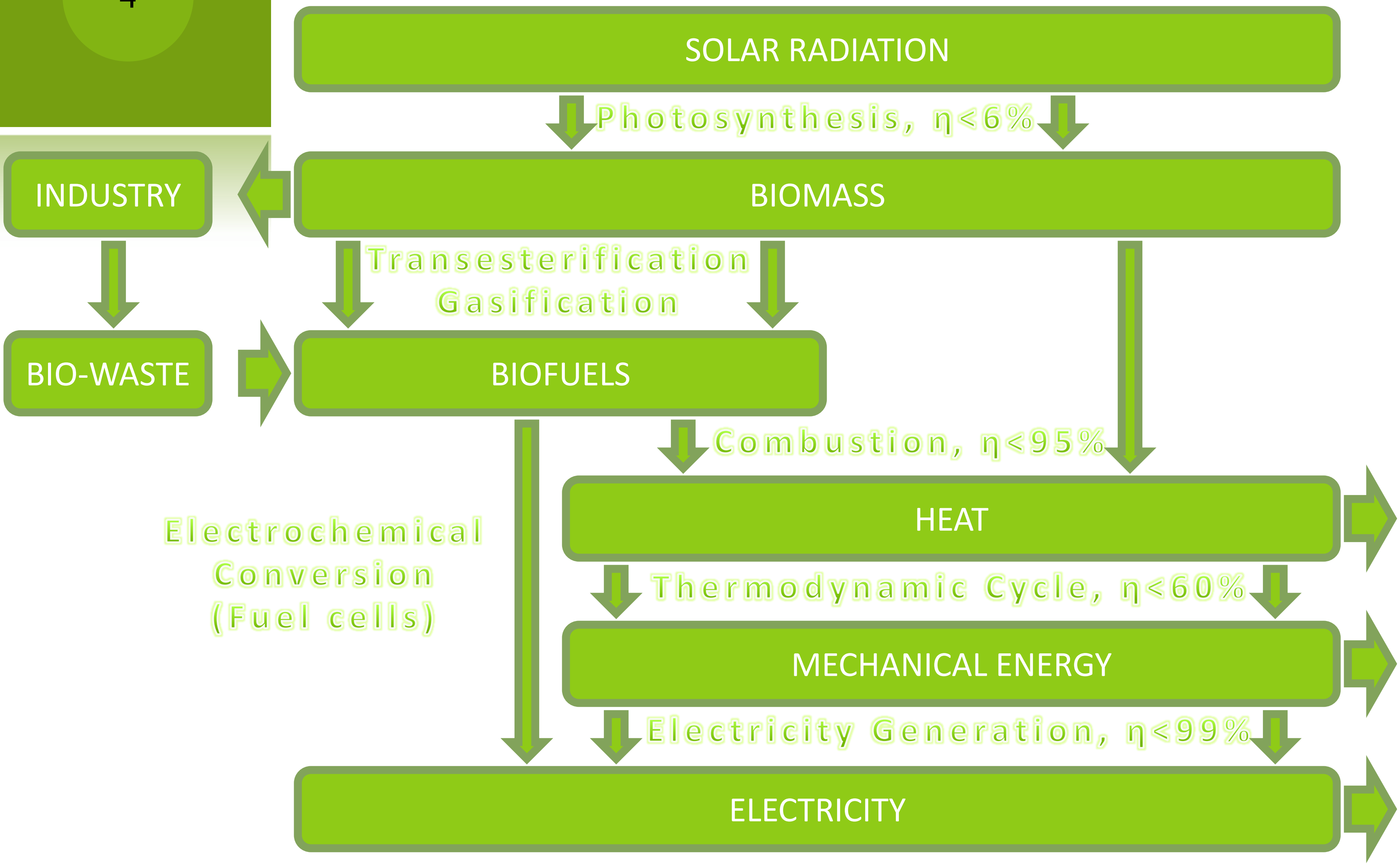
Energy Conversion Diagram



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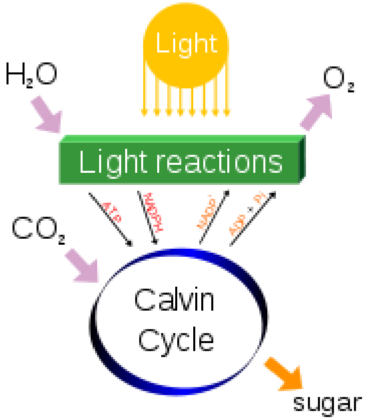
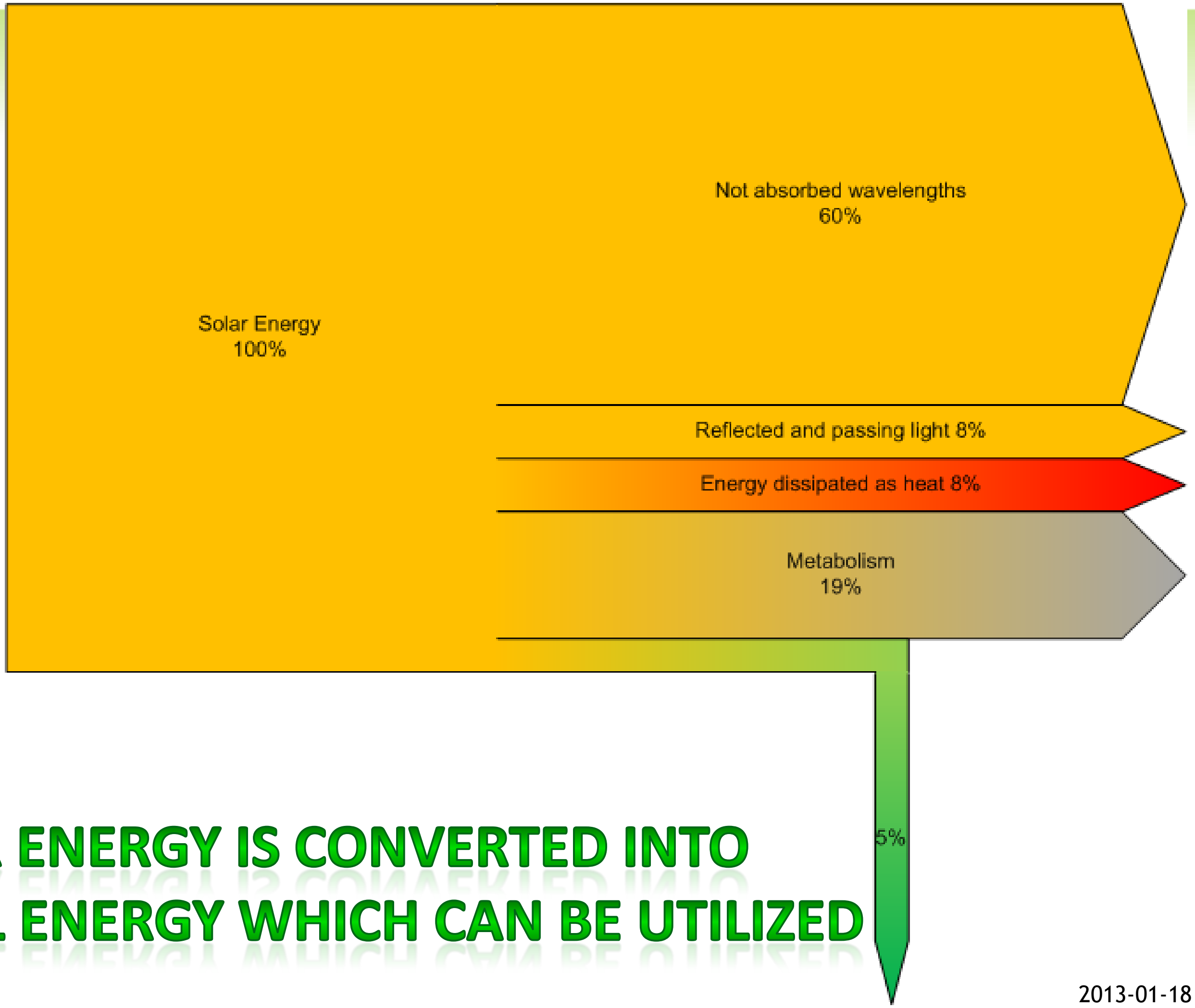
Photosynthesis

$$2nCO_2 + 2nH_2O \xrightarrow{\text{Photons}} 2(CH_2O)_n + 2nO_2$$

CARBON DIOXIDE + WATER ➔ CARBOHYDRATE (SUGAR) + OXYGEN



PHOTOSYNTHESIS



4-6 % OF SOLAR ENERGY IS CONVERTED INTO BIOMASS CHEMICAL ENERGY WHICH CAN BE UTILIZED

Biomass

- Organic compounds
- Consist of:
  - Carbon
  - Hydrogen
  - Oxygen
  - Nitrogen
  - Alkali components

Biomass is combustible

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Biomass
Chemical Energy Storage

- Long-term storage
  - Lifetime of an organism
  - Later storage (limited)
- Direct use (combustion)
- Production of processed biofuels
  - Solid
  - Liquid
  - Gaseous

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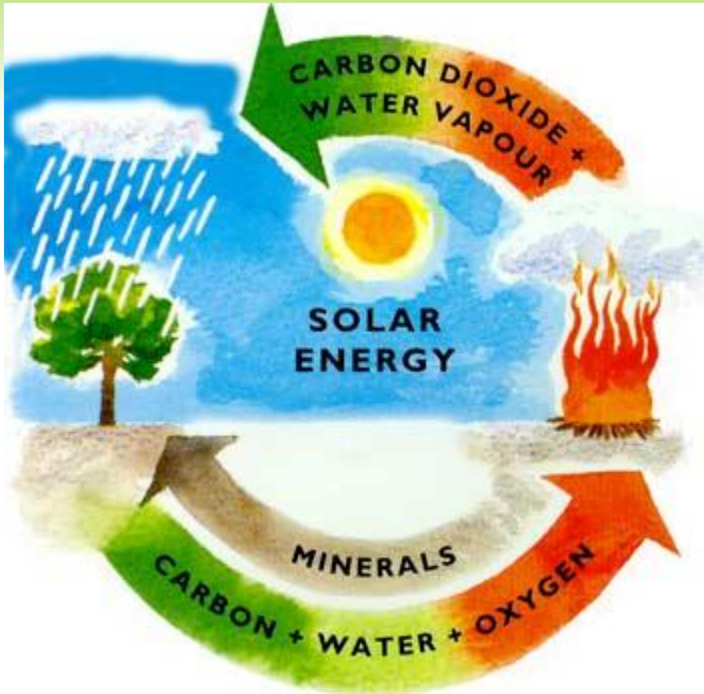
Why use biomass? Closed carbon cycle



Biomass is a “zero-emission” fuel

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Biofuels By form

Solid

- Wood
- Woodchips
- Spent grain
- Energy crops

Liquid

- Biodiesel (FAME)
- Crude vegetable oil
- Waste vegetable oil (post-frying etc.)

Gaseus

- Biogas
- Syngas (e.g. from wood gasification)

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Biofuels By origin

„Raw”

- Wood
- Energy crops (willow, poplar, miscanthus)
- Crude vegetable oil

Waste

- Woodchips, sawdust (from sawmills)
- Waste frying oil
- Biogas from biological wastes

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Biofuels By generation

First generation

- Bioethanol
- Biodiesel
- Crude vegetable oil
- Biogas & syngas

Second generation

- Inedible oils
- Biohydrogen
- Biomethanol

Third generation biofuels

- Algae

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Biofuels – general parameters

Fuel	Net calorific value (MJ/kg)	Mass output (Mg/ha/a)	Energy output	
			(GJ/ha/a)	(MWh/h/a)
Wood (forestry residues, SRW, thinnings, etc.) @ 30% MC	13	2.9 (2 odt)	37	10.3
Willow – Short Rotation Coppice @ 30% MC	13	12.9 (9 odt)	167	46
Miscanthus @ 25% MC	13	17.3 (13 odt)	225	63
Wheat straw @ 20% MC	13.5	4.6 (3.7 odt)	62	17
Biodiesel (from rapeseed oil)	37	1.1	41	11.3
Bioethanol (from sugar beet)	27	4.4	119	33
Bioethanol (from wheat)	27	2.3	62	17
Biogas (from cattle slurry)	20	0.88	18	4.9
Biogas (from sugar beet)	20	5.3	106	29

Solid biofuels

Solid biomass

Forestry

- Dedicated felling
- Forest maintenance
- Industry waste (wood processing etc.)

Agriculture

- Waste from food industry
- Farming waste(straw, chicken litter)
- Dedicated energy crops

Industrial & Municipal waste

- Wastewater sludge
- Recycled wood

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Solid biomass applications

Combustion in custom-built power plants and heating plants

Co-combustion with fossil fuels (coal)

Production of liquid and gaseous biofuels

- Fermentation → bio-alcohols
- Fermentaton → biogas
- Pyrolisis → wood gas (Holzgas)

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Solid biofuels vs. fossil fuels

Fuel	Energy density by mass		Bulk density kg/m³	Energy density by volume	
	GJ/Mg	MWh/Mg		MJ/m³	kWh/m³
Wood chips (30% MC)	12.5	3.5	250	3,100	870
Log wood (stacked - air dry: 20% MC)	14.7	4.1	350-500	5,200-7,400	1,400-2,000
Wood (solid - oven dry)	19	5.3	400-600	7,600-11,400	2,100-3,200
Wood pellets	17-18	4.7-5.0	600-700	10,800-12,600	3,000-3,500
Miscanthus (bale - 25% MC)	13	3.6	140-180	1,800-2,300	500-650
House coal	27-31	7.5-8.6	850	25,500-25,400	7,100-7,300
Anthracite	33	9.2	1,100	36,300	10,100
Heating oil	42.5	11.8	845	36,000	10,000
Natural gas (NTP)	38.1	10.6	0.9	35.2	9.8
LPG	46.3	12.9	510	23,600	6,600

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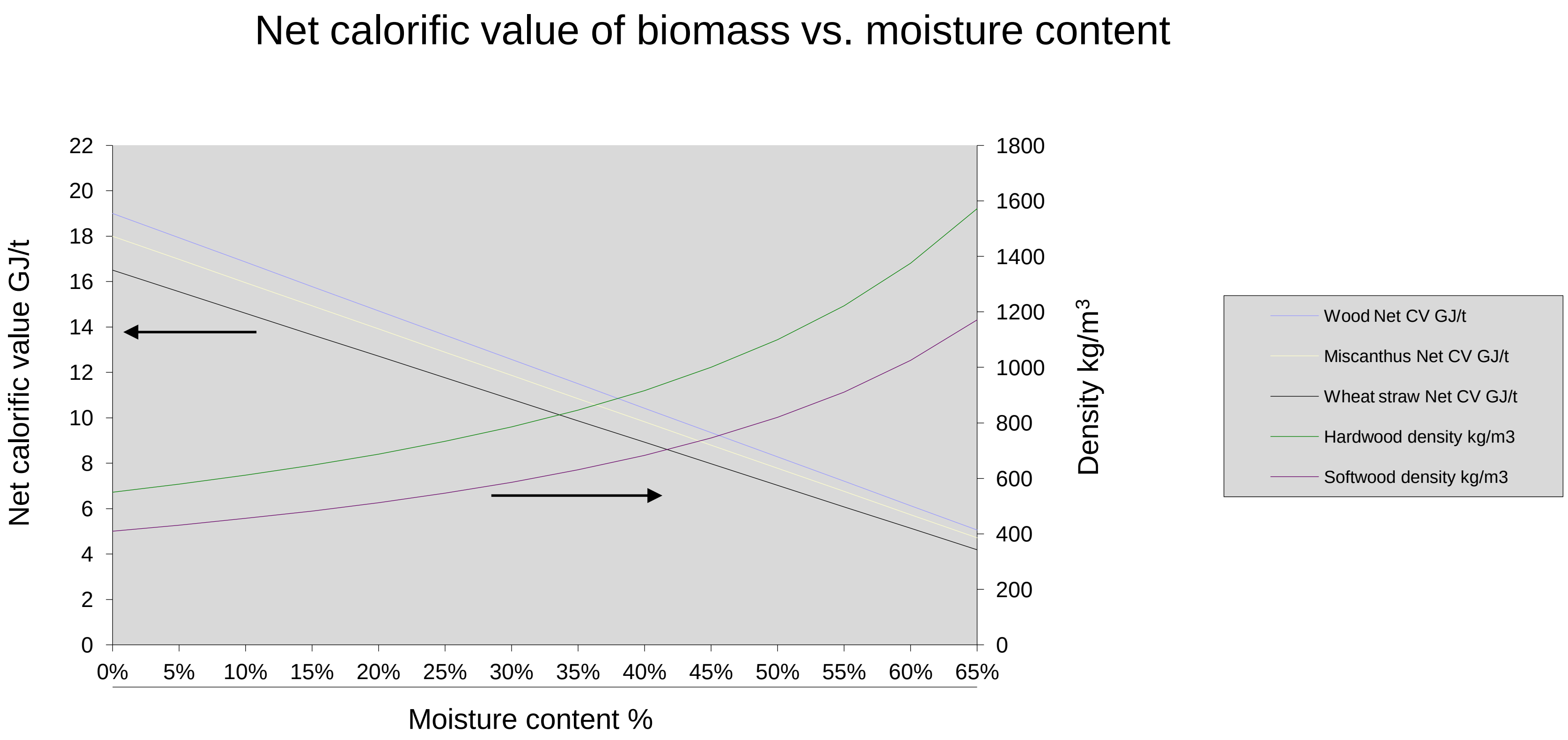
Solid biomass
Moisture impact



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Biomass from forestry




- Wood, 11-22 MJ/kg
- Bark, 18-20 MJ/kg
- Woodchips, 6-16 MJ/kg
- Sawdust
- Briquettes, 19-21 MJ/kg
- Pellets, 16.5-17.5 MJ/kg

Compare to:

- Lignite, 9 MJ/kg
- Hard coal, 18-32 MJ/kg



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Biomass-fired power unit

- Output limited by fuel availability
  - Long-distance wood hauling is not feasible
  - Plants fired with regionally collected fuel
- Municipal heating & CHP plants
- Small industrial CHP plants (next to sawmills)

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Woodchips

- Better for automatic handling and feeding
- Easier to combust in industrial boilers
- More uniform fuel
- Less convenient (than round wood) to transport, store and dry
- Option: chipping on the combustion site

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Fernheizkraftwerk Linz-Mitte

- Operator: Linz Strom GmbH
- Fuel input: 35 MW – “waste” round wood
  Chipped at the site
- Grate-type steam boiler
  - Live steam 67 bar(a), 462˚C
- Steam turbine
- Electrical gross output: 8.9 MW
- District heating output: 21 MW
- Commissioned: 2005
- Supplier: Aalborg Energie Technik

Aalborg Energie Technik a/s

Briquettes and Pellets

- Compressed and extruded sawdust
  - Pellets – smaller, 6…12 mm
  - Briquettes – larger, 50…100 mm × 60…150 mm (d × l)
- Low moisture content
- Useful for small-scale applications
- More expensive than „raw” biomass
- There are some standards

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SOLID BIOMASS FROM AGRICULTURE



Waste

- Spent grains
- Fruit processing waste
- Straw

Dedicated energy crops



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Solid biomass from agriculture

- Problems with combustion technology
  - The younger the biomass the higher alkali content
  - Lowered ash melting temperature
  - Increased boiler slagging/fouling
- Needs custom-built installations, not handy for co-combustion

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Straw as a fuel

- Only ca. 65% of produced straw is used in agriculture
- High humidity
- High alkali content (especially Cl)
- Low ash melting pont (risk of boiler fouling)
- High ash content (needs efficient de-dusting)
- Needs special boiler design

