MTU CFC Solutions GmbH

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Biogas and the HotModule®:

From Waste to Clean Energy

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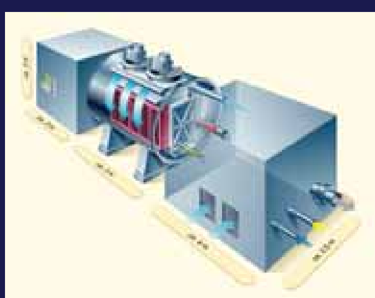

The MCFC flexibility
towards Fuel Utilization:

Utilization of Biogas and Other Gasification Products for Decentralized Consumable Energy Production

Gerhard Huppmann

New Fuel Cell Concepts and Applications
MTU CFC Solutions GmbH
D - 81663 München

Decentralized Consumable Energy Production:
The MTU Fuel Cell HotModule Unit 250 kW el

Content:

MTU CFC Solutions GmbH

- Spin off in January 2003
- Located near Munich / Germany
- 80 Employees
- Research & Development
- HotModule Assembly and Test
- Pilot Cell Manufacturing




Structure

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DaimlerChrysler AG

Off-Highway

MTU Friedrichshafen

74,9 %

MTU CFC Solutions

25,1 %

RWE

Fuel Cell Energy

Alliances & Partnerships

FuelCell Energy

ZSW

RWE

ruhrgas

ENERGI E2

inco special products

EnBW

e·on

IZAR

Ciemat

MAX-PLANCK-GESELLSCHAFT

SÜD-CHEMIE
Creating Performance Technology

Strong and Sustainable Commitment

MTU CFC Solutions

Research & Development

Product Development

Product Maturing

Field Trials

Commercialization

1990 | 1997 | 2003 | 2006

HotModule Manufacturing

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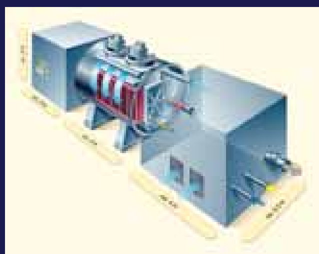
Stack, ready for Integration

Module Assembly

Shipment



Decentralized Consumable Energy Production:
The MTU Fuel Cell HotModule Unit 250 kW el

Content:

- MTU CFC Solutions GmbH: A portrait
- Decentralized stationary energy supply using decentralized secondary energy sources:
  Targets – the system – experience and challenges
- Research in biogas and other secondary gas utilization
- Economical aspects and outlook

Decentralized Stationary Consumable Energy Supply

Target: Stationary Energy Supply based on Fuel Cells

Production **on demand** of consumable energies

- electrical power
- heat
- cold

using decentralized energy sources

- natural gas, mine gas
- other gasified energy carriers
- **secondary gases from biomass and waste**

Two Classes of Secondary Fuels

- **Gaseous or gasified Hydrocarbons:**
  - biogases from anerobic fermentation
  - sewage gas, landfill gas, coal mine gas
  - gasified liquid and solid hydrocarbons, methanol, ethanol, gasoline, diesel, etc.
- **Synthesis gases:**
  - coal gas
  - biogases from thermal gasifiers
  - purge gases e. g. from refinieries, chemical industry

Secondary Fuels: Characteristics

- High Contents of inert components: N_2, CO_2, H_2O
- Low heating value
- Decentral available
- Fluctuating properties
- Contents of a variety of different contaminants

Consumable Energies from Secondary Energy Sources

Reasons, necessities for and advantages of the utilization of decentralized secondary energy sources for production of consumable energies:

Saving primary energy sources:

- Reduction of dependance on primary energy sources
- Reduction of pollution by greenhouse gases and contaminants
- Reduction of transport losses by in situ utlization of energy sources and in situ production of consumable energy forms

High quality utilization of secondary fuels:

- Trigeneration – electrical energy, thermal energy, cooling energy

To make use of the high efficiency of fuel cells

High performance with natural gas and biogas

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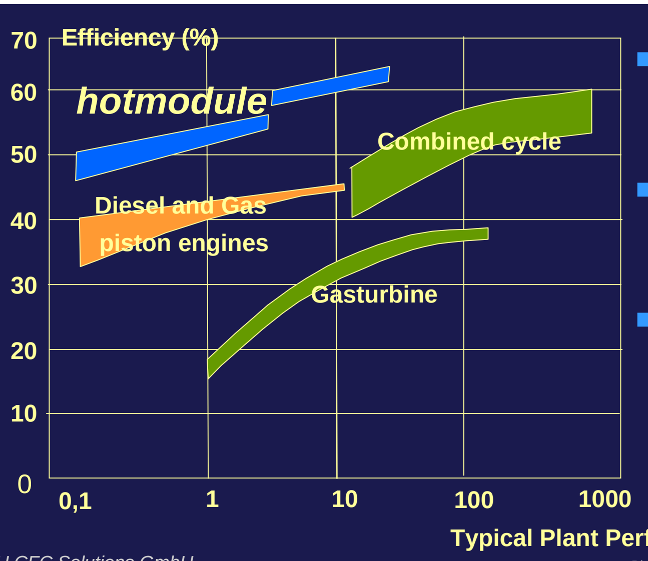

