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BIOMASS AS ENERGY STORAGE

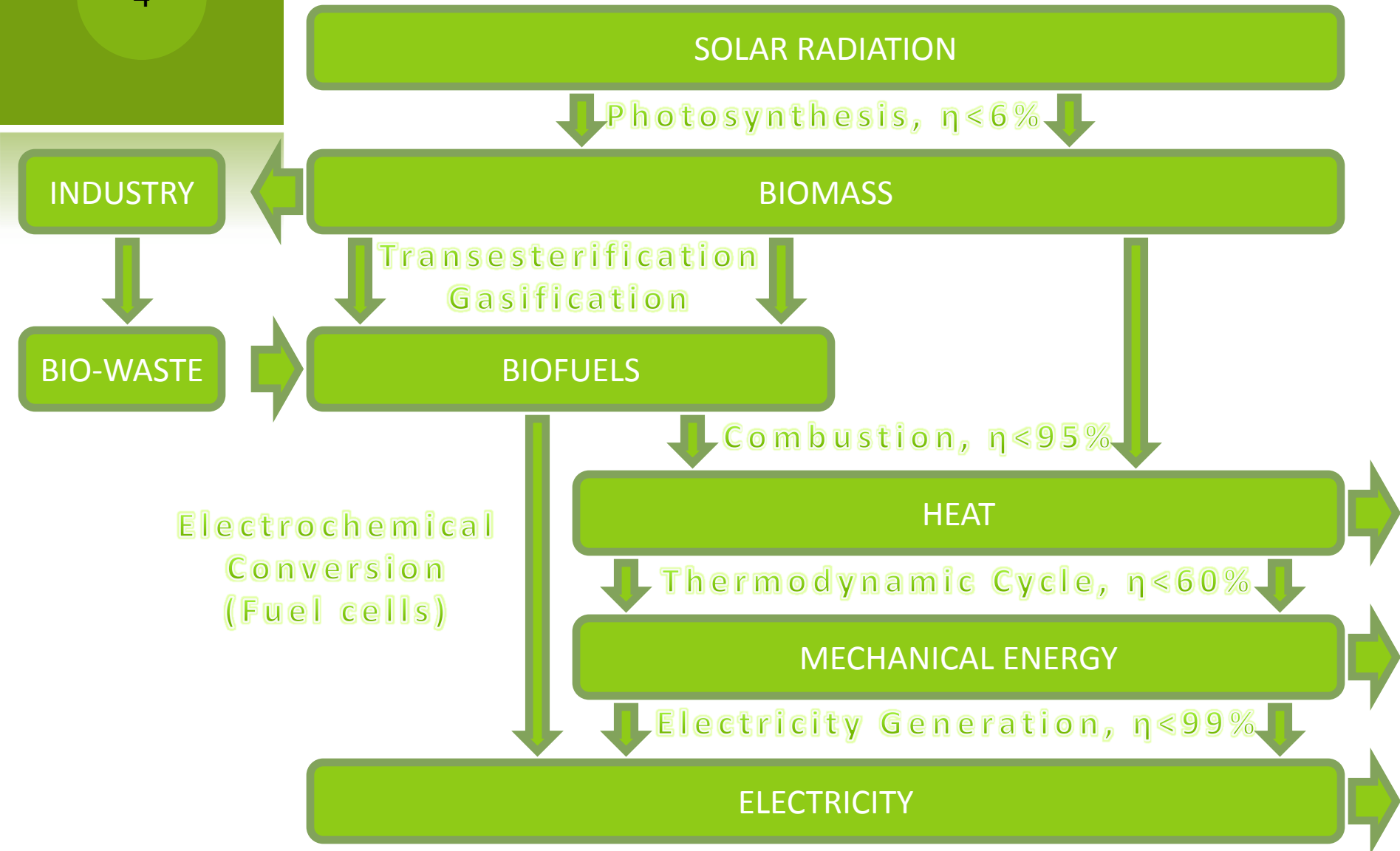
THEORY

WHAT IS BIOMASS?

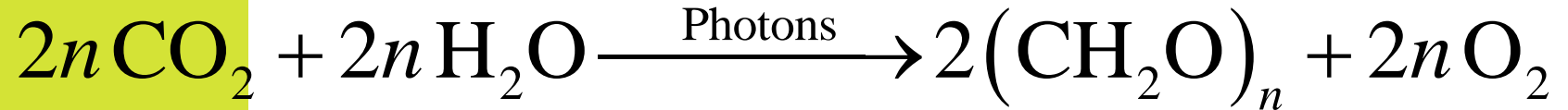
- ◎ In ecology: biological matter derived from living or recently living organisms.
- ◎ Legally (EU Directive): biodegradable fraction of products, waste and residues from agriculture, forestry and related industries, as well as biodegradable fraction of industrial and municipal waste.
- ◎ Physically: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

ENERGY CONVERSION DIAGRAM

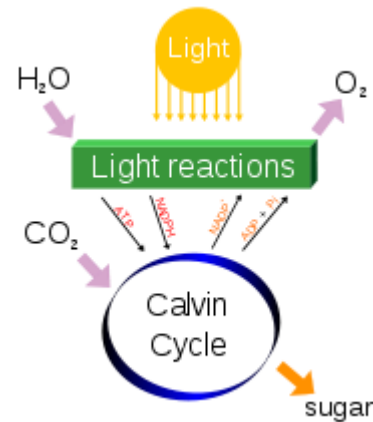
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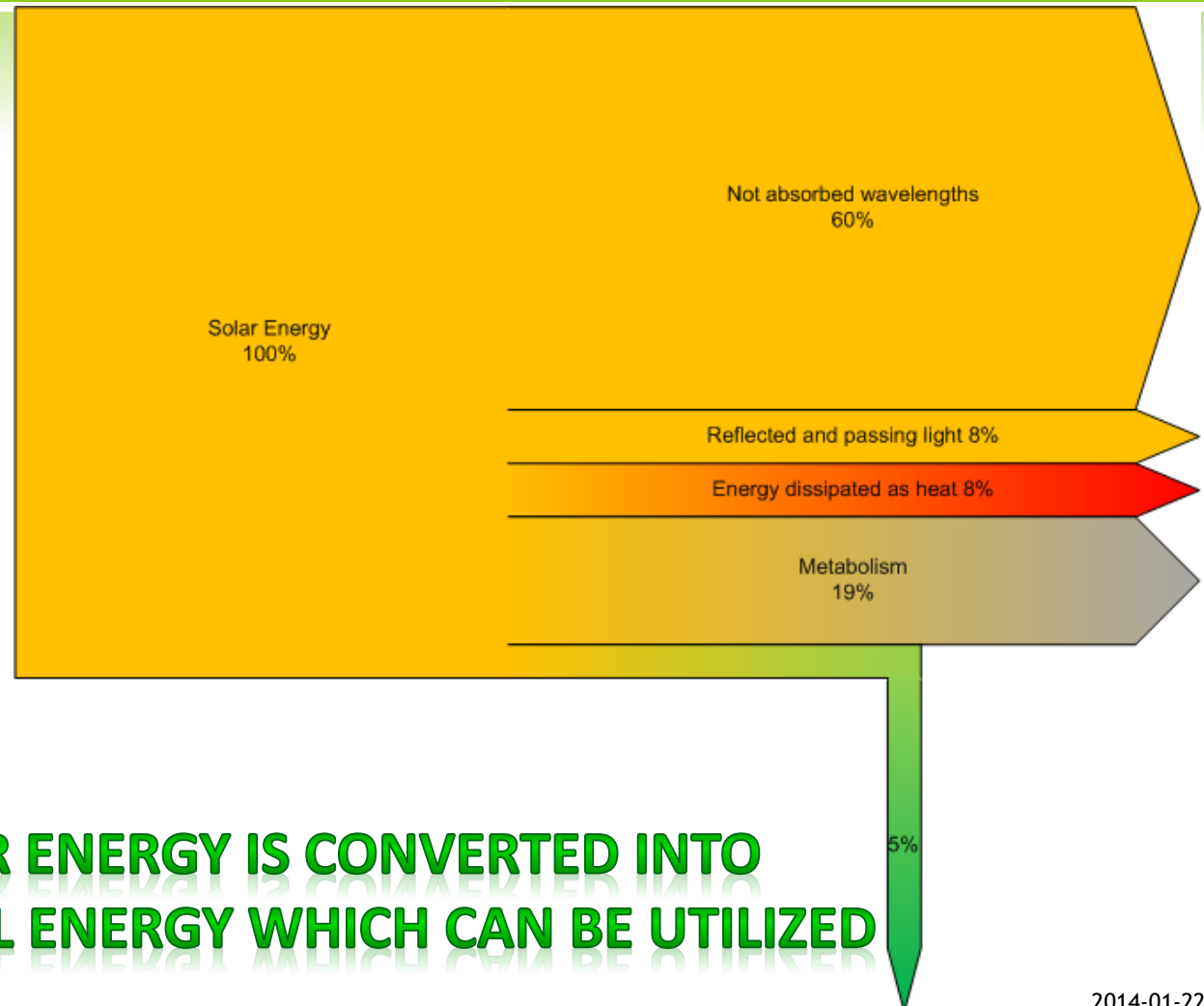
PHOTOSYNTHESIS



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

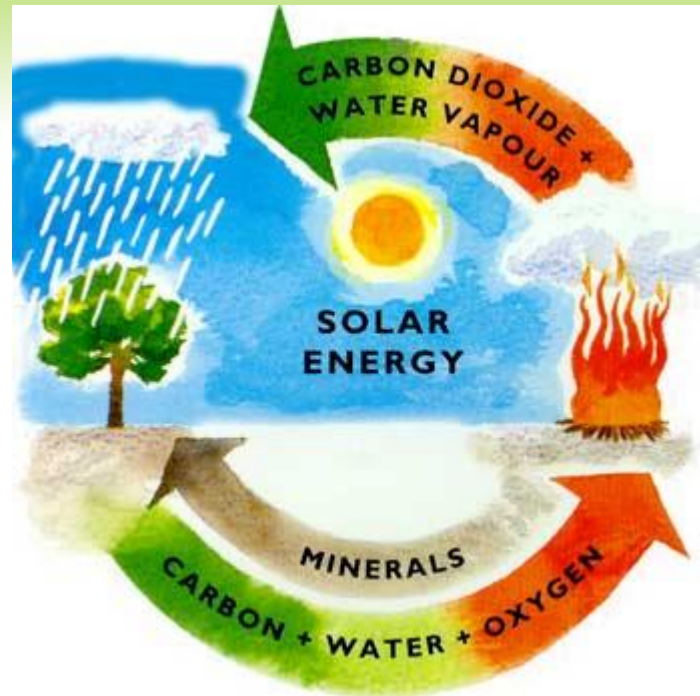
Biomass is combustible

BIOMASS CHEMICAL ENERGY STORAGE

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

WHY USE BIOMASS?

CLOSED CARBON CYCLE



Biomass is
a “zero-emission” fuel

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)

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

BIOFUELS BY GENERATION

First generation

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

Second generation

- Inedible oils
- Biohydrogen
- Biomethanol

Third generation biofuels

- Algae

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

SOLID BIOMASS APPLICATIONS

Combustion in custom-built power plants and heating plants

Co-combustion with fossil fuels (coal)

Production of liquid and gaseous biofuels

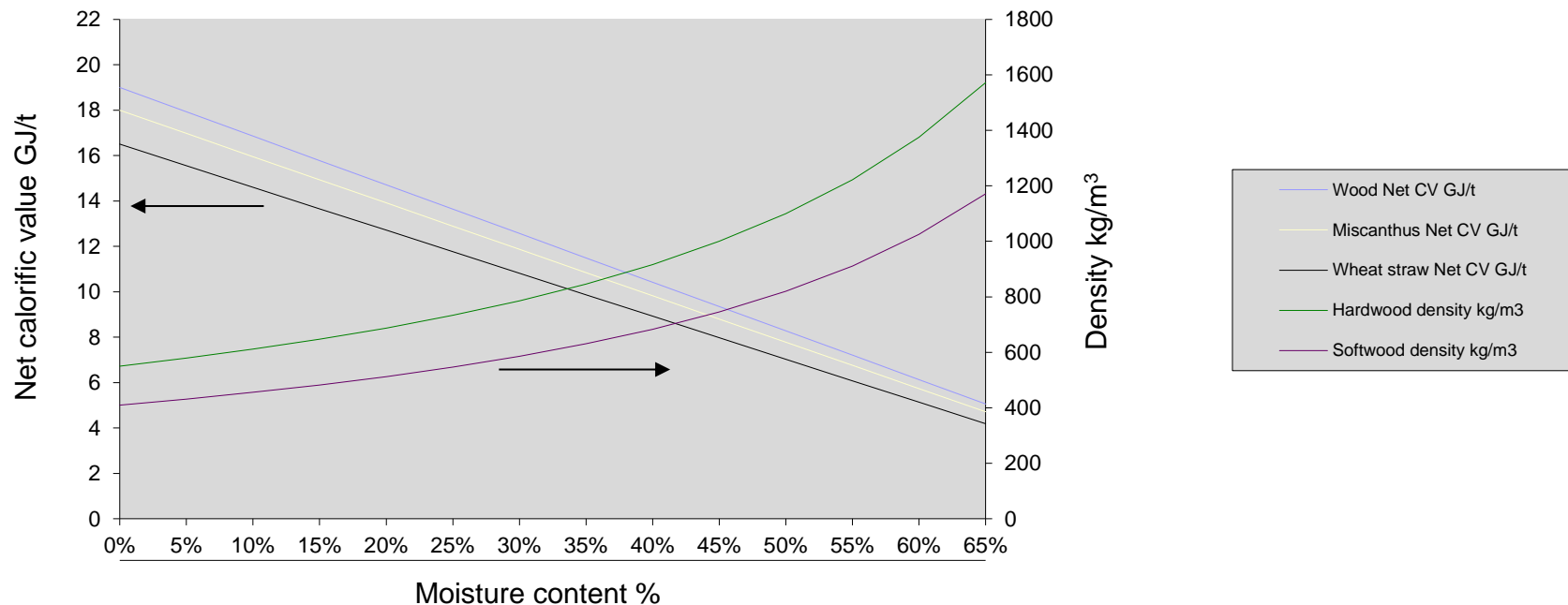
- Fermentation → bio-alcohols
- Fermentaton → biogas
- Pyrolysis → wood gas (Holzgas)

SOLID BIOFUELS VS. FOSSIL FUELS

Fuel	Energy density by mass		Bulk density kg/m ³	Energy density by volume	
	GJ/Mg	MWh/Mg		MJ/m ³	kWh/m ³
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

SOLID BIOMASS MOISTURE IMPACT

Net calorific value of biomass vs. moisture content



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



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)

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





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

SOLID BIOMASS FROM AGRICULTURE

Waste

- Spent grains
- Fruit processing waste
- Straw

Dedicated energy crops



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

STRAW AS A FUEL



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

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



- ◎ 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



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)

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

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*)



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



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



SPENT GRAIN FROM BREWERY

Spent grain



Woodchips



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



AQUATIC PLANTS

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

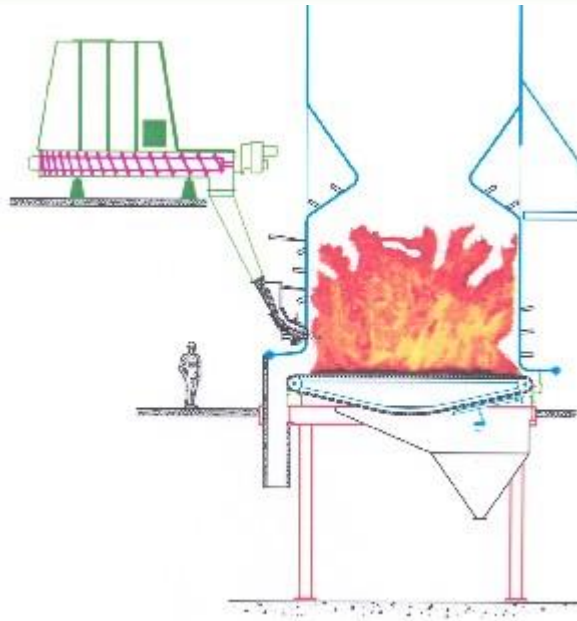
CO-COMBUSTION BIOMASS + FOSSIL FUELS

- ⊙ 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.