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Straw as a fuel

Type of straw	LHV, dry (MJ/kg)	Humidity, fresh (%)	LHV, fresh (MJ/kg)
Wheat	17,3	12÷22	12,9÷14,9
Barley	16,1	12÷22	12,0÷13,9
Corn	16,8	50÷70	3,3÷7,2

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EPR Ely Ltd

- World’s largest straw-fired power plant
- Operator: Energy Power Resources Limited
- Fuel input: straw, 200,000 Mg/a
- Vibrating grate steam boiler
  - Live steam 92 bar, 540˚C
- Steam turbine
- Electrical gross output: 38 MW
- Supplier: FLS miljø, Denmark

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Energy crops

- Short rotation energy crops
  - Short rotation coppice (SRC)
  - Short rotation forest (SRF)
- Grasses and non-woody energy crops
- Agricultural energy crops
  - Sugar crops
  - Starch crops
  - Oil crops
- Aquatics (hydroponics)

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Short rotation coppice

- Fast-growing tree species
- Felling after breast height diameter reaches 10-20 cm
- Cycles of 8…20 years
- Suitable species:
  - Poplar
  - Willow

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Short rotation coppice

Parameter	Unit	Poplar	Willow
Planting density	ha^{-1}	10,000…12,000	15,000
Yield (approximate)	Mg/ha/a	8	7…12
Harvesting cycle	a	4 or 5	2…5

Short rotation forest

- Fast-growing tree species
- Cut down to a low stump when dormant (winter)
- Allows for new stems in the following season
- Cycles of 2…5 years
- Suitable species:
  - Eucalyptus
  - Nothofagus
  - Poplar
  - Sycamore
  - Ash

Grasses and non-woody energy crops

- Yield on an annual basis
- Suitable crops:
  - Miscanthus
  - Other grasses (switchgrass, rye, giant reed)
  - Hemp (*Cannabis sativa*)

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Grasses vs. SRC

Parameter	Unit	Poplar	Willow	Miscanthus	Hemp
Planting density	ha^{-1}	12,000	15,000	20,000	
Yield (dry)	Mg/ha/a	8	7…12	14	9…11 (UK) 25 (NL)
Harvesting cycle	a	4 or 5	2…5	1	1

Agricultural energy crops

Sugar crops

- Sugar beet, sugar cane
- Converted into bioethanol

Starch crops

- Wheat and others
- Combustion fuel (US) or converted into bioalcohol

Oil crops

- Rapeseed, sunflower, oil palm, jatropha
- Oil pressed and combusted straight or processed into biodiesel

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Przedsiębiorstwo Energetyki Cieplnej Sp. z o.o. w Płońsku, Poland

- Boiler capacity: 10.2 MW_{th} (steam)
- Electrical gross output: 2.1 MW
- Commissioned: 2008
- Supplier: Gros-Pol, Poland
- Investment cost: 33.7 MPLN
- Fuel: wood + willow

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Spent grain from brewery

Spent grain

Woodchips

mw power
metso-wärtsilä joint venture

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Spent grain from brewery

Parameter	Unit	Spent grain	Wood chips	Mixture
Moisture	%	58	45	52.4
Heat value, dry	MJ/kg	20.14	18.84	19.49
Heat value, wet	MJ/kg	7.0	9.3	8.0
Bulk density	kg/m^3	257	236	247
Mass ratio (wet)	%	54.6	45.4	
Elements, dry				
C	%	51.2	50.9	51.1
H	%	7.0	6.3	6.7
N	%	3.63	0.1	1.9
S	%	0.27	0.02	0.15
Cl	%	0.015	0.011	0.01
O	%	34.485	41.169	37.8
Ash	%	3.4	1.5	2.45

Manchester – CHP plant fired with spent grains from brewery

- Operator: Scottish & Newcastle
- Location: Manchester
- Electrical output: 2 × 3.1 MWe
- Thermal output: 2 × 7.4 MWe
- Rotating grate boilers (BioGrate®)
  - Live steam parameters: 52 bar, 465°C
- Supplier: Wärtsilä, Finland

WÄRTSILÄ
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Aquatic plants

- Do not require soil
- Microalgae
- Macroalgae
- Pond and lake weeds

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Co-Combustion Biomass + Fossil fuels

- Biomass can be mixed with fossil solid fuel (coal or lignite)
- "Old" (forestry) biomass can be added to the fuel mixture for grate, pulverized bed or fluidized bed boilers up to certain percentage
  - Need to dry biomass prior to mixing
  - Increased maintenance cost of the boiler (lowered ash melting temperature – faster boiler slagging; extra wear on the mills, mill clogging etc.)
- "Young" (agro) biomass is not convenient for co-combustion due to high alkali content and resulting low ash melting temperature (boiler fouling)
- Co-combustion is very easy to implement in large-scale power stations
  - If supported develops rapidly
  - Can significantly distort local wood market – problems for timber industry, paper-making industry, furniture manufacturers etc.

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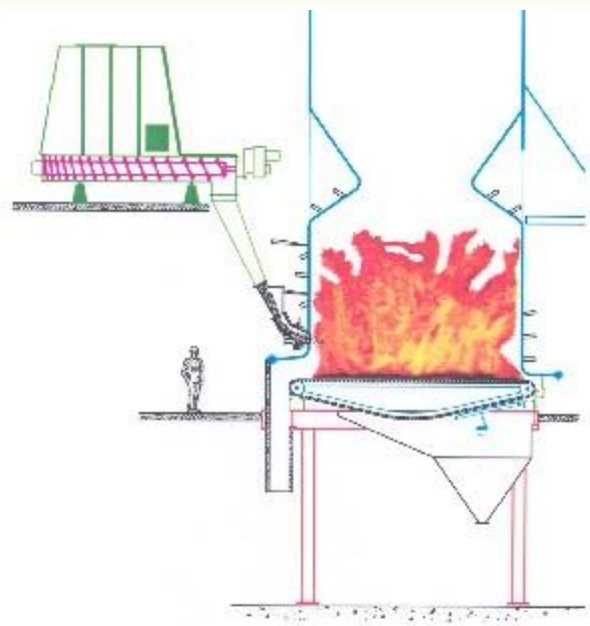
Biomass boiler technology
Moving grate boiler



Aalborg Energie Technik a/s

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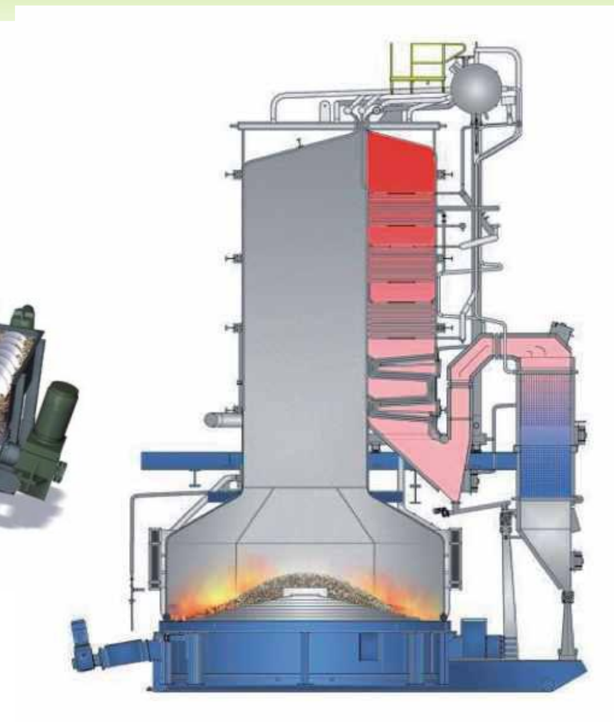
Biomass boiler technology Rotating grate boiler



WÄRTSILÄ

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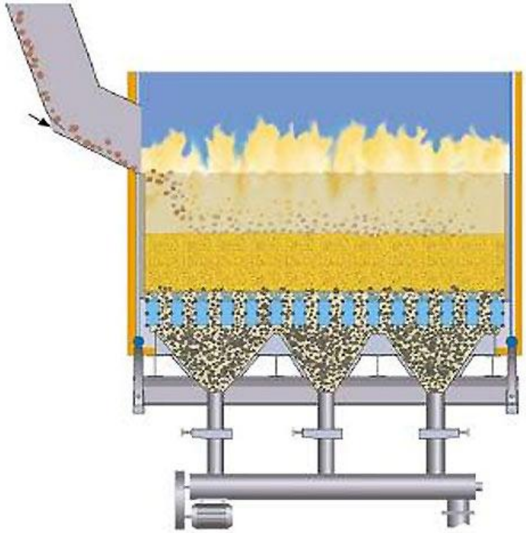
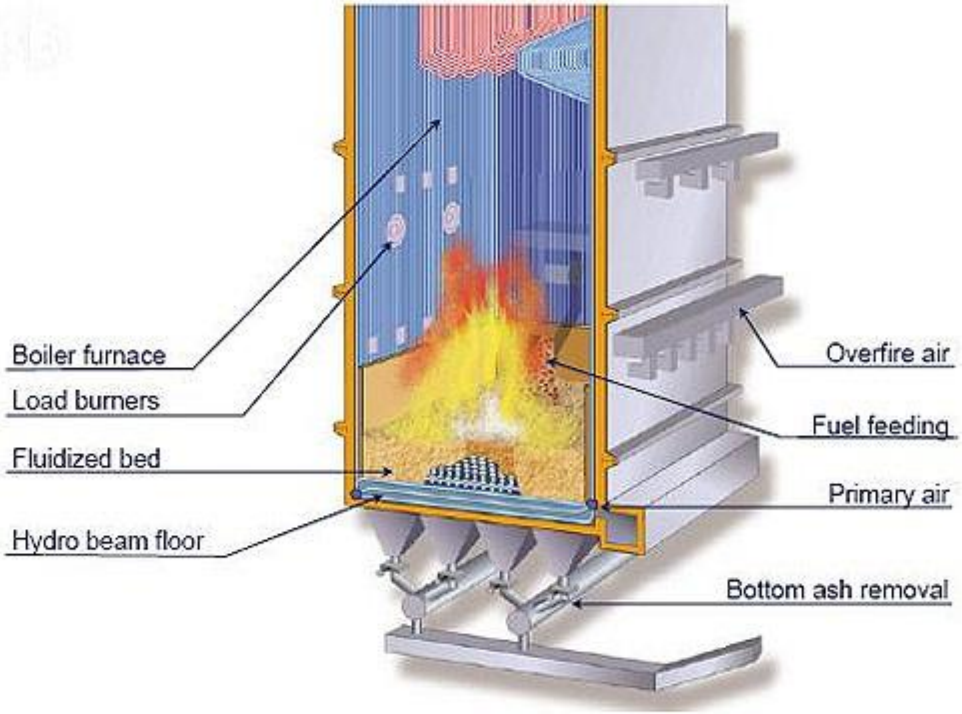
Biomass boiler technology Bubbling Fluidized Bed





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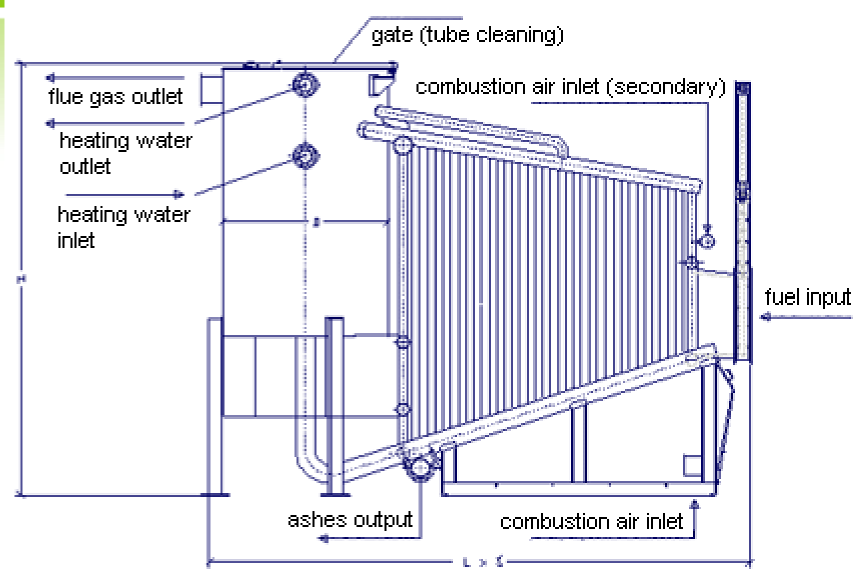
Straw boiler technology

Straw boiler technology



- Combustion of whole straw bales
- Hot-water or steam boilers
- Fuel supplied by belt conveyor

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Small scale pellet boiler

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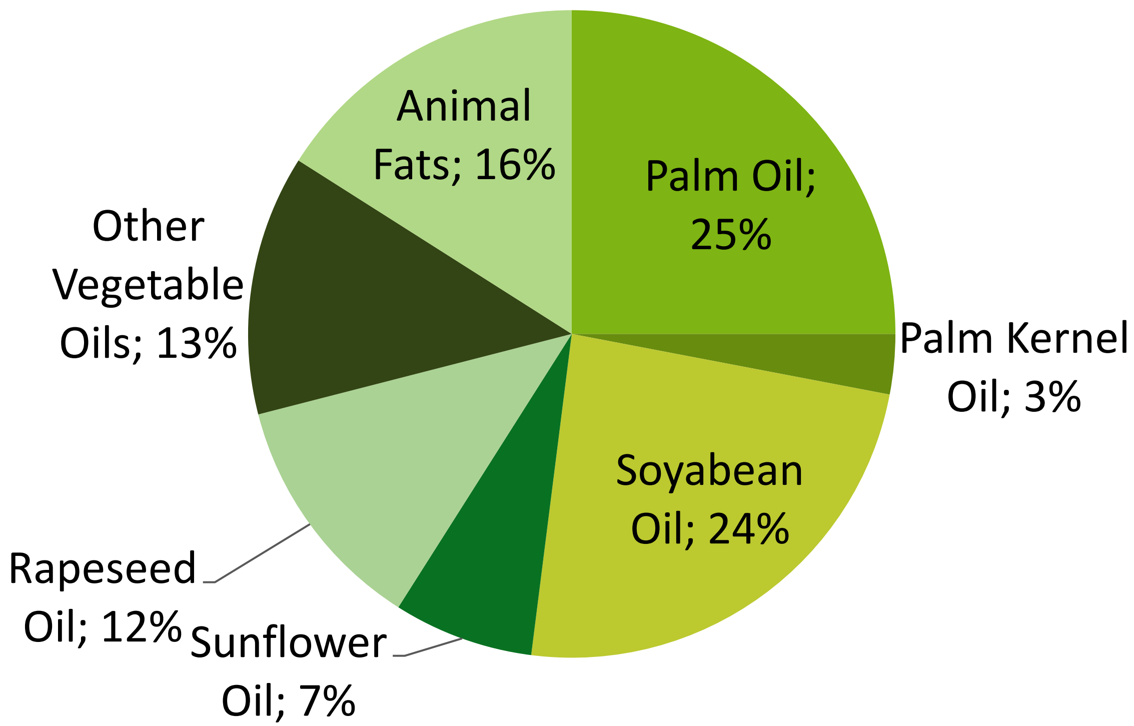
Liquid biofuels

World's production of oils and fats in 2007

Total production: 154 mi. Mg (without Jatropha)



Biodiesel (FAME)

- Biodiesel is a mixture of Fatty Acid Methyl Esters
- Can be substituded for mineral diesel oil or light fuel oil for all types of machines and engines
- Standards for biodiesel exist (EN14214)

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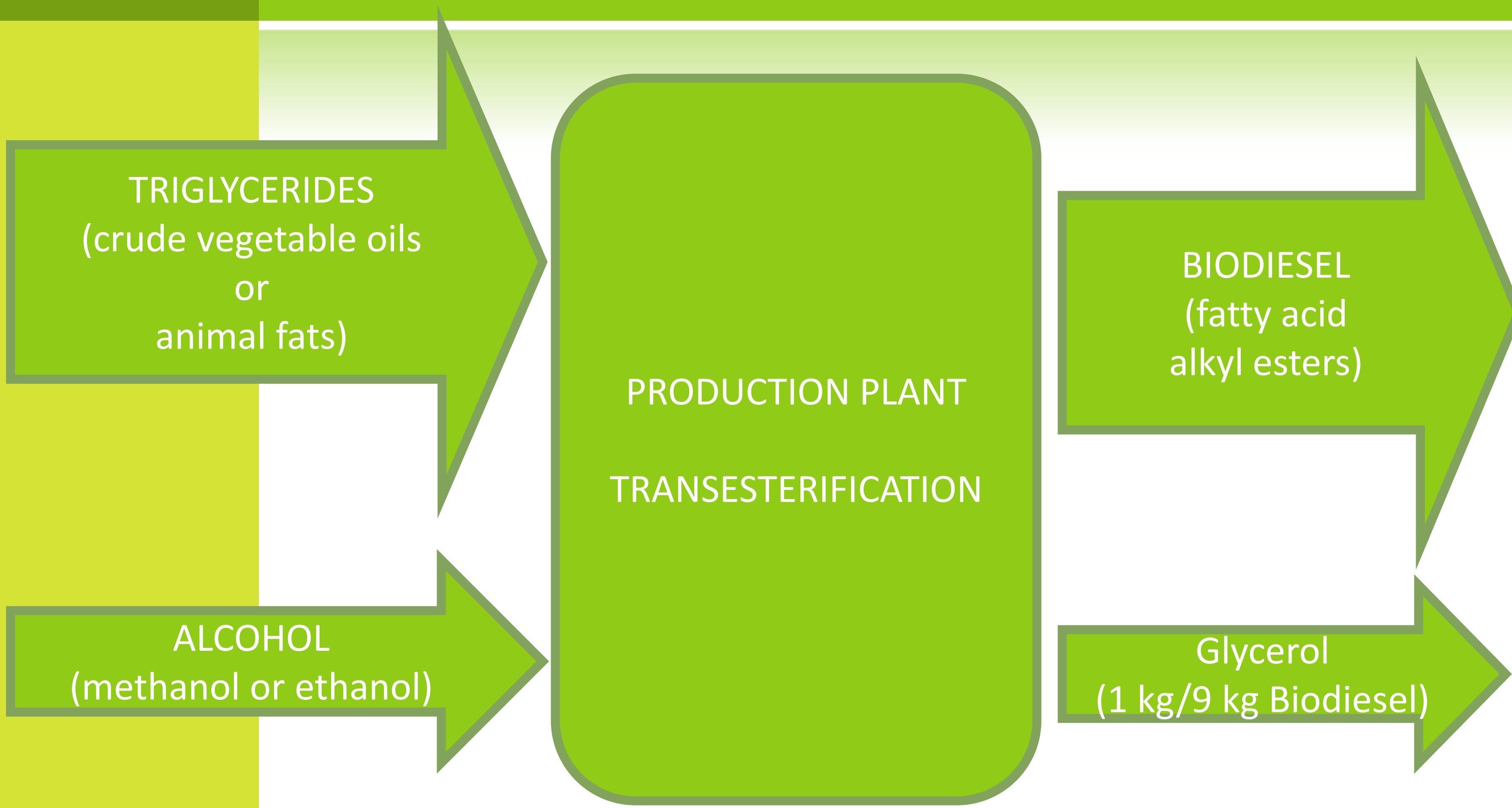
BIODIESEL PRODUCTION



