Increase in Biogas Utilization

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Content

- **Introduction**
- **How to produce Biogas – Case Study Food Waste**
- **Energy Utilization from Biogas**
  - **Internal Combustion Engines**
  - **Gas Turbines**
  - **Fuel Cells**
  - **Organic-Rankine-Cycle**
- **Conclusions**

Who we are …

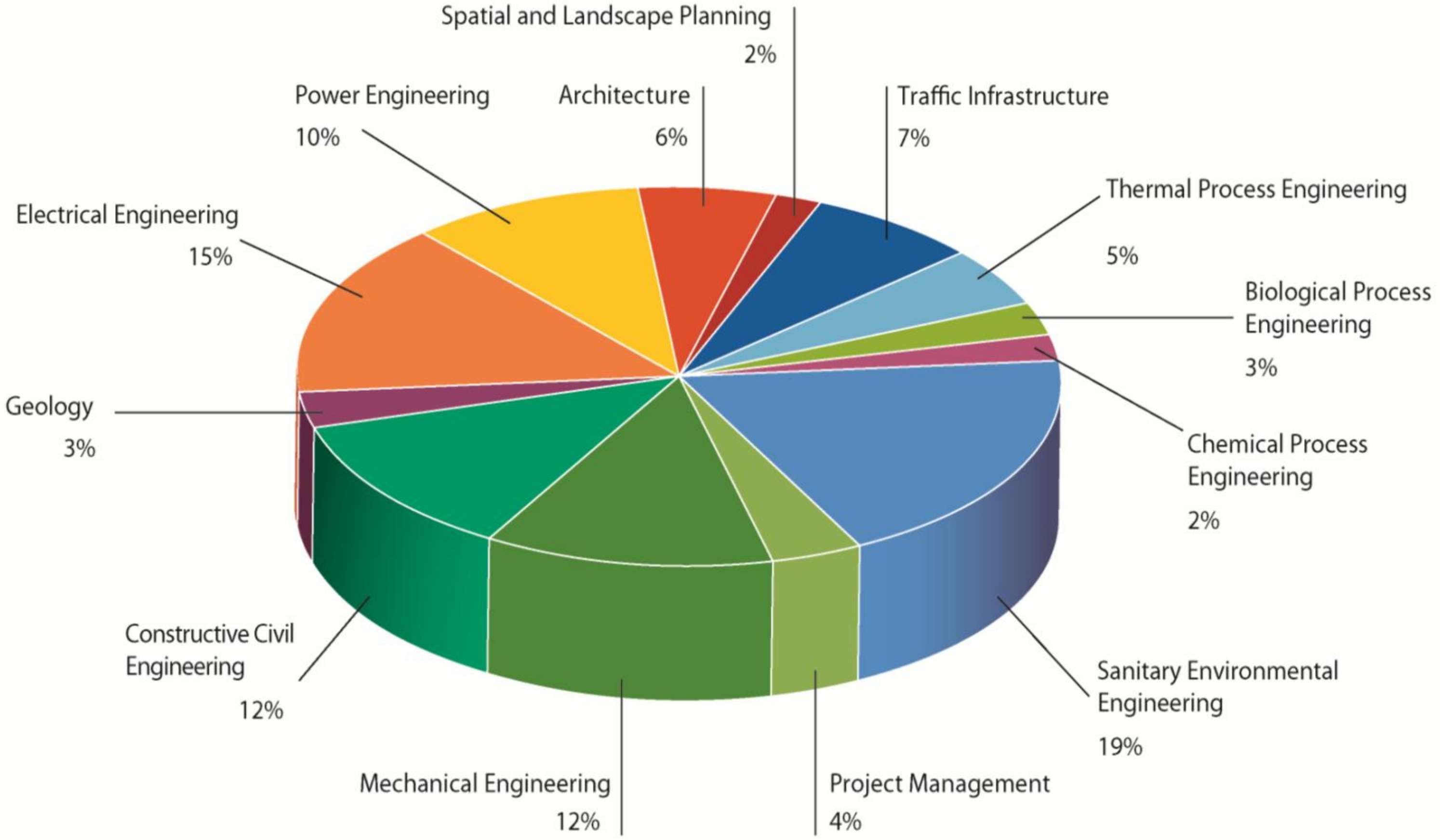
- **Privately owned Engineering Consultancy Company**
  - Founded 1972
  - Independent
  - For public and private / industry customers
  - DIN ISO 9001:2015 Certified
- **Consultancy**
- **Concepts and Studies**
- **Design and Planning**
- **Construction Supervision**
- **Project Management**
- **Expert Views and Reports**

Our Fields of Activity

- Water
- Waste Water
- Sludge
- Waste
- Energy
- Biogas
- Electrical
- Control Technology
- Industry Plants
- Civil Engineering
- Airport Planning
- Hazardous Waste
- Geo-technic