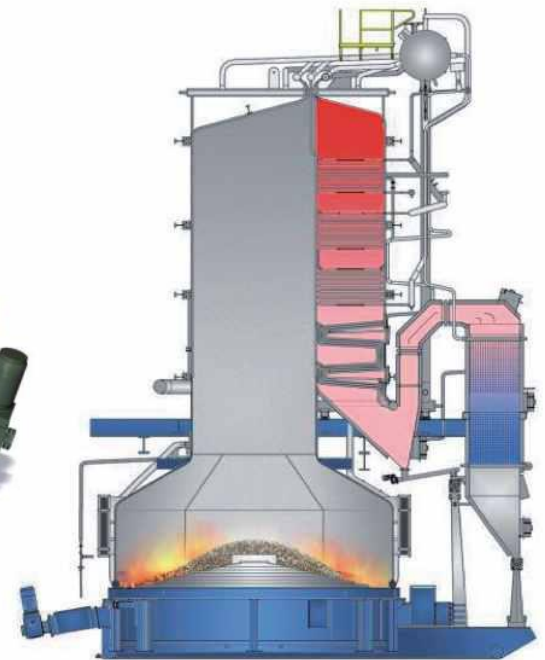
BIOMASS BOILER TECHNOLOGY

MOVING GRATE BOILER



BIOMASS BOILER TECHNOLOGY

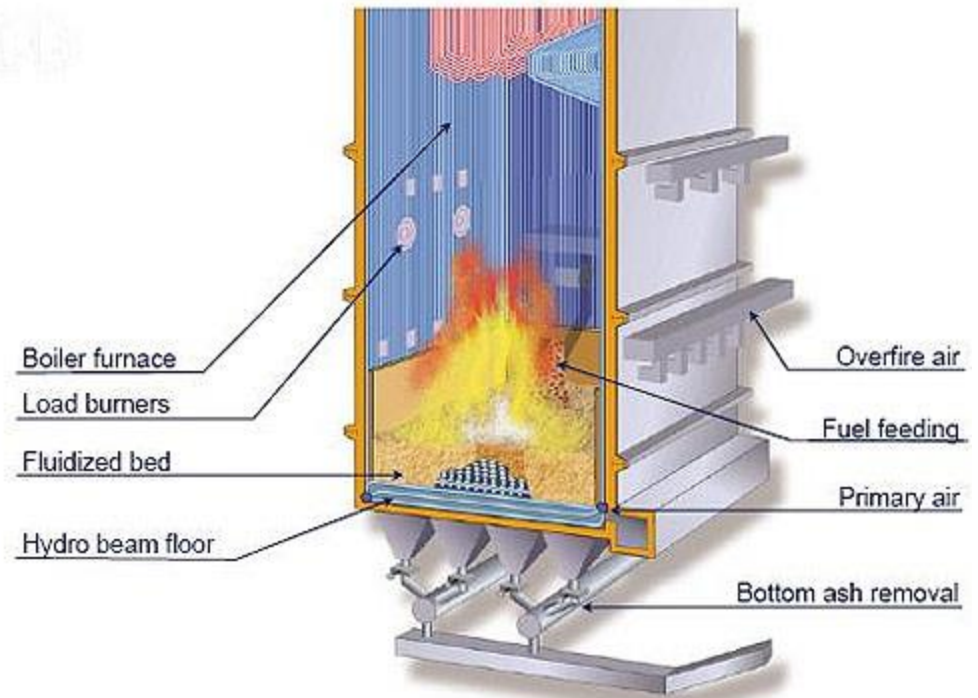
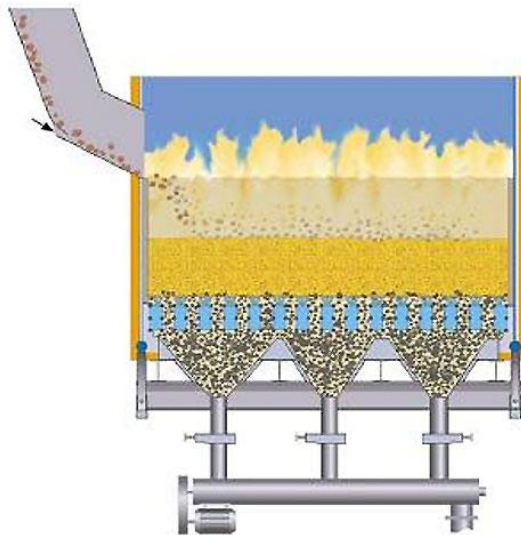
ROTATING GRATE BOILER




WÄRTSILÄ
mw power
metso-wärtsilä joint venture

BIOMASS BOILER TECHNOLOGY

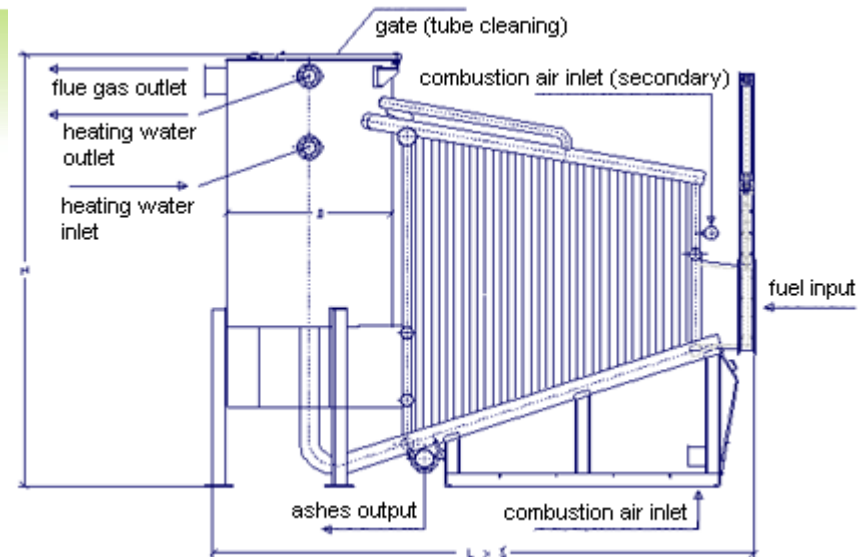
BUBBLING FLUIDIZED BED



STRAW BOILER TECHNOLOGY



STRAW BOILER TECHNOLOGY



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



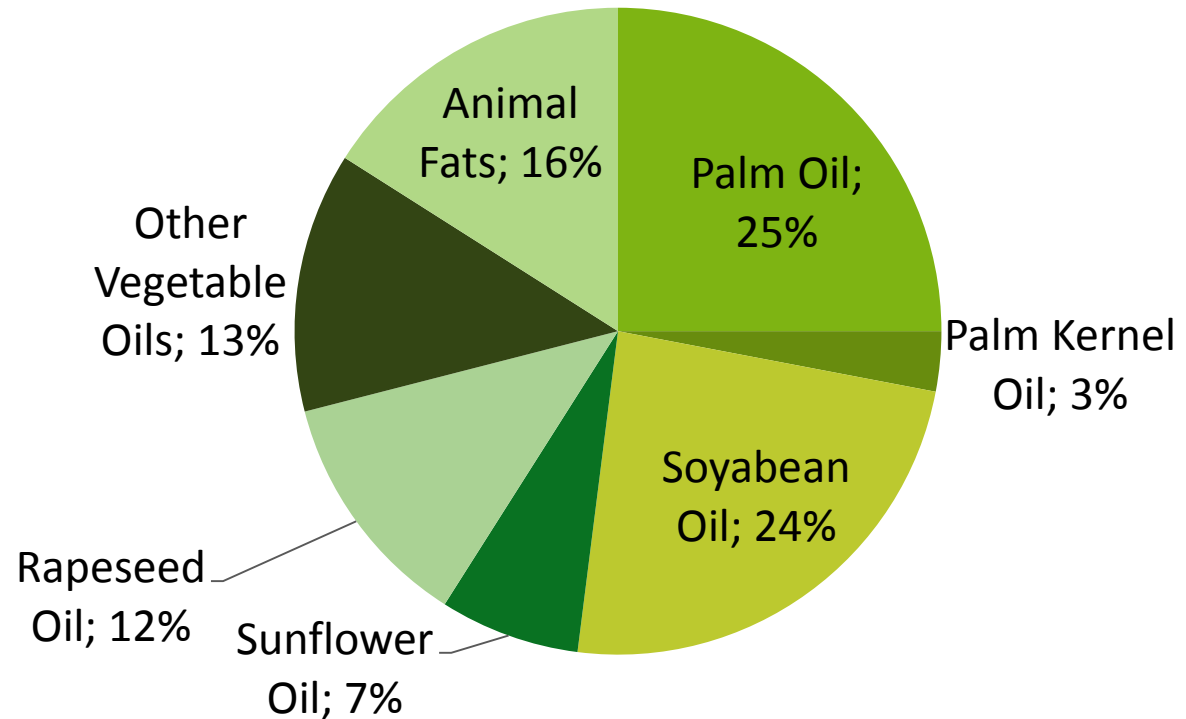
SMALL SCALE PELLET BOILER



LIQUID BIOFUELS

WORLD'S PRODUCTION OF OILS AND FATS IN 2007

Total production: 154 mi. Mg (without Jatropha)

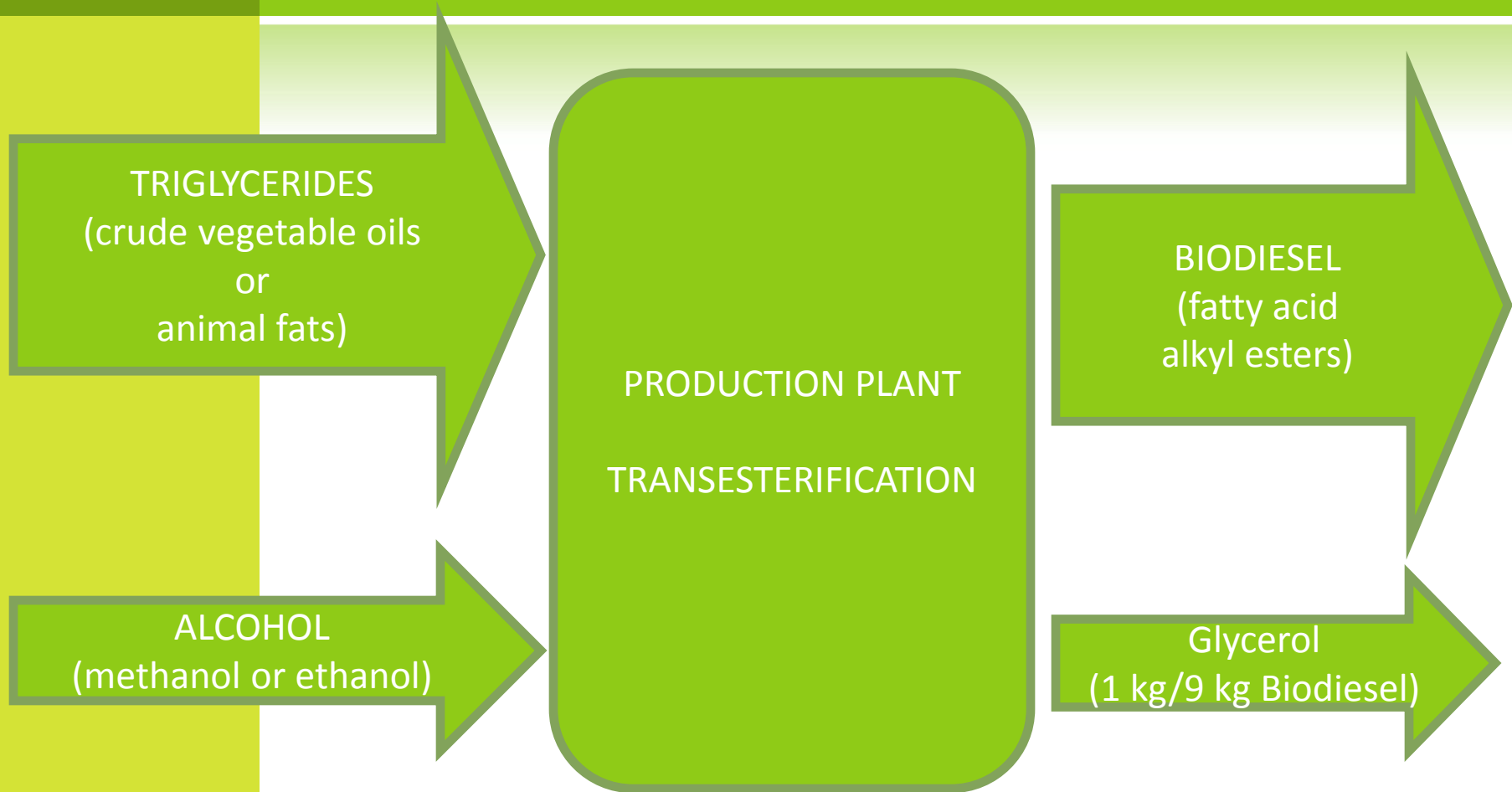


BIODIESEL (FAME)

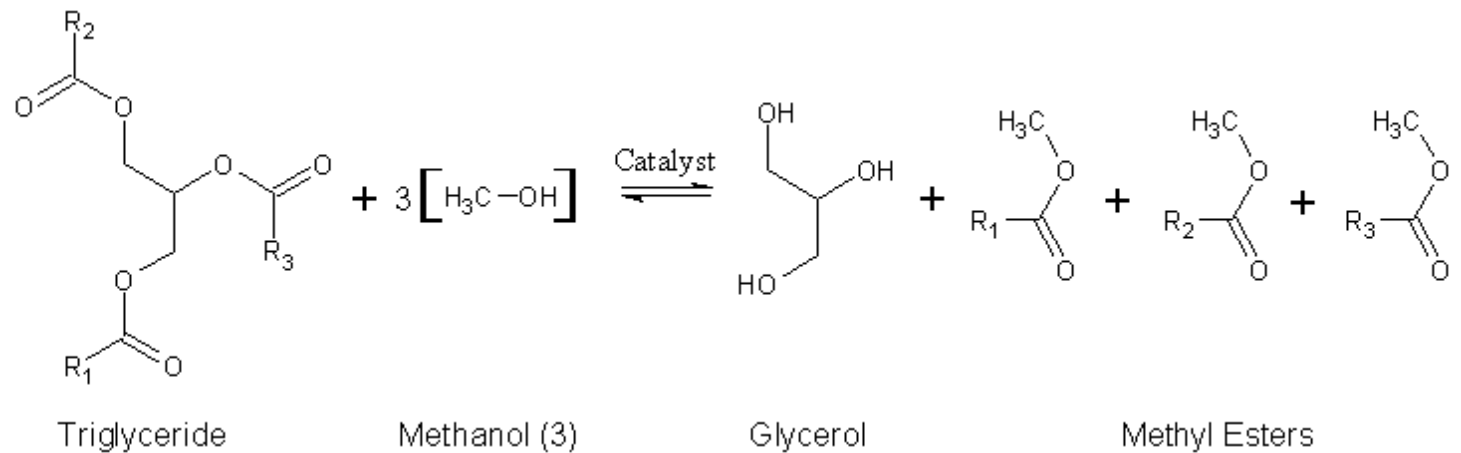
- ⊙ Biodiesel is a mixture of Fatty Acid Methyl Esters
- ⊙ Can be substituted for mineral diesel oil or light fuel oil for all types of machines and engines
- ⊙ Standards for biodiesel exist (EN14214)



BIODIESEL PRODUCTION



TRANSESTERIFICATION



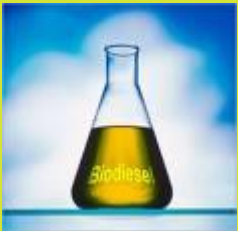
BIODIESEL PROPERTIES ACCORDING TO EN14214



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

BIODIESEL USAGE

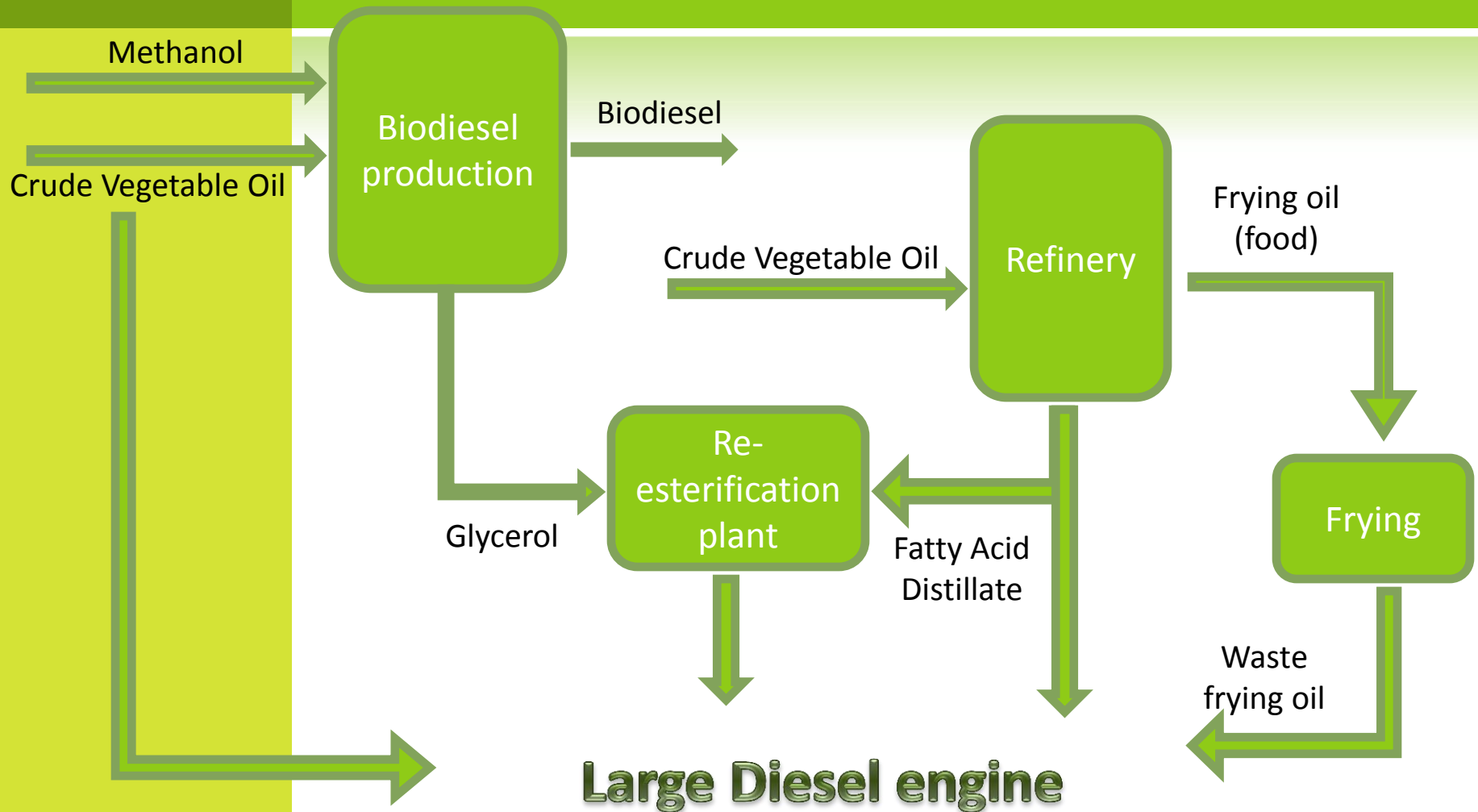
- ⊙ Can be freely substituted for mineral diesel oil
- ⊙ Can be used by any diesel engine
- ⊙ Mainly used in transport
- ⊙ Too expensive to be used for power generation
 - ⊙ Power industry can use cheaper unprocessed biofuels



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!