- Today: > 47%

  Target: > 50%
- Top Performance for 250 kW Units
- Superior to Conventional Solutions

Types of Fuel Cells

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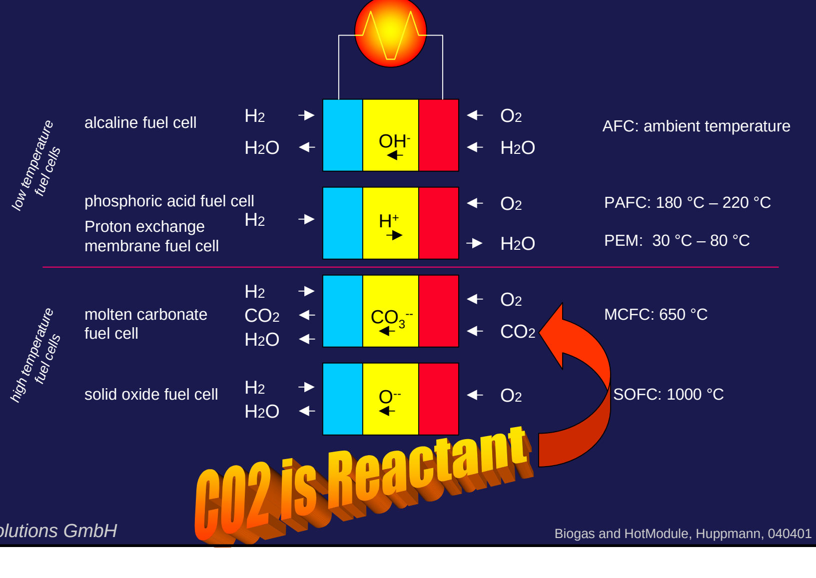

Why MCFC?

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right operating temperature

- utilization of „waste“heat With high exergy
- Internal reforming
- metallic compomnents

due to CO_2 as reactant high fuel flexibility

gaseous hydrocarbons

- natural gas
- biogas (digestion gas)
- sewage gas, landfill gas
- mine gas

Synthesis gases

- biogas from thermal gasification
- Pyrolysis gas
- gasification products from waste material
- coalgas

Why MCFC? Operating Temperature

MTU CFC Solutions

Efficiency Increase by *Internal Reforming* within High Temperature Fuel Cells

reforming reaction of methane

CH_4 + 2 H_2O + thermal energy → CO_2 + 4 H_2

heat of fuel cell reaction

1 Nm3 → 4 Nm3

10 kWh + 2 kWh → 12 kWh

2 kWh primary energy production in form of hydrogen from „waste“ heat

15 % gain of efficiency at 75 % fuel utilization

The HotModule System

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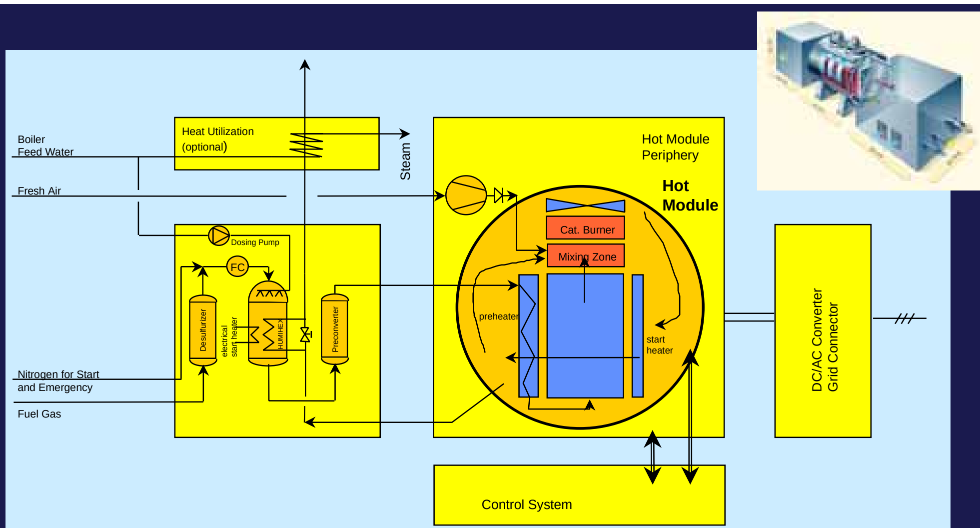

Feasibility of secondary fuel utilization with the MTU Fuel Cell HotModule

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The Molten Carbonate Fuel cell HotModule is most suitable for direct use of hydrocarbons and synthesis gases:

- Compact and reliable for cogeneration and trigeneration
- Right power class (220 kW el) for secondary energy sources and decentralized power and heat demands
- Highest electrical and thermal efficiencies even fueled by low caloric gases with high amounts of inert components with the result of a very low specific CO_2 production rate,
  - in the case of biomass based secondary energy utilization no CO_2 production
- Adjustable power to heat ratio in a wide range