Our Assets

- **180 Employers with some 80 % of Engineers**



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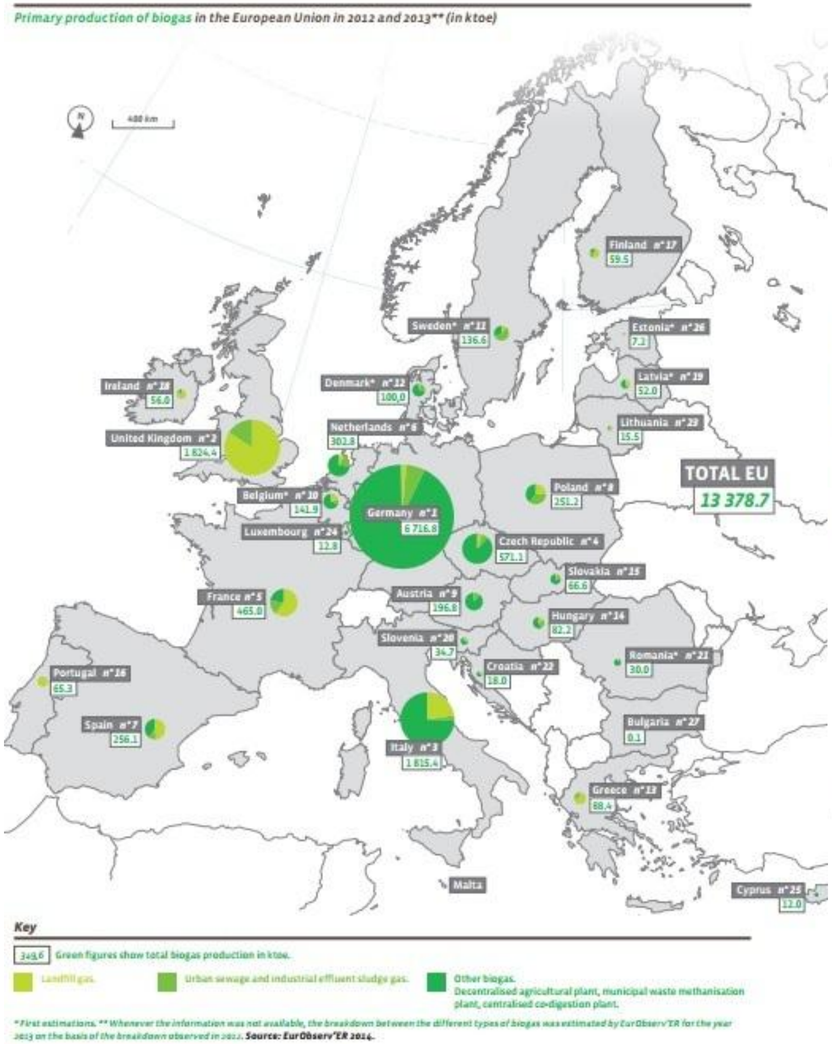
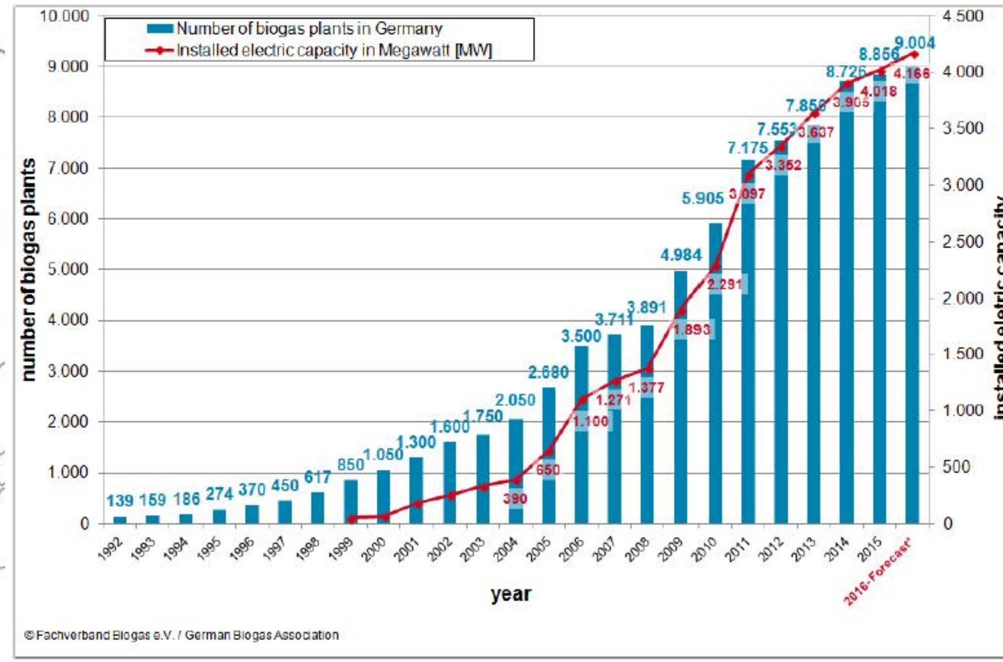
Biogas Plants EU and Germany





Source: EurObserv'ER 2016; German Association of Biogas, 2016

Typical Organic Waste Fractions

Waste Wood

Grass Silage

Manure

Municipal Organic Waste

Food Waste

Packed Food Waste

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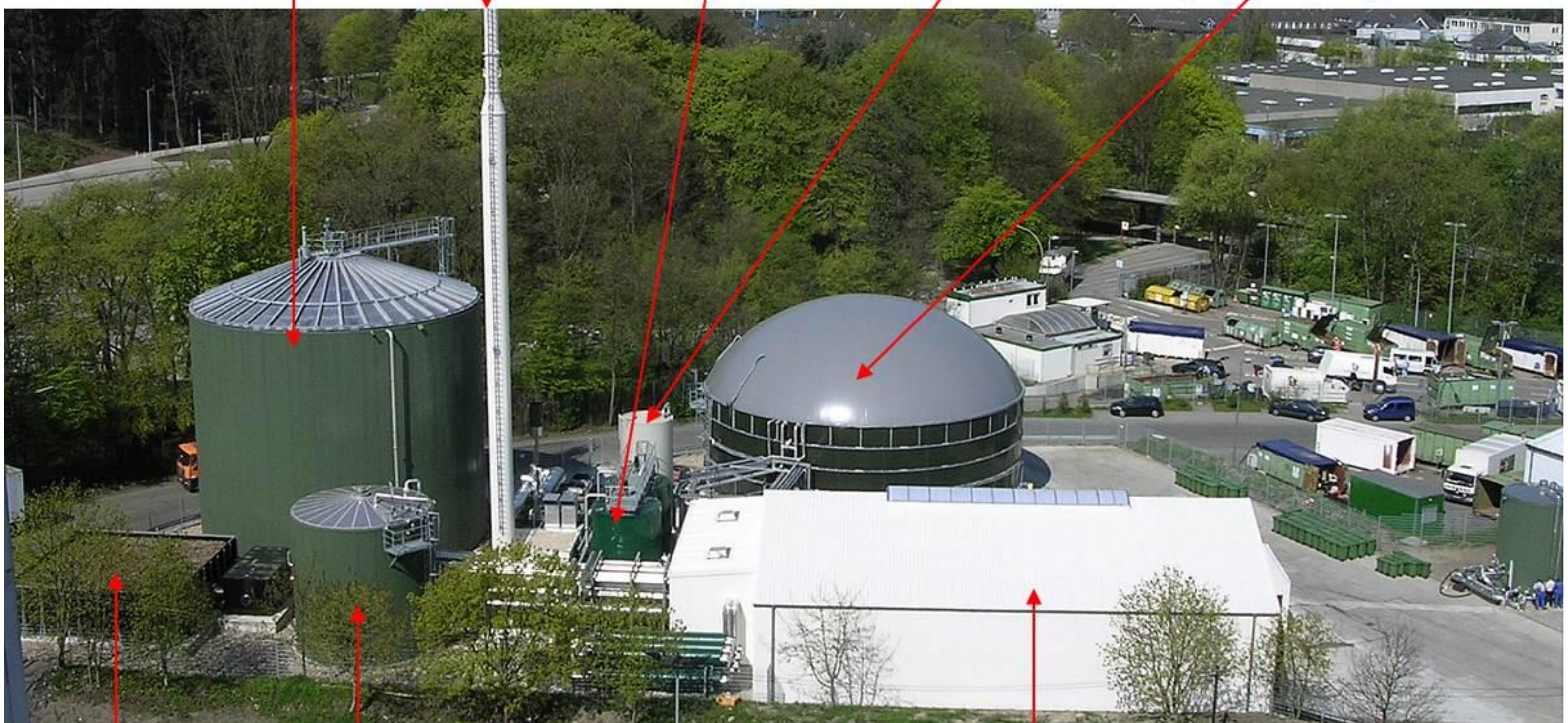
General Classification of Biomass