LIQUID 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



PALM OIL



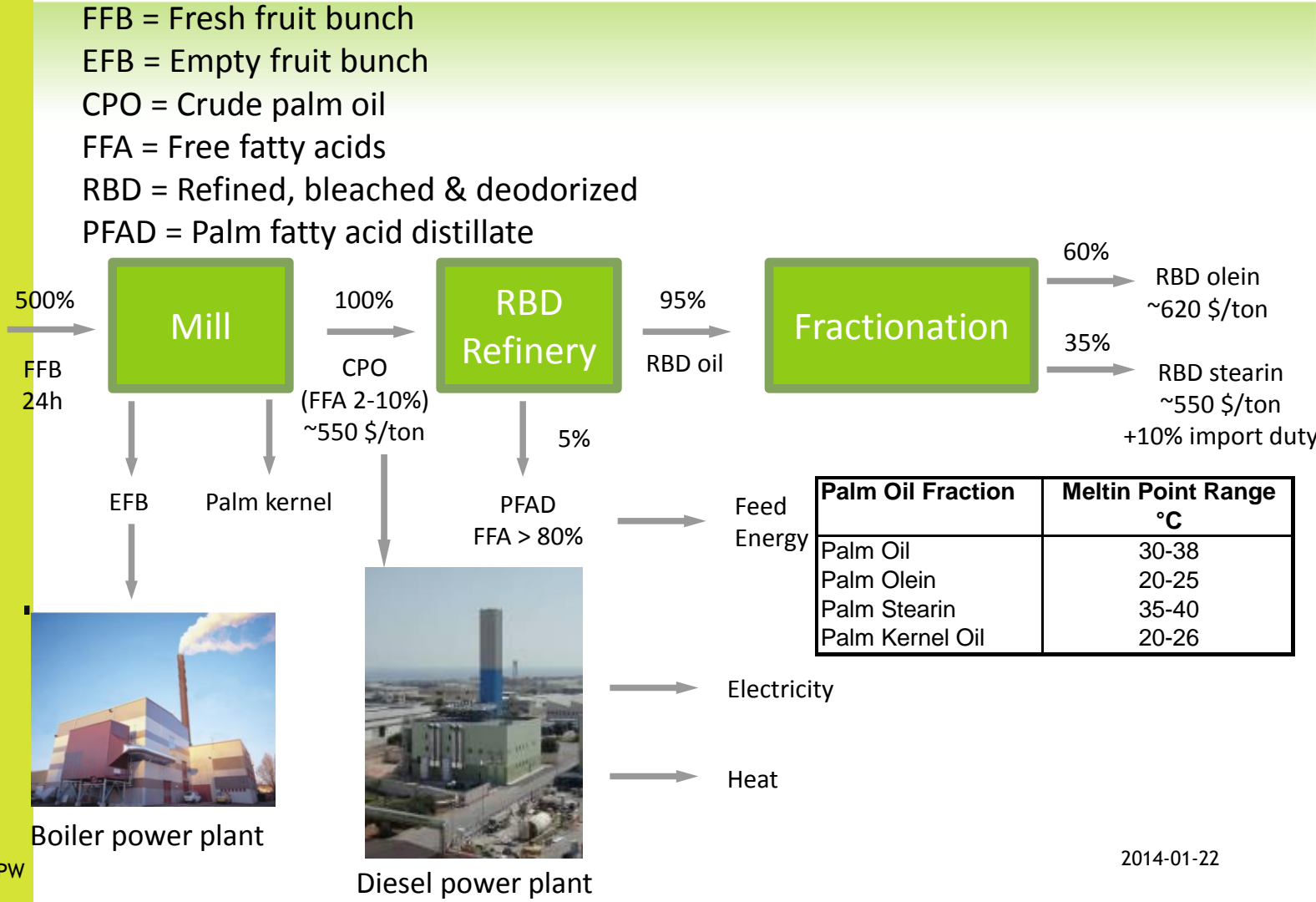
- ◎ Oil palm is the most rapidly expanding crop in South-East Asia
- ◎ Oil mainly used as food or in food industry
- ◎ Over 85% of production in Asia, Africa & Latin America
- ◎ Annual yield – 4000-6000 dm³/ha
- ◎ Malaysia and Indonesia plan to divert 40% of their palm oil output for fuel market

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

PALM OIL PRODUCTION



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

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.

JATROPHA OIL



GEOGRAPHY

JATROPHA VS. OIL PALM



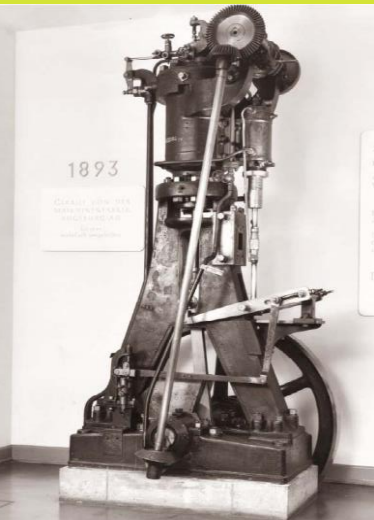
RAPSEED OIL



- ◎ 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

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 efficiency
 - ⊙ Up to 48% simple cycle
 - ⊙ Over 50% combined cycle
- ⊙ Increased NO_x 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

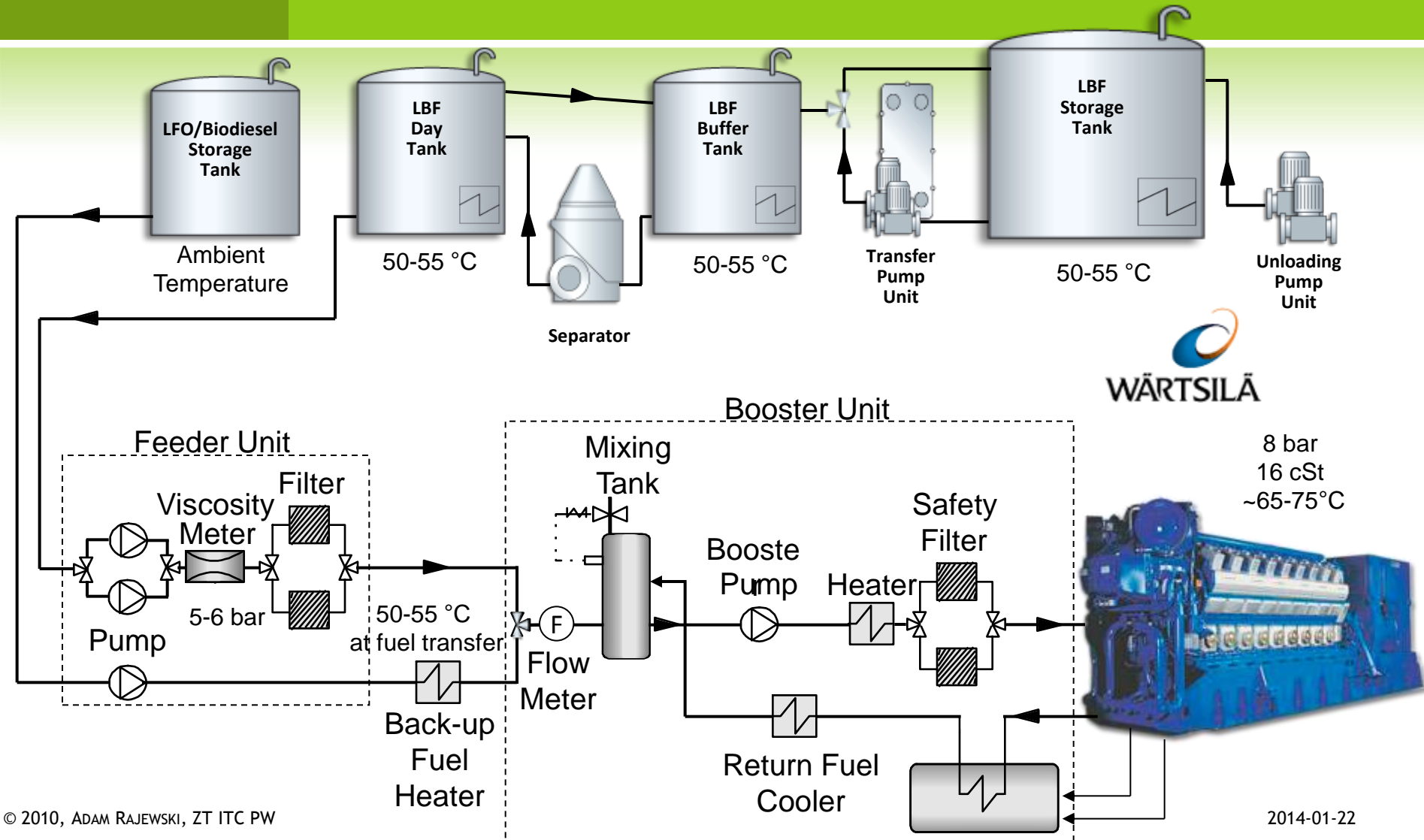


CRUDE VEGETABLE OIL PROPERTIES

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Property	Unit	Wärtsilä	Typical	Typical	Typical	Typical
		LBF	Crude Palm	Jatropha	Diesel	Heavy Fuel
		Spec.	Oil	Oil	Oil	Oil
Viscosity, max.	cSt @ 40 °C	100	39	36	3.5	700
Density, max.	kg/m ³ @ 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





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





S.E.C.A. PIOMBINO FUEL





S.E.C.A. PIOMBINO

FUEL FILTER CLEANING





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



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



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.



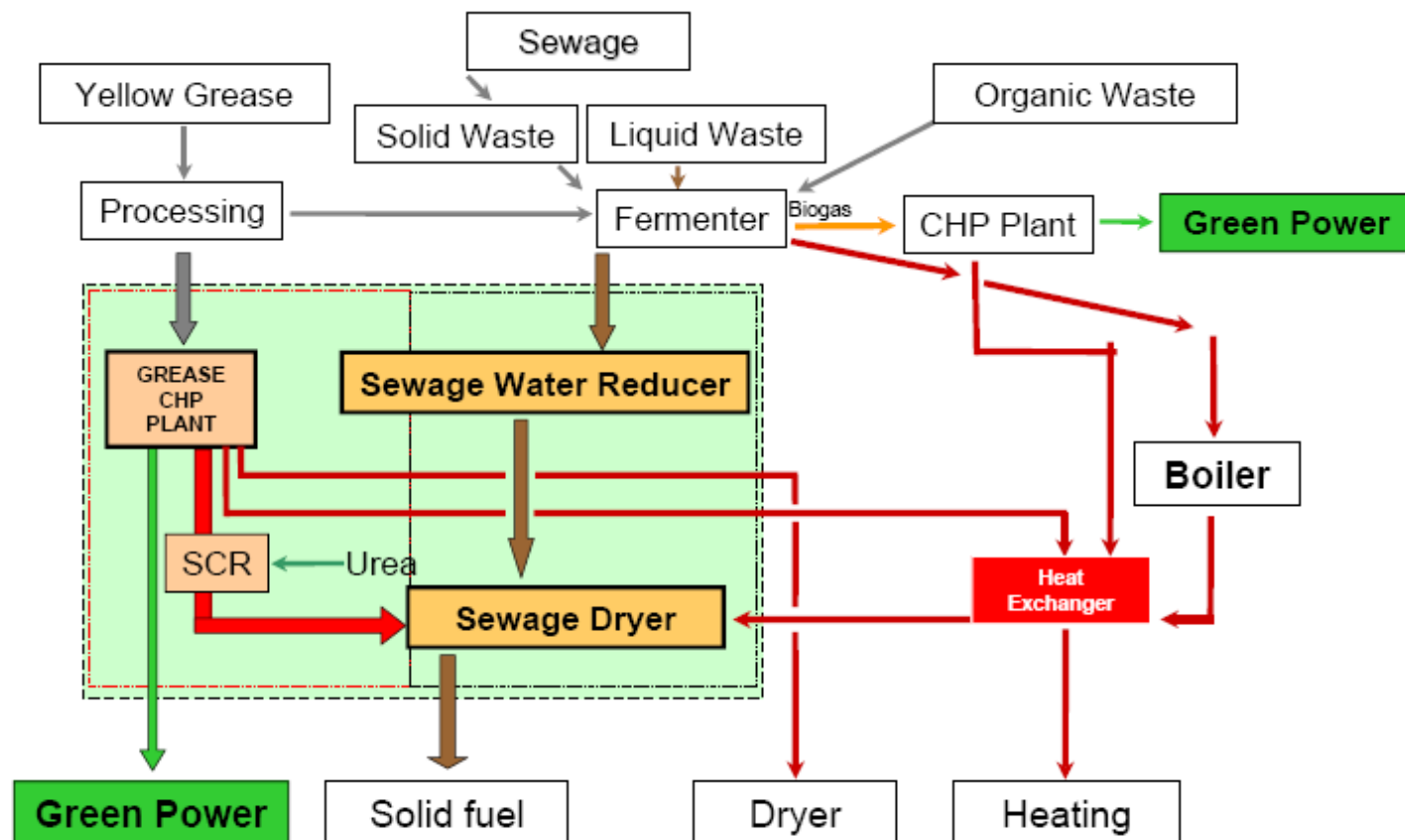
FRITZENS, AUSTRIA

- ③ Installation at a wastewater treatmentn plant
- ③ Single MAN engine, 1.1 MWe, 1.3 MWth
- ③ Oil from restaurants & households
- ③ Municipal oil collection scheme





FRITZENS, AUSTRIA



BIOETHANOL

- ③ Alcohols (mainly ethanol and methanol) can be used as fuels
- ③ Ca. 95% of world's ethanol is produced from biological sources (other 5% is a petroleum product)
- ③ Ethanol (pure or blend with petrol) is suitable as fuel for spark-ignited (Otto) car engines
- ③ Ethanol blend can be also used in Diesel engine

BIOETHANOL PRODUCTION



Fermentation



Distillation

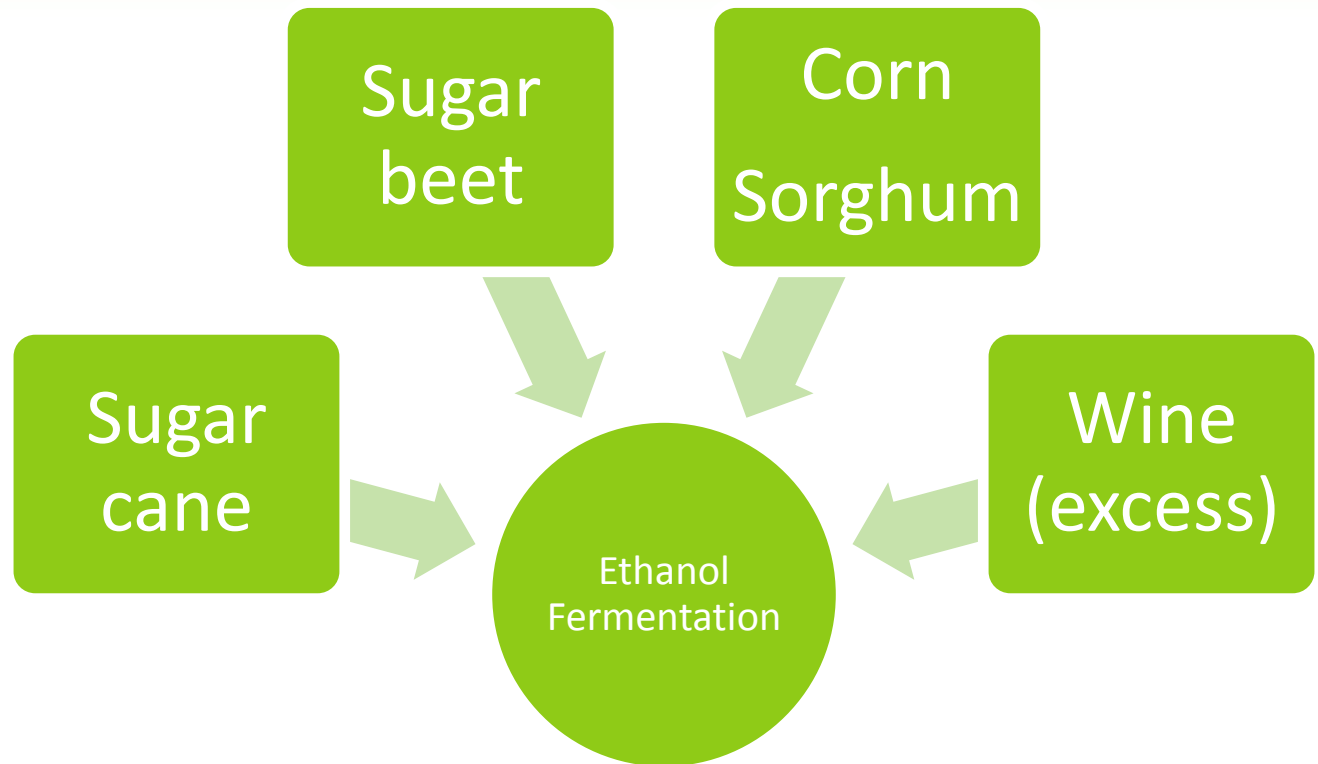


Dehydration



Denaturing (optional)

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.