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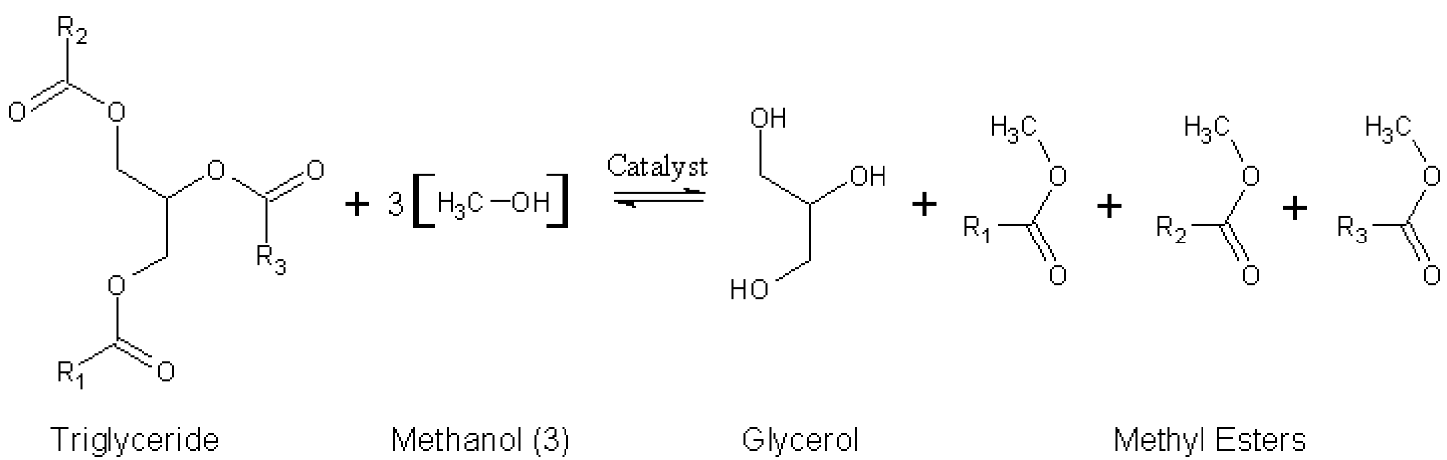
Transesterification



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Biodiesel properties According to EN14214

Parameter	Unit	Min	Max	Typical diesel
Ester content	%wt	96.5	-	N/A
Density @15˚C	kg/m^3	860	900	830
Viscosity @40˚C	mm^2/s	3.5	5.0	3
Flash point	˚C	101	-	60
Sulfur content	mg/kg	-	10	600
Cetane number	-	51.0	-	>51
Water content	mg/kg	-	500	0
Total Acid Number	mg KOH/g	-	0.5	<1
Free glycerol	%wt	-	0.02	0
Total glycerol	%wt	-	0.25	0
LHV	MJ/kg	37.7 (not defined by EN14214)		42.6

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Biodiesel usage

- Can be freely substituted for mineral diesel oil
- Can be used by any diesel engine
- Mainly used in transport
- Too expensive to be used for power generation
    - Power industry can use cheaper unprocessed biofuels

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Biofuels for power industry

- Crude vegetable oils (triglycerides) – used directly
- Fatty acid distillate – by-product of oil refining (food industry)
- Waste frying oil (triglycerides)
- Tryglicerides synthetized from fatty acid (food industry waste) distillate and glycerol (biodiesel production waste)
- Some animal fats: fish oil, chicken oil
- There are no standards for such fuels!

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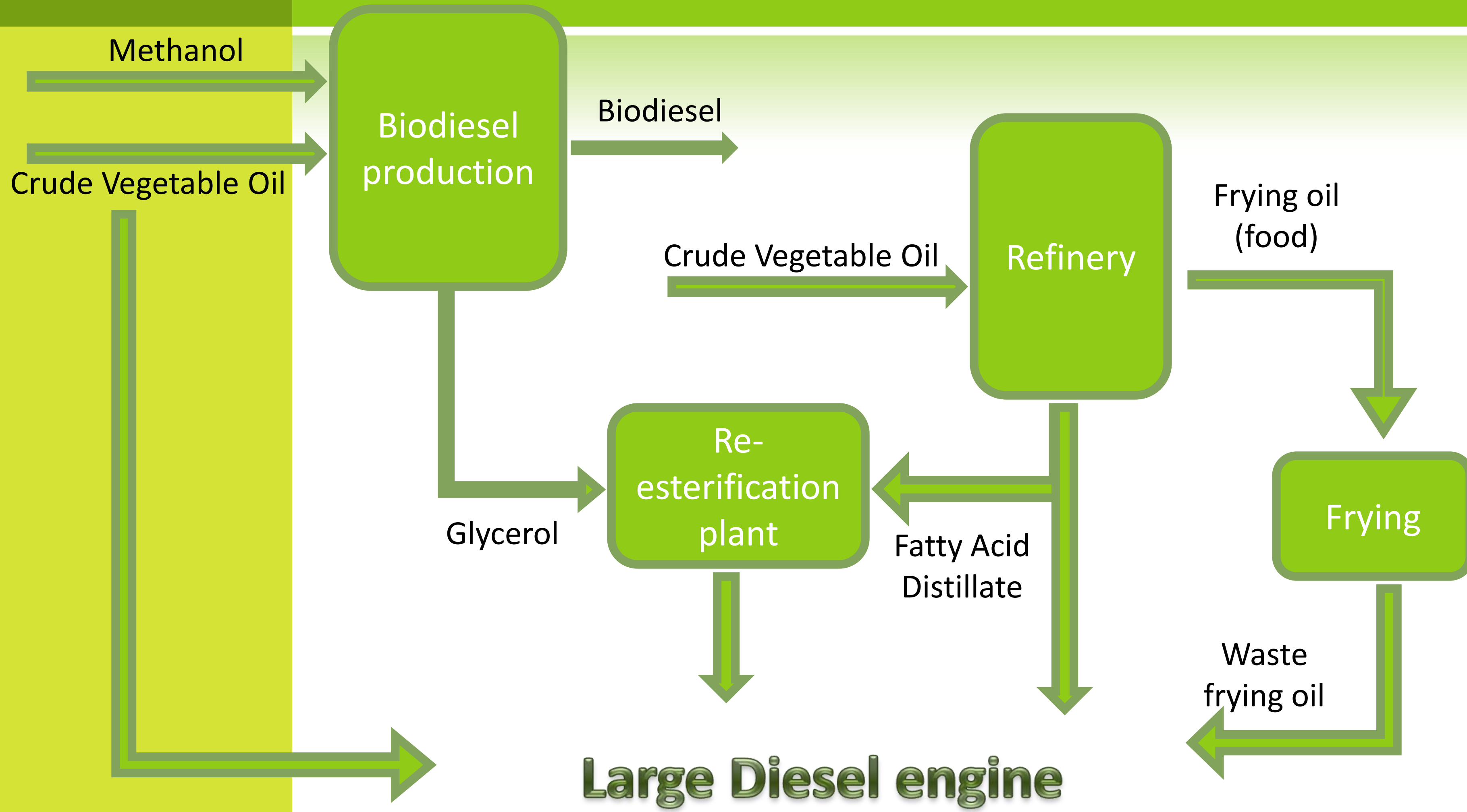
Liqiud biofuels for power generation



Crude vegetable oils

- Various types of oil:
  - Palm oil
  - Rapeseed oil
  - Sunflower oil
  - Jatropha oil
- LHV – 35-37 MJ/kg

- High melting point – above ambient temperatures
  - Necessity to heat fuel systems!
- High viscosity
- High acid numbers
- Long-term storage impossible

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Palm Oil

- Oil palm is the most rapidly expanding crop in South-East Asia
- Oil mainly used as food or in food industry
- Over 85% of production in Asia, Africa & Latin America
- Annual yield – 4000-6000 dm^3/ha
- Malaysia and Indonesia plan to divert 40% of their palm oil output for fuel market

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Palm oil controversies

- Rain forests are cut down to create oil palm plantations
- Native population of some areas is displaced
- Plantation employees are often abused
- Energy use of palm oil drives food prices in poor regions of the world high

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Palm oil production

FFB = Fresh fruit bunch
EFB = Empty fruit bunch
CPO = Crude palm oil
FFA = Free fatty acids
RBD = Refined, bleached & deodorized
PFAD = Palm fatty acid distillate

500% FFB 24h → Mill → 100% CPO (FFA 2-10%) ~550 $/ton → RBD Refinery → 95% RBD oil → Fractionation

Fractionation → 60% RBD olein ~620 $/ton

Fractionation → 35% RBD stearin ~550 $/ton +10% import duty

Mill → EFB → Boiler power plant

Mill → Palm kernel

RBD Refinery → 5% PFAD FFA > 80% → Feed, Energy

CPO → Diesel power plant

Palm Oil Fraction	Meltin Point Range °C
Palm Oil	30-38
Palm Olein	20-25
Palm Stearin	35-40
Palm Kernel Oil	20-26

Boiler power plant

Diesel power plant

→ Electricity

→ Heat

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Jatropha oil

- Draught-resistant shrub/tree producing oil containing seeds
- Originates from Central America, but has spread to other areas of the world
- Cannot be eaten (is poisonous)
- Can be grown on marginal lands not useful for food production
  - …but on good soil gives better yield, so some controversy remains

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Jatropha oil

- Jatropha oil industry is in its infancy
- No reliable figures concerning the yield
- No real market – prices hard to predict
- Plantations will reach maturity in a couple of years
- Some controversy remains. BP has stepped out of this business after initial investments.

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Jatropha oil

Geography
Jatropha vs. Oil palm

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Rapeseed oil

- World's production in 2007: 18.5 mi. Mg
- Biggest producers:
  - EU-27 (mainly Germany, France, UK, Poland)
  - China & India
  - Canada
- Yield of approximately 1000 kg/ha/a
- In most places more expensive than palm oil

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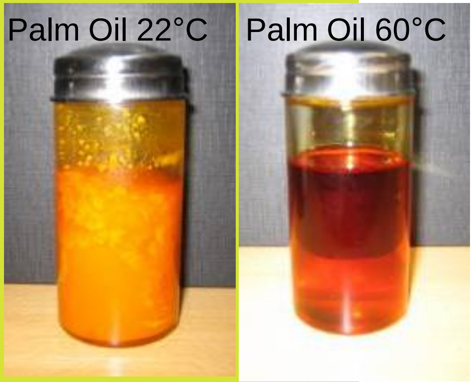
Crude vegetable oils

- Fuel for large reciprocating engines:
  - medium-speed 4-stroke engines (MAN, Wärtsilä), 0.2-22 MWe per unit
  - low-speed 2-stroke engines (MAN B&W, HCP), up to 80 MWe per unit
- Back-up fuel needed for start-ups, shut-downs and fuel system flushing (normal diesel or biodiesel)
- Power plants of various sizes: 0.2 to 102 MWe (at this moment)

Biofuels in power industry

- „Zero-emission" power generation
- High energy conversion efficency
  - Up to 48% simple cycle
  - Over 50% combined cycle
- Increased NOx emission – need to use catalysts
- Difficult flue gas de-dusting – ESP does not „catch" dust from biofuel combustion
- Difficult fuel handling (temperature control)
  - Too low temperature: fuel solidifies
  - Too high temperature: fuel polymerises



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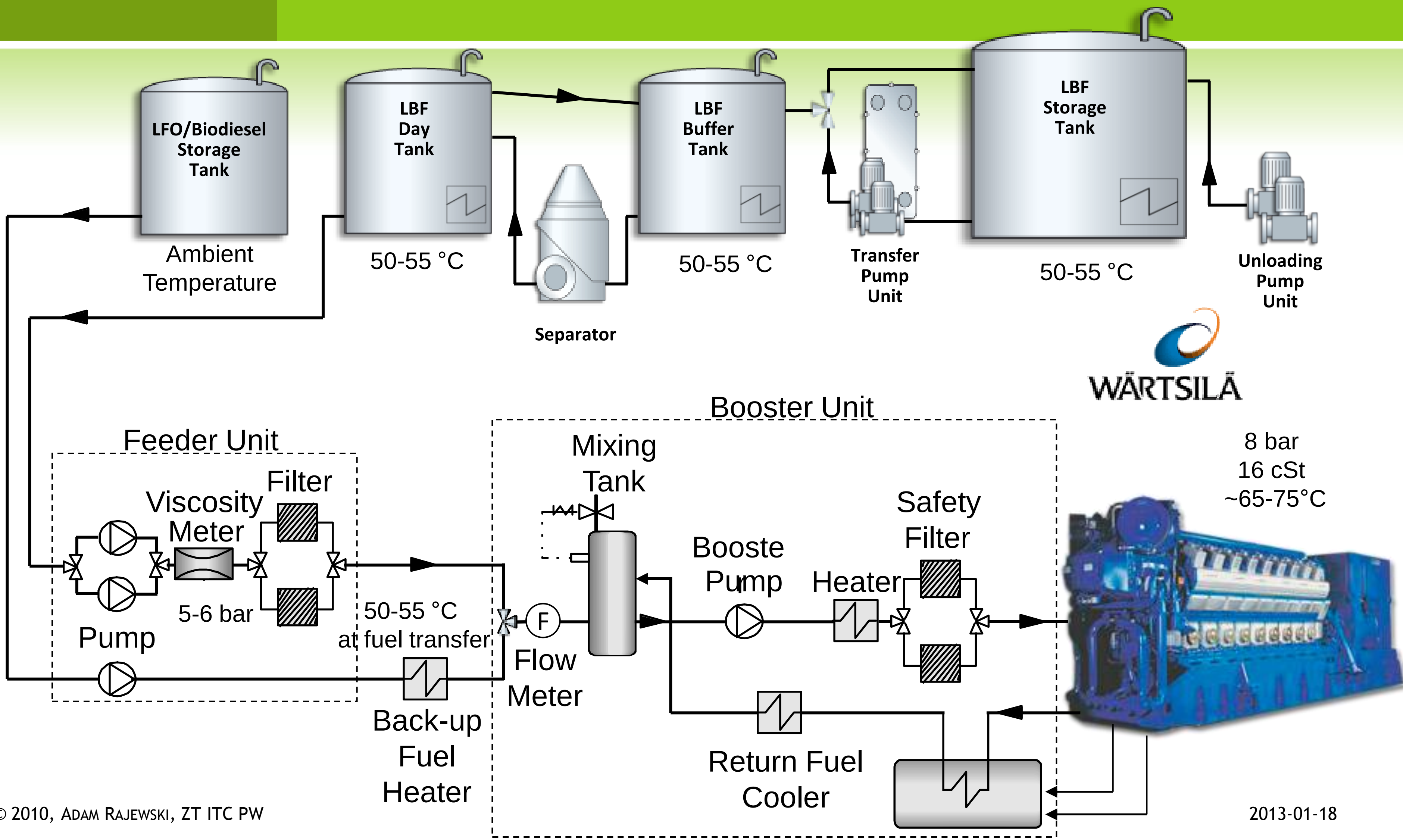
CRUDE VEGETABLE OIL PROPERTIES

Property	Unit	Wärtsilä LBF Spec.	Typical Crude Palm Oil	Typical Jatropha Oil	Typical Diesel Oil	Typical Heavy Fuel Oil
Viscosity, max.	cSt @ 40 °C	100	39	36	3.5	700
Density, max.	kg/m³ @ 15 °C	991	915	917	864	993
Sulphur, max.	% mass	0.05	<0.05	<0.050	0.6	2.3
Total sediment existent, max.	% mass	0.05	0.01	<0.01	0	0.08
Water, max. before engine	% volume	0.2	<0.1	0.1	0	0.5
Micro carbon residue, max.	% mass	0.5	0.17	0.4	<0.5	13
Ash, max.	% mass	0.05	0.01	0.015	0.01	0.082
Phosphorus, max.	mg/kg	100	10	12-40	<1	<1
Silicon, max.	mg/kg	15	1	1-5	<1	10
Alkali content (Na+K), max.	mg/kg	30	3	10-30	<1	30
Flash point (PMCC), min.	°C	60	>200	>200	60	90
Pour point, max.	°C	*)	30	8	-15	15
Cloud point, max.	°C	*)	38	16	-10	n/a
Cold filter plugging point, max.	°C	*)	38	20	-10	20
Copper strip corrosion, max.		1b	1a	1a		
Steel corrosion, max.		No corr.	No corr.	No corr.	No corr.	No corr.
Acid number, max.	mg KOH/g	15	13	10-15	<1	<3
Strong acid number, max.	mg KOH/g	0	0	0	0	0
Iodine number, max.		120	55	80-110	n/a	n/a
Net calorific value	MJ/kg	*	36.8	36.8	42.6	40.1

Liquid biofuel (palm oil) system for diesel engine



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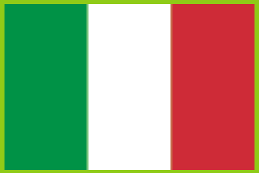

S.E.C.A. Piombino

- Fuel: crude palm oil
- Prime movers: 3 × Wärtsilä W18V32 gen-set
- Output: 3 × 8032 kWe
- Efficiency 43.5%
- NOx abatement: SCR

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S.E.C.A. Piombino Fuel

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S.E.C.A. Piombino
Fuel filter cleaning

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S.E.C.A. Piombino Prime movers

- Wärtsilä W18V32 engine
- Supplier: Wärtsilä Finland Oy
- Cylinder configuration: 18V
- Cylinder bore: 320 mm
- Stroke: 400 mm
- Valves per cylinder: 2+2
- Speed: 750 rpm
- Mean piston speed: 10 m/s
- Compression ratio: 16.0:1

WÄRTSILÄ

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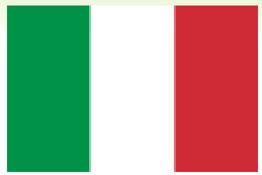
ItalGreenEnergy, unit 2



- Location: Monopoli near Bari
- Combined cycle plant
  - 6 x Wärtsilä18V46, 91,5 MWe
  - 1 x steam turbine, 11 MWe
- Fuel: mainly palm oil
- NOx abatement: SCR
- Commissioned in 2008

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Waste frying oil

- Great variability of properties
- Possibility of using has to be analyzed case-by-case for local conditions
- Possible sources:
  - Food industry (e.g. chips factories)
  - Restaurants & bars
  - Households
- Can also be used for biodiesel production.