	Incineration	Composting	Dry Ferment., discontinuous	Dry Ferment., continuous	Wet Fermentat.
Typical Material	Wood waste	Gardening, park waste	Org. household waste	Org. household waste	Food waste
Dry Matter Feedstock (%)	100 – 60	70 - 30	40 - 30	30 - 20	15 - 10
Dry Matter Residue (%)	-	> 80	30 - 20	20 - 10	10 - 3

Typical Biomass Feedstock Specifications

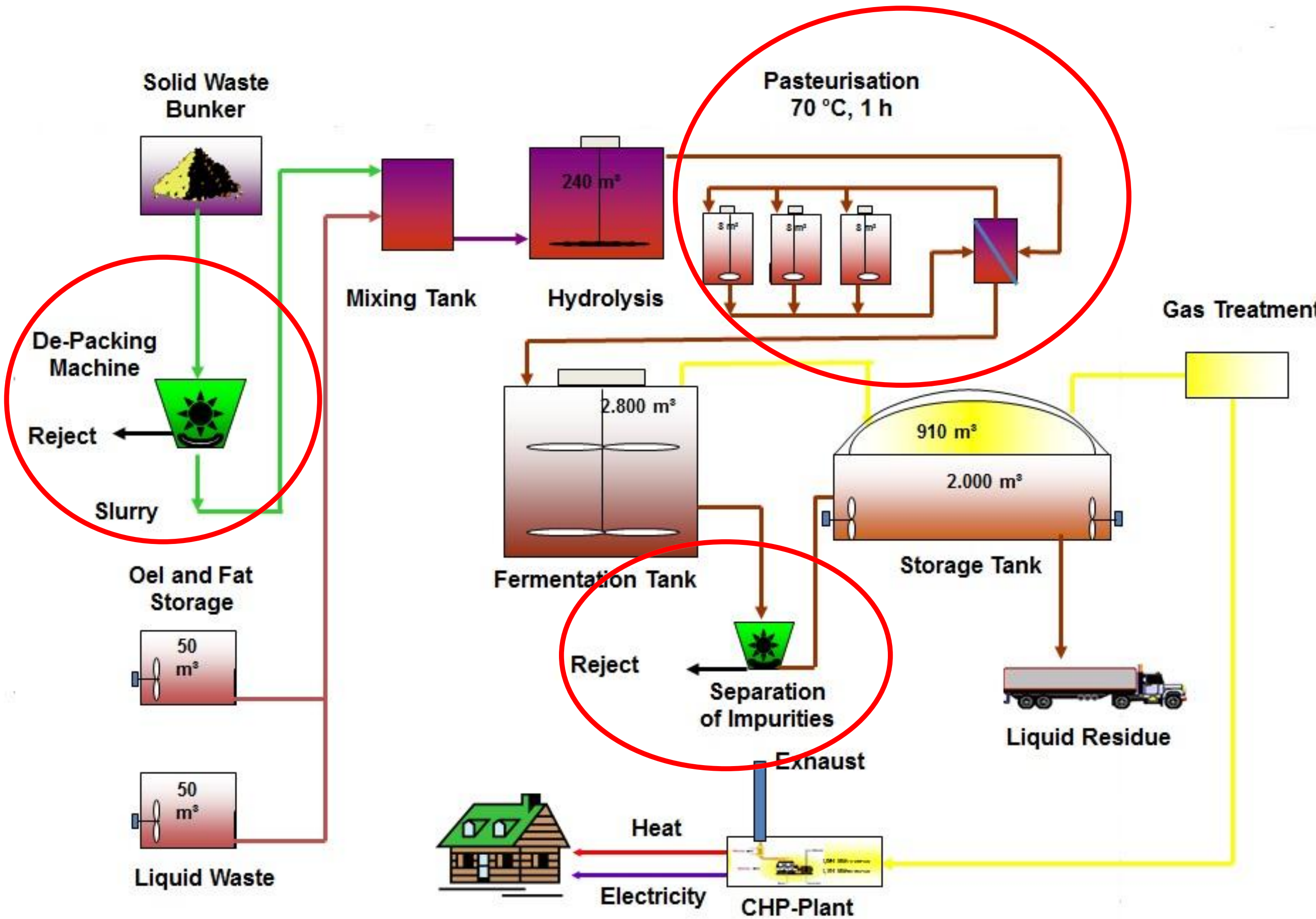
		Gras Silage	Cow Manure	Municipal Organic Waste	Kitchen Waste / Leftovers
Dry Matter	%	25-50	8-11	40-75	9-37
Organic Matter	% DM	70-95	75-82	50-70	80-98
Biogas Yield	m^3/t	170-200	20-30	80-120	50-480
Biogas Yield	m^3/t Org	550-620	200-500	150-600	200-500
Methane Content	%	54-55	60	58-65	45-61
Nitrogen Content	% DM	3.5-6.9	2.6-6.7	0.5-2.7	0.6-5
Ammonia Content	% DM	6.9-19.8	1-4	0.05-0.2	0.01-1.1
Phosphor Content	% DM	0.4-0.8	0.5-3.3	0.2-0.8	0.3-1.5