WITH 10%
ETHANOL
(GASOHOL)

BIOMETHANOL

- ⊙ Methanol is produced from pyrolysis 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

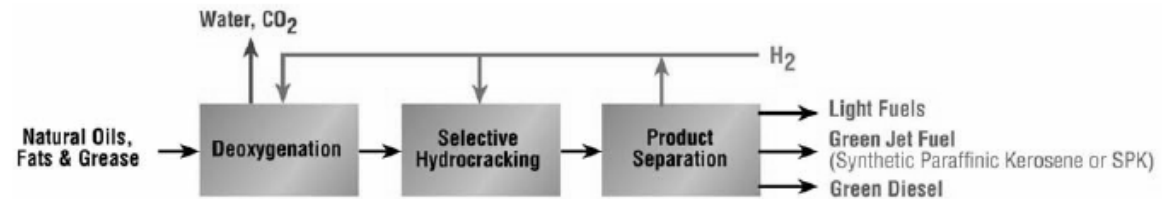


JATROPHA FUEL FOR AIRCRAFT



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 Jatropa (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



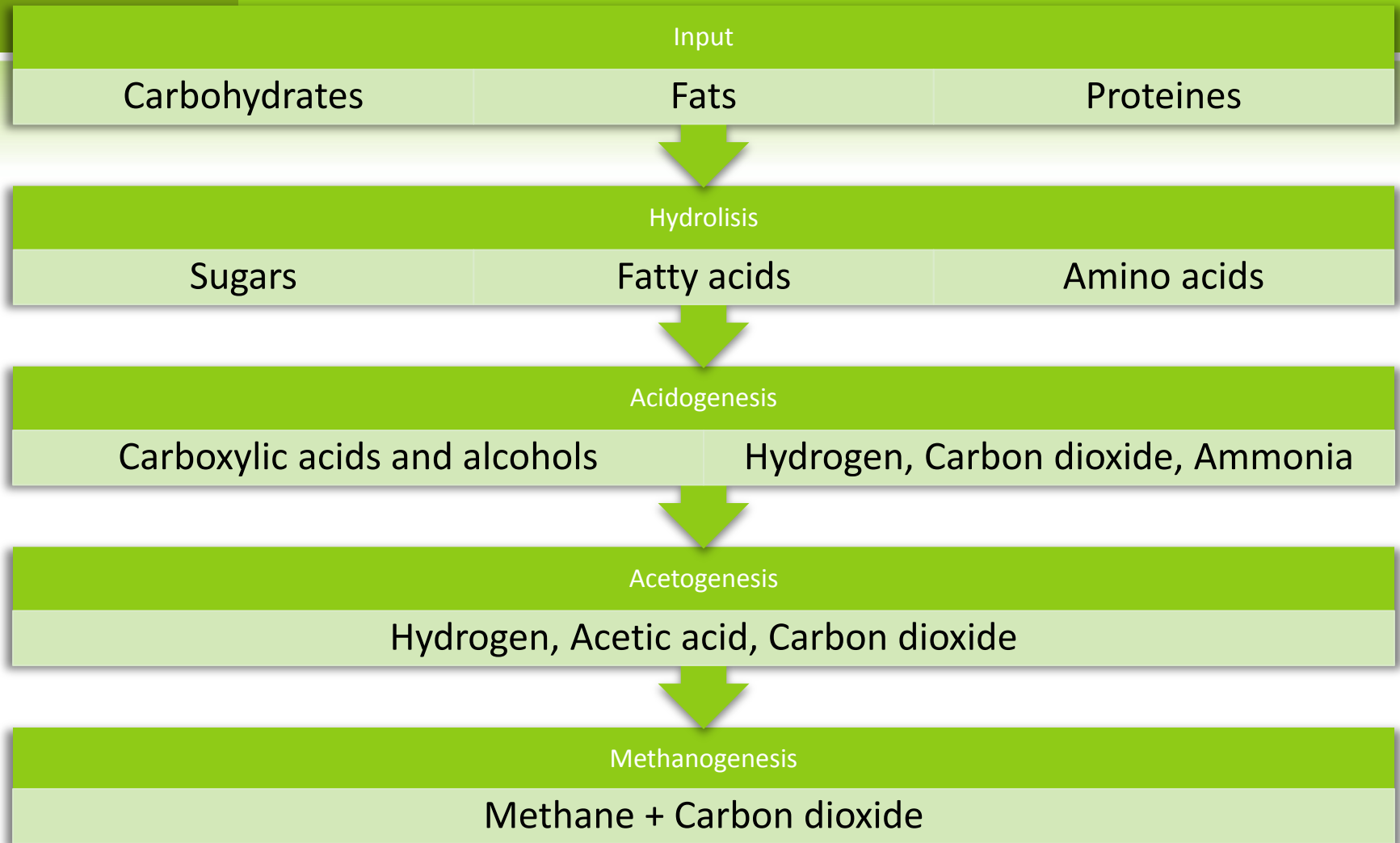
GASEOUS BIOFUELS

- ◎ Result of anaerobic biological breakdown of organic matter
- ◎ Production methods:
 - ◎ Anaerobic digestion → “proper” biogas
 - ◎ Gasification → wood gas (technically also biogas)
- ◎ LHV 17...28 MJ/m³ (natural gas ca. 34 MJ/m³)

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 ₂ S	0	3
Oxygen	O ₂	0	2

ANAEROBIC DIGESTION



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

BIOGAS SOURCES

Waste treatment

- Digestion of wastewater sludge
- Digestion of mixed municipal waste

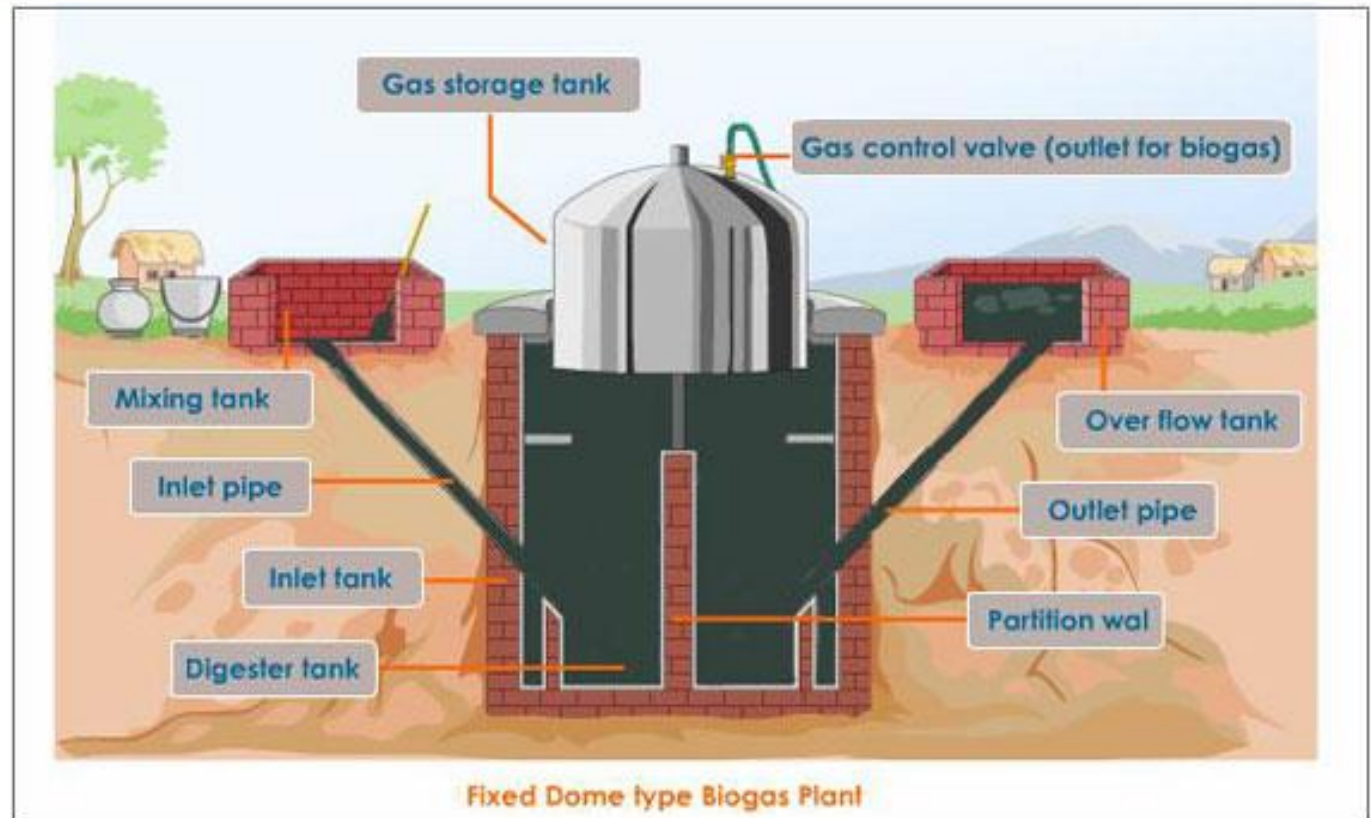
Agriculture

- Digestion of biological waste

Landfills

- Landfill gas (LFG)

ARGRICULTURAL BIOGAS PRODUCTION



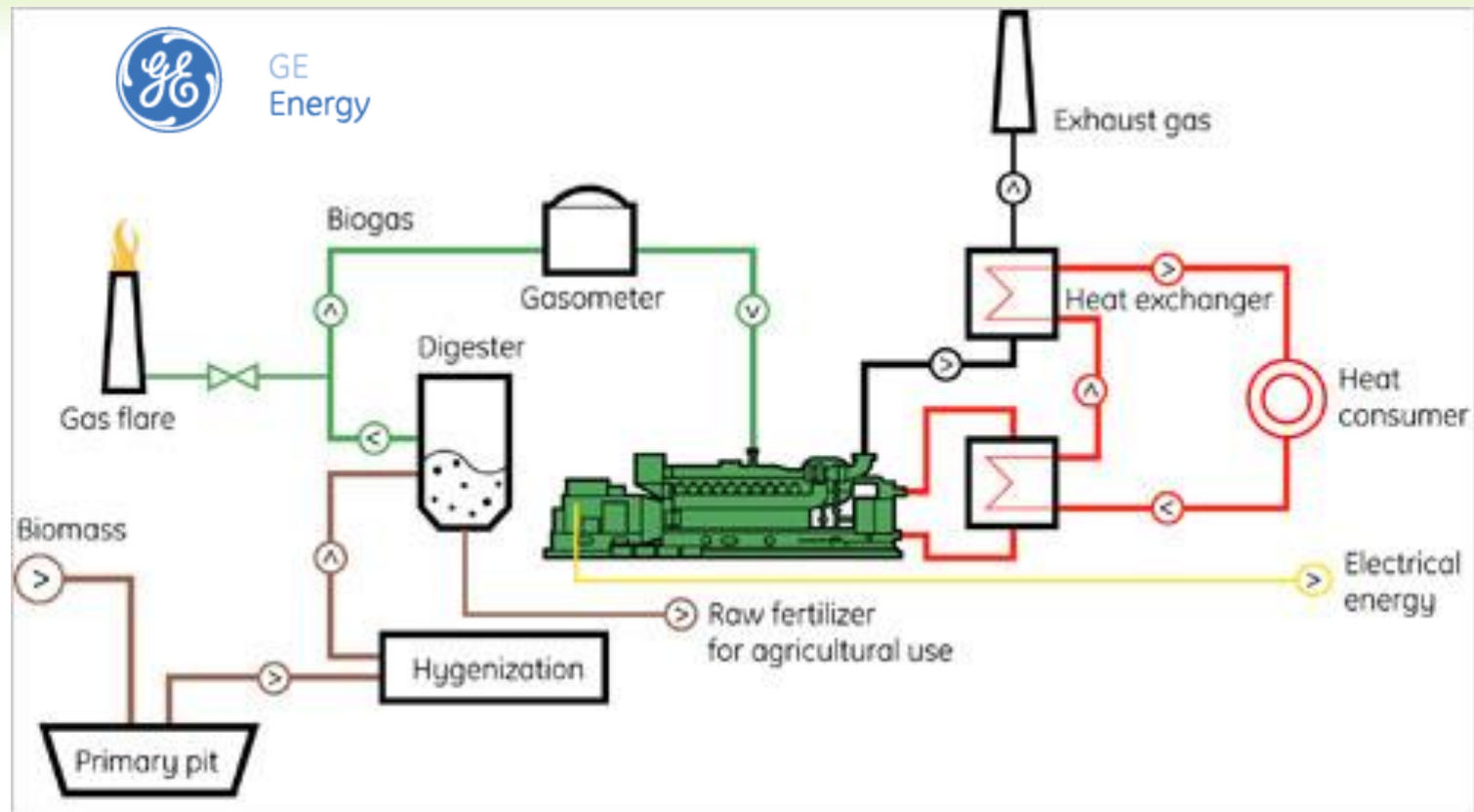
ARGRICULTURAL BIOGAS PRODUCTION



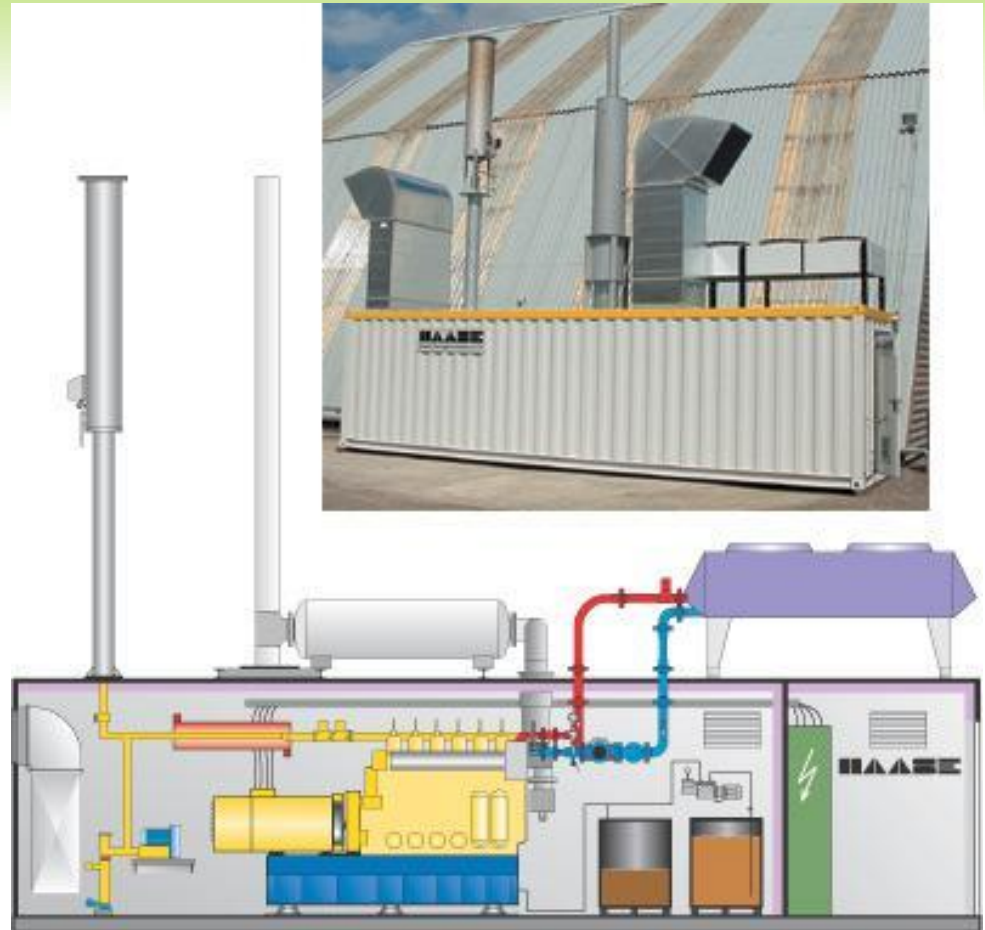
- ⊙ Feedstock:
 - ⊙ Manure
 - ⊙ Silage
 - ⊙ Grass
 - ⊙ Corn
 - ⊙ Slaughterhouse waste
 - ⊙ Waste fats & oils
 - ⊙ Food waste



