Schweizerische Eidgenossenschaft
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Eidgenössisches Departement für
Umwelt, Verkehr, Energie und Kommunikation UVEK

Bundesamt für Energie BFE

Schlussbericht 30. September 2013

IEA AFC Annex 25
Fuel cell systems for stationary application

Subtask 5: Status of large fuel cells – market and demonstrations

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BFE-Vertrags- und Projektnummer: 101772 / 154447 (neu SI/500048-01)

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Abstract

Fuel cells are one of the promising technologies for generating electricity from the conversion of chemical energy sources. Applications are seen for the mobility sector, in portable devices or in stationary use. Within the framework of the Energy Technology Network of the IEA, a working group (Implementing Agreement) is dealing with the topic. Six subgroups (Annexes) are discussing and investigating the technology and possible applications of fuel cells. Annex 25 deals with stationary applications and Subtask 5 with the status of large fuel cells.

The most successful fuel cell installation to date was realized in Birsfelden and commissioned in 2000. The 200 kWe plant is a PAFC (Phosphoric Acid) from UTC (United Technology Coorperation). It was in operation for 40'000 hours and achieved an electrical efficiency of 40 %. A "follow-up project" was commissioned in 2010. The 230 kWe plant is an MCFC (Molten Carobonate) based on the stack technology of Fuel Cell Energy but built by MTU Onsite Energy in Germany.

In 2013, the PAFC and the MCFC are still the systems that are installed the most among the larger fuel cells and thus have the greatest market success. Nevertheless, the breakthrough has not yet been achieved. MTU Onsite Energy has ended its activities and UTC one of the pioneering companies in this field has sold its entire fuel cell business. New suppliers such as Bloom Energy, on the other hand, are showing success with SOFC in market niches (data centers). Other developers of large SOFC are not offering products yet. Compared to combustion-based power generation, fuel cells in the comparatively small power range show electrical efficiencies of 40%-50% with very low emissions. Combustion engines achieve similar values with additional components (waste heat to electricity), but have considerably smaller dimensions and weights at higher outputs.

The large fuel cells are showing improvements, but there is still a need for further development.

Zusammenfassung

Brennstoffzellen sind eine der vielversprechenden Technologien zur Erzeugung von Strom aus der Umwandlung von chemischen Energieträgern. Anwendungen werden für den Mobilitätsbereich, in portablen Geräten oder in stationären Einsatz gesehen. Im Rahmen der Energie Techologie Netzwerks der IEA befassen sich eine Arbeitsgruppe mit dem Thema. In 6 Untergruppen werden die Technologie und die Einsatzmöglichkeiten von Brennstoffzellen diskutiert und untersucht. Der Annex 25 beschäftigt sich mit der stationären Anwendung und im Subtask 5 der Status von grossen Brennstoffzellen.

Die bisher erfolgreichste Brennstoffzelleninstallation wurde in Birsfelden realisiert und 2000 in Betrieb genommen. Die 200 kWe Anlage ist eine PAFC von UTC. Sie war während 40‘000 Stunden in Betrieb und erreichte einen elektrischen Wirkungsgrad von 40 %. Ein „Nachfolgeprojekt“ wurde 2010 in Betrieb genommen. Die 230 kWe Anlage ist eine MCFC basierend auf der Stacktechnologie von Fuel Cell Energie aber von MTU Onsite Energy in Deutschland gebaut.

Die PAFC und die MCFC sind auch 2013 noch die Anlagen, die bei den grösseren Brennstoffzellen am meisten installiert werden und damit den grössten Markterfolg haben. Der Durchbruch ist trotzdem noch nicht geschafft. MTU Onsite Energy hat ihre Aktivitäten beendet und UTC eine der Pionierfirmen hat den gesamten Brennstoffzellenbereich verkauft. Neue Anbieter wie Bloom Energy zeigen hingegen Erfolge mit SOFC in Marktnischen (Datacenter). Andere Entwickler von grossen SOFC sind bieten bisher keine Produkte an. Im Vergleich zur verbrennungsbasierten Stromerzeugung, zeigen die Brennstoffellen im vergleichsweise kleinen Leistungsbereich elektrische Wirkungsgrade von 40 % – 50 % bei sehr geringen Emissionen. Verbrennungsmotoren erreichen mit Zusatzkomponenten (Abwärme-Verstromung) ähnliche Werte habe aber bei höheren Leistungen erheblich geringere Dimensionen und Gewichte.