Wet Fermentation of Food Waste – Case



Source: BioWerk Hamburg, 2010

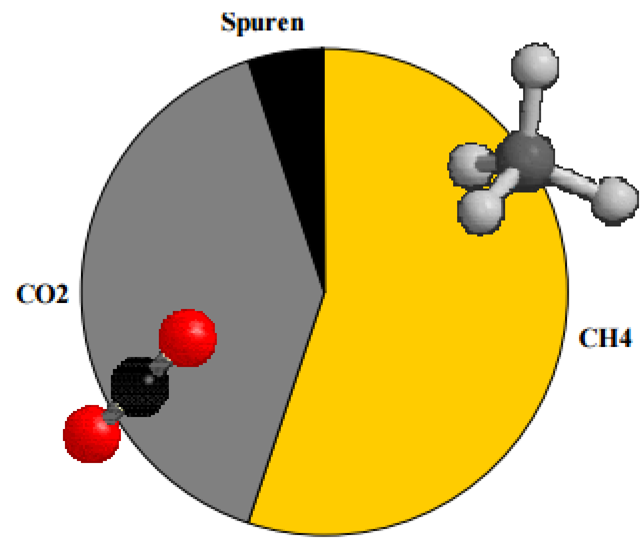
Wet fermentation Process, Simplified Flow Chart – Food Waste



Source: BioWerk Hamburg, 2011

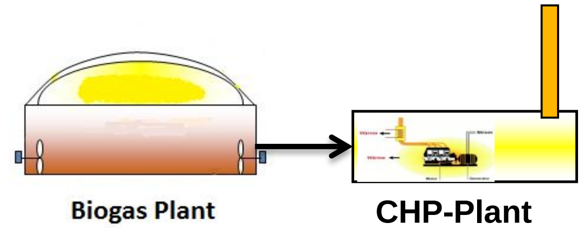
Typical Biogas Composition

- **Methane**
  - 45– 65 Vol.-%
  - Depending on feedstock
- **Carbon Dioxide**
  - 30 – 50 Vol.-%
- **Hydrogen Sulphate**
  - Up to 2 Vol.-%
  - Toxic
    - 10 ppm = 14 mg/m³ MWPC
    - lethal > 500 ppm
  - > 4.3 Vol.-% Explosive < 45.5 Vol.-%
- **Others**
  - e.g. Ammonia



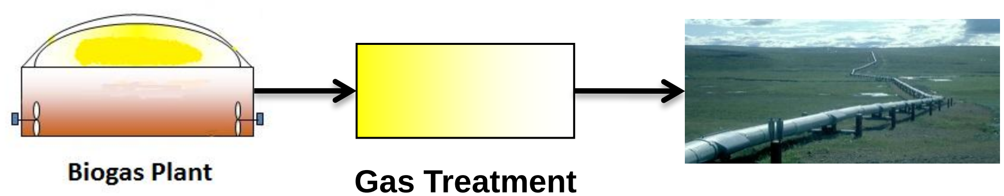
Biogas Utilization, Options

- **CHP Plant on site**

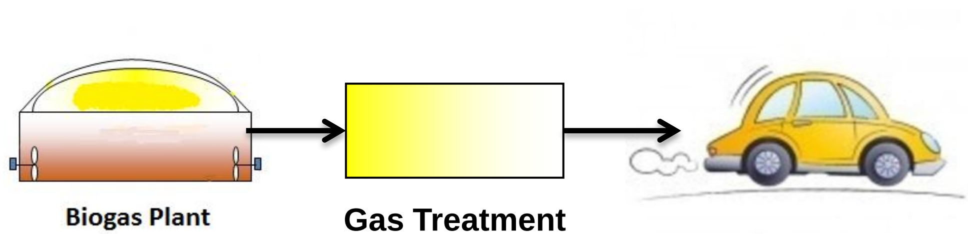


- **Remote CHP plant**

- **Gas feed to national grid**



- **Gas treatment for mobility**



Biogas Utilization, Specifications

	CHP Plant on-site	Remote CHP plant	Gas delivery to public gas grid	Gas for mobility
Pro´s/Con´s	Reliable technique/requires heat demand on site	Heat off-site/high investment for gas line	Gas off-site/high cost for investment and gas treatment	Petrol substitution/high cost for investment
Gas requirements	Only removal of H2O and H2S	Only removal of H2O and H2S	Removal of H2O, H2S and CO2	Removal of H2O, H2S and CO2
Gas Treatment technol.	Cooling and biological desulphurisation	Cooling and biological desulphurisation	Pressure swing process, scrubbing	Pressure swing process, scrubbing
Gas pressure	30 – 80 mbar	150 – 300 mbar	20 – 75 bar	200 bar

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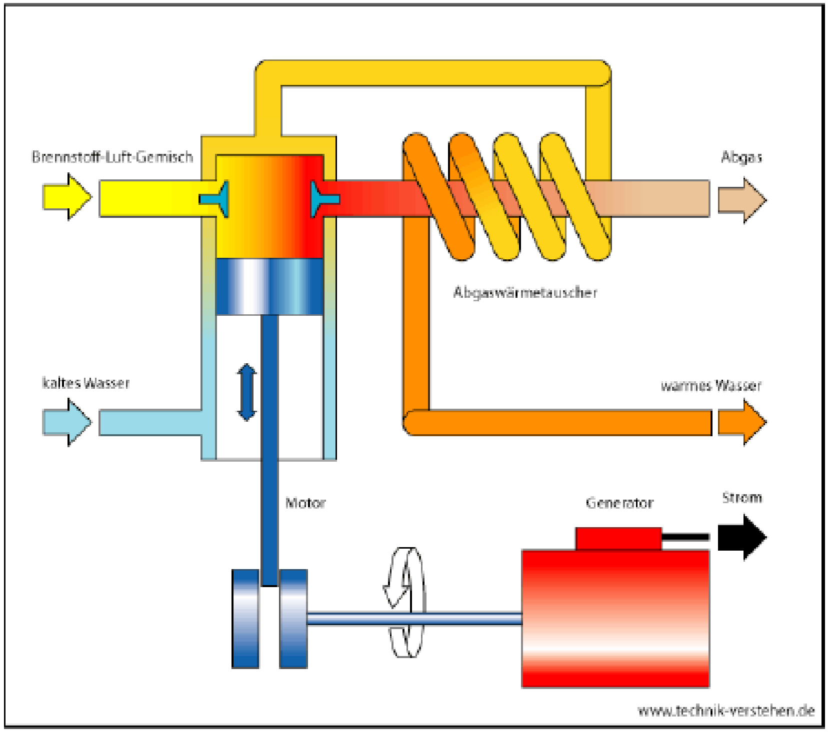
Internal Combustion Engine – Principle