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Fritzens, Austria

- Installation at a wastewater treatmentn plant
- Single MAN engine, 1.1 MWe, 1.3 MWth
- Oil from restaurants & households
- Municipal oil collection scheme

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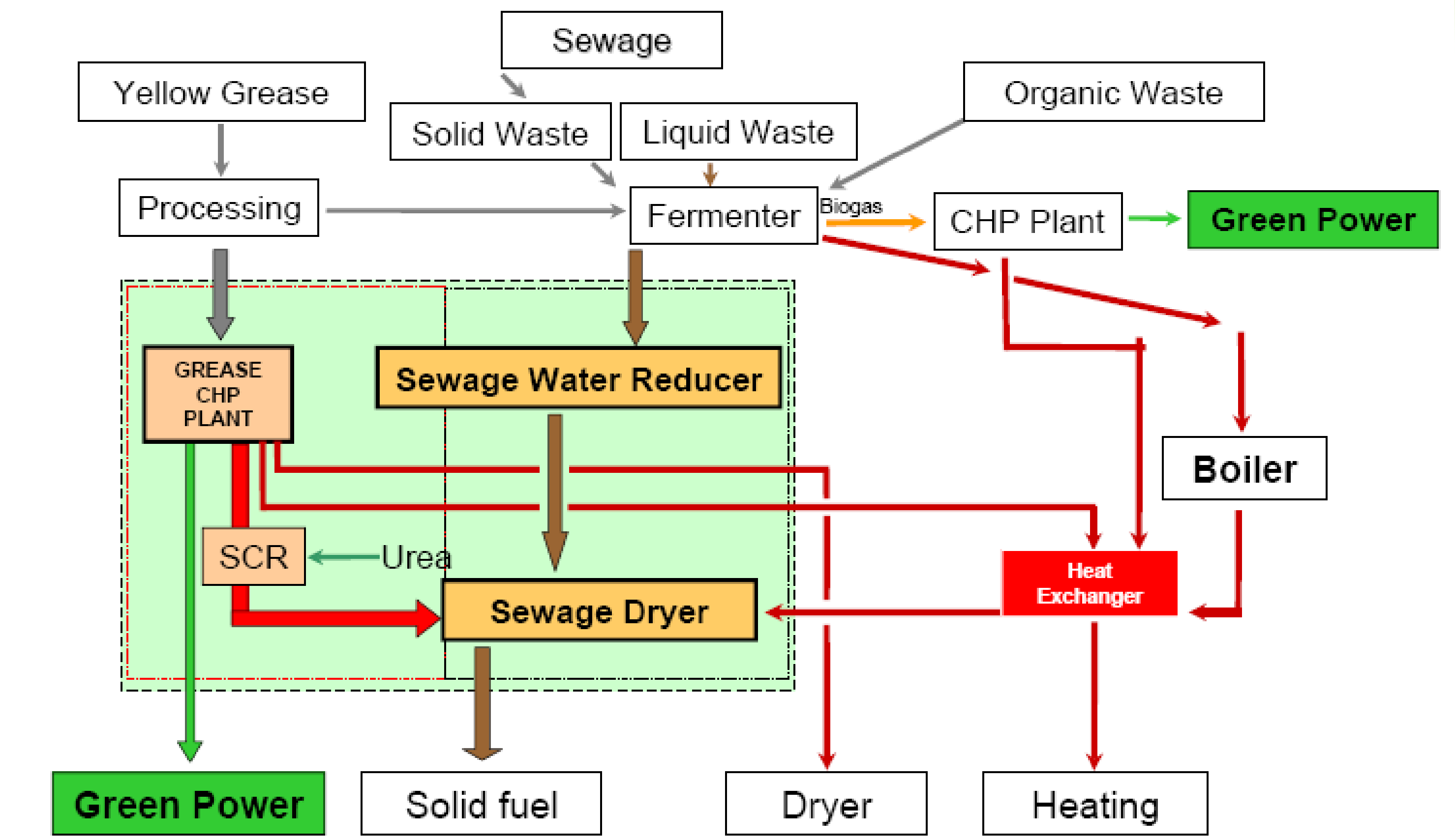
Fritzens, Austria



Bioethanol

- Alcohols (mainly ethanol and methanol) can be used as fuels
- Ca. 95% of world's ethanol is produced from biological sources (other 5% is a petroleum product)
- Ethanol (pure or blend with petrol) is suitable as fuel for spark-ignited (Otto) car engines
- Ethanol blend can be also used in Diesel engine

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Bioethanol production

- Fermentation
- Distillation
- Dehydration
- Denaturing (optional)

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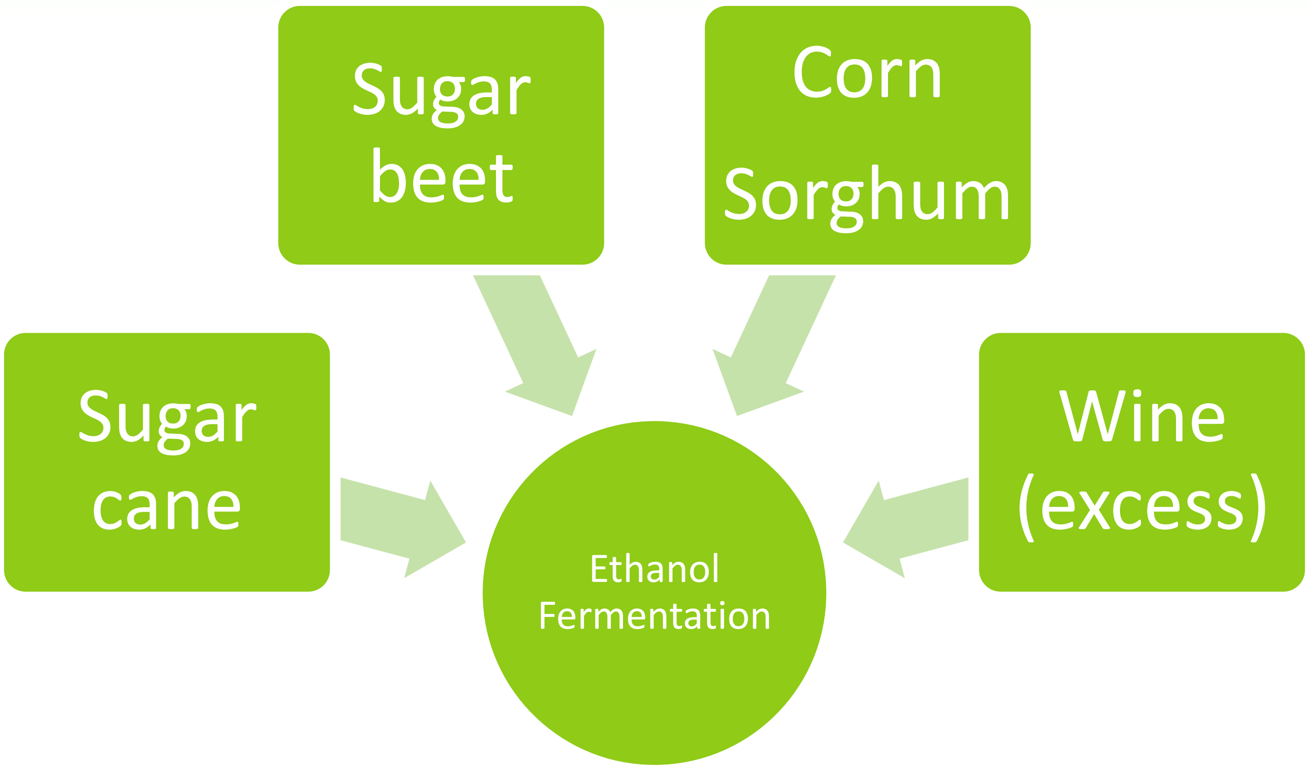
Feedstock for ethanol production



Ethanol use in car engines

- Popular ethanol blends for car engines: E5, E7, E10, E15, E20, E25, E70, E75, E80, E85, E100.
- Ethanol LHV is 26.7 MJ/kg, 21.1 MJ/dm³.
  Petrol LHV is 43.5 MJ/kg, 35.0 MJ/dm³.
- Due to lower car fuelled with ethanol fuel displays higher fuel consumption and lower range.
- Possible problems with engine cold-start in winter.
- Modern cars can use mixtures up to E10 without modifications. Other blends require modifications or custom-designed engines.
- Use of ethanol fuel for cars is popular in Brasil, USA and some EU countries.
- Modified Diesel engines can be fuelled with the ED95 blend (95% ethanol) – this is used in Sweden.

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Biomethanol

- Methanol is produced from pyrolisis of wood or from synthetic gas.
- It can be used as fuel for spark-ignited engines.
- Limited use in racing cars.
- Limited use in USA (California).
- Plans to use methanol-petrol blends in Brasil.

Jatropha fuel for aircraft

Air New Zealand Boeing 747-400

- Joint experiment by Air New Zealand, Boeing, Rolls-Royce and Honeywell's UOP
- Test flight in Auckland on December 30, 2008
- Test aircraft: Boeing 747-400
- One of RB211 engines fuelled with 50/50 mixture of Jet A1 and jatropha-based refined biofuel

AIR NEW ZEALAND BOEING ROLLS ROYCE uop A Honeywell Company

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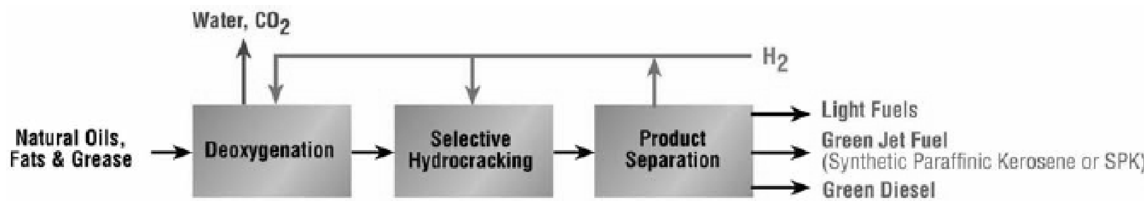
Jatropha fuel for aircraft

Air New Zealand Boeing 747-400

UOP's Green Jet Fuel Process



Green Jet Fuel Specifications

Property	Limits	Jet A-1 *(Specification)*	Renewable Jet Fuel from Jatropha *(Actual Value)*
Flash Point	Min	38°C	46°C
Freeze Point		-47°C	-57°C
Net Heat of Combustion	Min	42.8 MJ/kg	44.3 MJ/kg

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Gaseous biofuels

Biogas

- Result of anaerobic biological breakdown of organic matter
- Production methods:
  - Anaerobic digestion ➔ “proper” biogas
  - Gasification ➔ wood gas (technically also biogas)
- LHV 17…28 MJ/m^3 (natural gas ca. 34 MJ/m^3)

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Biogas composition

Compound	Symbol	Minimum (%)	Maximum (%)
Methane	CH_4	50	75
Carbon dioxide	CO_2	25	50
Nitrogen	N_2	0	10
Hydrogen	H_2	0	1
Hydrogen sulfide	H_2S	0	3
Oxygen	O_2	0	2

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Anaerobic digestion

Input		
Carbohydrates	Fats	Proteines

Hydrolisis		
Sugars	Fatty acids	Amino acids

Acidogenesis	
Carboxylic acids and alcohols	Hydrogen, Carbon dioxide, Ammonia

Acetogenesis
Hydrogen, Acetic acid, Carbon dioxide

Methanogenesis
Methane + Carbon dioxide

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Anaerobic digestion

Psychrophilic

- Ambient temperatures
- 3+ months
- Open basins

Mesophilic

- Temperatures 20...45°C
- Optimally 37…41°C
- Ca. 20 days
- Closed digesters, most popular type

Thermophilic

- Temperatures up to 70°C
- Optimally 50…52°C
- 12-14 days
- Closed digesters

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Biogas sources

Waste treatment

- Digestion of wastewater sludge
- Digestion of mixed municipal waste

Agriculture

- Digestion of biological waste

Landfills

- Landfill gas (LFG)

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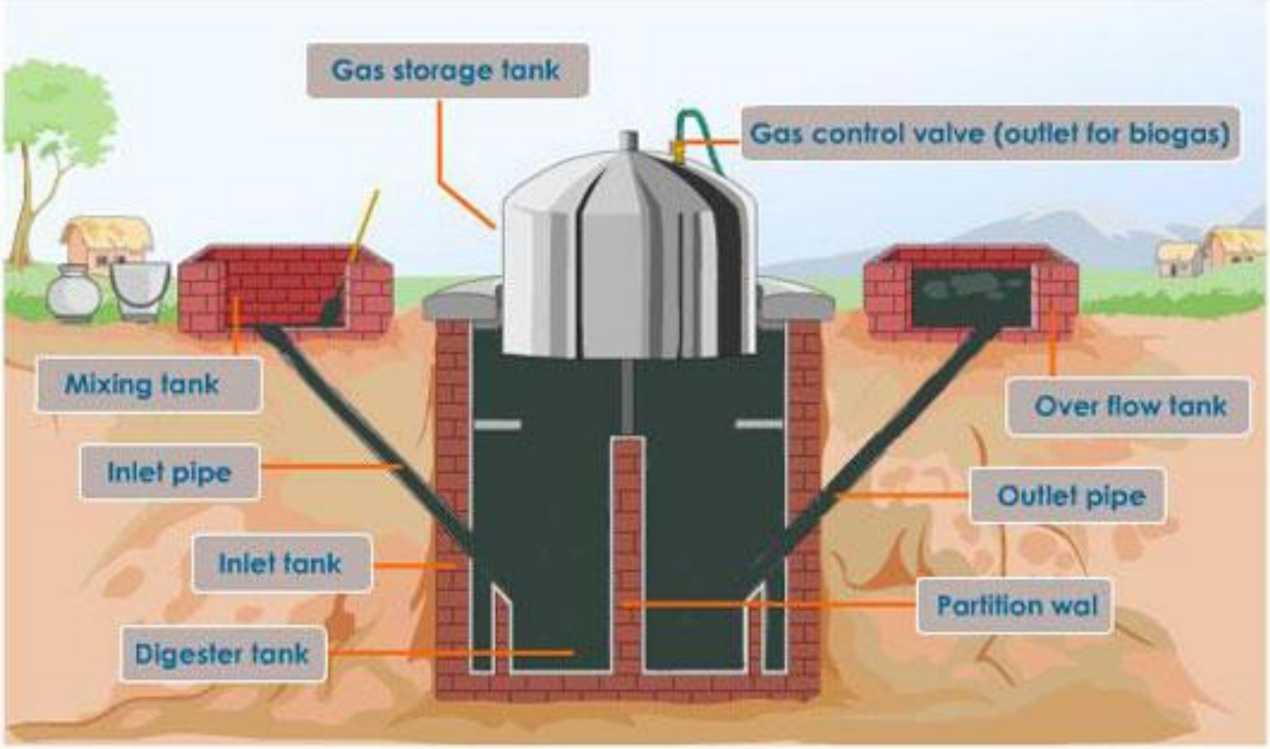
Argricultural biogas production



Fixed Dome type Biogas Plant

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ARGRICULTURAL BIOGAS PRODUCTION

- Feedstock:
  - Manure
  - Silage
  - Grass
  - Corn
  - Slaughterhouse waste
  - Waste fats & oils
  - Food waste

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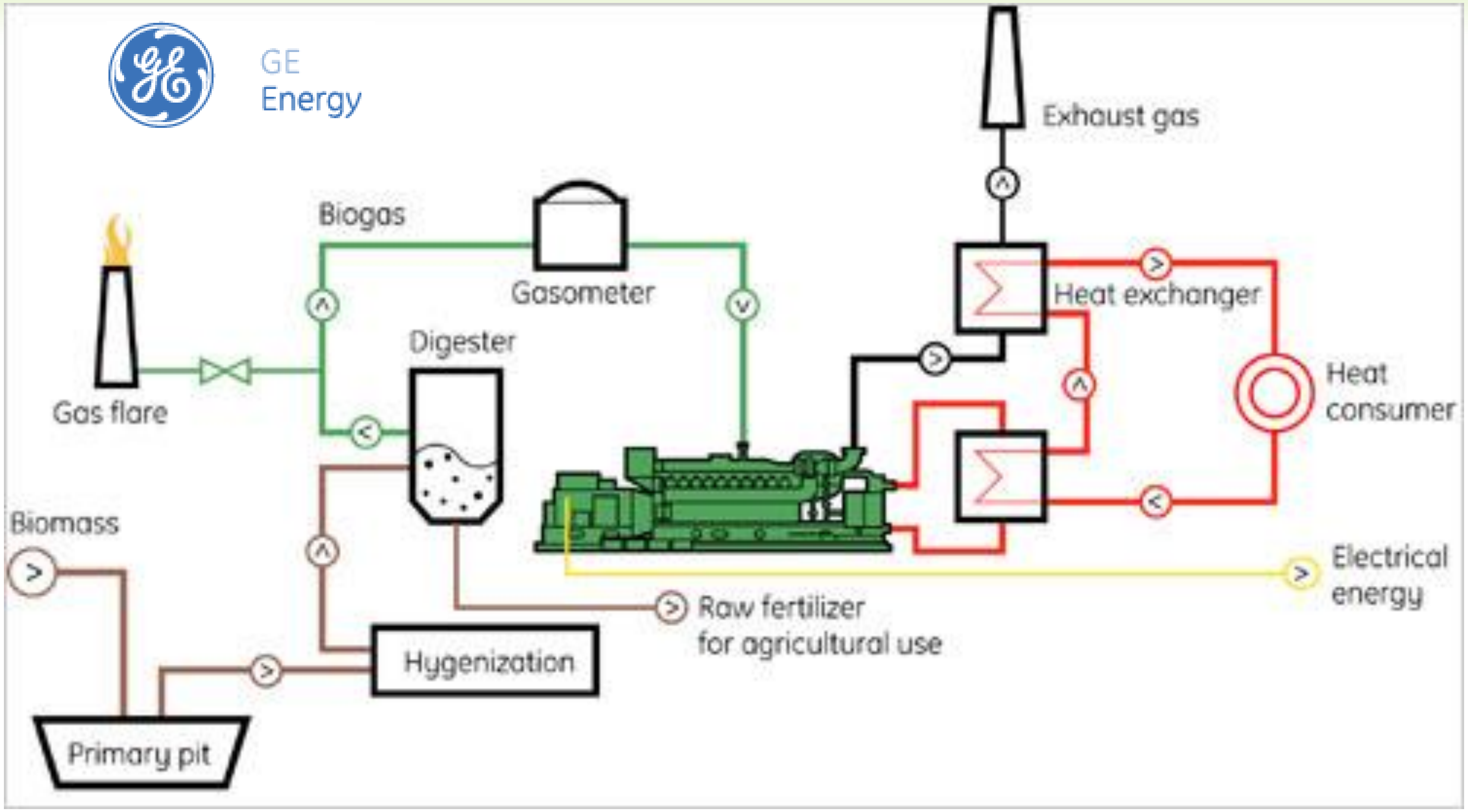
Agricultural biogas plant concept



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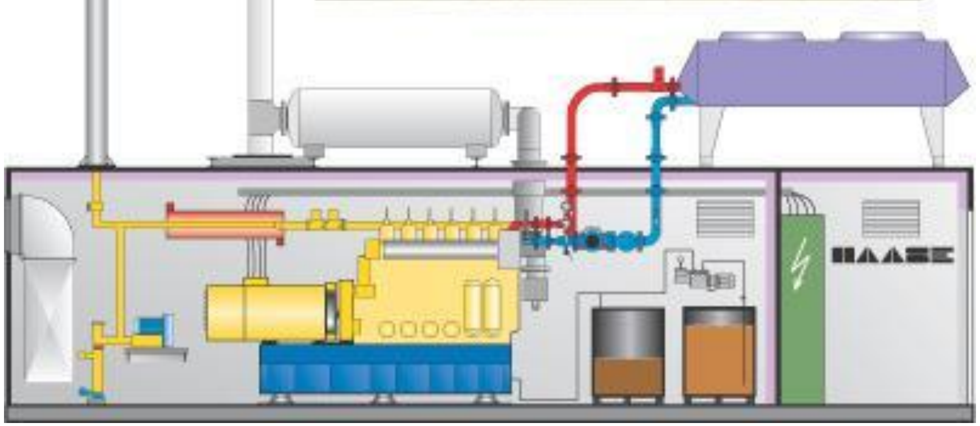
Agricultural biogas plant concept



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HAASE Energietechnik AG

Wolkow Biogas Plant

- Year of construction: 2004
- Digests ca. 30,000 Mg/a of biomass
- 2 × 1250 m^3 digester tanks
- Containerized CHP system with gas engine:
  - 311 kW_{el}
  - 306 kW_{th}
- Supplier: HAASE Energietechnik AG