Die grossen Brennstoffzellen zeigen Verbesserungen, aber es besteht noch ein weiterer Entwicklungsbedarf.

Introduction

IEA Advanced Fuel Cells Implementing Agreement

Advanced Fuel Cells Implementing Agreement (AFC IA) is on of 40 Technology Collaboration Programmes with in the Energy Technology Network (ETN) of the International Energy Agency. The participants in this Agreements are organizations from IEA-Member Countries.

The scope of the Implementing Agreement for a Program of Research, Development and Demonstration on Advanced Fuel Cells (AFC IA) is to advance the state of understanding of all Contracting Parties in the field of advanced fuel cells. It achieves this through a coordinated program of information exchange on the research and technology development underway internationally, as well as performing systems analysis. The focus is the technologies most likely to achieve widespread deployment – molten carbonate fuel cells (MCFC), solid oxide fuel cells (SOFC) and polymer electrolyte fuel cells (PEFC) – and applications of fuel cells, specifically stationary power generation, portable power and transport. There is a strong emphasis on information exchange through Annex meetings, workshops and reports. The work is undertaken on a task-sharing basis with each participating country providing an agreed level of effort over the period of the Annex.

Advanced Fuel Cells Implementing Agreement (AFC IA) consist of six different groups that work together in different topics in the period from 1 March 2009 until 31 December 2013. This tasks are called “Annexes” and are an addendum to the implementing agreement.

Annex 22: Polymer Electrolyte Fuel Cells

- Identification and development of improved stack materials: membranes, electrode catalysts, bipolar plates, cells and stack assemblies.
- Resolution of stack and system issues such as contaminants, humidification and thermal management, operating environments and duty cycles, rapid-start, durability, freeze-thaw cycling, and characterisation of materials and components.
- R&D on direct fuel polymer electrolyte fuel cells, e.g. Direct Methanol Fuel Cells, including cell materials research, investigation of effects of operating conditions and stack/system modelling.

Annex 23: Molten Carbonate Fuel Cells

- Improvement of performance, endurance, and cost effectiveness, for cells and stacks.
- Development and optimisation of MCFC system for various applications by evaluating performance of previous demonstrations or early market products.
- Identification of present and envisaged problems to be solved for rapid and further market penetration.
- Identification of possible opportunities for collaboration.

Annex 24: Solid Oxide Fuel Cells

- Continuation and intensification of information exchange on SOFC through annual workshops and topic meetings, focusing on durability and costs of SOFC stacks and systems.

Annex 25: Fuel Cells for Stationary Applications

- Evaluation of major demonstration projects.
- Identification of new early commercial applications for stationary fuel cells.
- Fuels for fuel cells, including locally produced fuels.
- Economic factors for market introduction.

Annex 26: Fuel Cells for Transportation

- Advanced Fuel cell systems for transportation
- On-board Hydrogen storage
- Hydrogen infrastructure
- Technology validation and economics

Annex 27: Fuel Cells for Portable Applications

- System analysis and hybridisation
- System, stack and cell development
- Codes and standards
- Fuels and fuels packaging
- Lifetime enhancement

This reports describes the work of “Annex 25” and its Subtask 5.

Annex 25: Fuel Cells for Stationary Applications

The objective of this annex is to understand better how stationary fuel cell systems may be deployed in energy systems The objective of Annex 25 is to better understand how stationary fuel cell systems may be deployed in energy systems. The work focuses on the requirements from the market for stationary applications; both opportunities and obstacles. Market development is followed closely with a special focus on fuels, system optimization, environment and competitiveness together with following up on the real status of stationary fuel cell systems. The Annex has been in operation since February 2009 and will run until February 2014. The Operating Agent for this Annex is Bengt Ridell, from Grontmij AB, financed by The Swedish Energy Agency. Stationary fuel cells are defined as fuel cells that provide electricity and potentially heat, and are designed not to be moved. Such systems can utilize the widest range of fuel cell technologies, with MCFC, PEFC, PAFC and SOFC systems all in operation around the world. A key element of the work of this Annex is that the conditions for the introduction of stationary fuel cells are different in each country, even if they are neighbors. Electricity production systems vary between different countries, influenced by historic domestic sources of primary power or the introduction of nuclear power. The varying environmental, policy and economic environments that exist amplify these differences. This Annex is extremely active as there is considerable expansion of stationary fuel cells occurring currently, with both the growth in domestic level systems for CHP and commercial systems that provide power and backup power such as for the telecoms industry or for data centers.