- **Spark Ignition Engine (extraneous ignition)**
  - Biogas
  - Natural Gas
  - Gasification Process
- **Diesel engine (self-ignition)**
  - Diesel
- **Energy Efficiency**
  - 30 – 40 % electrical
  - 40 – 50 % thermal
  - 10 % losses

- **Priority 1: Electricity Generation**
- **Priority 2: Heat Generation**



Source: Technik-verstehen.de

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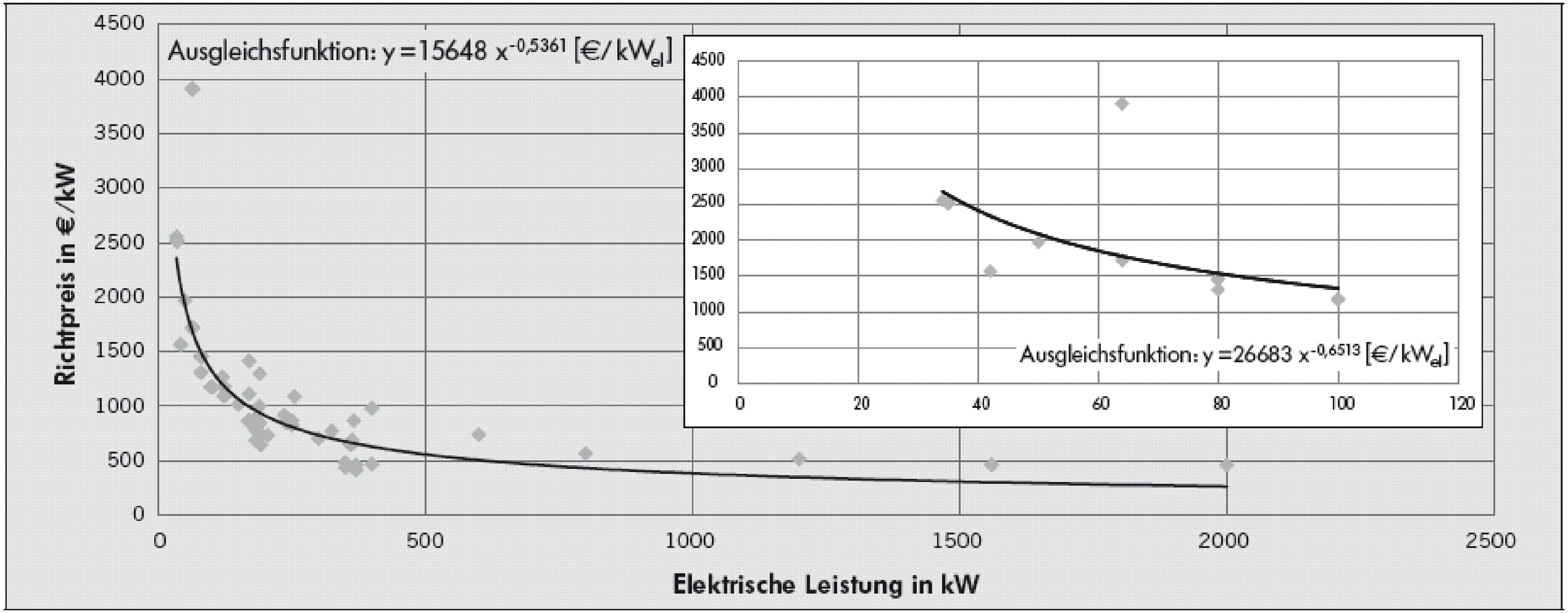
Internal Combustion Engine – Requirements

Fuel Requirements

- Max. Biogas Temperature: 40 °C
- Gas Composition: 45 % - 70 % Methane, Rest CO_2
- Lower Calorific Value: 4,3 – 7 kWh/m_N^3
- Relative Moisture: max. 80 % Vol.
- Hydrogen Sulphide: < 700 (@ 100 % Methane) or < 280 ppm (@ 50 % Methane)
- Ammonia: < 50 mg/m_N^3 (@100 % Methane)
- Halogen (F, Cl): < 100 mg/m_N^3 (100 % Methane)
- Silicon: < 5 mg/m_N^3 to 10 mg/m_N^3

Internal Combustion Engine – Economy

- **Power Range Biogas: 1,3 – 2.000 kW_{el}**
- **Investment Cost**



Source: BHKW-Kennzahlen 2011

Internal Combustion Engine – Pros and Cons

Advantage	Disadvantage
Electrical Efficiency up to 40 % and above	High Methane Concentration required (> 45 %)
Small Energy Losses (approx. 2 % - 5 % due to Emergency Cooling)	Heat disposal required if no Heat utilization available
Insensitive to Variations in Gas Pressure and Temperature	Sensitive to Hydrogen Sulphide in the Gas Phase (Oil Deterioration)
Waste Heat Recovery (Cooling Water and Recovery Boiler)	Continuous operation preferred (4 – 6 h/day)
Life Span > 100.000 Hours of Operation	Intermitting operation reduces Economy
Good part-load Behaviour (50 – 100%)	Comparatively high Operating Cost (Service, Oil, Spare Parts, etc.)
Comparatively low Investment Cost	Gaseous Emissions

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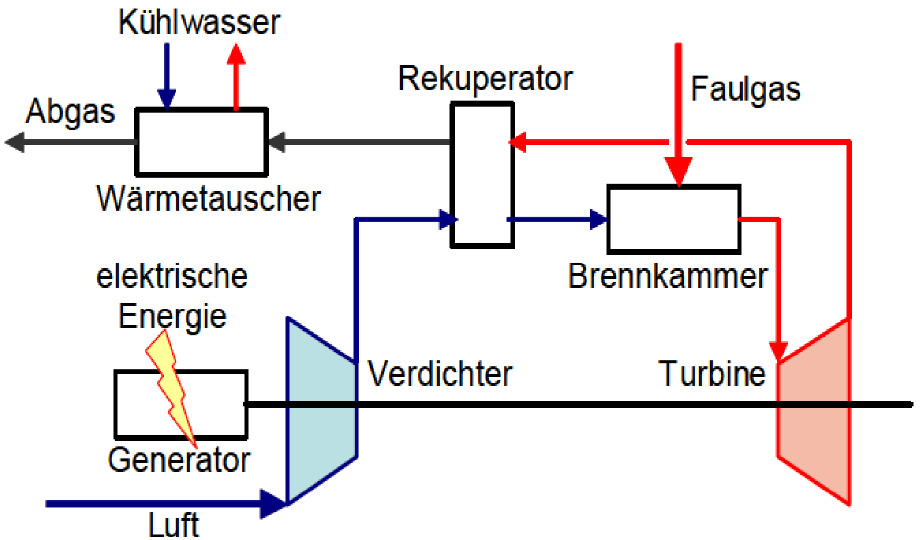
Gas Turbine – Principle