AGRICULTURAL BIOGAS PLANT CONCEPT



AGRICULTURAL BIOGAS PLANT CONCEPT



WOLKOW BIOGAS PLANT



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

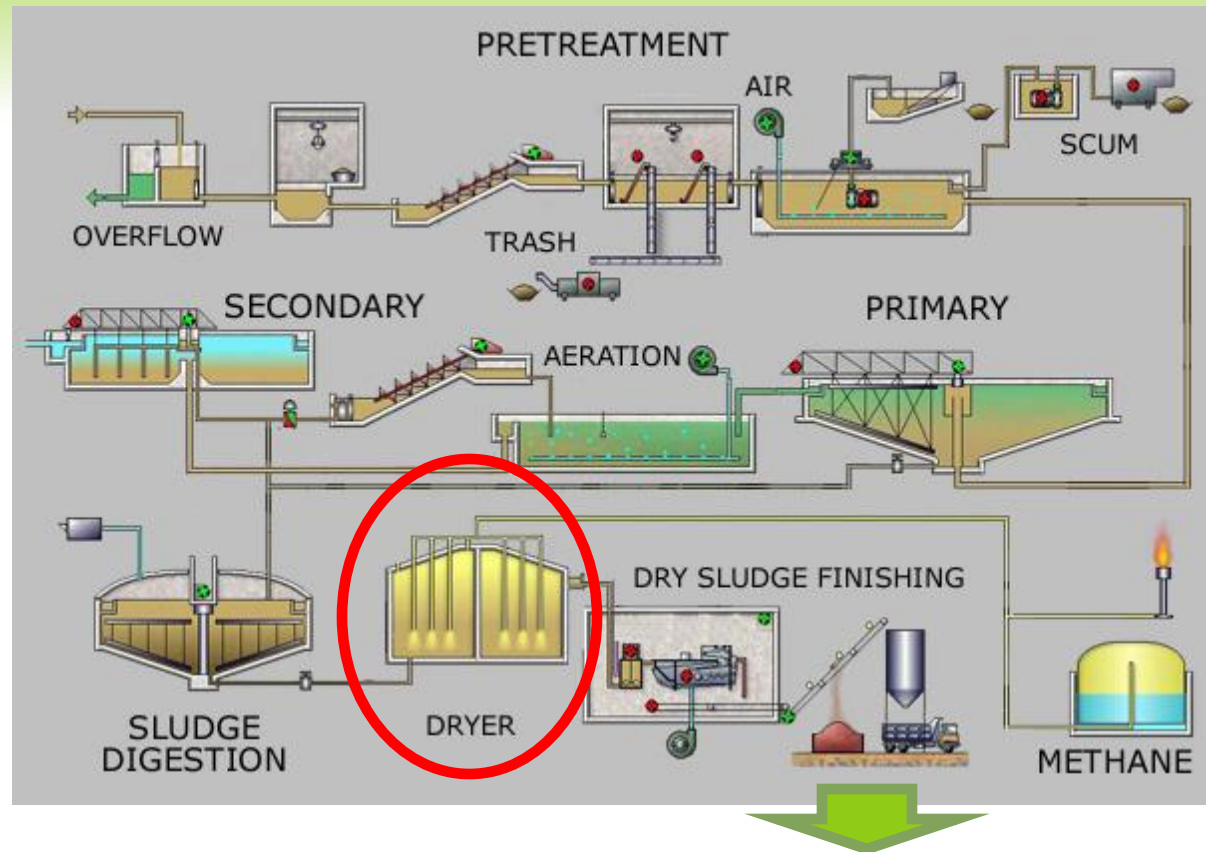


WOLKOW BIOGAS PLANT



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 sludge and screenings
- ◎ Combined cycle unit



VERA HAMBURG



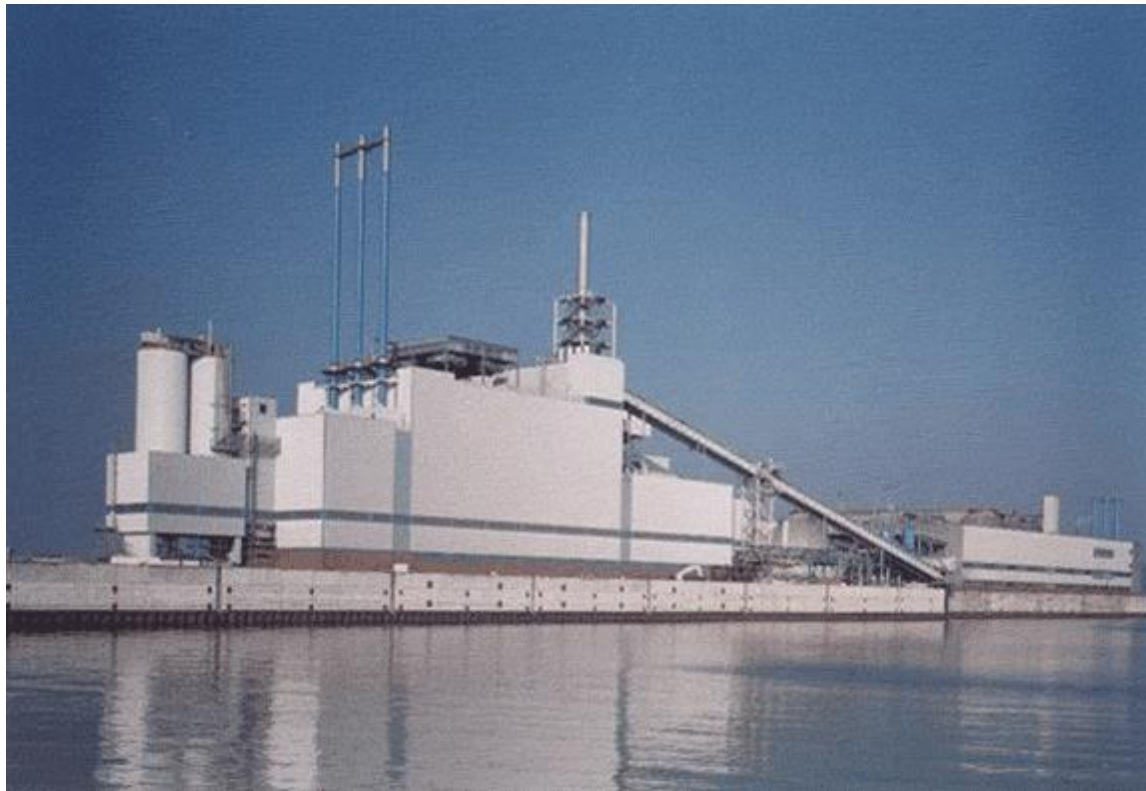


VERA HAMBURG



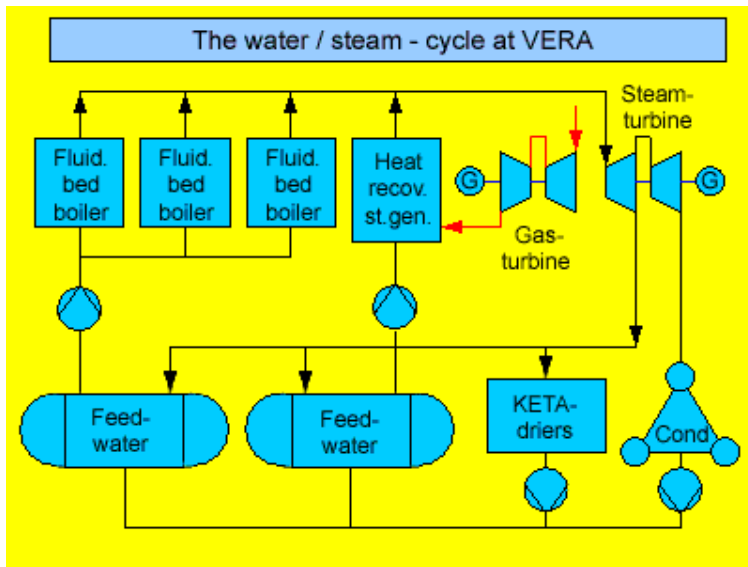


VERA HAMBURG





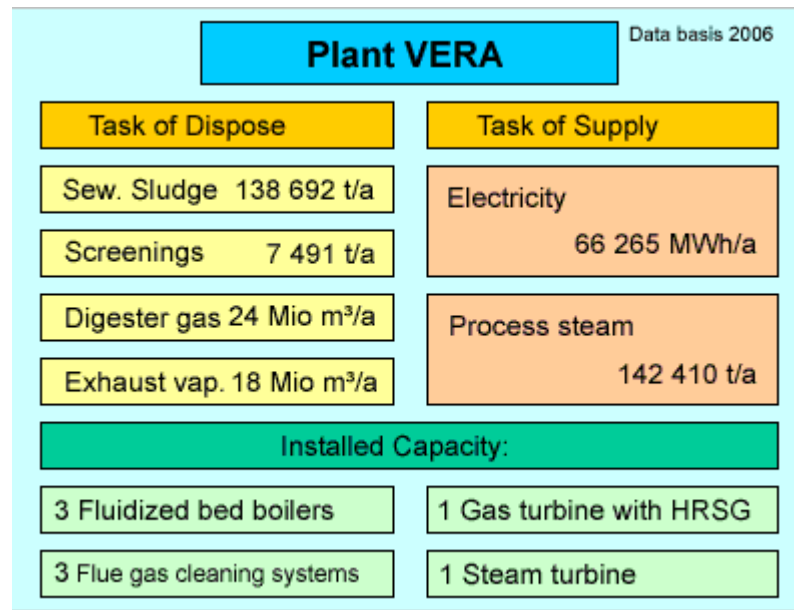
VERA HAMBURG PROCESS SCHEME



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



VERA HAMBURG



+ 1 reciprocating engine (as of 2008)



VERA HAMBURG

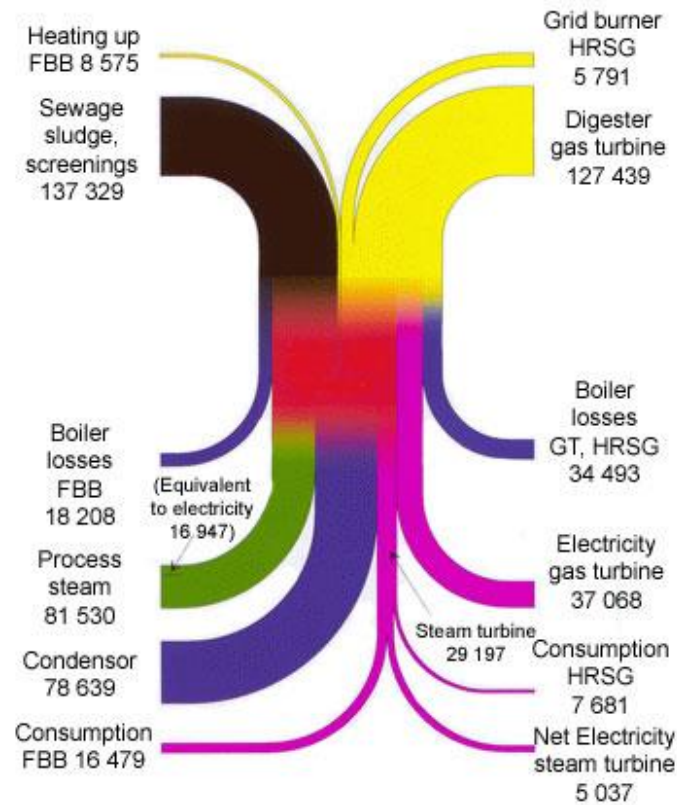


- | | | |
|-------------------------|------------------------------|------------------------|
| 1. Sluge conveyor | 7. ESP | 13. Boiler stack |
| 2. | 8. Heat exchanger | 14. Fly ash silos |
| 3. Receiving tanks | 9. HCl Scrubber | 15. Gas turbine unit |
| 4. Proportioning silo | 10. SO ₂ Scrubber |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



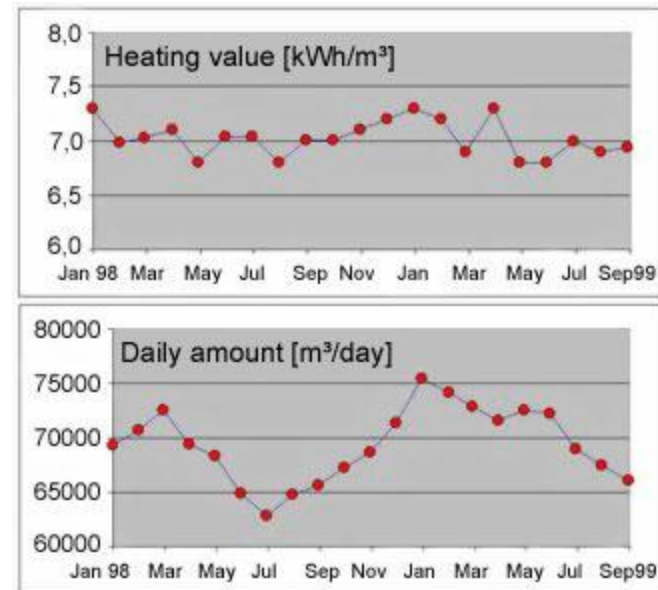
VERA HAMBURG

Diagram of Energy Flow at VERA



all data in MWh/a, data basis 2006

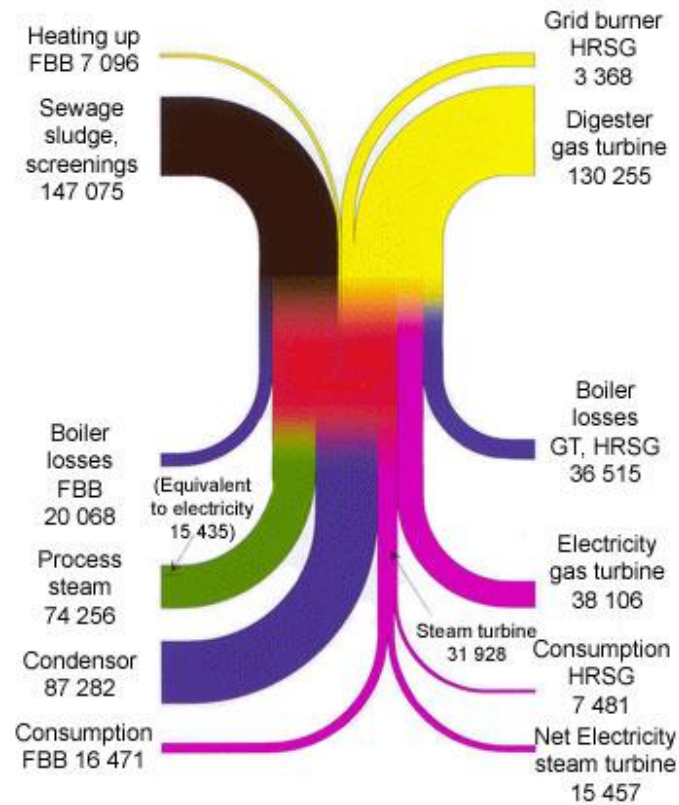
Gas properties at VERA plant:





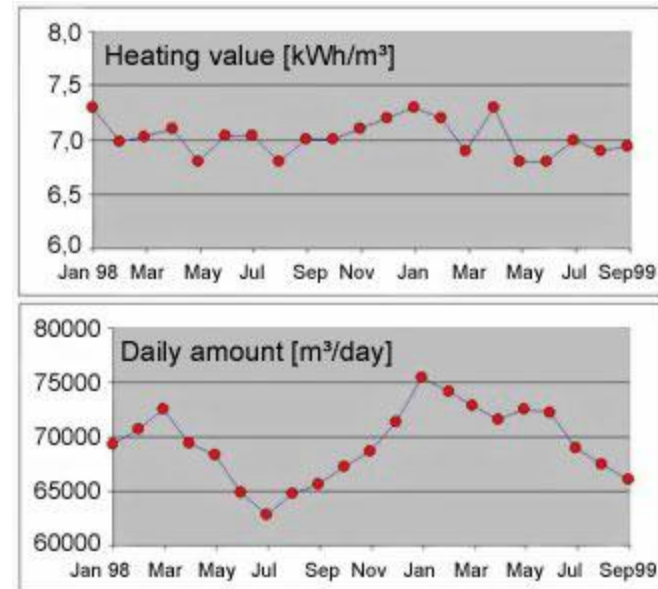
VERA HAMBURG

Diagram of Energy Flow at VERA



all data in MWh/a, data basis 2009

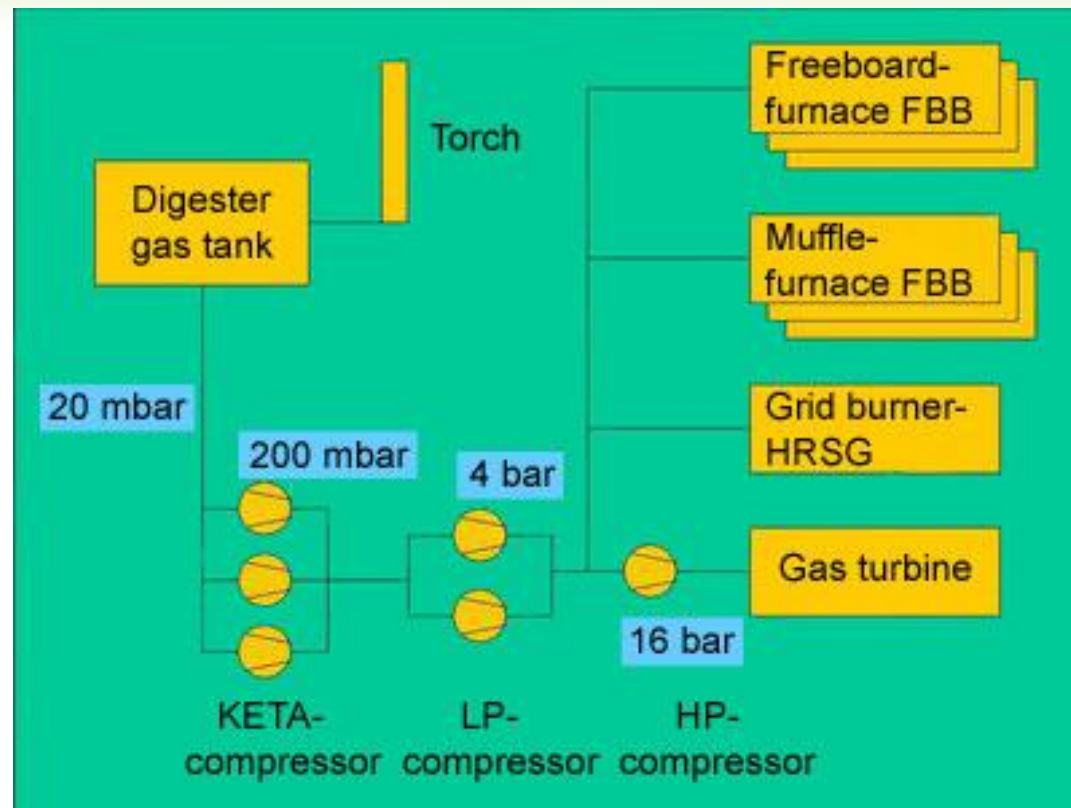
Gas properties at VERA plant:





VERA HAMBURG

BIOGAS FLOW

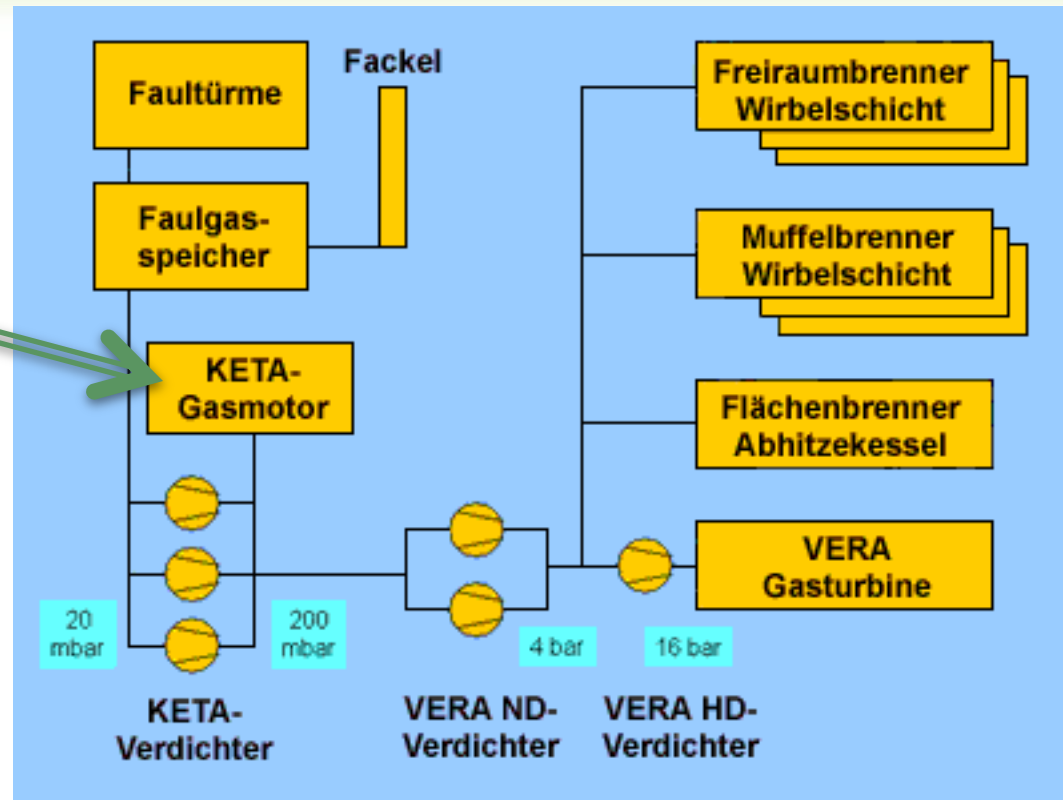




VERA HAMBURG

BIOGAS FLOW

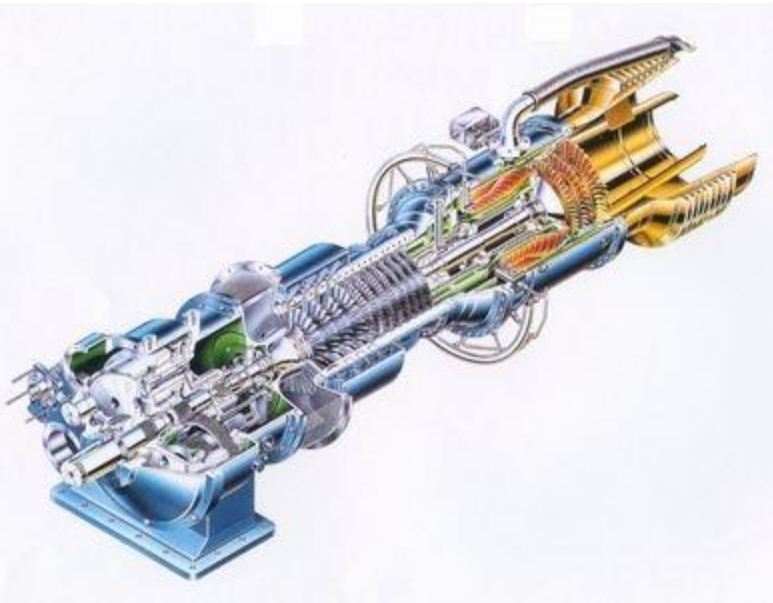
NEW
GAS ENGINE





VERA HAMBURG GAS TURBINE UNIT

Solar Turbines
A Caterpillar Company

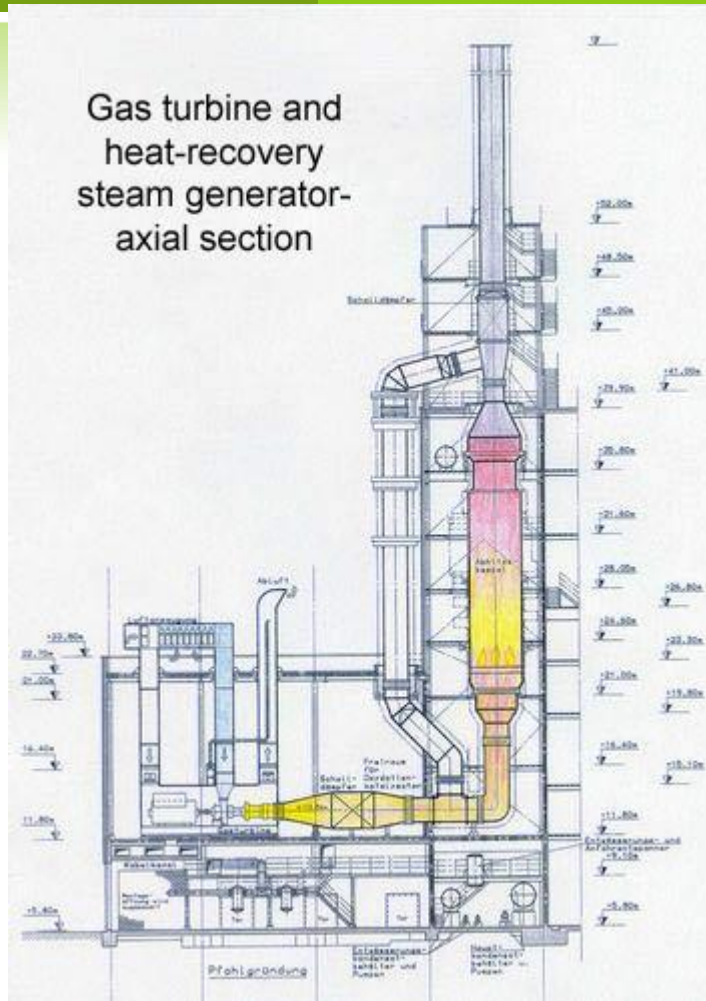


- ⊙ Solar Taurus 60 S
- ⊙ Rated output 5 MW_{el}
- ⊙ Compression ratio 12
- ⊙ Turbine speed 14,950 rpm
- ⊙ Generator speed 1500 rpm
- ⊙ Exhaust gas temperature 480°C



VERA HAMBURG

HEAT RECOVERY STEAM GENERATOR

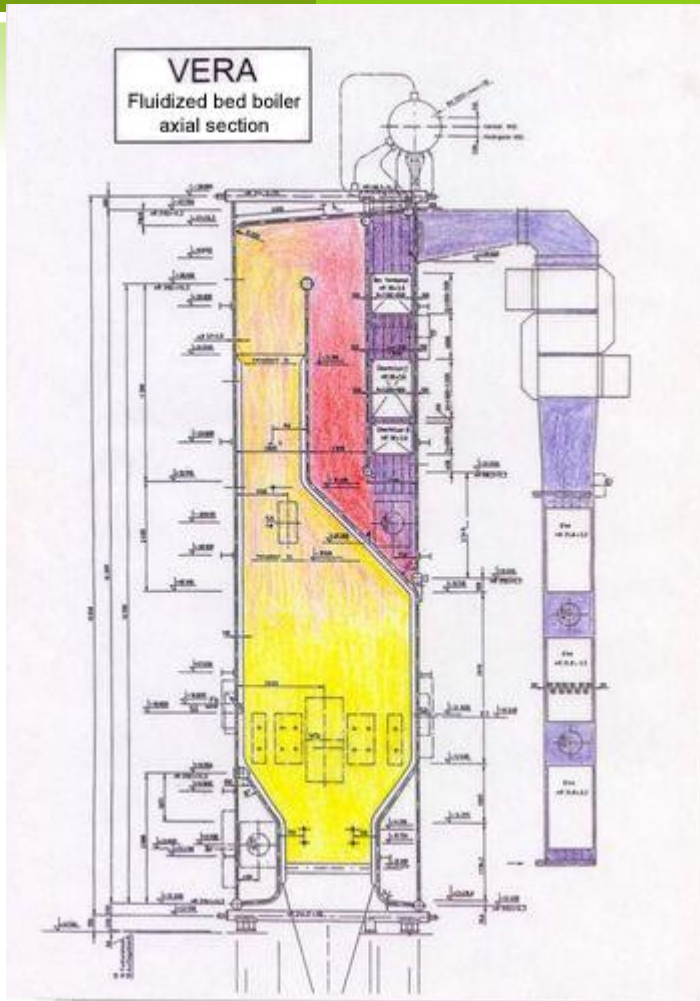


- ⊙ Inlet gas temperature 480°C
- ⊙ Exhaust gas temperature 180°C
- ⊙ Natural circulation boiler
- ⊙ Live steam pressure 40 bar
- ⊙ Live steam temperature 400°C
- ⊙ HR mode capacity 9 Mg/h
- ⊙ Possible supplementary gas firing up to 18 Mg/h
- ⊙ Possible fresh-air operation up to 22 Mg/h



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

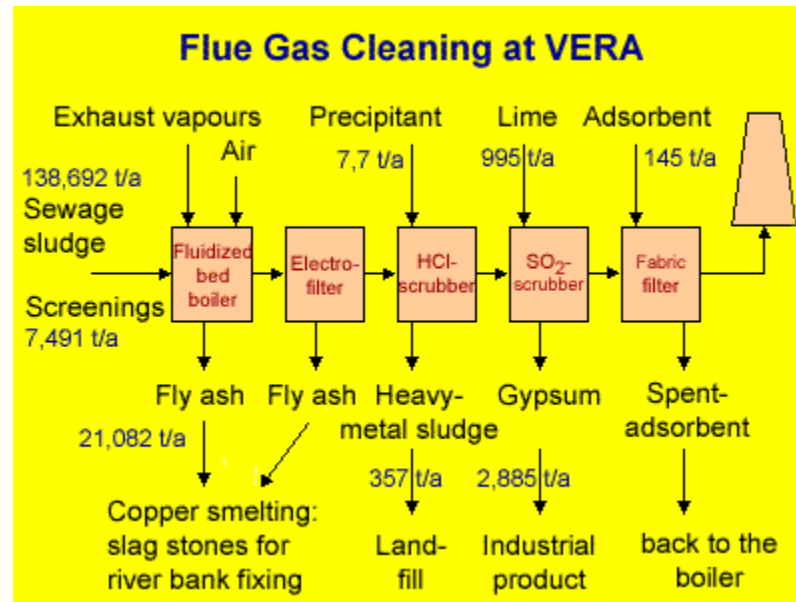
WASTEWATER SLUDGE - BOILER FUEL





VERA HAMBURG

FLUE GAS CLEANING UNIT





VERA HAMBURG

GAS ENGINE-GENERATOR UNIT

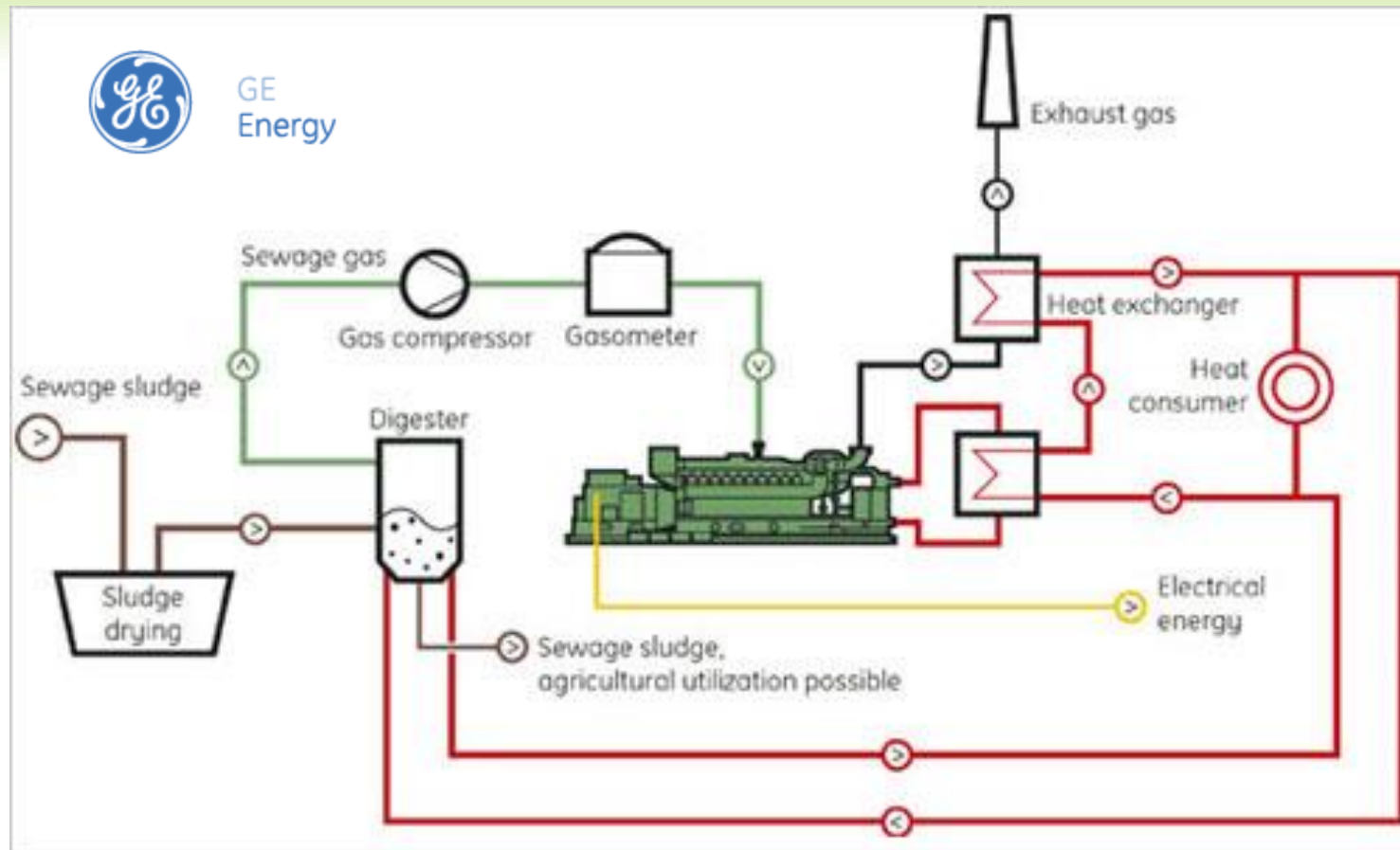


- ⊙ Supplier: CAT-Zeppelin
- ⊙ Engine: Cat 3520C
- ⊙ 20-cylinder V engine
- ⊙ Cummins AvK generator
- ⊙ Rated output 2035 kW
- ⊙ Efficiency 39.5%
- ⊙ Process heat for sludge drying