The motto for Annex 25 is ‘to prepare stationary fuel cells for the market and the market for stationary fuel cells’. It is important to advise authorities and developers of the key steps necessary for market introduction and expansion.

Participants

Country Participant	Associated Institution
Australia	Ceramic Fuel Cells Limited
Austria	Austrian Energy Agency
Denmark	Haldor Topsoe, Dantherm Power
Finland	Technical Research Centre of Finland, VTT, Wärtsilä
France	GDF-Suez
Germany	Forschungszentrum Jülich, E.ON New Buildings and Technology, Fuel Cell Energy Solutions
Italy	Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)
Japan	The New Energy and Industrial Technology Development Organisation (NEDO)
Panasonic	Aisin Seiki, Toshiba
Sweden	Grontmij
Switzerland	Beratung Renz Consulting, Swiss Federal Office of Energy
USA	US Department of Energy, EPRI UTC Power, SA Inc

Substasks overview

The Annex 25 consists of six subtasks, each with one or two task leaders. The topic of the subtasks is discussed during the Annex-Meetings and all participants contribute to the content.

Subtask 1: Small stationary fuel cells
(FZJ Forschungszentrum Jülich, Germany and NEDO, Japan)

The market activities for small stationary fuel cells have increased significantly. In this subtask the task is to investigate if there is a competitive viable market for small stationary fuel cells.

The possible application of high temperature PEFC and SOFC units will be investigated also for larger grid connected CHP units if their heat can be directly used to operate a small heat grid in a large buildings like hospitals, office building, large residential buildings etc.

The intention is that the subtask will have interest for all participating countries. Ownership private or utilities, operation control, virtual utility

- Tri-generation application will be studied electricity, heat and air-condition.
- Description of the competitive position in the national markets,
- National promotion, funding, and programs for subsidising
- Safety issues and legal requirements/conditions.

Subtask 2: Fuel for Fuel Cells
(MTU Onsite Power, Haldor Topsö and VITO, Belgium)

The new subtask fuel for fuel cells will focus on the use of waste to energy by the use of fuel cells, mainly waste biofuels and used biofuels. A major focus will be biomass suitable for gasification or anaerobic digestion. A special study will focus on the availability of surplus and cheap hydrogen.

Additional items would be:

- Availability and use of biomass, which is not competing food production,
- Biomass already used and available native and already existing or growing biomass, for which no other use is known till now (Examples Brazilian nuts, algae, sewage slurry, etc.)
- Use of residual and waste material originated from fossil and renewable sources (rubber, tyres, plastics, sewage slurry, paper, cartoons, wood, packaging material, demolition wood and other materials, …) Use of depleted air with additives like solvents with fuel cells instead of combustion

For all these energy sources the available technology to use them shall be described and suppliers shall be defined. Technologies needed for improvement of existing fuel cell technologies, reformers etc will be investigated.

Waste-hydrogen

At the moment several stationary demonstration projects are realised based on waste hydrogen from chemical industries especially the chlorine production industry. This hydrogen is today often just flared or vented off. The quality of the by-product or surplus hydrogen is very interesting for use in fuel cells.

Worldwide there is a market for several 100 MW of fuel cells in this specific application.

This subtask will study

- Summary of available waste hydrogen (collecting more of less available data)

- Description of the experience and results of running demonstration projects in this area and follow up op new demonstration projects
- Definition of a roll-out scenario for fuel cells in this application

Subtask 3: Fuel cell plants components
(VTT Finland, ECN, The Netherlands and FZJ Germany)

The subtask regarding balance of plant was much more difficult than anticipated when we started. Therefore more effort is needed and a somewhat new approach needs to be taken. Therefore the task would comprise the following actions.