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Wolkow Biogas Plant

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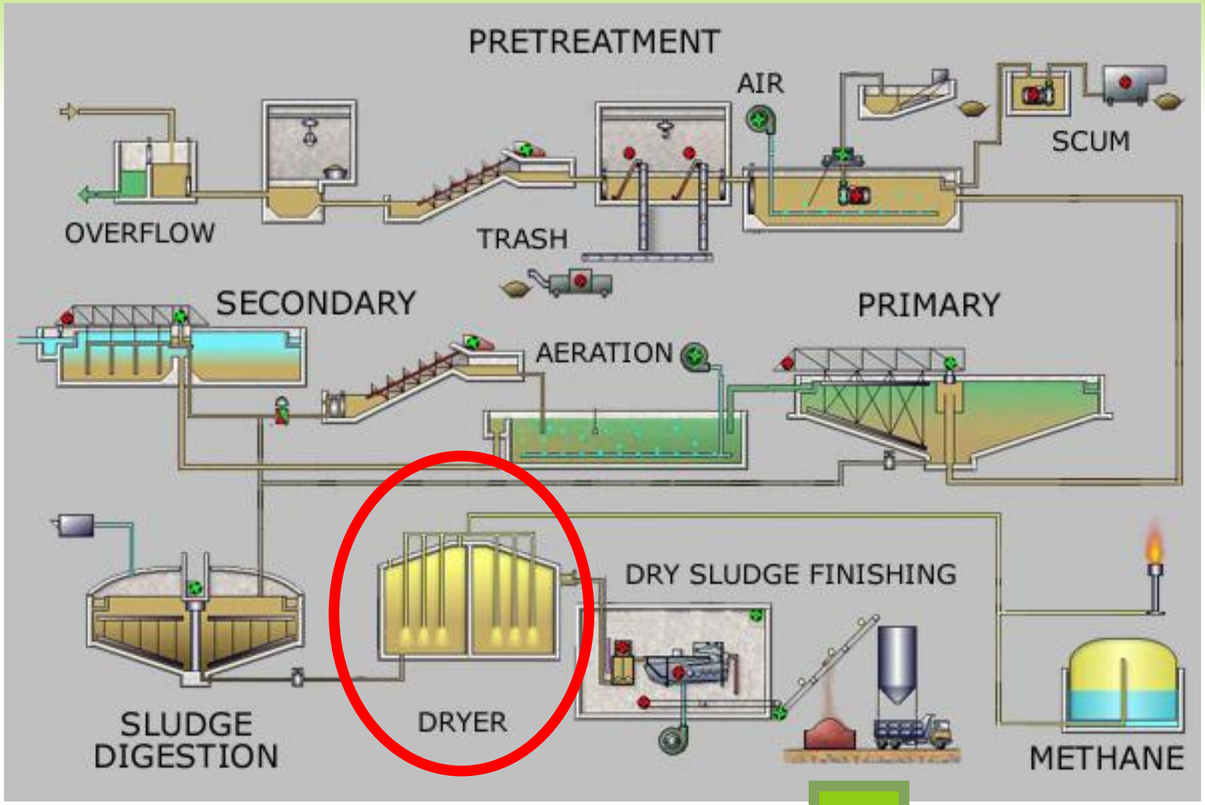
Biogas from wastewater

Process scheme

of a large

wastewater

treatment plant



Can be combusted in boilers

VERA Hamburg

- **VERA** Klärschlammverbrennung GmbH
- CHP plant at Hamburg wastewater treatment plant
- Fuels: biogas, wastewater sluge and screenings
- Combined cycle unit

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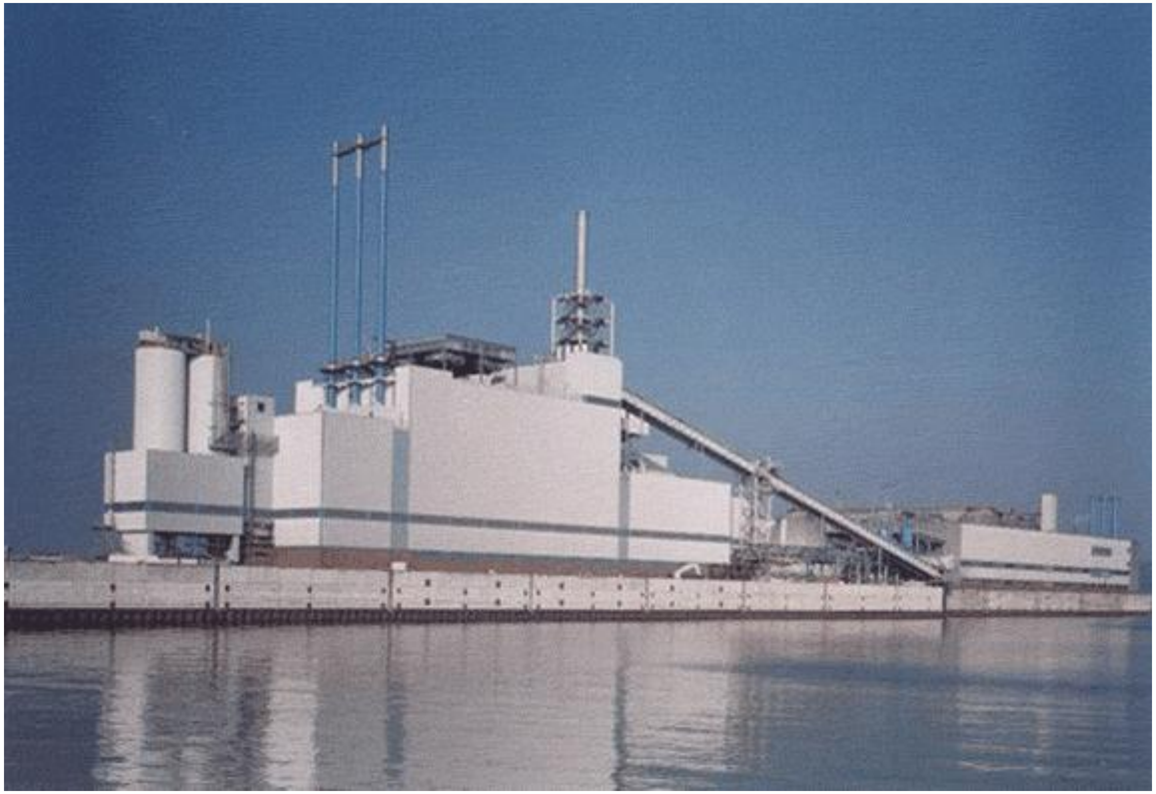
VERA Hamburg

VERA Hamburg

VERA Hamburg



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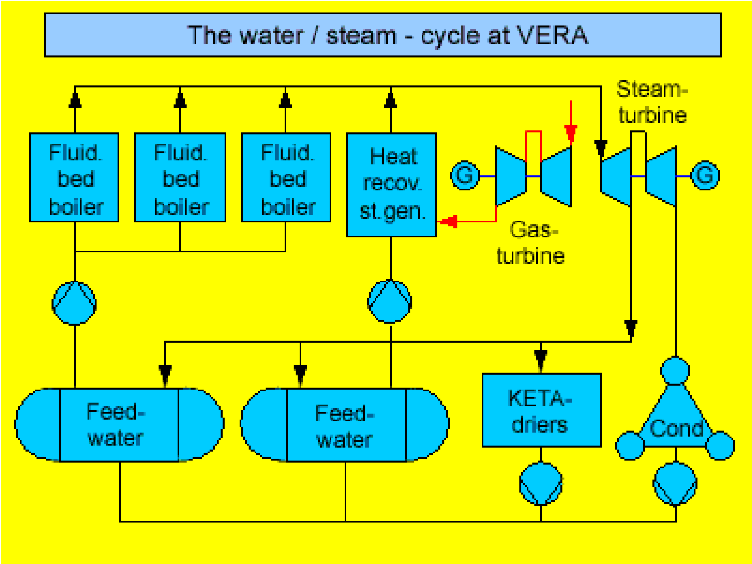
VERA Hamburg Process scheme



- 1 × Gas Turbine, 5 Mwe (biogas)
- 1 × Exhaust gas boiler (suppl. biogas firing)
- 3 × Fluidized bed boiler (dried sludge)
- Max steam flow 37 Mg/h
- Steam parameters 40 bar/400°C
- Steam turbine exctraction at 7 bar

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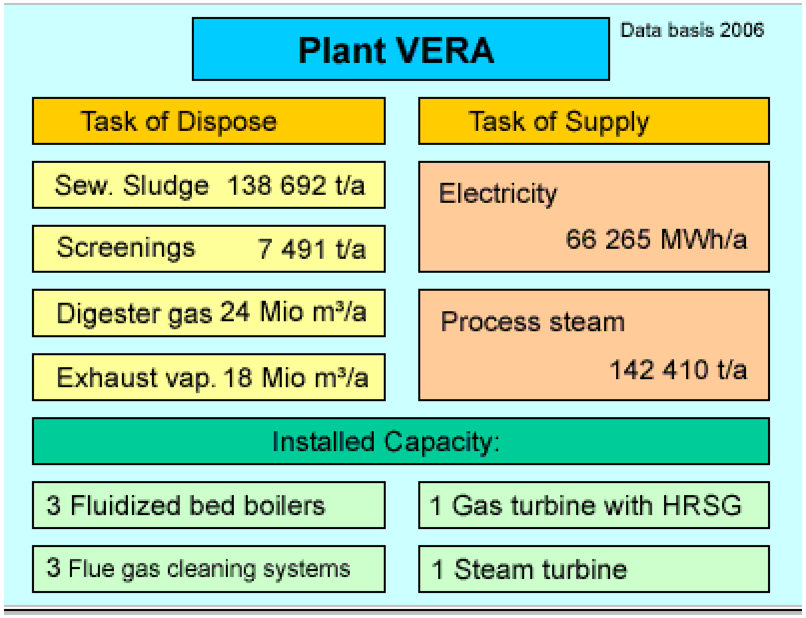
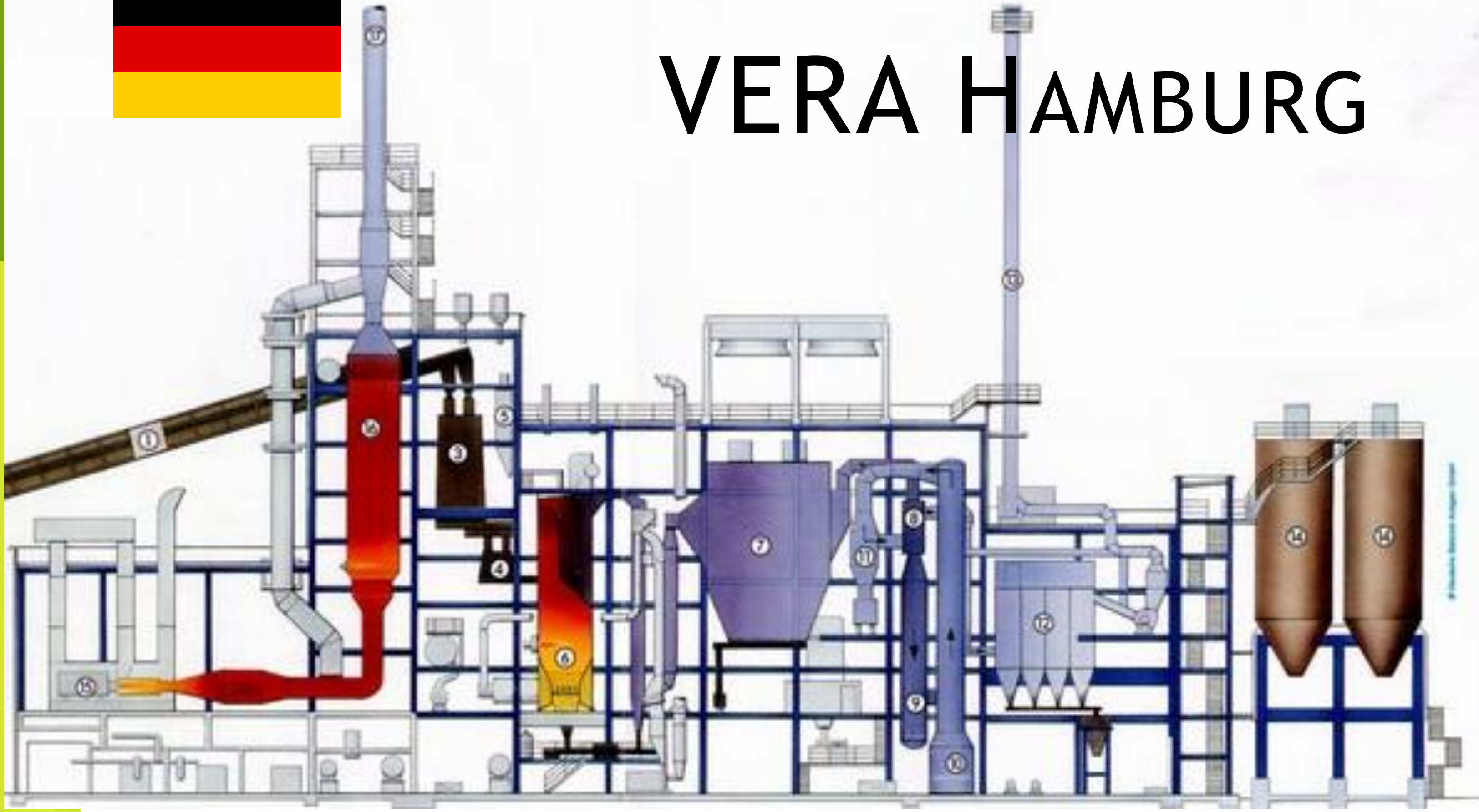
VERA Hamburg



+ 1 reciprocating engine (as of 2008)

VERA Hamburg



1. Sluge conveyor
2.
3. Receiving tanks
4. Proportioning silo
5. Sand silo
6. Fluidized Bed Boiler
7. ESP
8. Heat exchanger
9. HCl Scrubber
10. SO2 Scrubber
11. Flue gas intercooler
12. Fabric filter
13. Boiler stack
14. Fly ash silos
15. Gas turbine unit
16. Exhaust gas boiler
17. Gast turbine stack

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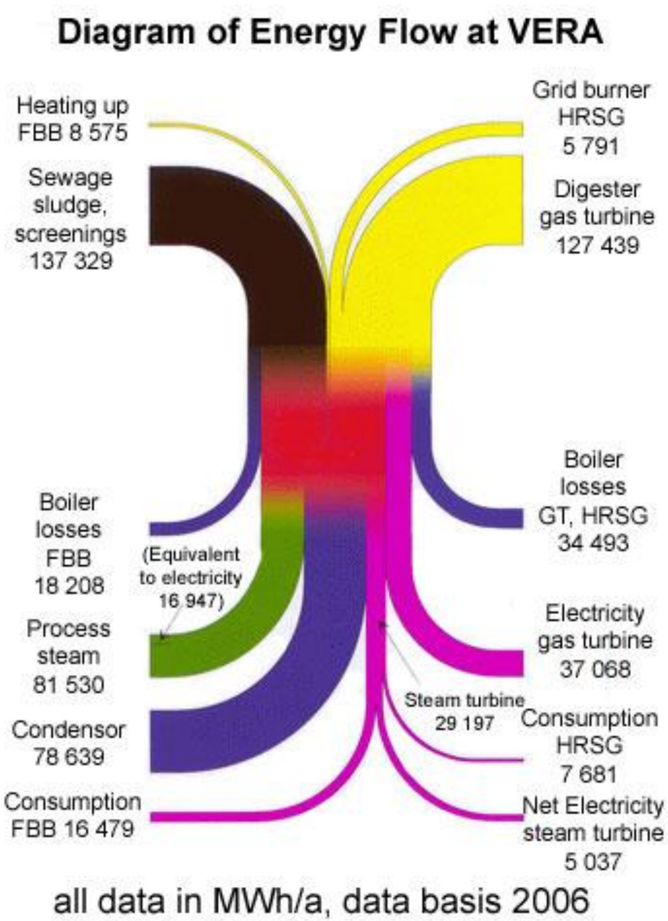
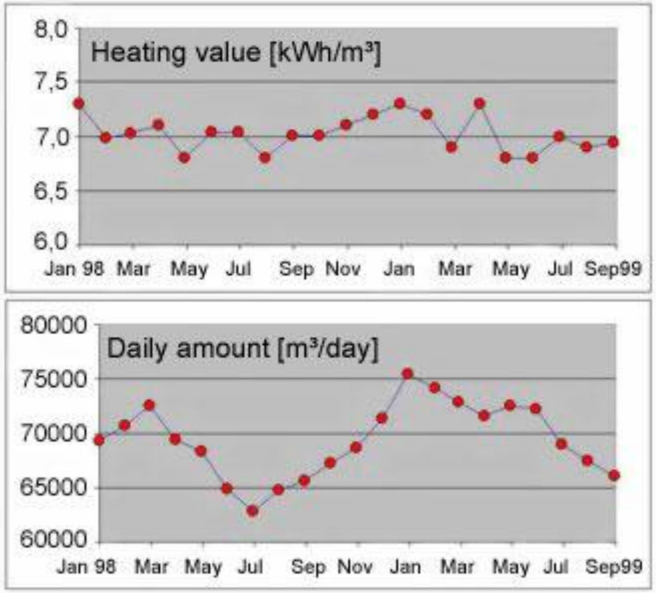
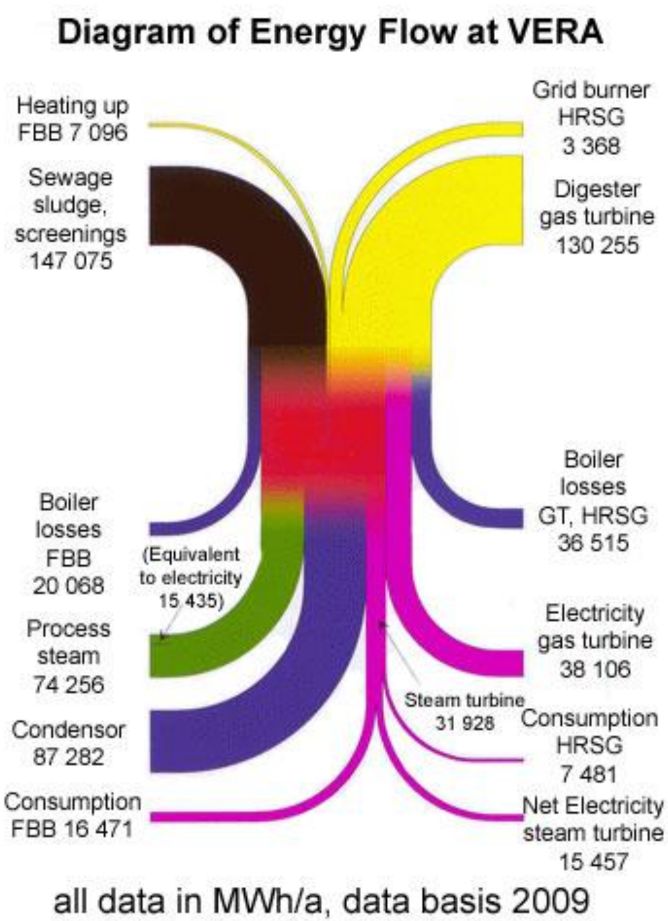
VERA Hamburg



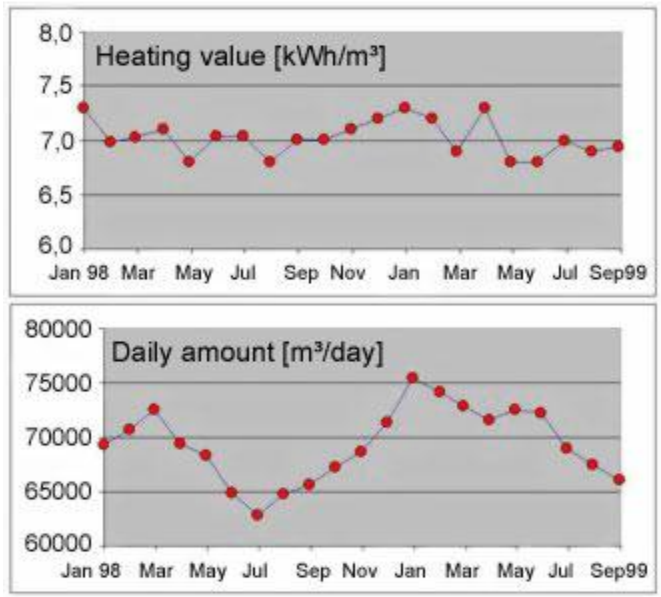
Gas properties at VERA plant:



VERA Hamburg



Gas properties at VERA plant:



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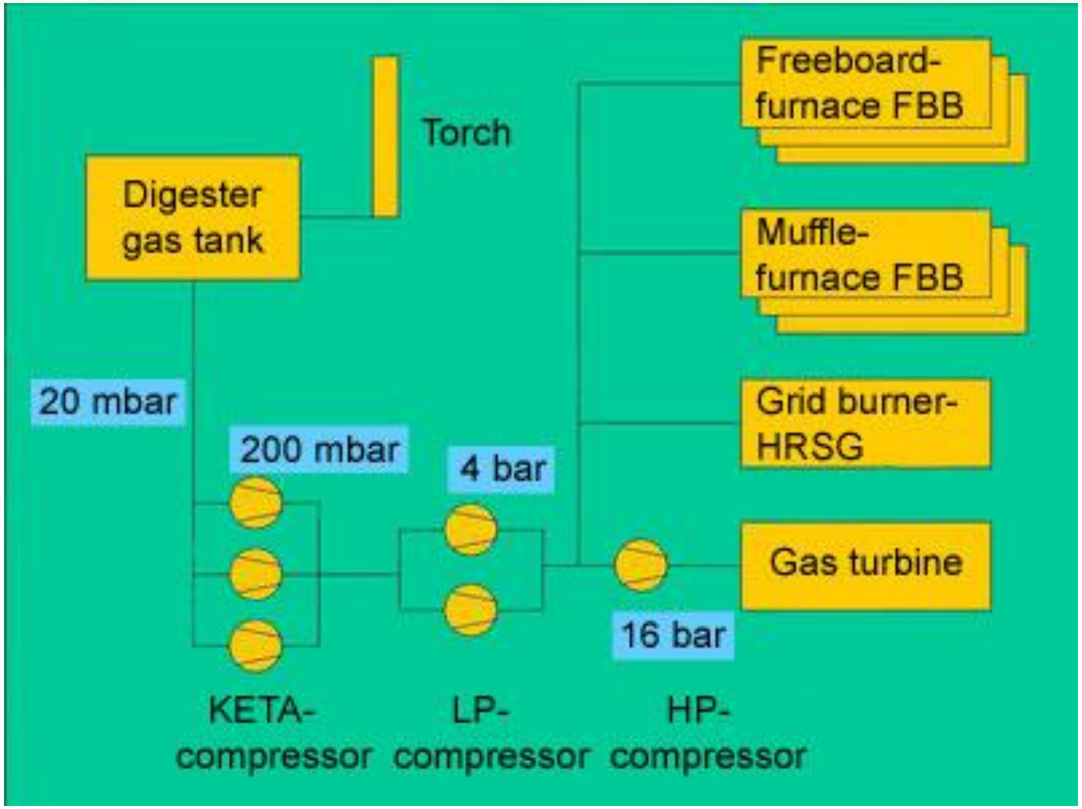
VERA Hamburg Biogas flow



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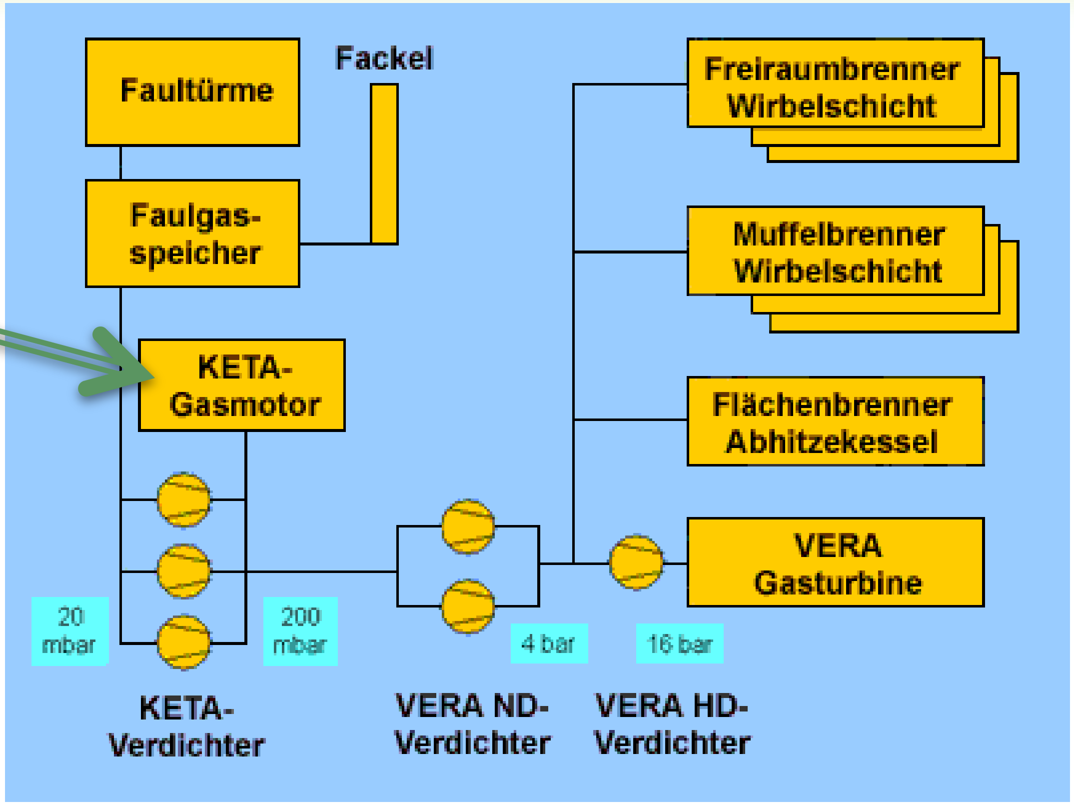
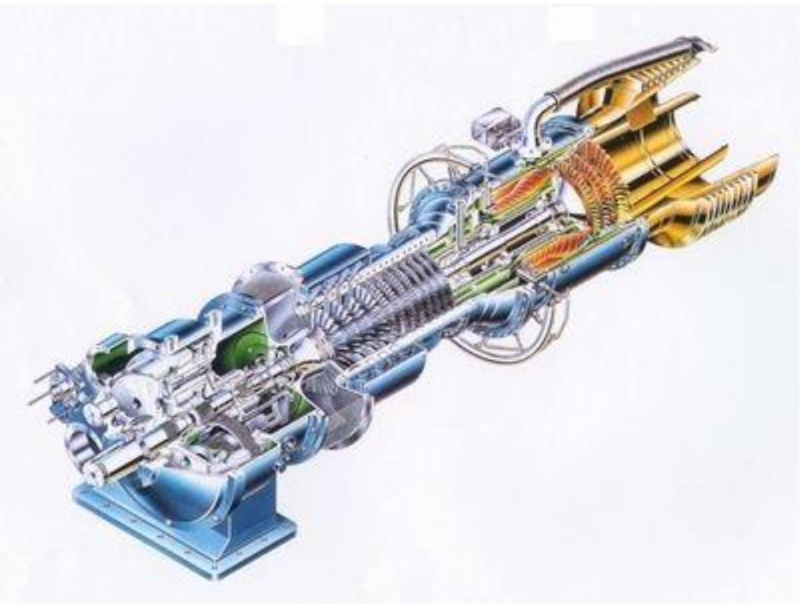
VERA Hamburg Biogas flow

NEW GAS ENGINE



VERA Hamburg Gas Turbine Unit

Solar Turbines
A Caterpillar Company



- Solar Taurus 60 S
- Rated output 5 MW_{el}
- Compression ratio 12
- Turbine speed 14,950 rpm
- Generator speed 1500 rpm
- Exhaust gas temperature 480°C

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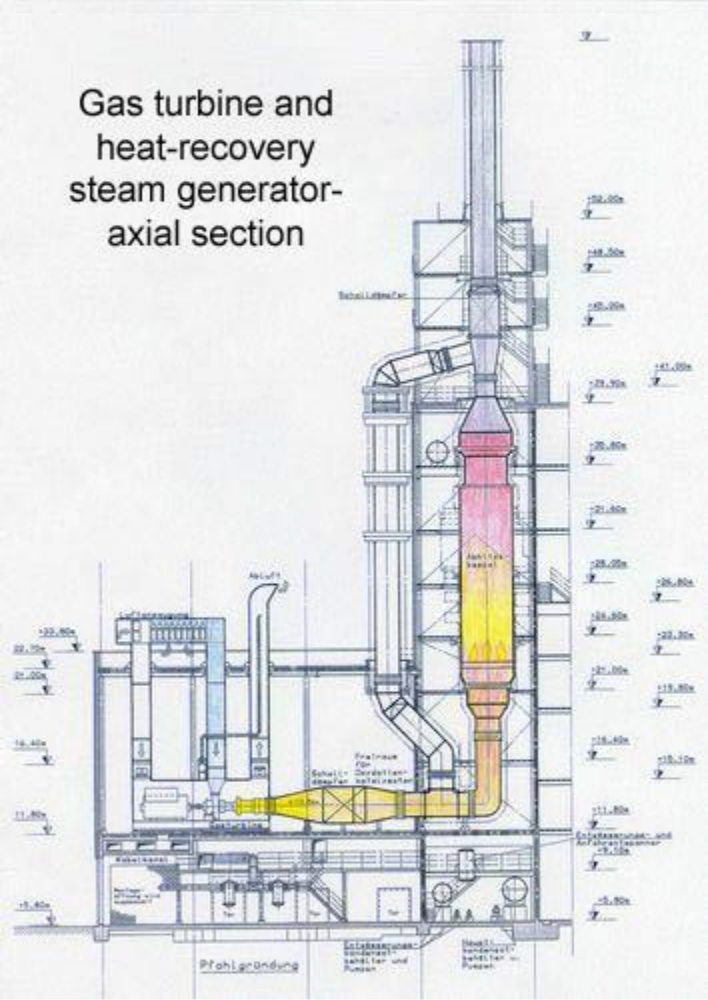
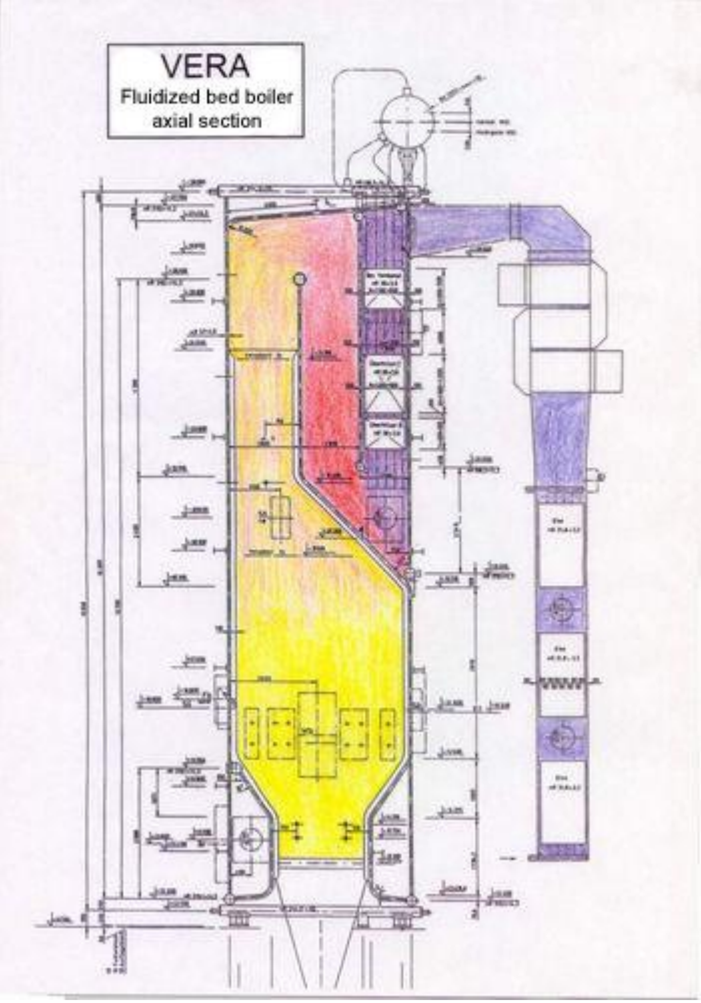
VERA Hamburg
Heat Recovery Steam Generator



- Inlet gas temperature 480°C
- Exhaust gas temperature 180°C
- Natural circulation boiler
- Live steam pressure 40 bar
- Live steam temperature 400°C
- HR mode capacity 9 Mg/h
- Possible supplementary gas firing up to 18 Mg/h
- Possible fresh-air operation up to 22 Mg/h

VERA Hamburg
Fluidized bed boiler



- Fuel: dried sludge
- Fluidized bed temperature ca. 800°C
- Max combustion temperature ca. 900°C
- Natural circulation boiler
- Live steam pressure 40 bar
- Live steam temperature 400°C
- NOx abatement: SNCR + recirculation
- Exhaust gas temperature 190°C

VERA Hamburg

Wastewater sludge – boiler fuel

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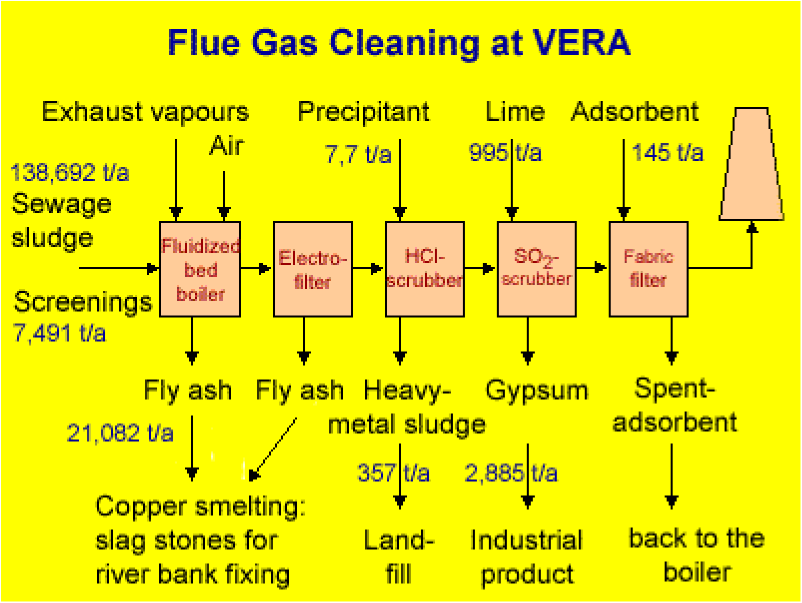
VERA Hamburg
Flue gas cleaning unit



VERA Hamburg
Gas Engine-Generator Unit

- Supplier: CAT-Zeppelin
- Engine: Cat 3520C
- 20-cylinder V engine
- Cummins AvK generator
- Rated output 2035 kW
- Efficiency 39.5%
- Process heat for sludge drying

ZEPPELIN Power Systems CAT

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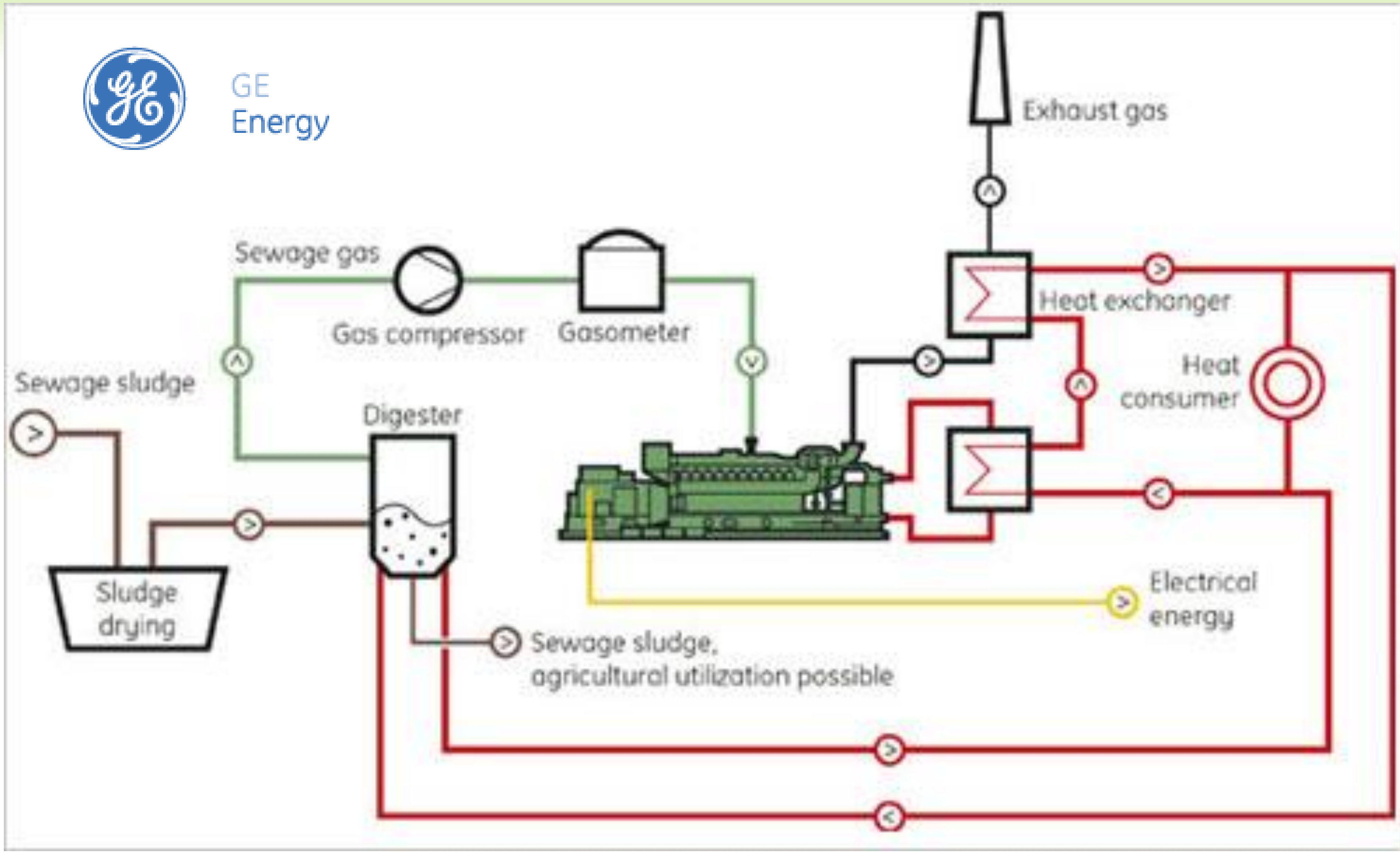
Wastewater treatment plant – small scale