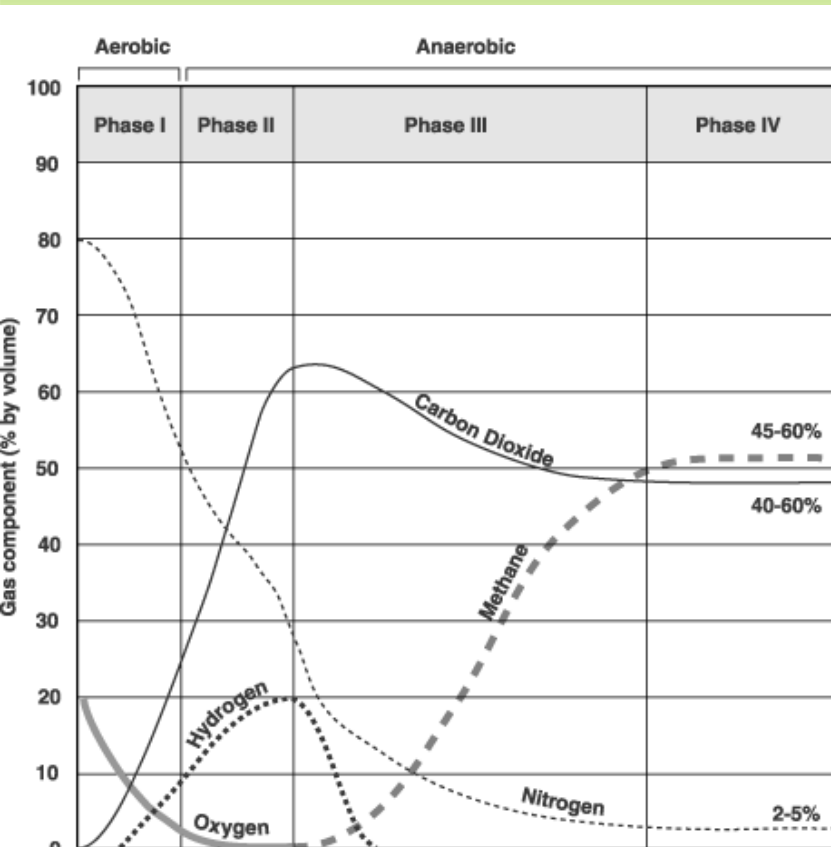
ZEPPELIN
Power Systems



WASTEWATER TREATMENT PLANT - SMALL SCALE



LANDFILL GAS



Note: Phase duration time varies with landfill conditions

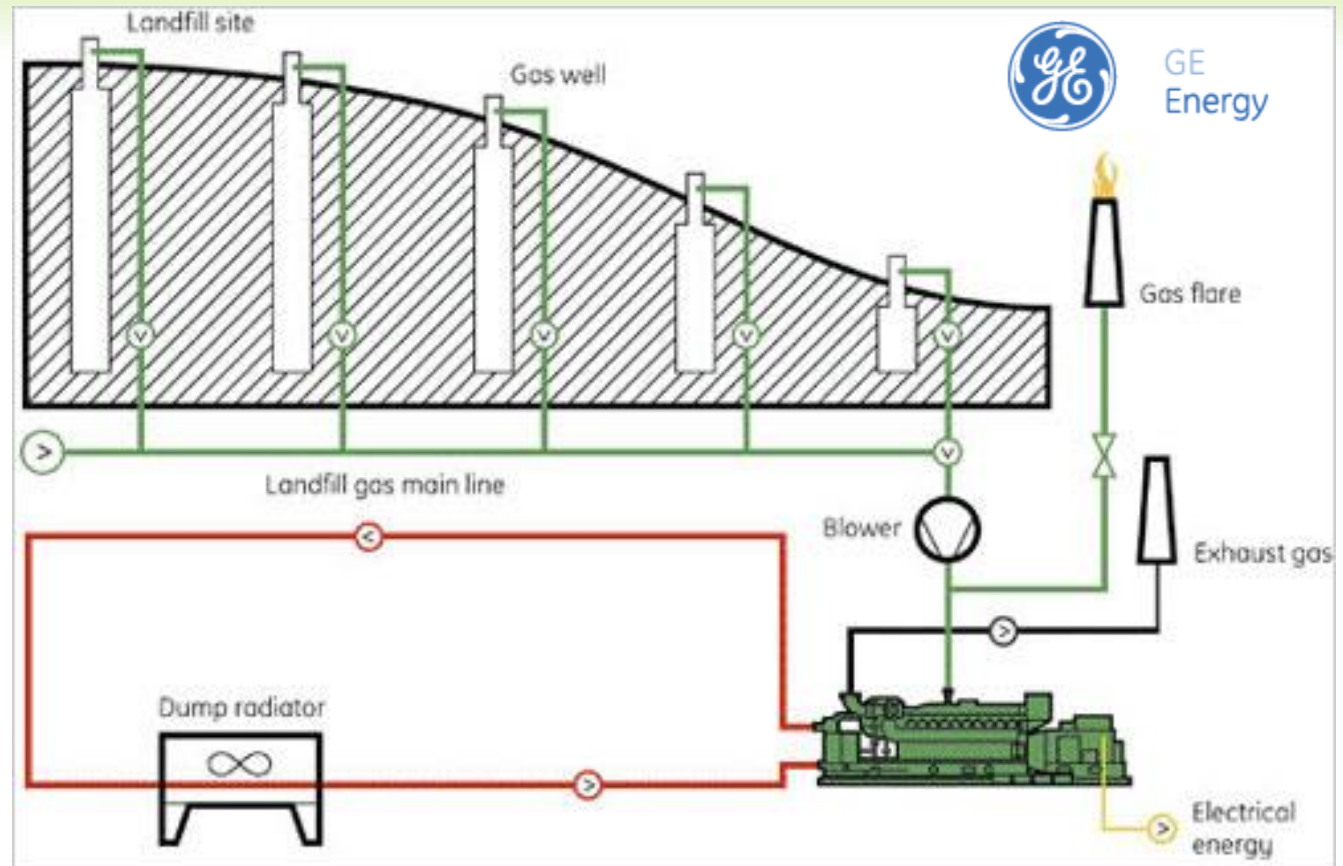
Source: EPA 1997

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

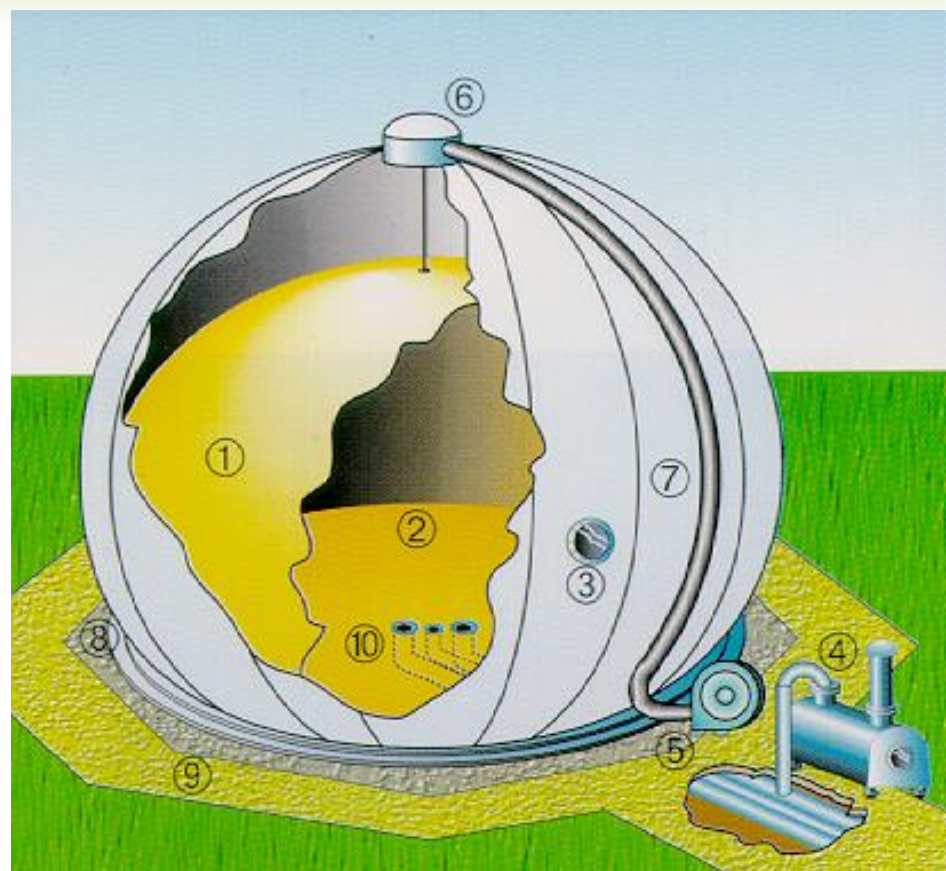
LANDFILL GAS PLANT

LHV = 18 MJ/m³

CH₄+CO₂+N₂



BIOGAS STORAGE



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/m³ (natural gas ca. 34 MJ/m³)

WOOD GAS PRODUCTION GASIFIER

- ⊙ Several processes:
 - ⊙ Pyrolysis, temperatures 200...600°C
 - ⊙ Combustion, temperatures > 700°C
$$\text{C} + 0.5 \text{O}_2 \rightarrow \text{CO} + \text{Energy}$$
$$\text{C} + \text{O}_2 \rightarrow \text{CO}_2 + \text{Energy}$$
$$\text{H}_2 + 0.5 \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{Energy}$$
 - ⊙ Gasification / reduction – contact of gas and char
$$\text{C} + \text{CO}_2 + \text{Energy} \rightarrow 2 \text{CO}$$
$$\text{C} + \text{H}_2\text{O} + \text{Energy} \rightarrow 2 \text{CO} + \text{H}_2$$
$$\text{C} + 2\text{H}_2 + \text{Energy} \rightarrow \text{CH}_4$$

SIMPLE GASIFIER, 1920

GEORGES IMBERT'S CONCEPT

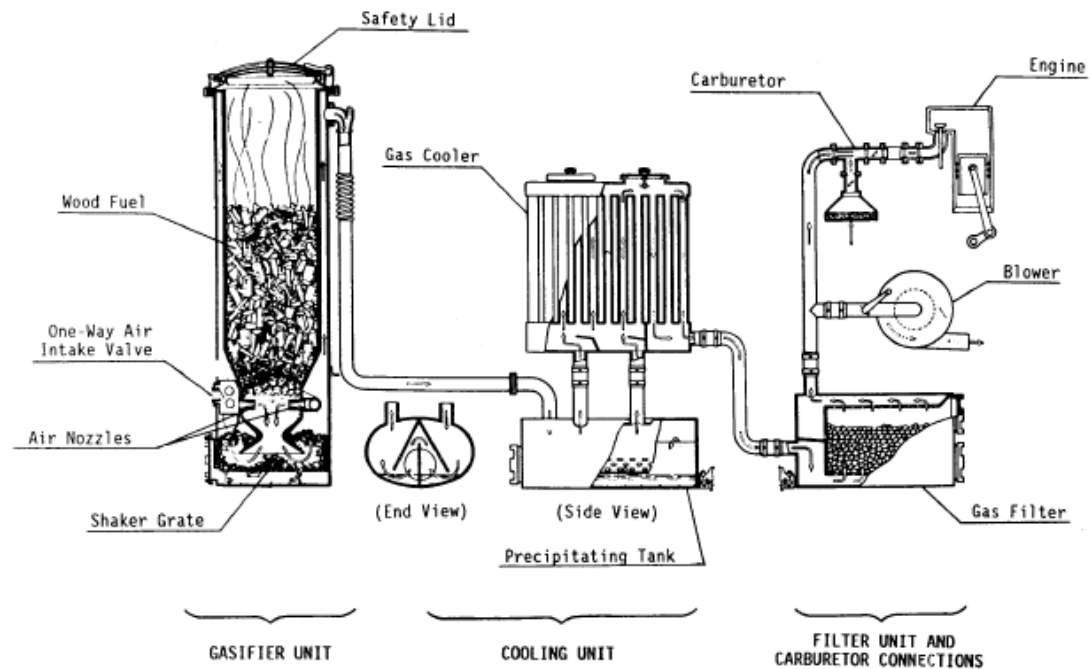


Fig. 1-2. Schematic view of the World War II, Imbert gasifier.

WOOD GAS-POWERED VEHICLES 1930s - 1940s



PzKpfw II tank

WOOD GAS-POWERED VEHICLES

1930s - 1940s



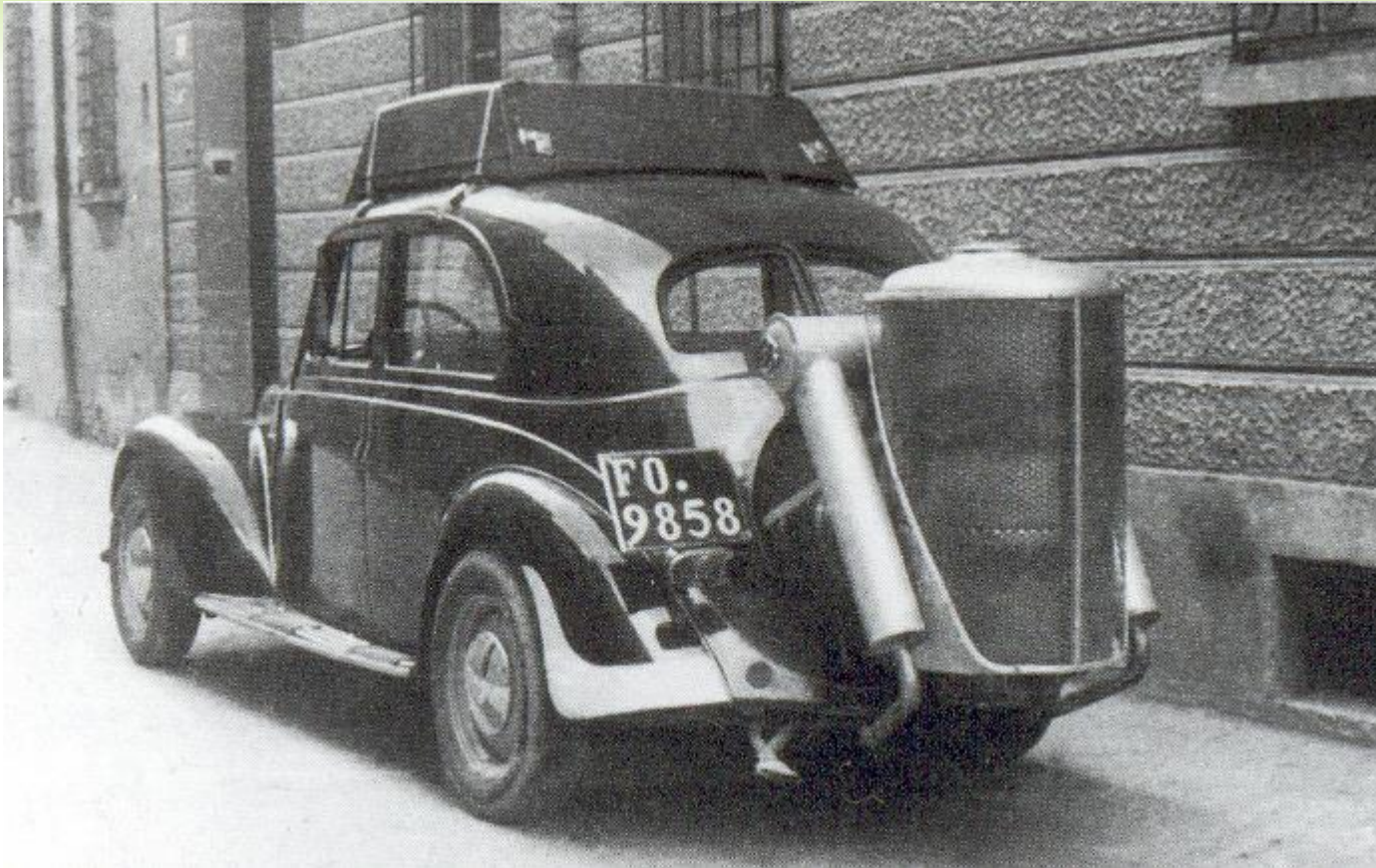
WOOD GAS-POWERED VEHICLES

1930s - 1940s



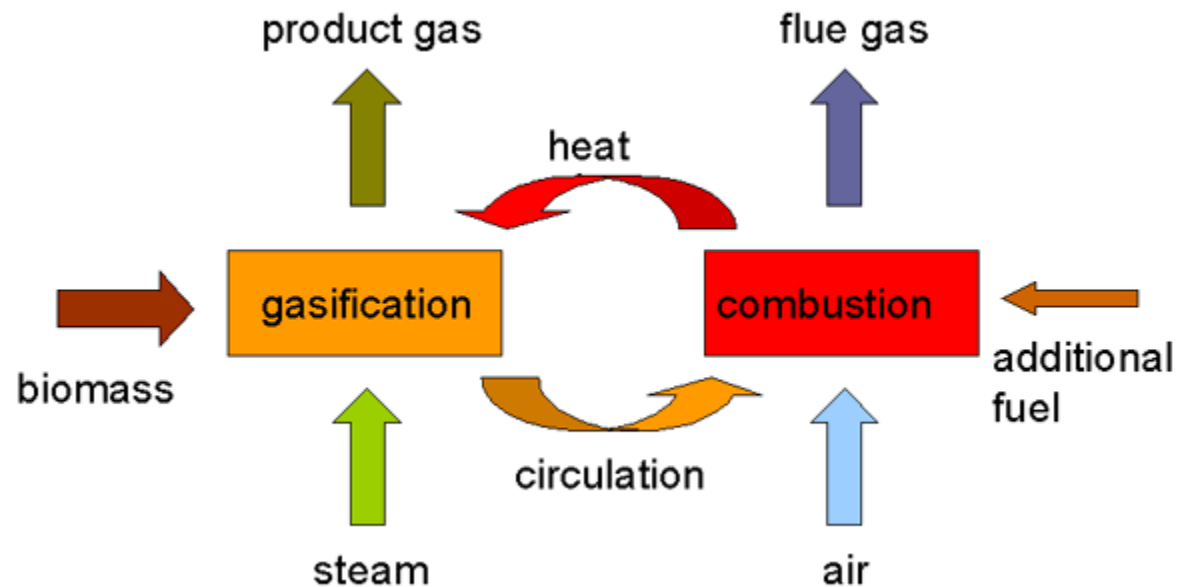
Adler Diplomat

WOOD GAS-POWERED VEHICLES 1930s - 1940s



FICB GASIFICATION

FAST INTERNAL CIRCULATING FLUIDIZED BED





Rev. 2 04.10.2000 Tremmel H.