- **Turbocharger technology**
  - Thermal conversion in separate Combustion Chamber
  - Exhaust Gas drives Gas Turbine and Compressor (same shaft)
  - Turbine and Generator on one Shaft (no gearbox)
  - Speed 70.000 – 100.000 U/min
  - Max. Engine Power rating for Micro Gas Turbine: 300 kW_{el}
- **Energy Efficiency**
  - 15 – 25 % electrical
  - 60 – 70 % thermal
  - 5 – 15 % Loss (Gas Compression)

- **Priority 1: Heat Generation**
- **Priority 2: Electricity Generation**



Source: W. Frey, Leobendaorf

Gas Turbine – Requirements

Fuel Requirements

- Max. Biogas Temperature: 50 °C
- Lower Calorific Value: 3,8 – 8,3 kWh/m_N^3
- Gas Composition: 35 % - 75 % Methane, CO_2 max. 50 Vol%
- Moisture: max. 3 Vol %
- Particulates: < 10 µm, 20 ppm
- Hydrogen Sulphide: < 200 ppm (turbine is insensitive → Exhaust gas quality)
- Silicon: < 5 ppb

Gas Turbine – Economy

- **Power Range: 30 – 75 (max. 300) kW_{el} Micro Gas Turbine**

- **Investment Cost**

el. Power	Unit	specific Investment costs
30 – 75 kW_{el}	€/kW_{el}	1.300 – 4.000

Gas Turbine – Pros and Cons

Advantage	Disadvantage
Insensitive to Variations in Gas Quality	High specific Investment cost
Insensitive to low Methane concentration	Low electrical Efficiency
Heat Recovery	External Energy for start-up required
Low Abrasion	Emergency power supply only with additional device
Waste-gas heat exchanger with by-pass (using no emergency cooling)	Life span: 40.000 hours of operation
Constant Efficiency for large load range	
Part-load operation (50 - 100 %)	

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Fuel Cell – Principle

- **Fuel Cells for Biogas**

	Operating Temperature	Electrolyte	Fuel	Oxidant
MCFC (Molten Carbonate Fuel Cell)	650 °C	Lithium and Potassium Carbonate	Natural Gas, Coal and Biogas	Air
PEMFC (Proton Exchange Membrane Fuel Cell)	80 °C	Solid Polymer	Hydrogen, Methanol	Oxygen, Air

Fuel Cell – Principle

- **Principle of reverse electrolysis**
  - controlled electrochemical reaction, referred to:

    Anodic reaction:

    $H_2 \rightarrow 2\,H^+ + 2\,e^-$

    Cathodic reaction:

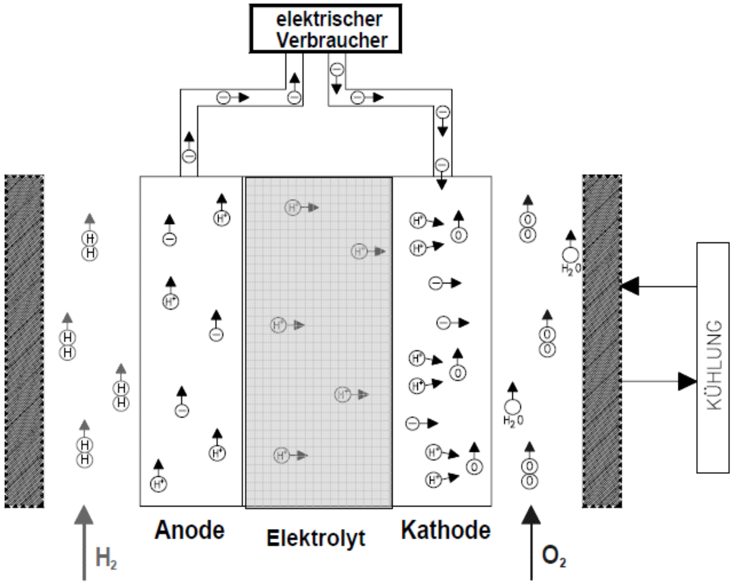
    $\frac{1}{2}\,O_2 + 2\,H^+ + 2\,e^- \rightarrow H_2O$

- **Energy Efficiency**

  MCFC:
  - 50 – 55 % electrical
  - 35 – 40 % thermal

  PEMFC:
  - 38 – 42 % electrical

- **Priority 1: Electricity Generation**
- **Priority 2: Heat Generation (MCFC)**

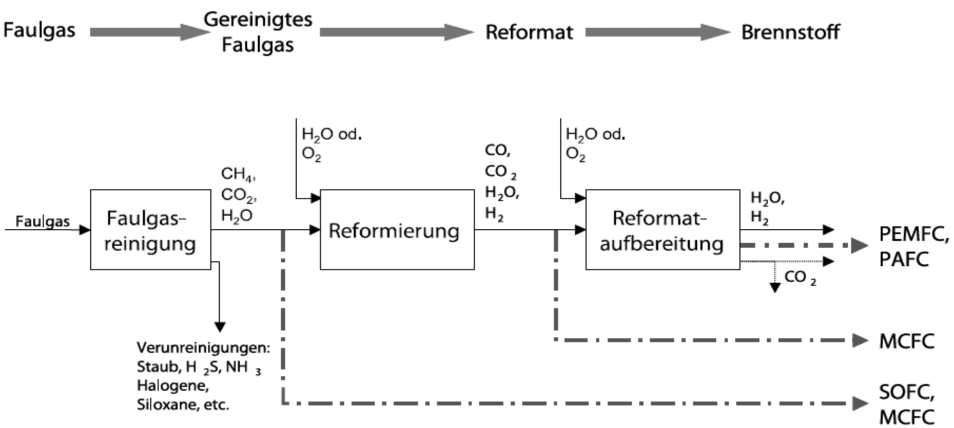


Source: DWA-M 299

Fuel Cell – Requirements

Fuel Requirements

- MCFC: optional fuel reformation
- PEMFC: fuel reformation (from Methane to hydrogen)