A new approach to discover the cost for balance of plant components will be taken. The allowed cost for different components in a commercial stationary fuel cells will be estimated based on plant costs 5000 €/kW for residential and 1500 €/kW stationary systems. Component developers will be approached to get their views on how realistic the cost estimates are. In addition to SOFC also MCFC and HT-PEFC- systems will be dealt with.

Therefore the coming new Subtask will try to identify component developers and producers through other means. The plans for the Subtask will be to identify projects in which BoP components are developed and look at their approaches to what and how is developed and which the targets are. Another task will be to look at systems and possibilities to decrease the number of components. Fuel cell hybrid systems will be investigated.

Subtask 4: Analyzing design, operating, and control strategies for stationary fuel cell systems in the context of diverse markets. Sandia, USA,

The aim of Subtask is suggested to be to identify optimal design, operating, and control strategies for fuel cell systems in globally diverse installation contexts.

To identify crucial data inputs needed for scenario modelling efforts. This input data describes the installation context for fuel cell systems in different IEA member countries. It may include such variables as spark spread in different regions and building energy demand over time, which varies with variations in each regions climate, energy pricing, government incentives, usage habits, and building design, among other variables.

In the Subtask one important issue will be to gather some of this crucial data from different IEA member countries. Based on this data, to compare and contrast the benefits and drawbacks of different control strategies within these globally diverse installation contexts.

Subtask 5: Status of large fuel cells – market and demonstrations
(Renz Consulting Switzerland)

There are today (2009) several new large demonstration projects coming up. They are of course all subsidized but how far way are these technologies from commercialization?

What have been the outcome of demonstrations, lessons learned etc. In this subtask a follow up and analyze for instance purpose, testing programs, business plan, subsidies, lifetime, degradation etc. is elaborated.

A template for a questionnaire describing demonstration projects is worked out.

In the recent period of IEA Annex XIX significant differences between the (governmental) research and support and demonstrations programs in different countries have been observed. In the US the focus is on large fuel cells in the MW scale, whereas in Japan an important program for small stationary fuel cells is running. In Europe there are variety of divers programs (in the EU and the different countries), with focus on small and large stationary fuel cells. It would be interesting to collect the different research and support programs from member countries (with a questionnaire), to analyze the differences, the influence on the development of stationary fuel cells, success stories, timetables, budgets, etc. It will be important to follow up the different programs and to recognize changes and the causes. In addition the differences in politics (energy, ecology, economy related) can be analyzed and legislation concerning stationary fuel cells can be compared. A discussion among the experts of the IEA Annex on stationary fuel cell about the influences, the importance and the success of the governmental activities could be useful.

Subtask 6: Market status for stationary fuel cells
(Grontmij, Sweden)

The aim of this subtask is to present and discuss the latest development in the area of stationary fuel cells for instance new technology break-through, major programs, market development etc

One additional important topic will be to follow up development of Codes and Standards

Subtask 5:
Status of large fuel cells – market and demonstrations

Summary

The large fuel cell units of over 100kWe are located in just a few countries; most of them are in the USA, Korea and Germany. The market expansion of fuel cells, especially large MCFC in Korea is impressive. LG from Korea has also recently bought SOFC technology from Rolls-Royce and POSCO has started to produce MCFC with technology from Fuel Cell Energy. Government support for deployment of large fuel cells remains essential for market expansion, and approaches include tax credits and support for the use of renewable energy sources. Furthermore Fuji Electric has started to export larger units from Japan again. The major supplier of large SOFC plants is Bloom Energy in the USA, who provides large plants from 100KWe up to several MWe. The customers are mostly large companies like eBay, Apple, Google, Coca-Cola and Walmart and several power utilities. The Bloom Energy SOFC reuses the produced heat; the systems are not designed for CHP. The power density is low; a 200kWe system weighs 19 tons.

Subtask 5 consists of three Work Packages (WP):

- **WP1 Follow up of fuel cells technology status**
- **WP2 Efficiency and differences**
- **WP3 Differences and influences between governmental support programs**

For each of the work packages, a question catalogue was developed and distributed to the group participants. (See **appendix 1 - 3**). Unfortunately, the questions were answered very sparsely. The representatives of the fuel cell industry were reluctant to provide specific information and there was no access to information on various question. However, the questionnaires were a basis for the discussions in the meetings and for collecting information.