Hot Module Plants Worldwide

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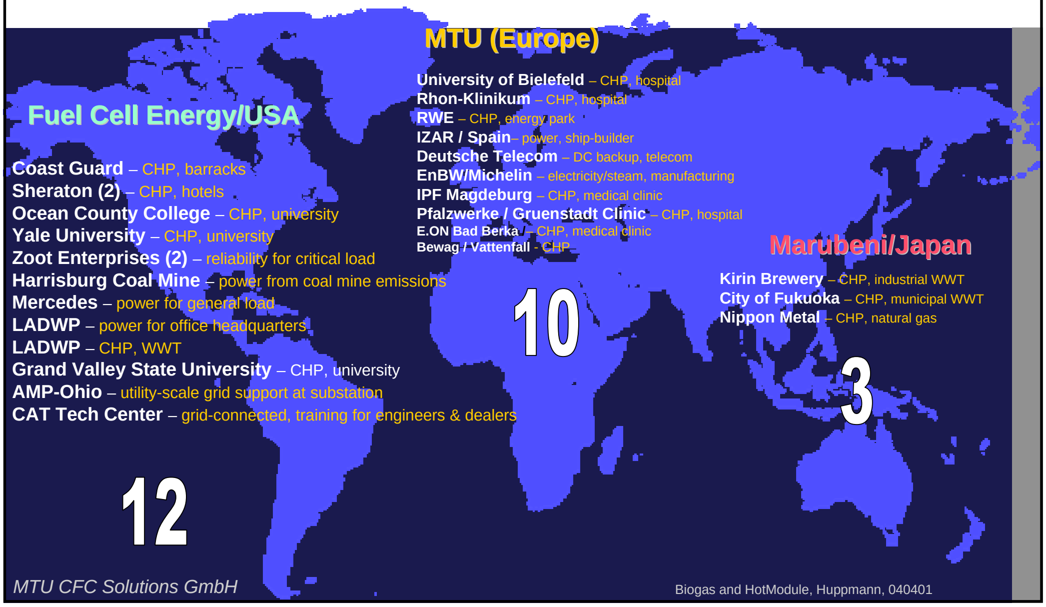
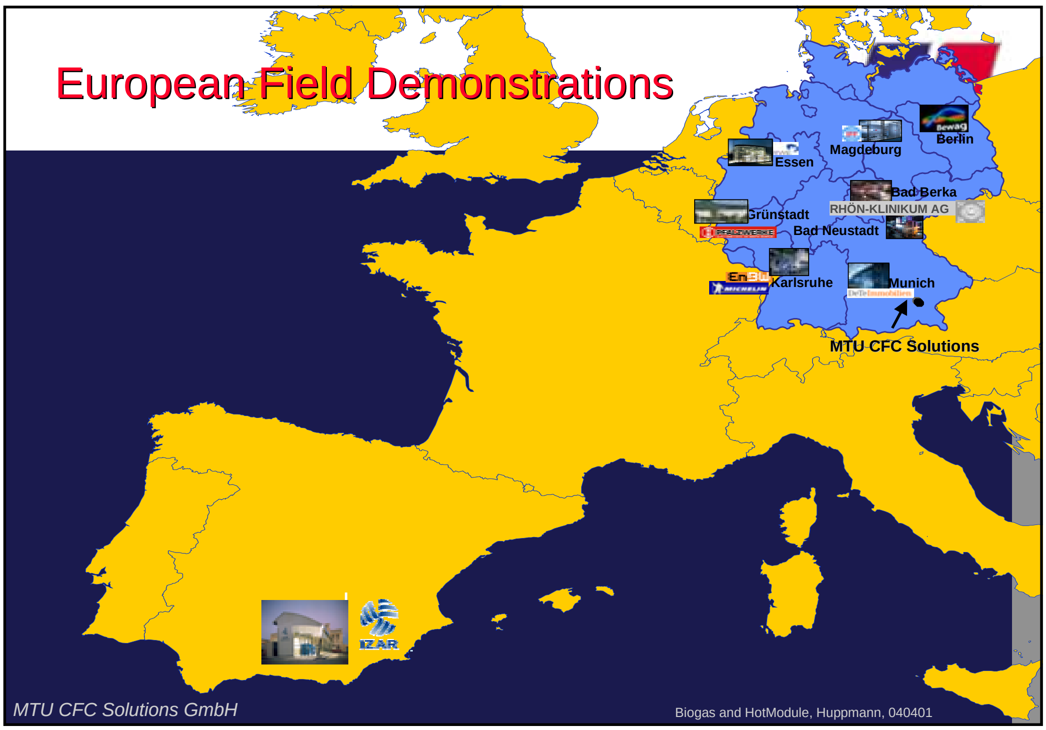


European Field Demonstrations



MTU Field Test Installations in Germany

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MTU Field Test Installations – Operating hours