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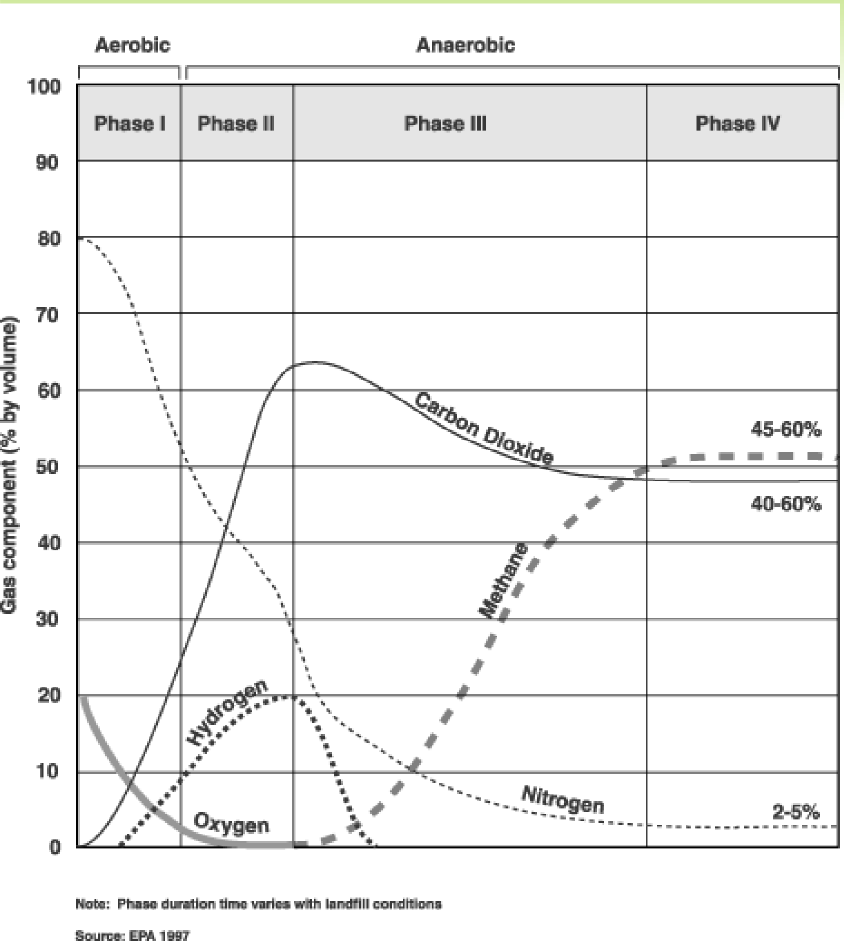
Landfill gas

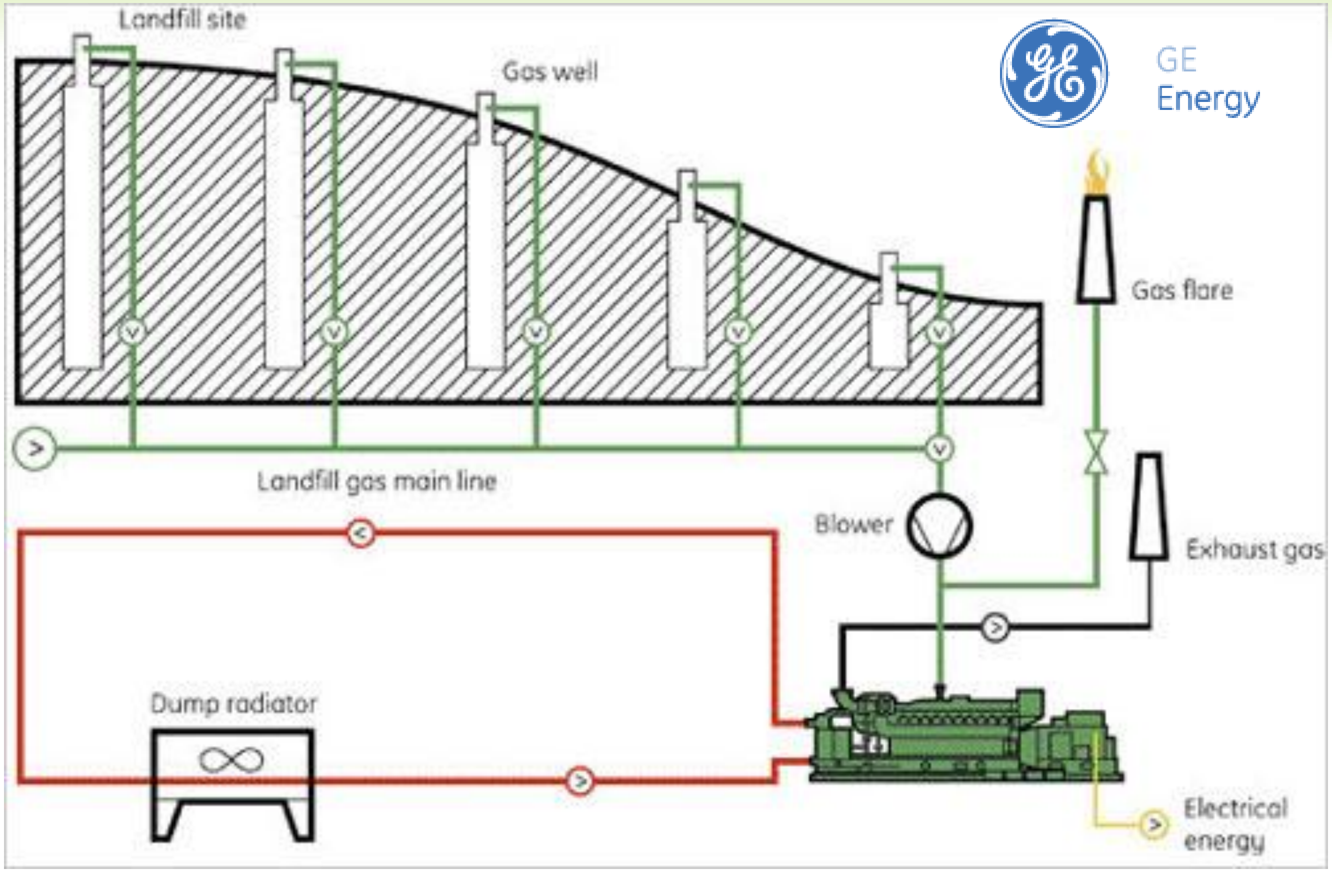


- Gas production starts 3-12 months after depositing waste
- Peak production in 5-10 years
- Lifetime of 25-30 years

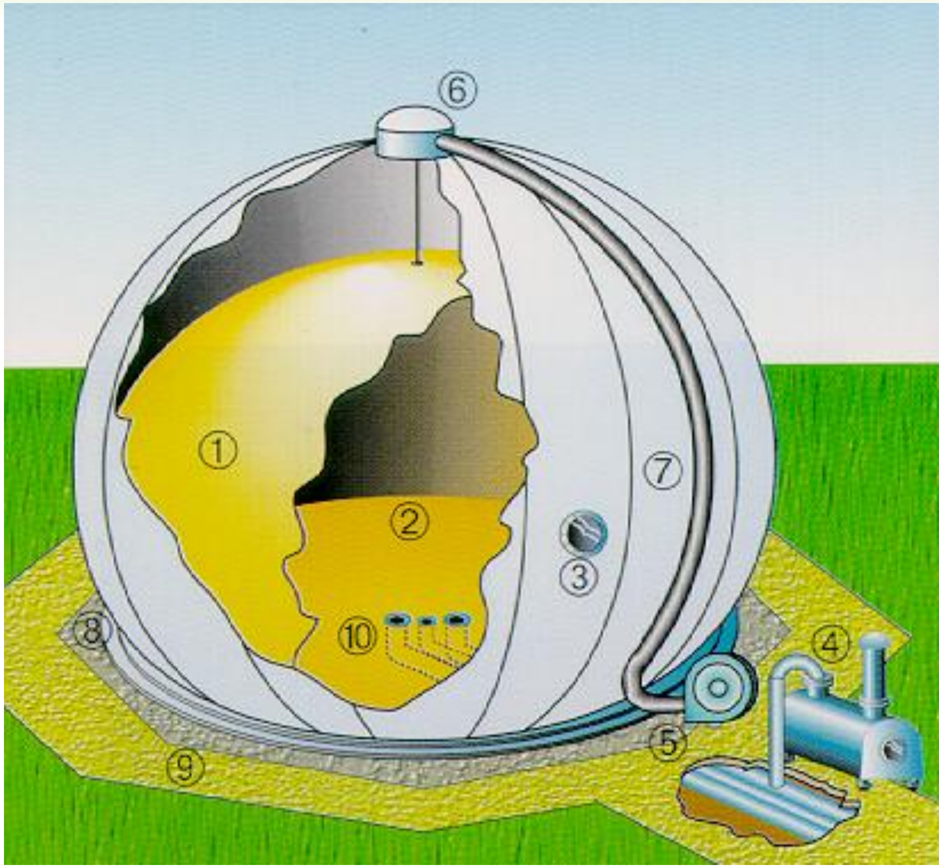
Landfill gas plant

LHV = 18 MJ/m³

$CH_4+CO_2+N_2$



Biogas storage



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Wood gas

- Product of biomass thermal gasification
- Exemplary composition:
  - Nitrogen: 50.9%
  - Carbon monoxide: 27.0%
  - Hydrogen: 14.0%
  - Carbon dioxide: 4.5%
  - Methane: 3.0%
  - Oxygen: 0.6%
- LHV ca. 6 MJ/m^3 (natural gas ca. 34 MJ/m^3)

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Wood gas production
Gasifier

- Several processes:
  - Pyrolisis, temperatures 200…600°C
  - Combustion, temperatures > 700°C
    $C + 0.5\ O_2 \rightarrow CO + Energy$
    $C + O_2 \rightarrow CO_2 + Energy$
    $H_2 + 0.5\ O_2 \rightarrow H_2O + Energy$
  - Gasification / reduction – contact of gas and char
    $C + CO_2 + Energy \rightarrow 2\ CO$
    $C + H_2O + Energy \rightarrow 2\ CO + H_2$
    $C + 2H_2 + Energy \rightarrow CH_4$

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Simple gasifier, 1920 Georges Imbert's concept

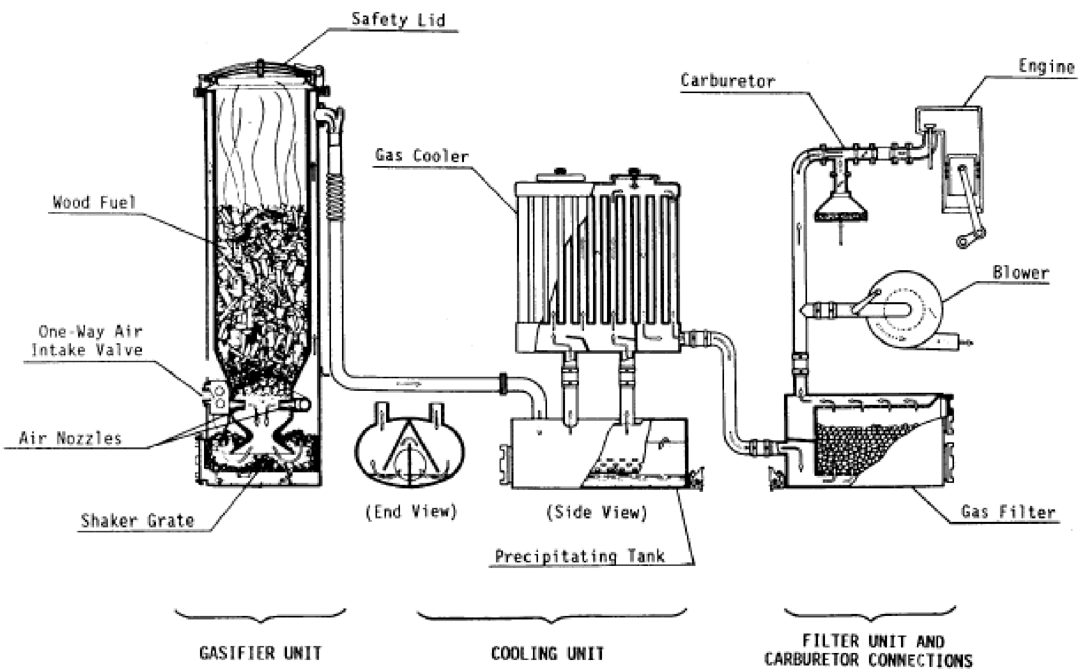

Fig. 1-2. Schematic view of the World War II, Imbert gasifier.

Wood gas-powered vehicles 1930s – 1940s

Wood gas-powered vehicles 1930s – 1940s

SdKfz 251 Armoured Personnel Carrier

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WOOD GAS-POWERED VEHICLES 1930S – 1940S

Adler Diplomat

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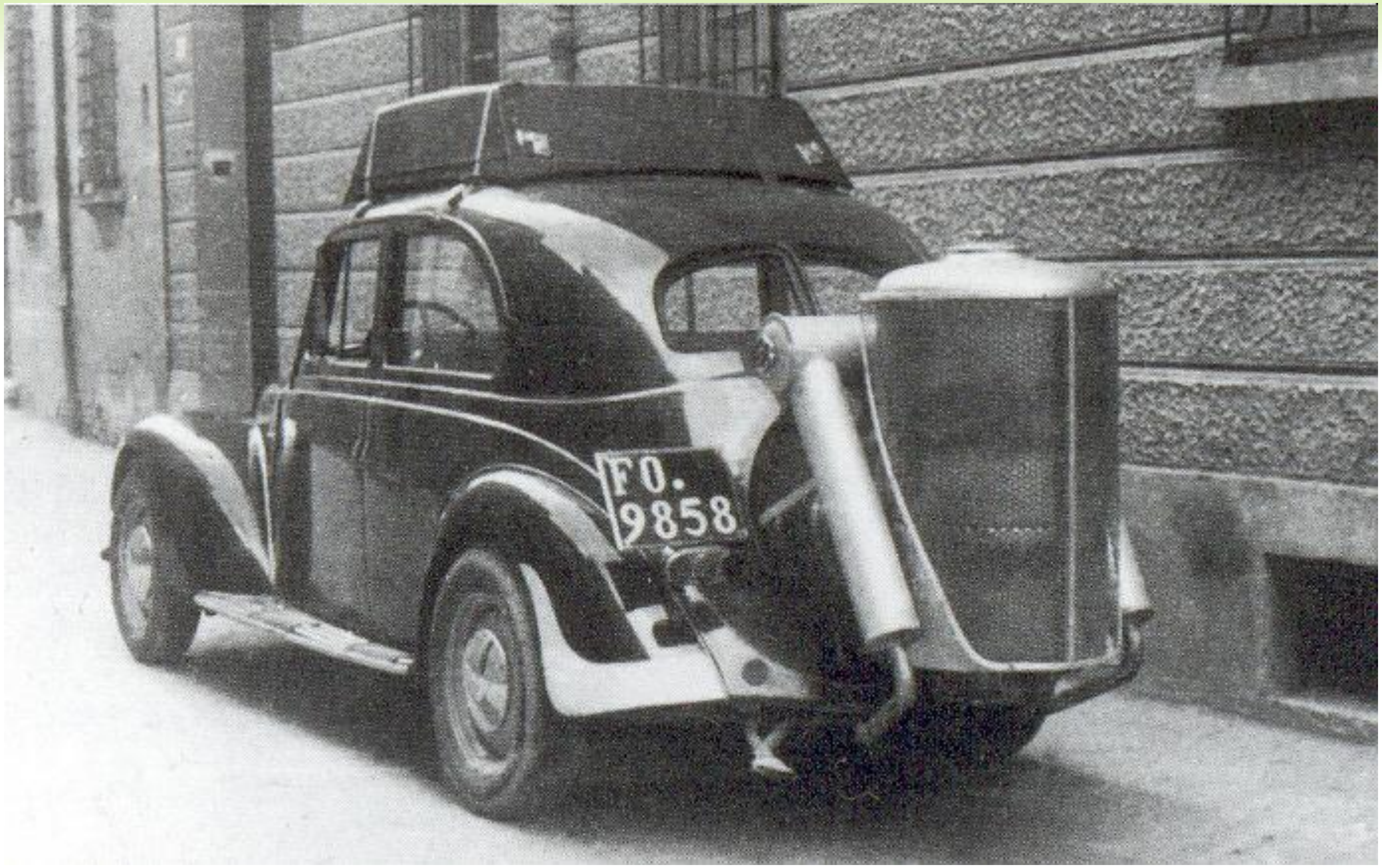
Wood gas-powered vehicles 1930s – 1940s



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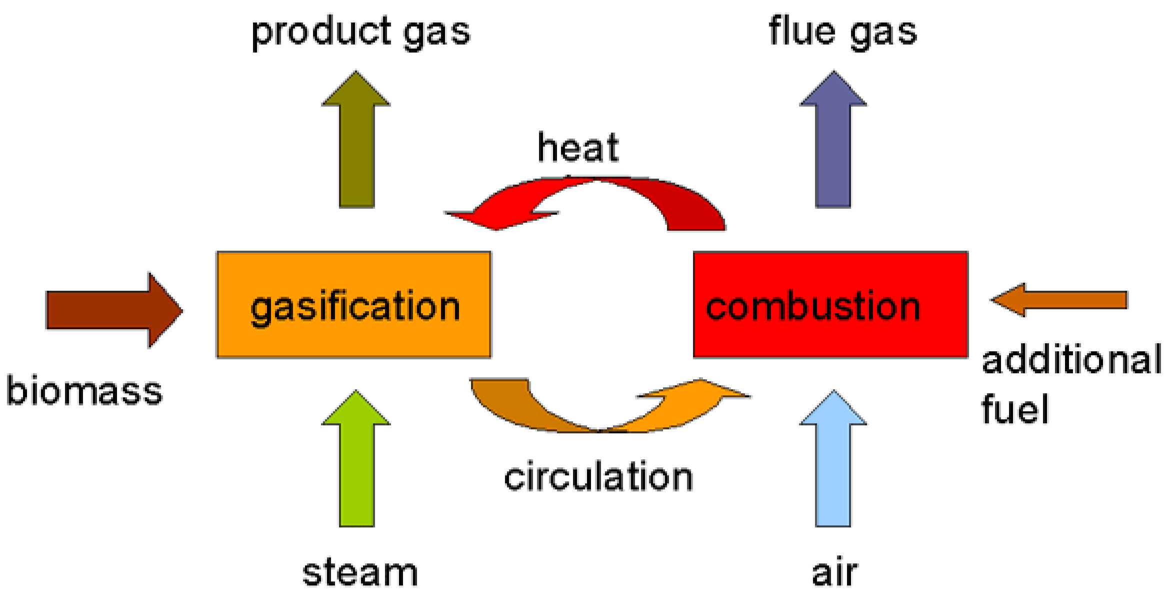
FICB Gasification
Fast Internal Circulating Fluidized Bed