Subtask 5 – WP1
Follow up of fuel cells technology status

Focus
- Large and mid-scale fuel cells : 50, 200, 1000, 1000 + [kW]
- All kind of fuel cells i.e. AFC, PEFC, PAFC, MCFC, SOFC
- Demonstration project means: Complete system (plant) is installed and working; realistic circumstances
- All kind of fuels, a variety of fuels is favourable
- Only plants in operation in 2008 and newer
- Pilot-, demonstration and commercial

Working program
- Analyse the different status reports about mid and large scale stationary fuel cells
- Find out differences and elaborate a working program for Annex 25
  (What is our "USP"?)
- Elaborate a questionnaire (discuss it in a meeting)
- Collect information about demonstration plants world wide; list
- Discuss the list and make a selection
- Adjust the questionnaire and send it to the participants or direct to the owners/ operators of the selected plants
- Ask to answer the questionnaire and ask again and again…..
- Analyze the questionnaires, elaborate a first report
- Discuss the report in a meeting -> elaborate the final report
- And: presentations of demonstration plants during our meetings

Results
- **Two** technologies are (worldwide) successful: **PAFC, MCFC**
- **Three** manufacturers are successful: **FCE (**Fuel Cell Energy, US)**, Fuji Electric** (JP), **UTC** (United Technology, US) and since 2013 **Clear Edge** Fuel Cells (US)
- **Four** main markets: **US, J, KR, EU** (GER)
  - Utilities, Gas network operator - Sewerage companies
  - Education, Healthcare - Retail, Hospitality
  - (Food) Industry, Data Centre - Office and public building
- Market drivers: power supply, governmental support, environment

Others
- **Bloom Energy** (US): assembling small **SOFC**-Stacks to large units; success in US; only power supply
- **Ballard** (CA)**:** 1 MW **PEFC** for mobile distributed power or back up power
- **Nedstack** (GE): 1 MW **PEFC** with H_2 from industrial process
- **LG Fuel Cell Systems** (JP/US) Inc.: SOFC in SECA-Program

Promising Developments (since 2008)

UTC United Technologies Corporation (PAFC) -> Clear Edge
- several units from 200 kW model achieved > 60'000 h (even 90'000)
- el. efficiency 38 – 40 %
- (new) 400 kW Model
  - 10 y warranty, 80'000 h lifetime
  - el. efficiency 40 – 42 % and th. efficiency 30 – 40 % (depends on temperature)
  - continuous running favourable
  - 50 Hz model for Europe announced
- Largest site with 12 units (total 4800 kW)
- 200 kW is not any more available
- New owner of UTC Power has developed a 5 kW "PAFC" unit

First National Bank of Omaha
Nebraska

Verizon Communications
New York

St. Francis Hospital
Connecticut

Mohegan Sun Resort & Casino
Connecticut

Whole Foods Market
Connecticut

South Windsor High School
Connecticut

Fig. 1: UTC Power PAFC PureCell® Model 200-400 Solutions in the USA (source: UTC)

FCE Fuel Cell Energy (MCFC)

- 250 kW EU, 300 kW, 1500 kW, 3000 kW model
- el. efficiency 42 % (Zurich) – 47 % (techn. Data FCE)
- Continuous running, load modulation
- Worldwide 80 plants in operation (FY 2012)
- Promising orders for 2013:
  - 14.9 MW plant in Connecticut
  - 58.8 MW plant in Korea (21 units)
- Fuels: NG, Biogas
- Additional value through tri-generation, CHHP
- Direct Fuel Cell: Reforming inside the cell
- 4 stacks = 3 MW unit
- Cost reduction from 3000.- to 2200.- EUR/kW
- Additional cost reduction -> mass production (A. Buttone)
- Increased lifetime 25'000 -> 40'000 h
- Over 100 MW installed and 300 MW incl. ordered
- Strategy: 3 sites world wide for manufacturing the cells/stacks:
  - US
  - Korea (cooperation signed Feb. 2013)
  - Germany (FCE-Solution) + R&D with Fraunhofer
- Service and warranty contract 10 y, 20 y (incl. stack exchange)