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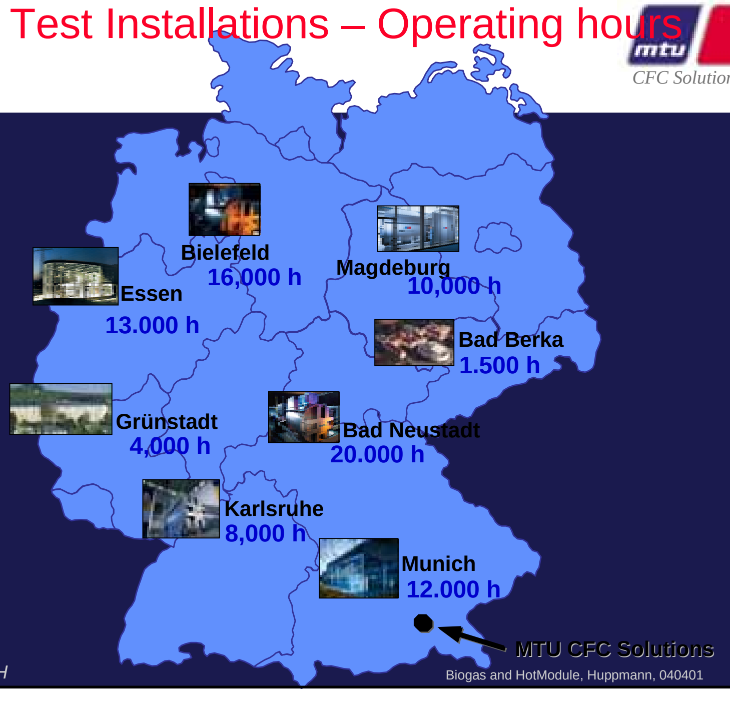


Ongoing Field Test Installations

Grünstadt Hospital / Germany

RWE / Germany

Otto-von-Guericke Clinic / Germany

Telekom / Germany

IZAR / Spain

Mercedes Benz / USA

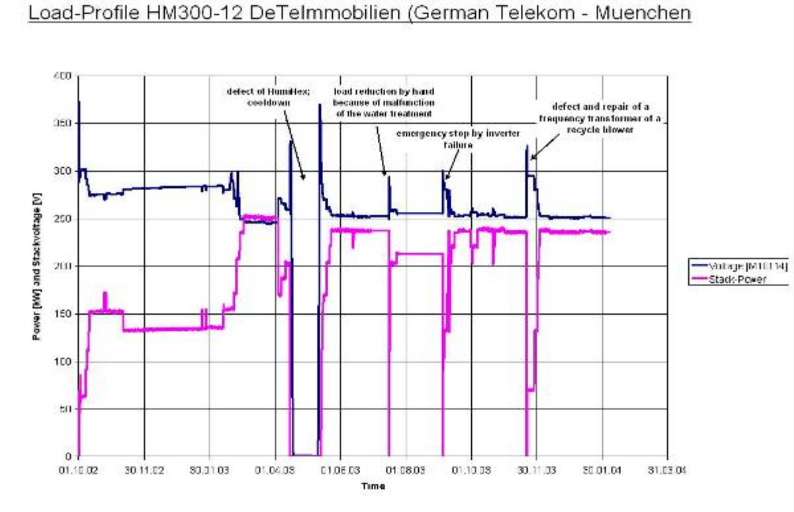
LADWP / USA

Bad Berka Hospital / Germany

Michelin / Germany

Rhön Klinikum / Germany

Load Profile Telekom Unit



e.on / Bad Berka Hospital– Germany

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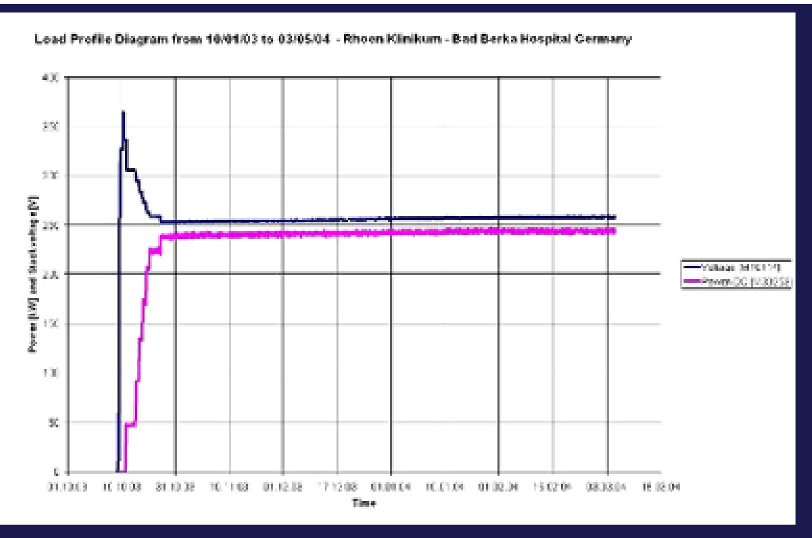

Field Test Experience

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- ✓ Electrical Plant Efficiency: 47 % Demonstrated
- ✓ Operating Time of First Field Test Unit > 20.000 h
- ✓ Total Accumulated Operating Time > 100.000 h
- ✓ Variable Power to Heat Ratio
- ✓ Over 90 % Total Efficiency by Multistage Heat Utilization
- ✓ Trigeneration Demonstrated: Power, Heat, Cooling
- ✓ DC Application Demonstrated