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 consumers:

- GE-Jenbacher gas engine
- Heating boiler

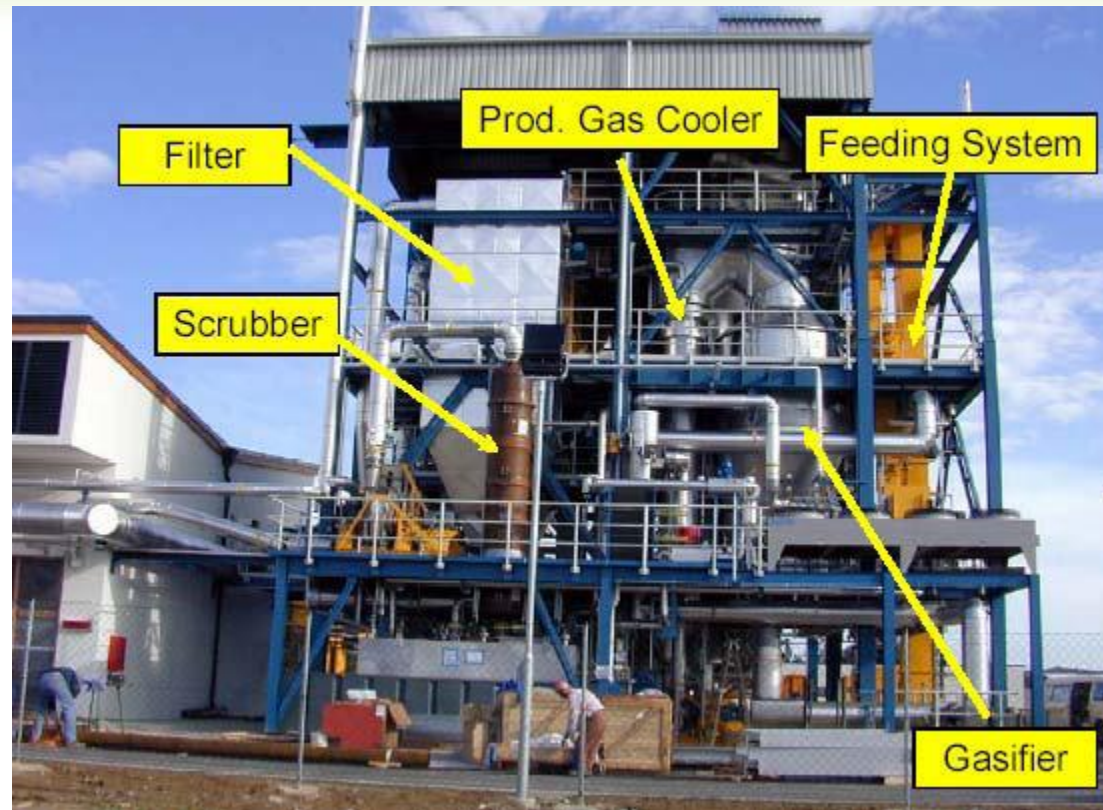
GÜSSING GASIFICATION PLANT

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

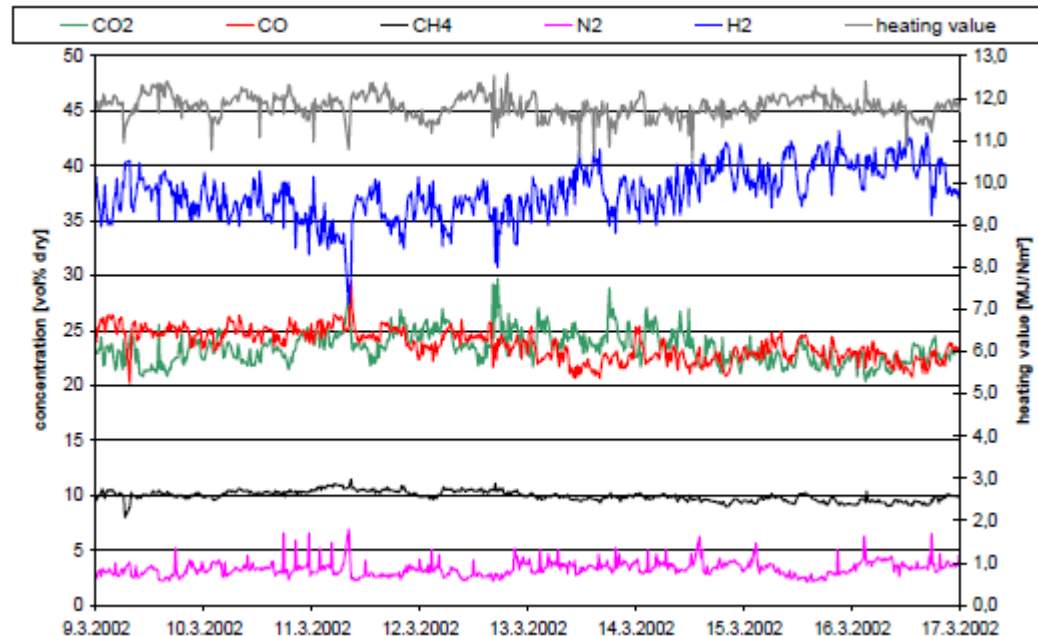
GÜSSING GASIFICATION PLANT



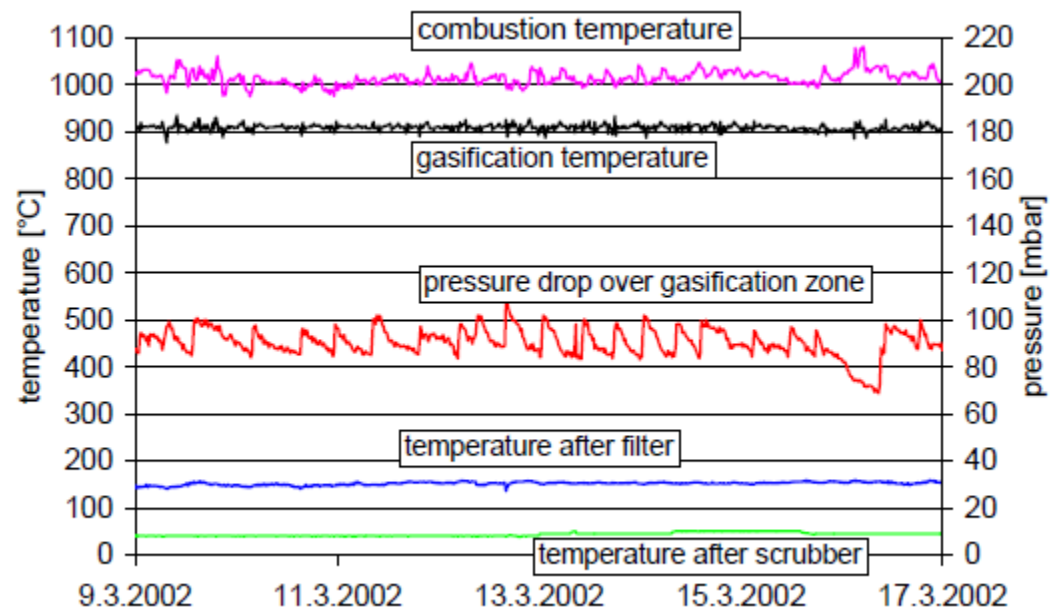
GÜSSING GASIFICATION PLANT



GÜSSING GASIFICATION PLANT GAS COMPOSITION (DRY)



GÜSSING GASIFICATION PLANT FICB PROCESS TEMPERATURES



ANIMAL FUELS

ANIMAL WASTE

- ② Animal waste can be used as a fuel for boiler
- ② Chicken waste can be converted for liquid biofuel
- ② Fish oil can be used in Diesel engines
- ② Animal fat (suet) may be used in Diesel engines

ANIMAL WASTE-FIRED PLANTS IN THE UK



Thetford

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



Eye

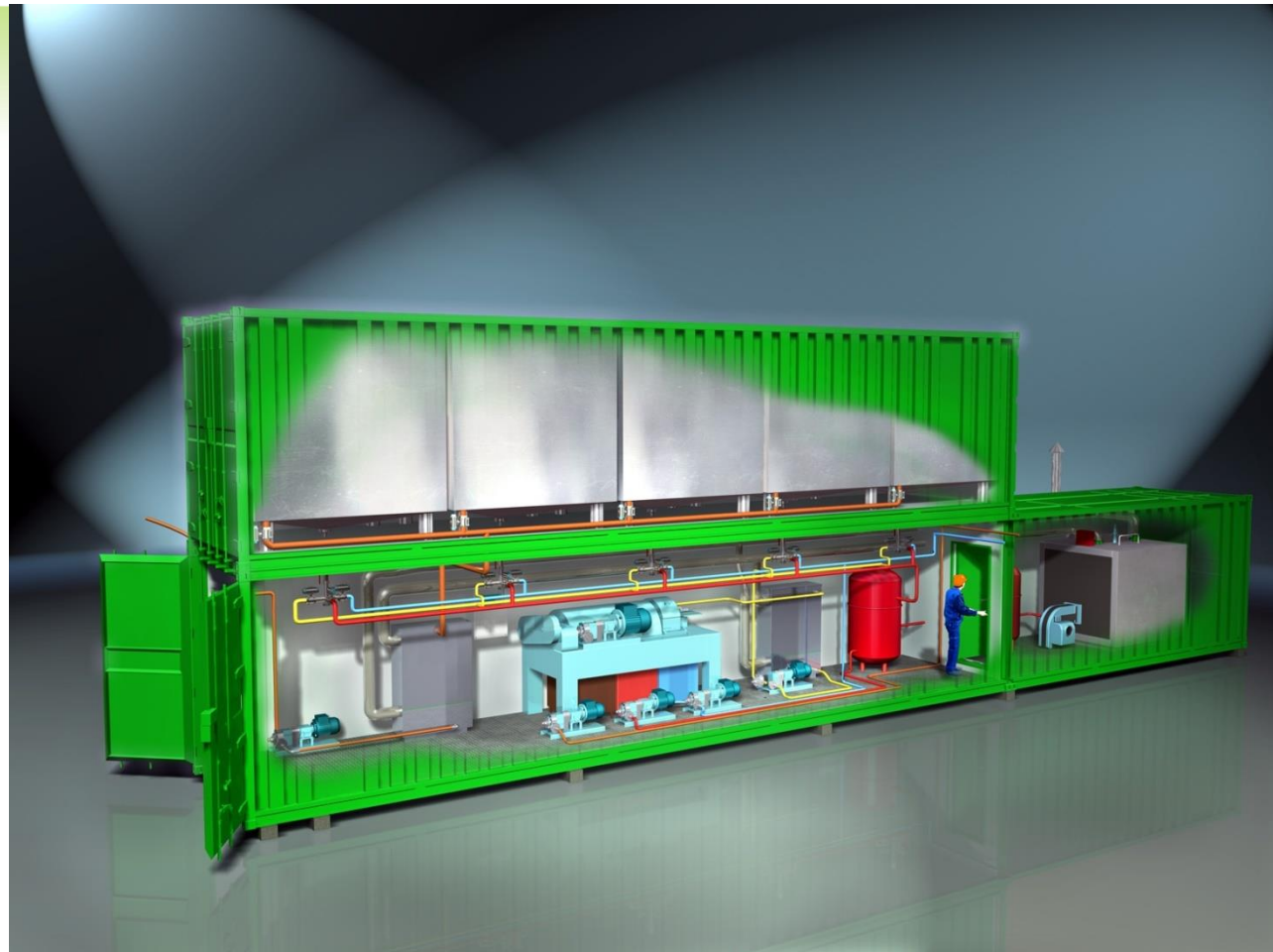
- 12.7 MW
- Poultry litter, horse bedding, feathers
- Grate boiler (Aalborg boilers)



Westfield

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

CHICKEN OIL - FUEL FOR DIESEL ENGINES



CHICKEN OIL - FUEL FOR DIESEL ENGINES

Waste is crushed

Formic acid (HCOOH) is added

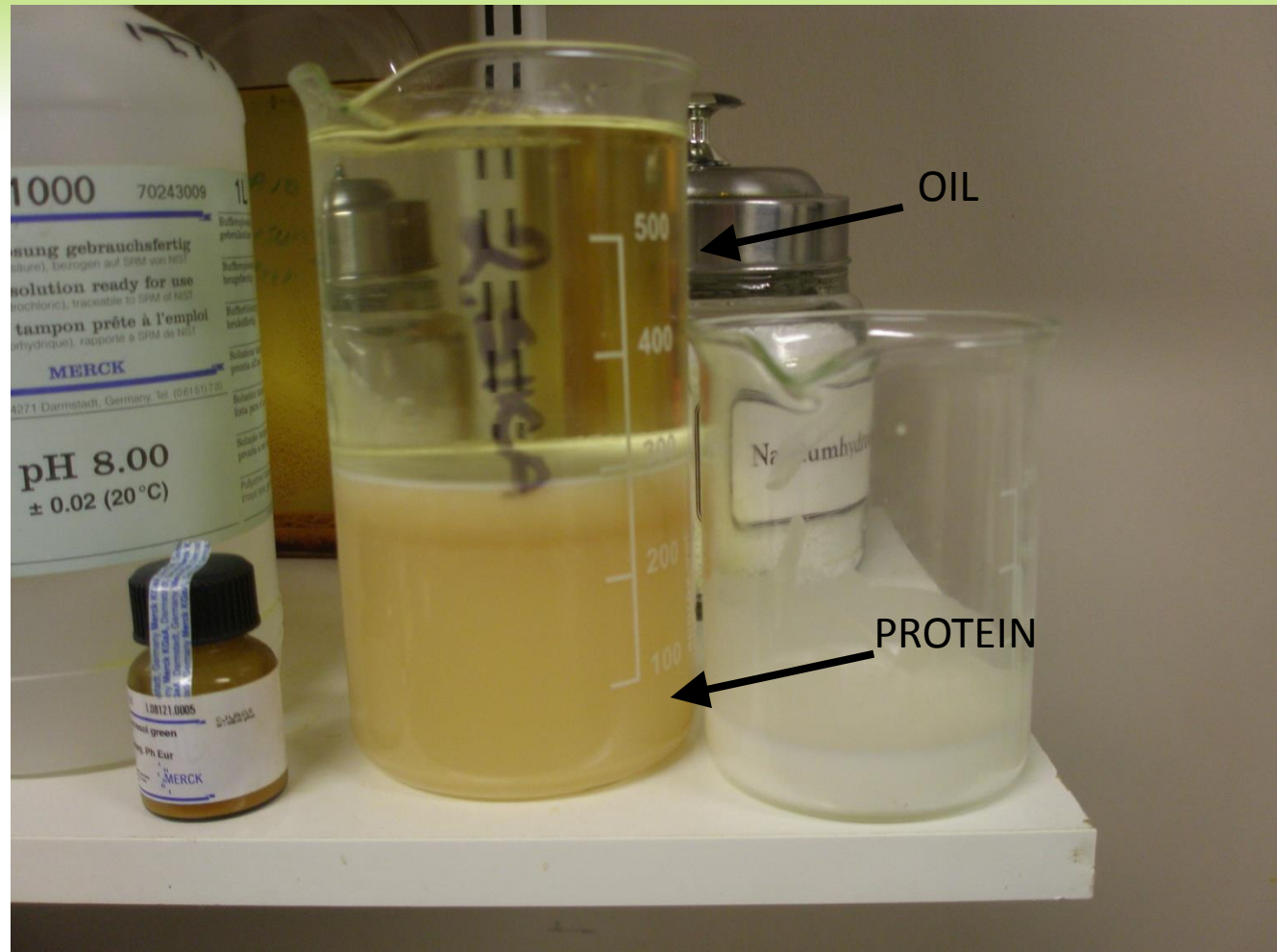
Mass is heated to 70°C for at least 1 hour

Mass is separated – 3-phase decanter

Water is separated



CHICKEN OIL - FUEL FOR DIESEL ENGINES



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

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

THANK YOU!

Adam Rajewski

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