Fig. 2: Fuel Cell Energy: Spinning Sewage into Gold (source: FCE)

An overview of fuel cell project in the US in 2010 can be found in **appendix 4**

Installation of a 250 kW unit in Switzerland (Grünau, Zürich) see **appendix 5.**

Bloom Energy

- 100 and 200 kW SOFC assembled small stacks
- Natural gas and biogas
- **Only power** production, el. efficiency 50%: **Bloom Energy Servers**
- ES-5400 Energy Server: 100 kW, 11 t, 4000 cells
- ES-5700 Energy Server: 200 kW, 19.4 t

Fig. 3: UPM-570 **Uninterruptible Power Module**: 150 kW, max. parallel 750 kW, max. standalone opertion duration during grid outage 96 hours (source Bloom Energy)

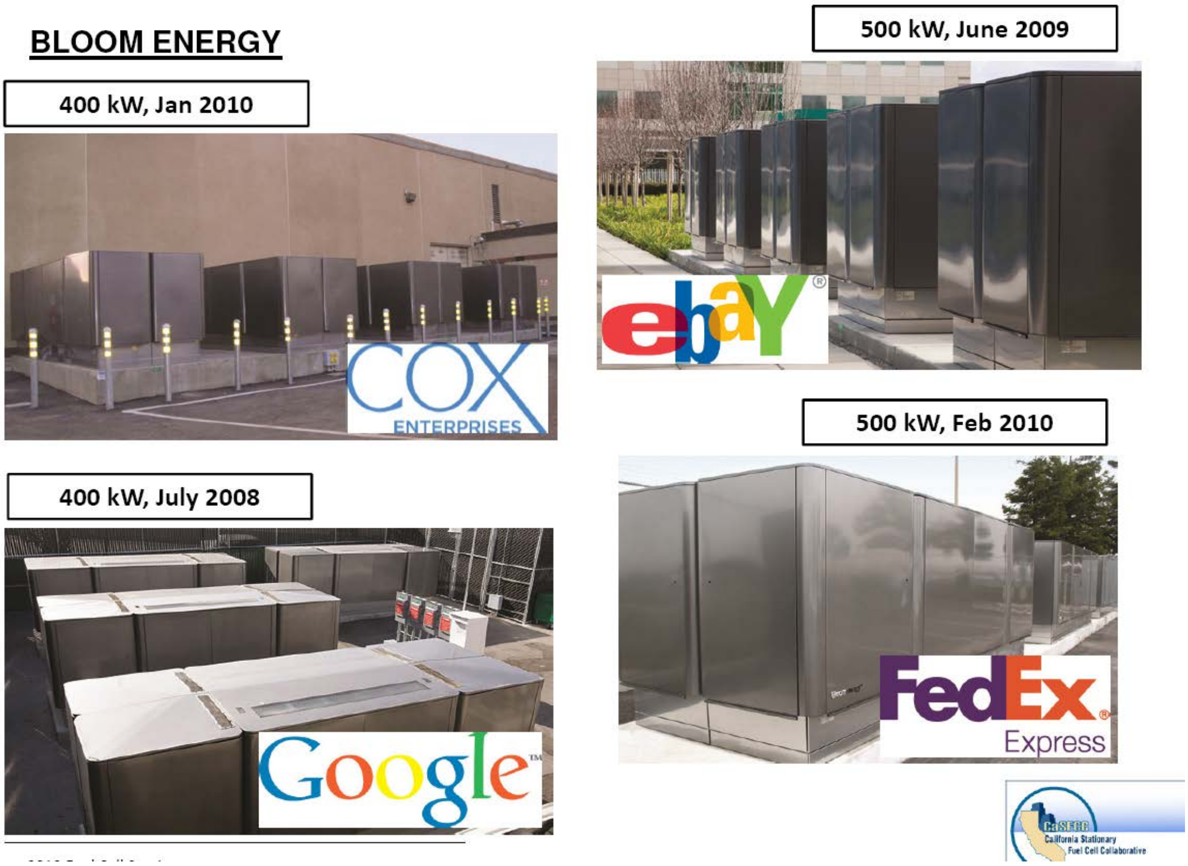


Fig. 4: Bloom Energy large SOFC electricity production: Different applications and customers