Operation and Monitoring
Entirely remote controlled Test Operation

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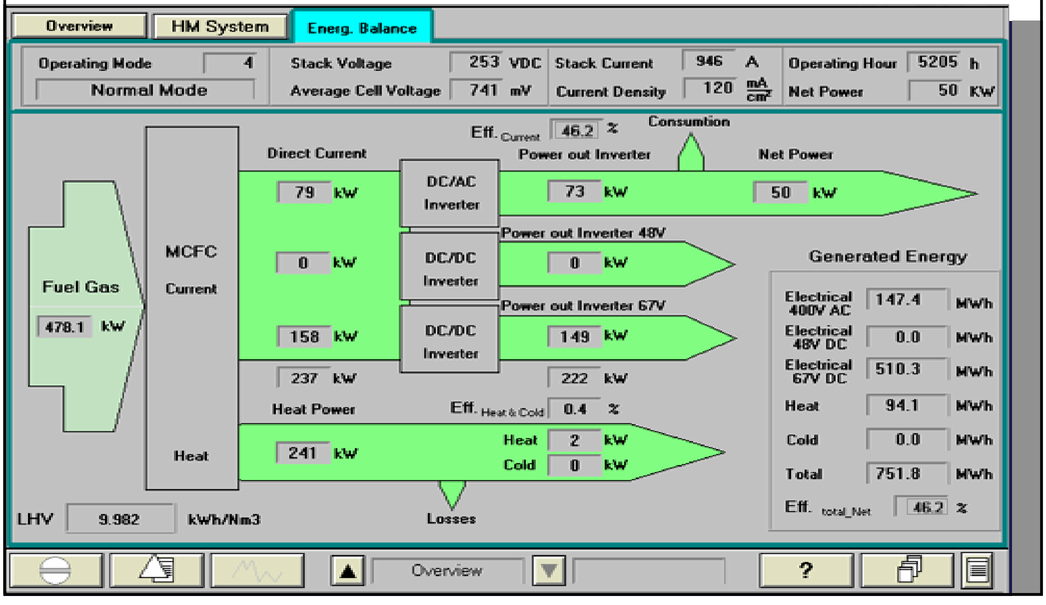

Comparison of Specific Emissions

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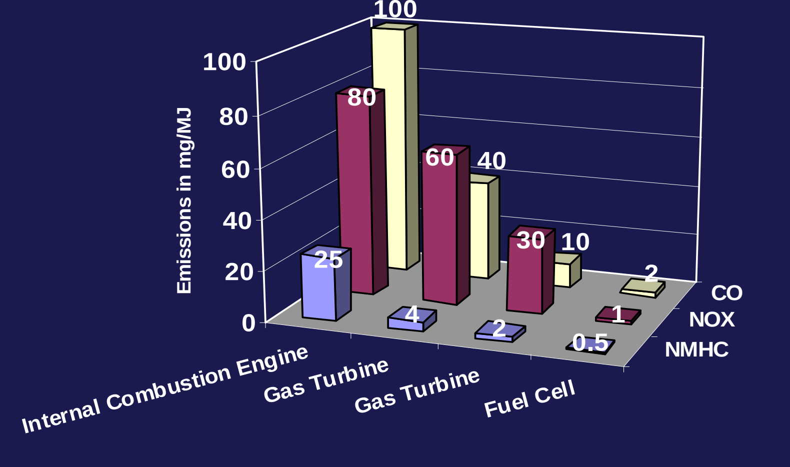
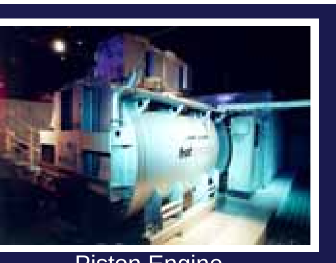


Molten Carbonate Fuel Cell
The MTU Fuel Cell HotModule Cogeneration Unit 250 kW el

CFC Solutions



- **_Emissions Measured:_**

		HotModule Pilot Plant	Piston Engine Cogeneration Unit
CO	mg/m³	14	30 – 480
NOx	mg/m³	< 2	10 – 750
Total Carbon	mg/m³	< 5	310 – 450
Organic Carbon	mg/m³	< 1	

Decentralized Consumable Energy Production:
The MTU Fuel Cell HotModule Unit 250 kW el

CFC Solutions

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Sustainable Energy Source:
Secondary Gas Utilization

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- **Anaerobic Digester Gas**
  - Agricultural biogas
  - Sewage gas
  - Landfill gas
- **Synthesis Gas**
  - from thermal gasification processes of biomass and organic waste material
  - Residual gases in industry
- **Coal mine gas**

Gas Availability

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Biogas:
Potential number of plants in the performance range of 400 to 2000 kW gas output in Germany 4000, realized till now ca. 1600. In case of consequent utilization of the gas produced for CHP 12 to 15 % of consumable energy can be reached.
(Meyer-Pittroff, TU München)

Sewage Gas:
Increasing number of biological sewage treatment plants. Most of the plants are equipped with piston engines already. Only replacement and small additional potential.