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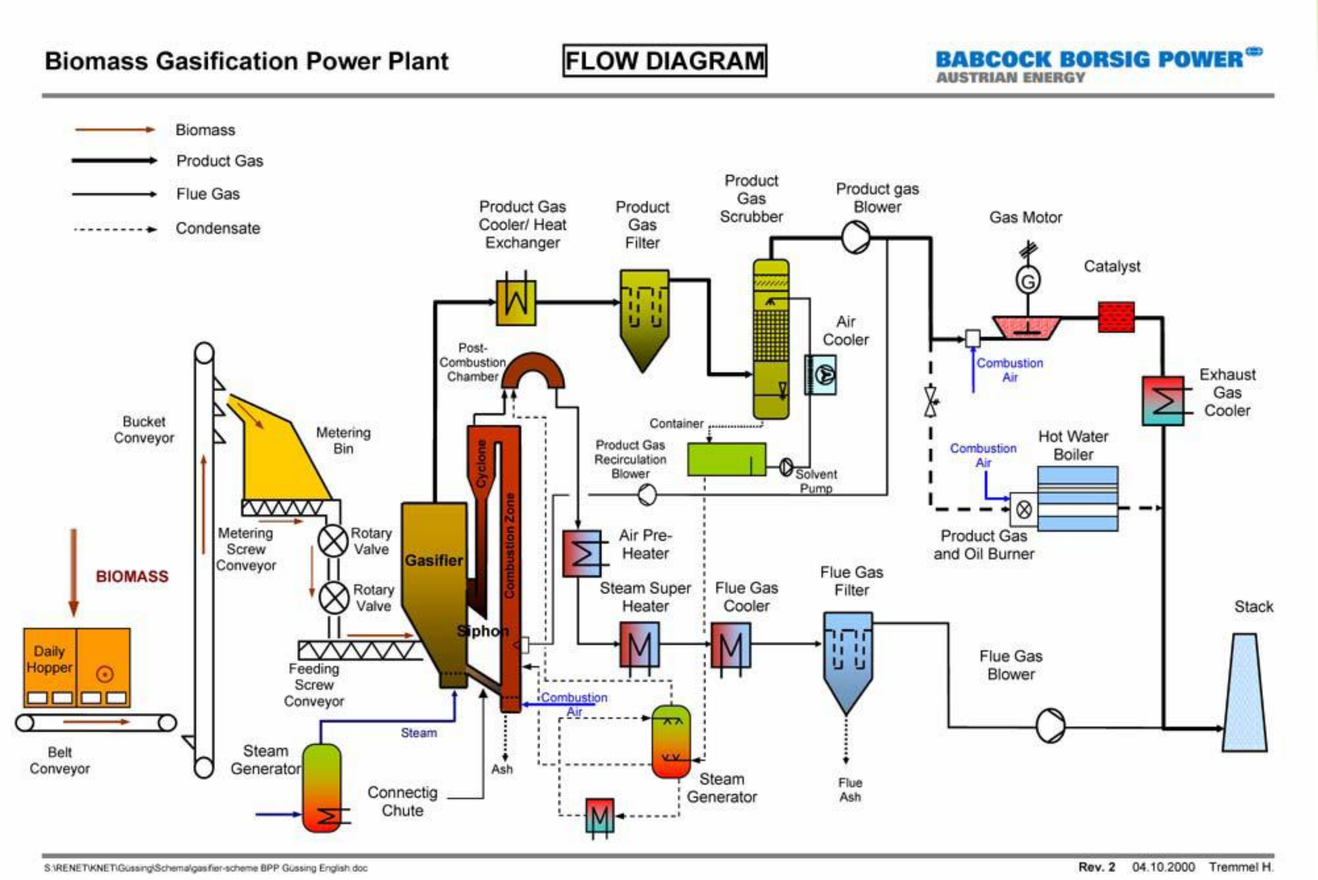
Güssing Gasification Plant Austria



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Güssing Gasification Plant Main parameters

Parameter	Unit	Value
Fuel	–	Wood chips
Gasification method	–	FICB
Fuel power	kW	8000
Electrical output	kW	2500
Thermal output	kW	4000
Electrical efficiency	%	31.0
Total efficiency	%	81.3

Gas consummers:
- GE-Jenbacher gas engine
- Heating boiler

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Güssing Gasification Plant
Gas composition (dry)

Component	Symbol	Content (vol. %)
Hydrogen	H_2	35-40
Carbon monoxide	CO	20-30
Carbon dioxide	CO_2	15-25
Methane	CH_4	8-12
Nitrogen	N_2	3-5

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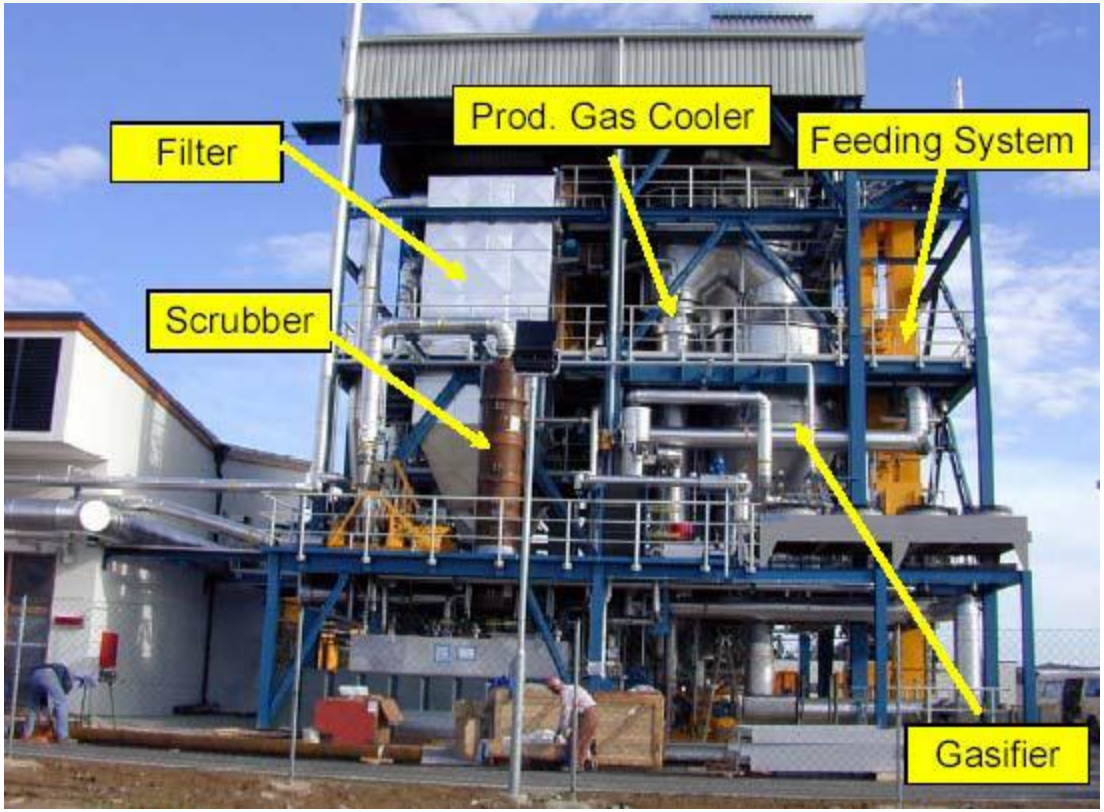
Güssing Gasification Plant



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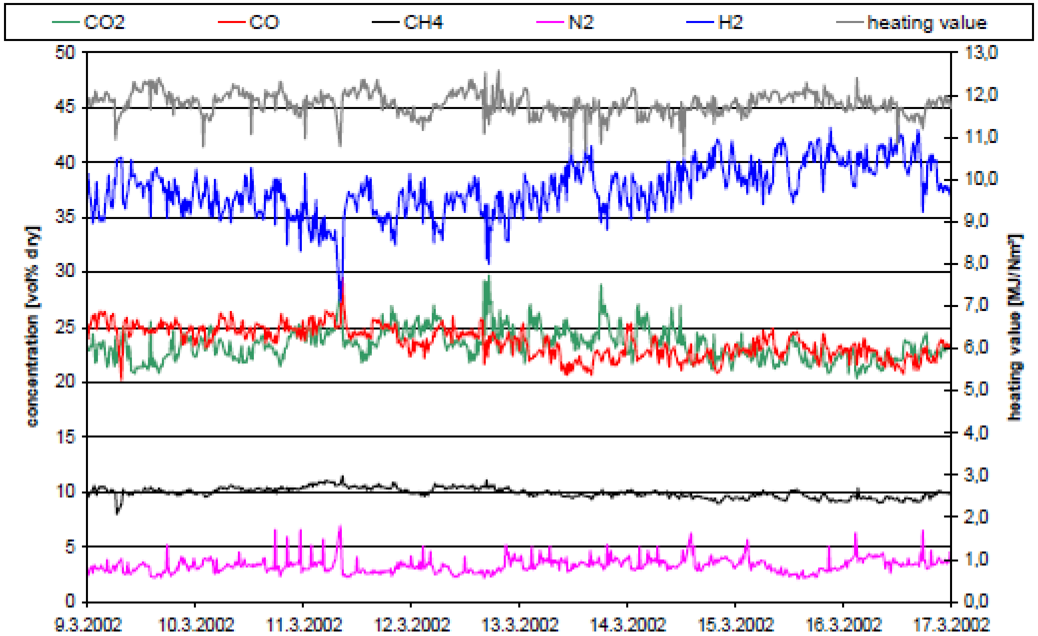
Güssing Gasification Plant

Güssing Gasification Plant Gas composition (dry)



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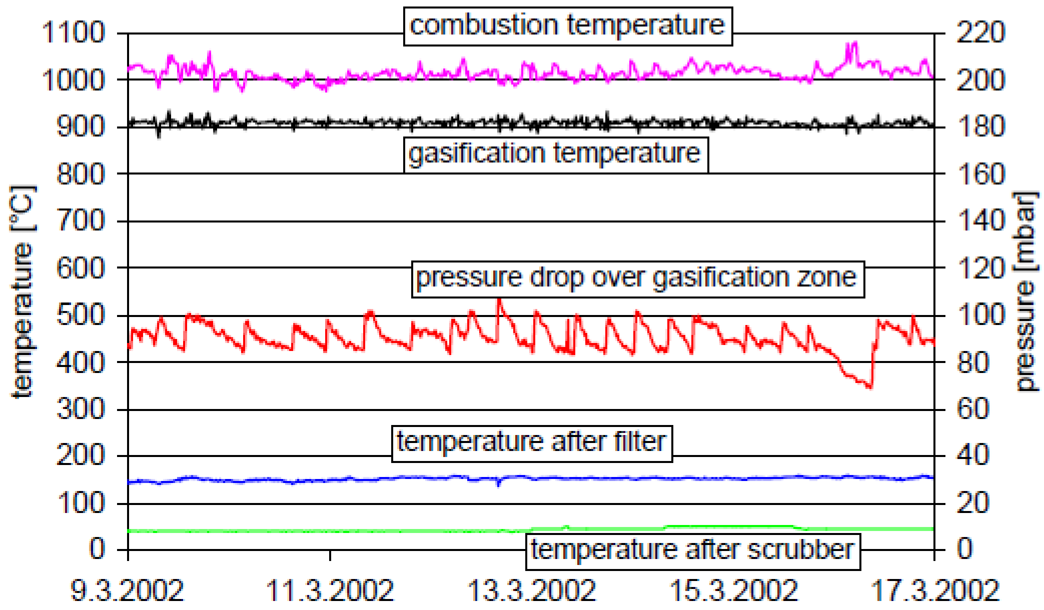
Güssing Gasification Plant FICB Process temperatures



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Animal fuels

Animal waste

- Animal waste can be used as a fuel for boiler
- Chicken waste can be converted for liquid biofuel
- Fish oil can be used in Diesel engines
- Animal fat (suet) may be used in Diesel engines

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Animal waste-fired plants in the UK

Thetford

- 38.5 MW
- Chicken litter
- Grate boiler (Detroit stoker + Foster Wheeler)
- Steam turbine

Eye

- 12.7 MW
- Poultry litter, horse bedding, feathers
- Grate boiler (Aalborg boilers)

Westfield

- 9.8 MW
- Poultry litter
- Bubbling fluidized bed boiler (Mitsui Babcock/ Abengoa)

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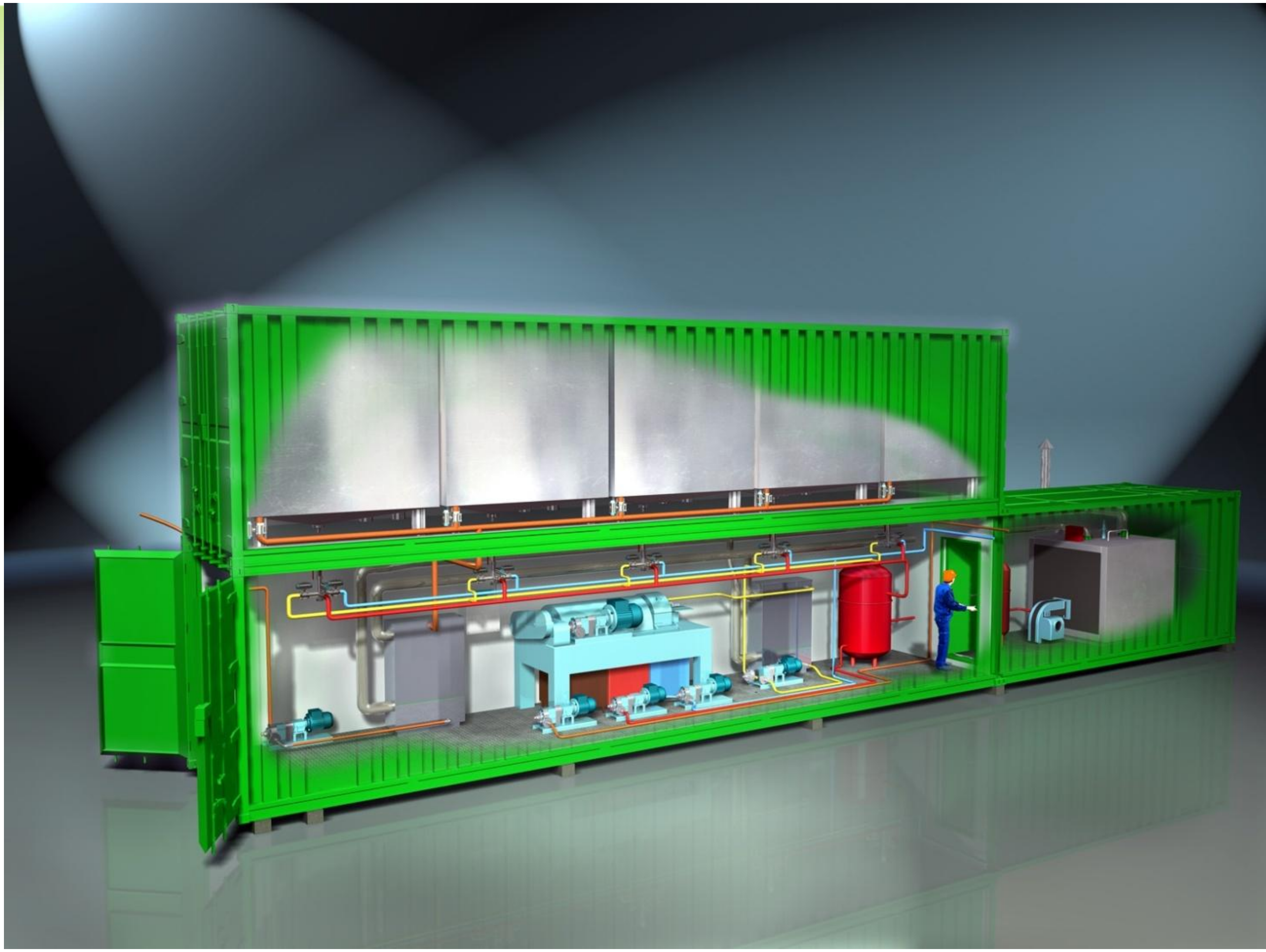
Chicken oil – fuel for Diesel engines

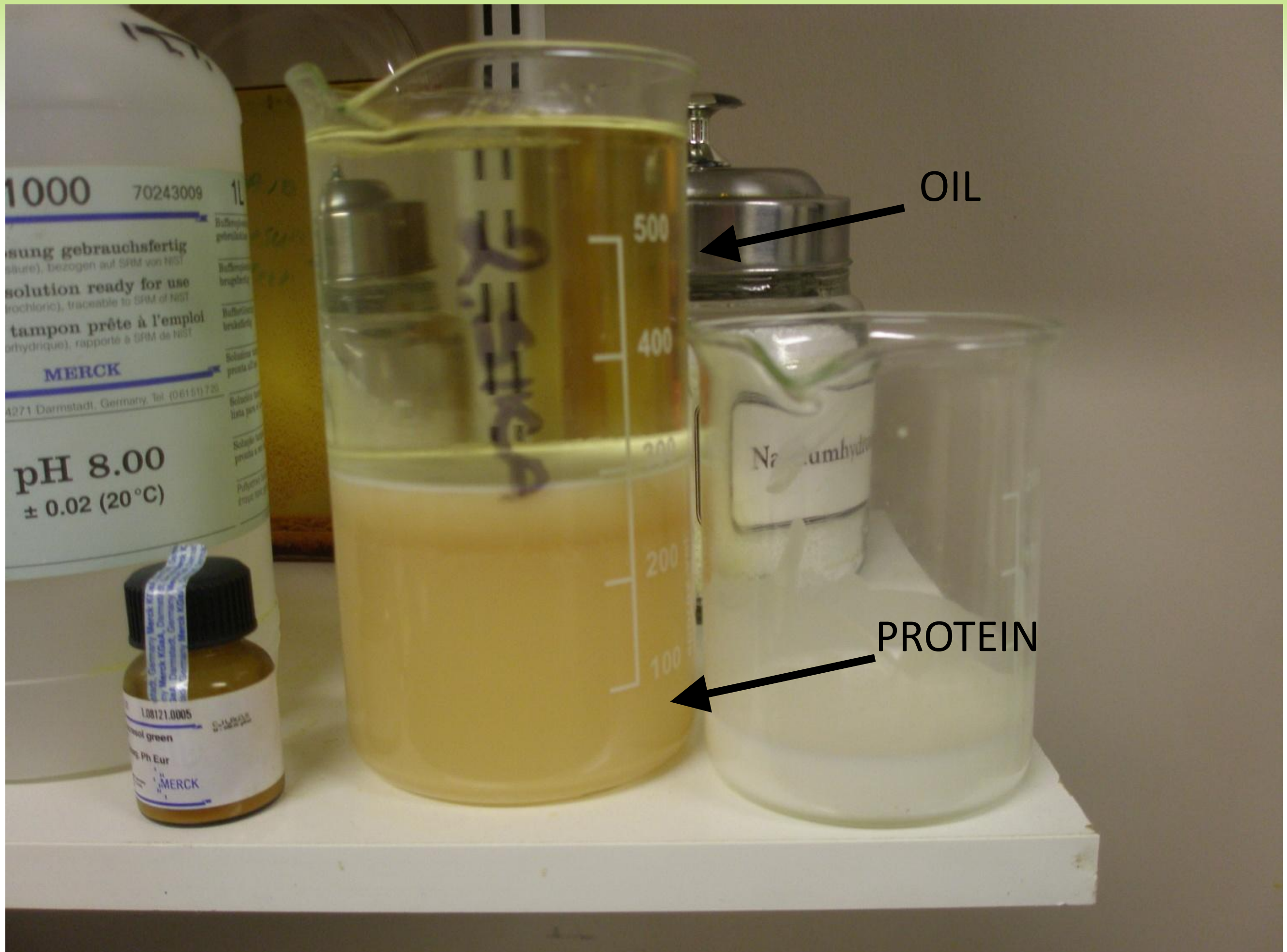


WÄRTSILÄ

Chicken oil – fuel for Diesel engines

1. Waste is crushed
2. Formic acid (HCOOH) is added
3. Mass is heated to 70˚C for at least 1 hour
4. Mass is separated – 3-phase decanter
5. Water is separated

Chicken oil – fuel for Diesel engines



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Chicken oil – fuel for Diesel engines

Case 1 – Finland

- Main product: chicken breasts, prefab. servings
- Waste: everything else
- Average oil content in waste: 12%
- 9 million chicken per year
- 100 Mg/d of waste
- 12 Mg/d of oil

Case 2 – Latvia

- Main product: whole chickens
- Waste: guts, heads, legs
- Average oil content in waste: 8%
- 12 million chicken per year

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Biomass/Biofuel business in power industry

- Feasibility:
  - Hardly feasible without some incentives
  - Sometimes not feasible without co-funding
  - Enough subsidies will make anything feasible
- Business based on legal regulations – market controlling. Can be risky!
- Fuel chain of supply – key factor in business planning

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THANK YOU!

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