Ballard Power Solutions

Developer and manufacturer of PEM Fuel Cells in the range from 10 kWe – 1 MWe

Fig. 5: Ballard 1 MW Distributed generartion fuel cell system based on a PEM fuel cell. Has to be operated with pure hydrogen (< 98%) (source: Ballard)

Nedstack Fuel Cell Technology BV (NL)

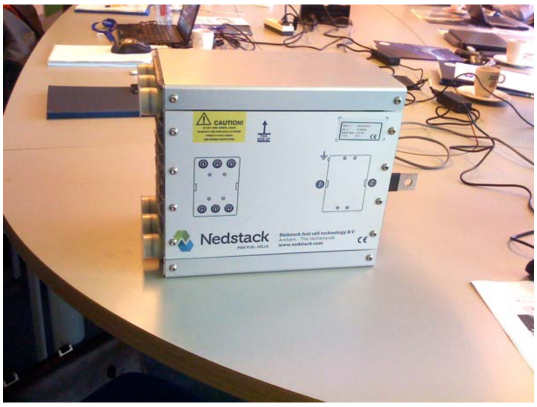


Fig. 6: Solvay's 1 MW fuel cell is an assembly of 168 stacks from Nedstack with 12'600 cells. It uses hydrogen from electrolyse for acid production (vinyl). Industrial plant in Antwerp (own pictures)

Fuji Electric

PAFC fuel cell 100kW for city gas, bio gas and pure hydrogen

Fig. 7: Fuji Electric 100kW PAFC installed in a unite from N_2telligence on a data center in Germany (https://www.sciencedirect.com/science/article/abs/pii/S146428591270069X)

Discouraging Developments (since 2008)

- **Siemens** stopped their SOFC activities
- **MTU** developed their own MCFC-Stack, sold a few units and stopped the FC-Activities (meanwhile the assets were bought by FCE)
- **Ansaldo** stopped their MCFC Activities
- SECA-Program: Industry-Partner 6 -> 2 ? (FCE, LG)
- SOFC-developer **Versa Power** has been bought by FCE
- LG is continuing SOFC-Technology from **Rolls Royce**
- **UTC** “the fuel cell leader since 1958” has sold the fuel cell business unit «UTC-Power» to Clear Edge; they will focus on two PAFC units: 5 kW, 400 kW. No news about the collaboration with Delphi in SECA.
- **Wärtsilä** stopped the development of SOFC-systems
- **Increase** of renewable energy systems **wind** and **photovoltaic**

Example of discouraging news:
Ad-hoc-Notice according to § 15 WpHG by Tognum Dec. 29, 2010
„Fuel-cell activities for stationary power generation discontinued due to a lack of medium-term commercial viability, given current market conditions and subsidy schemes“
*„The Executive Board of Tognum AG has decided to discontinue its fuel-cell activities for stationary power generation. Having carefully examined the most **recent demand forecasts** and carried out a thorough risk/reward analysis, Tognum opted against further active engagement in this area. The company has come to the conclusion that the **fuel-cell business is unlikely to become commercially viable** in the medium term, given current market conditions and subsidy schemes.*
*In the course of this year, management had actively looked at **additional market initiatives in support of fuel-cell technology in Asia**. Management also analysed potential **partnerships for serial production in Asia**, which, however, proved not sufficiently promising. After negotiations with a potential Asian partner, which had appeared promising at first, **ended without agreement** on 28 December 2010, the Executive Board took the decision to discontinue its fuel-cell activities.“*

Challenges and Opportunities

- Design + needs of future energy distributing and supplying systems
- Smart grids
- Renewable energies wind & photovoltaic
- Fluctuating energy production: hour, day, season
- Competing systems (ICE, GT, GTC)
- Cheap natural gas?
- Countries like Germany target to raise CHP-Power-Production from today 15 % to 25 % by 2020 (!) ->> incentives !!!
- European Energy Efficiency Directive (Oct. 2012)
- Reducing emissions (NOx, PM, Aerosols etc.)