Source: DWA-M 299

	Unit	PEMFC	MCFC
Methane	%	< 90	rd. 65
Lower heating value	kWh/m_N^3	> 9	6,5
Carbon dioxide	%	< 3	No requirements
Hydrogen sulphide	ppm	< 6	< 10
Halogen	ppm	< 1	< 0,1
Silicon	ppm	< 1,2 mg/m^3	< 1,2 mg/m^3

Fuel Cell – Economy

- **Power Range:** **MCFC: 100 - 300 kW_{el}**
  PEMFC: up to several 100 kW_{el}

- **Investment Cost**

el. Power	Unit	specific Investment costs
250 kW_{el}	€/kW_{el}	7.000

Fuel Cell – Pros and Cons

Advantage	Disadvantage
High electrical Efficiency (no limit by Carnot-Cycle)	Complex Biogas conditioning
Good Part Load Behaviour	Poor Reference Situation (mainly Pilot Plants)
Low / no gaseous Emissions	High Safety Requirements (Hydrogen)
	High Investment Cost
	Life span: 30.000 hours of operation

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Organic-Rankine-Cycle – Principle

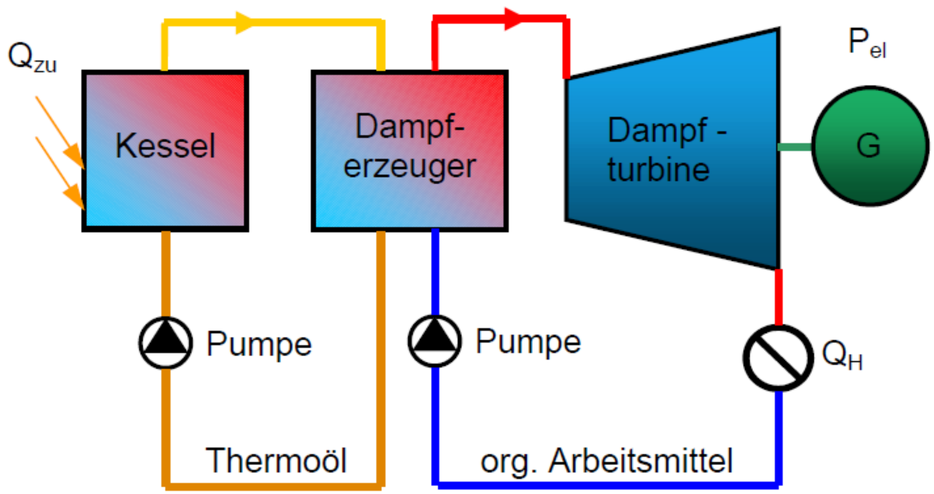
Principle of steam turbine but without steam (water)

- Low Level Energy Recovery (> 150 °C) e. g. from Combustion Processes
- Evaporation of an organic Working Fluid
- Expansion Cycle with turbine or reciprocating engine

Energy Efficiency

- 7 – 19 % electrical
- 76 – 88 % thermal
- 5 % losses

Priority 1: Electricity Generation



P_{el}	elektrische Leistung		org. Arbeitsfluid
Q_H	Wärmeverbraucher		Dampf
Q_{zu}	zugeführte Wärmemenge		Welle
G	Generator		

Organic-Rankine-Cycle – Requirements

Requirement Biogas

- Temperature: > 150 °C
- Composition (Prevention of Corrosion inside Heat Exchanger)

Requirement Heat Transfer Medium

- Choice of Heat Transfer Medium depends on Temperature level (Attention to thermal degradation)
- Heat Transfer Medium Oil / hot Water (depends on ORC type and energy-power class)

Working Fluid

- Iso-pentane, Iso-Octane, Toluol or Silicone Oil

Organic-Rankine-Cycle – Economy

- **Power Range:** **3,5 – 5.000 kW_{el}**

- **Investment Cost**

el. Power	Unit	specific Investment costs
35 – 70 kW_{el}	€/kW_{el}	3.400 – 6.900

Organic-Rankine-Cycle – Pros and Cons

Advantage	Disadvantage
Waste Heat Recovery for low Temperature Processes	Low electrical Efficiency
Heat of Condensation for District Heating	Organic working fluid (Water Pollution)
120.000 Hours of Operation	Thermal stability of Working Fluid (Oil) is limited at high temperature
Proven Reference Situation	
No high Pressure Boiler (Low Requirements on Operational Staff)	

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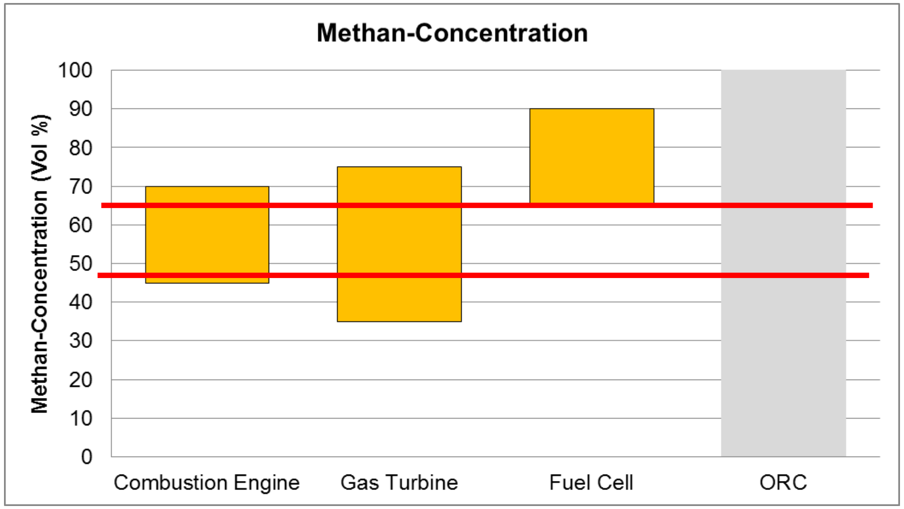
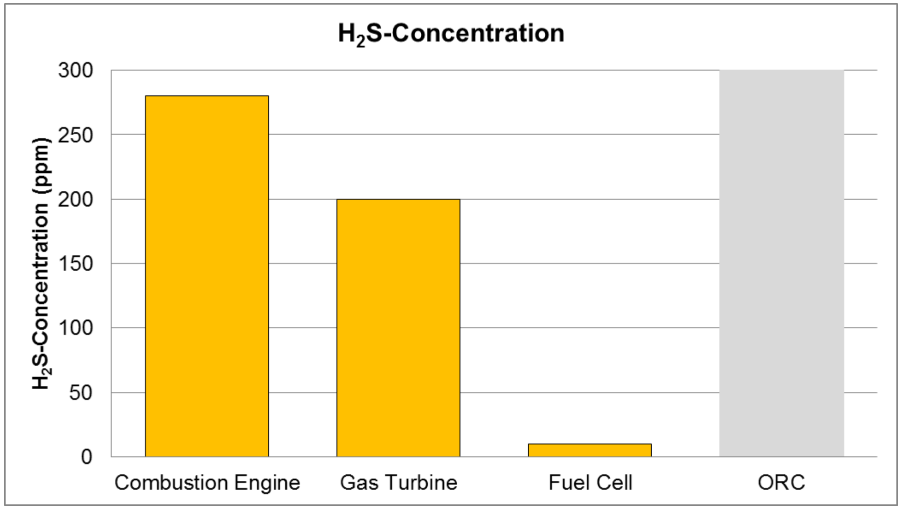
Conclusions – Fuel Requirements