Synthesis gas from thermal gasification of waste material: Several gasification systems under development (Choren, Thermoselect, ElectroFarming, DMT and others). Potential for MCFC dependent on development of gasification systems.

High potentials in purge gas in chemical and petrochemical industry, in particular at methanol production from synthesis gases: Choren et al.

Secondary Gas Utilization: Research Projects

- Lab-Scale Testbed Operation with:
  - Agricultural Fermentation Gas – Seaborne (G), Univ. Nitra (Sk), Schmack (G) - 2002 – 2004
  - Municipal Sewage Gas or Landfill Gas – Linz AG (A) - 2003
  - Fermentation Gas from Organic Waste and Landfillgas – Urbaser/Madrid (E) - 2004
  - gasified Coal – RWE Essen (G) – 1993

Fuel - Contamination

O_2	Peak Shaving Gas, Air from Cleaning Process
Sulfur Containing Compounds	H_2S, THT, Mercaptanes, Thioester, Thioether, COS, (SO_2)
Nitrogen Containing Compounds	NH_3, NOx, Amines, N_2 (Gasification)
Olefinic Hydrocarbons, Tar	$R_2C{=}CR_2$, aromatic HC, undefined products from cracking reactions
Halides	F, Cl, Br, I, aliphatic, aromatic
Volatile metalorganic Compounds	R_3-Si-O-Si-R_3 (Siloxanes)
Moisture	Problem during Compression of the Biogas < 60% rel.
Heavy Metal Dust	

Experience with Secondary Gas

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Effective Testbeds

Designed and
constructed by
MTU CFC Solutions

Right
Control Unit

Center
Supervisor Control
System

Left
Operation Unit

EFFECTIVE Stack

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EFFECTIVE – MCFC-Process

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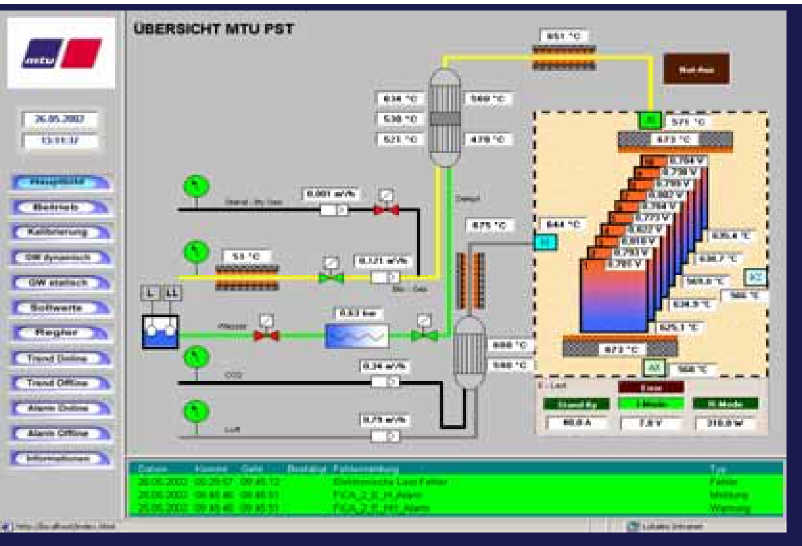

Results

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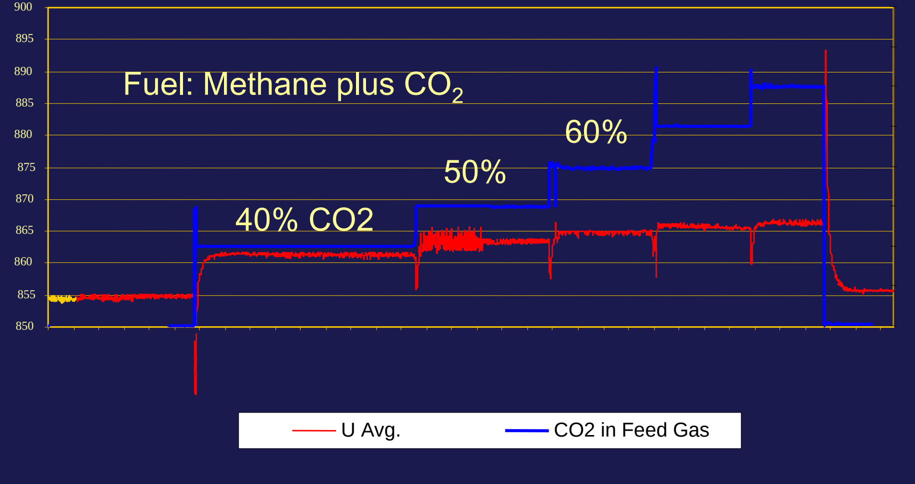
- Operation of MCFC-stacks with Biogas and Coal Gas without any problems
- Posttest analyzes indicates no severe interaction between biogas/coal gas and fuel cell system components
- NH_3 reduction by catalytic decomposition
  (labscale single cell experiments)

HotModule
Simulation of Field Conditions

- Addtion of CO_2 to Natural Gas increases performance of MTU's HotModule significantly