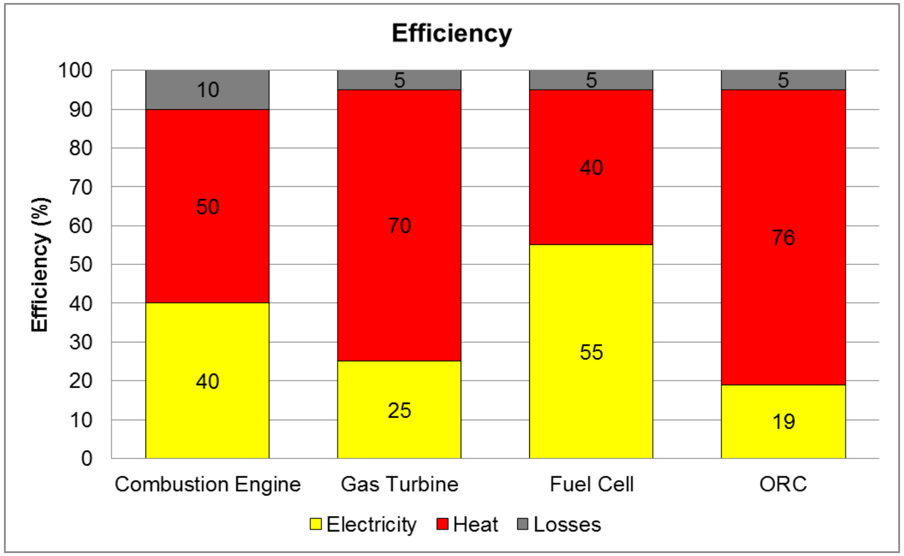
- **Fuel Requirements:**

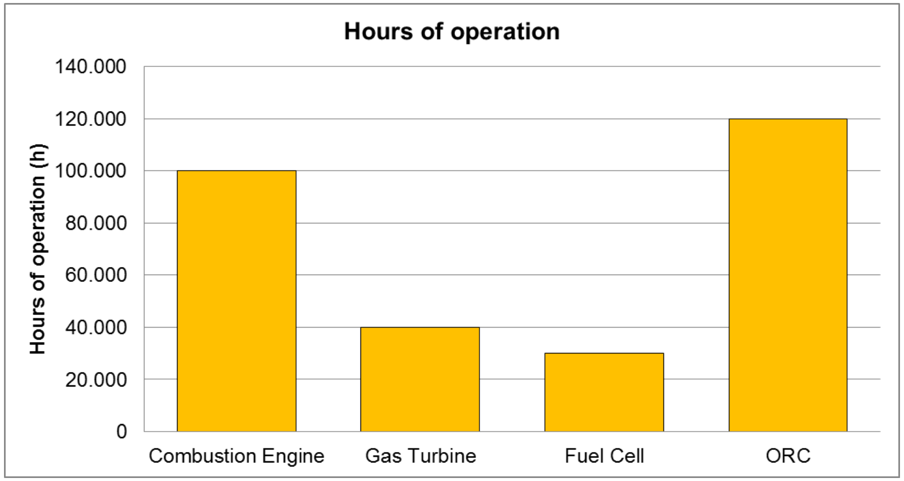


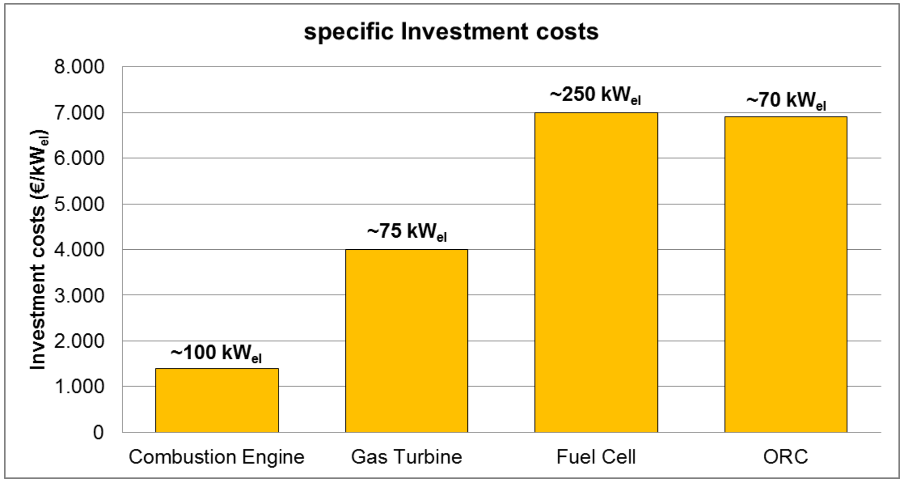


Conclusions – Energy Utilization

- **Energy Utilization:**







Conclusions

- **Electricity-oriented Operation:**
  - Internal Combustion Engine
  - Fuel Cell

  Applied for maximizing Electricity Production

- **Heat-oriented Operation:**
  - Gas / Micro Gas Turbine

  Applied for Waste Heat Utilization at high temperature levels, e.g. Drying Processes

- **Improvement in Efficiency (add on system)**
  - ORC

  Applied for Waste Heat Recovery at low temperature levels to increase overall Electricity Production