Cell Voltage depends on CO_2-Content in Fuel



HotModule
Simulation of Field Conditions

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- NH_3-Reduction

HotModule
NH_3-Decomposition

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- Conversion of more than 99% NH_3 (initial concentration > 5000 ppmV NH_3 added to natural gas**)**
- NH_3-Decomposition
  depends on Fuel-Utilization
  (high Fuel-Util. results in lower
  NH_3-exhaust concentration)

HotModule
Simulation of Field Conditions

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- Addition of N_2 to Natural Gas
  had no influence on the performance

  (simulating gases which are formed in the auto-thermal gasification of biomass)

HotModule – Nitrogen

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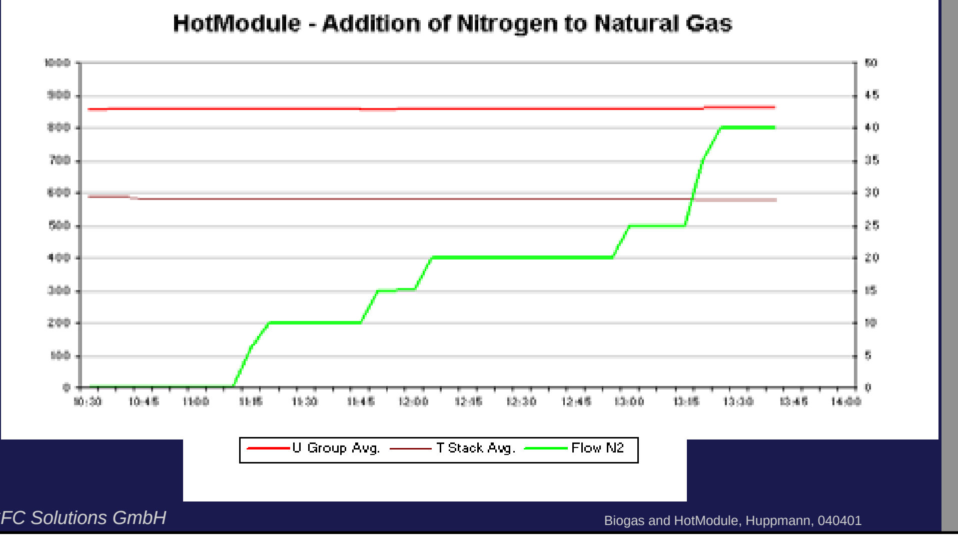

Conclusions

- Biogas-fueled operation of MCFC-stacks has been demonstrated in Field Tests
- High performance of the tested fuel upgrading systems
- No negative influence of biogas contaminants if eliminated
- Performance-dependence on CO_2-concentration
- Decomposition of NH_3
- No significant influence of inerts (N_2)

Decentralized Consumable Energy Production: The MTU Fuel Cell HotModule Unit 250 kW el

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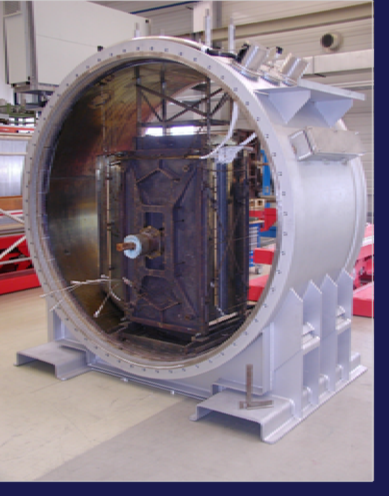
Outlook

MTU CFC Solutions

- Maturing & Extension of the Product Line
- Value Engineering for Cost Reduction
- Large Scale Serial Production and Assembly
- Market and Customer Development
- Development of a MegaWatt Module
- Domestic Heating Appliances / APU



Challenges
Fuel Flexibility opens different Markets

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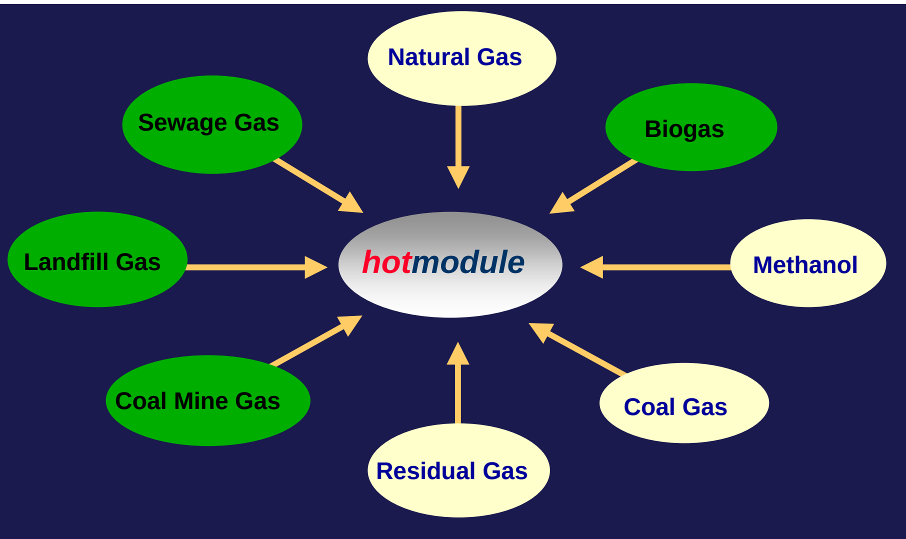

Full Range Product Portfolio

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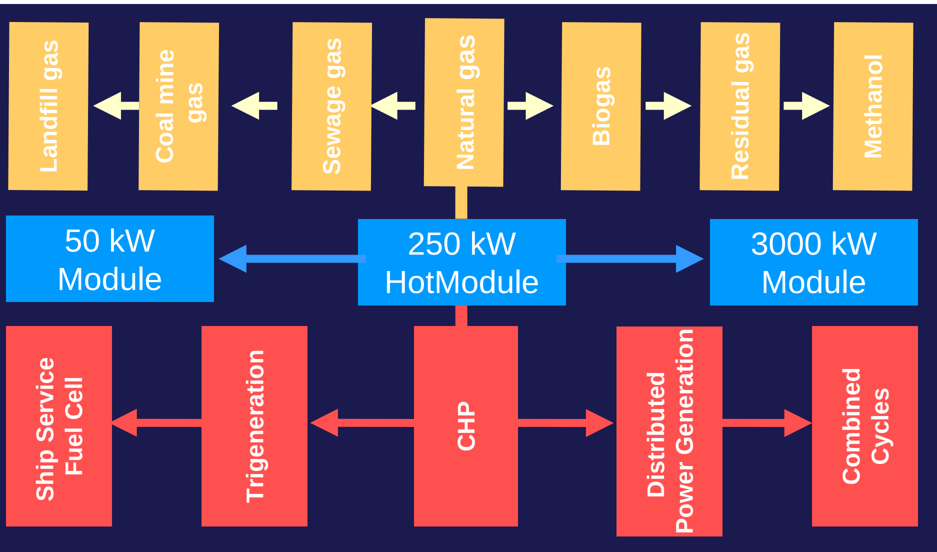

Cost Effective Power Production:
Lessons Learned

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- Avoided T&D Costs
- Base Load Operation
- Low Operating Costs
- High Reliability
- Excellent Partload Behaviour
- Variable Power to Heat Ratio
- Emission Benefits

Molten Carbonate Fuel Cell

The MTU Fuel Cell HotModule Cogeneration Unit 250 kW el

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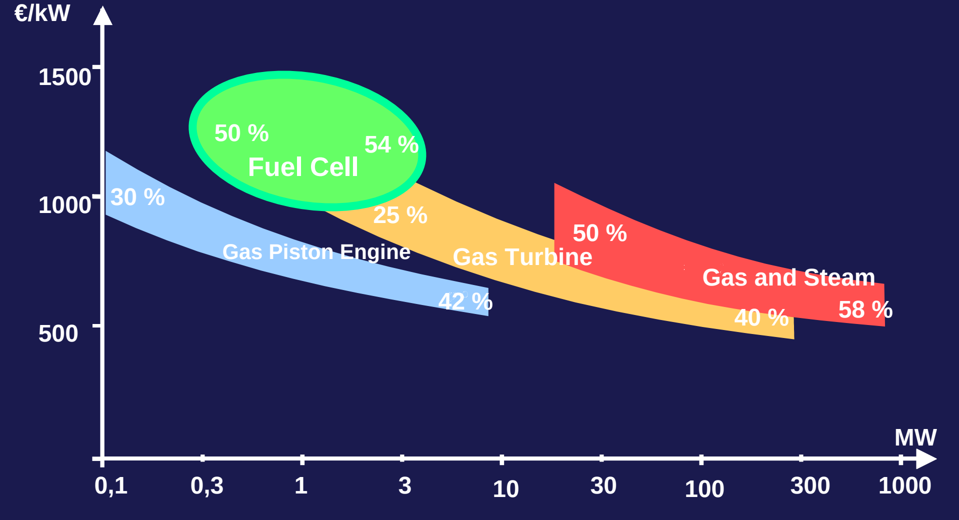
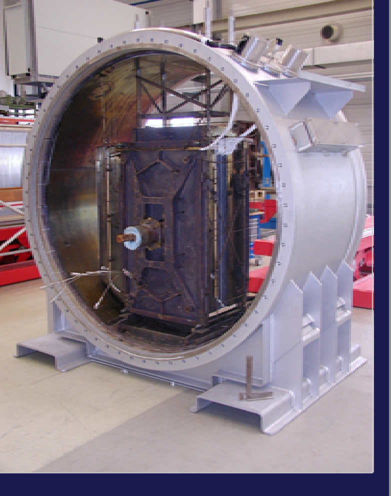


Looking Ahead

MTU CFC Solutions

- Maturing & Extension of the Product Line
- Value Engineering for Cost Reduction
- Large Scale Production and Assembly
- Market and Customer Development



End of Beginning

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“This is not the end,
this is not even the beginning of the end,
but perhaps this is the end of the beginning.” ***Sir Winston Churchill***

Thank you for your kind attention