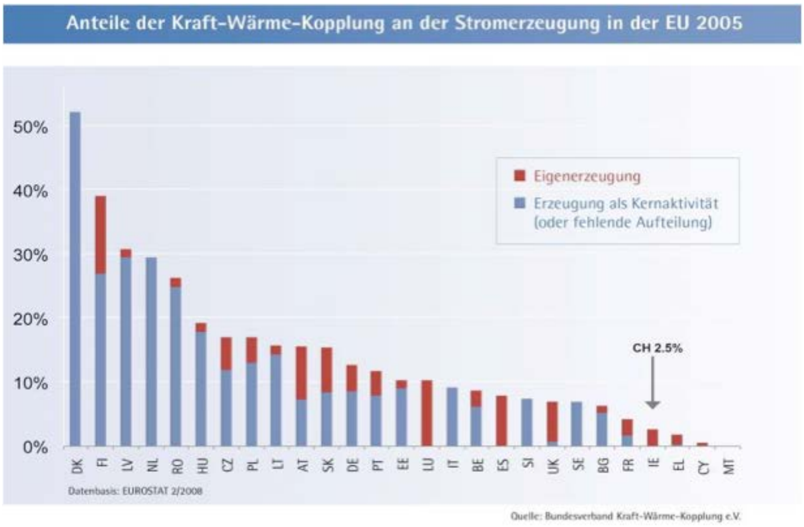


Fig. 8: Share of CHP on total of power generation in Europe

Additional Information
Other developments mid and large CHP "other technologies"

Schnell 250 kW CHP

- Internal Combustion Engine with NG or Biogas
- **250 kW**el. with efficiency: **47 %**; th. efficiency: 40 %
- Turbo-Compound connected with crankshaft
- NOx: 500 mg/m3

Fig. 9: Co-generation unit from Schnell with 250 kWe (based on a Scania Engine)

Wärtsilä 50 SG Gas Engine

- **18.3 MW** Spark ignited 4-stroke gas engine (bore 500 mm)
- el. efficiency with steam cycle: **53.7%**
- Start up time: 2 minutes from 0 to full load (19 MW)
- Grid synchronisation: 30 s
- **220 MW sold to Portland**
  General Electric

Aim of this plant:
„...to have the operational flexibility to quickly respond to variable input levels of wind and hydro power to the system.“

Fig. 10: Power generation installation with 8 Wärtsilä 50SG Gas Engines (souce Wärtsilä)

Subtask 5 WP 2
Efficiency and differences

Focus

- As we have seen in subtask 1 /Annex 19, the most important advantage of fuel cells should be high elect. efficiency
- What is electr. efficiency?
- How do we measure it, what is included, what not
- How do we compare electr. efficiency
- Which are the competing technologies?
- Are there any standards?
- And, don't forget the thermal efficiency (overall efficiency)

Working program

- Analyse the different definitions of efficiency for energy conversion systems
- Collect data and information about efficiencies of existing plants or systems (fuel cells, demonstration plants, competing technologies, the grid etc.)
- Find out differences and elaborate conclusions (1)
- Collect and analyse international standards
- Find out differences and elaborate conclusions (2)
- Status report and show the variety of standards and results
- How can we change it; get in contact with standardisation organisations?

Results

- **Methods** for **Calculating** Efficiency CHP: EPA United States Environmental Protection Agency
- **Test Method** fort he Performance of Stationary Fuel Cell Power Systems IEC 62282-3-200 = EN 62282-3-200
  Many Countries have adopted this standard
- Grid losses: 3 – 6 % (?)

Detail information see **appendix 5**

Missing

- Well to wheel (plug) comparison between different power generation systems with:
  - efficiency
  - GHG Footprint incl. down and upstream energy (direct + indirect)

Subtask 5 Part 3
Differences between governmental support programs

Focus

- Governmental support programs for R&D and P&D can help to develop and implement new technologies
- In the different member countries of the IEA the governmental support programs for fuel cells are different
- Within the EU we have country specific programs and joint programs (EU FP etc.)
- For the developer of a new and world wide distributed technology it is quiet difficult to focus their research work
- What are the main differences between the gov. programs

Working program

- Presentations (with a report) of the governmental fuel cell related support programs for R&D and P&D by the members of Annex 25 during our meetings (2 per meeting)
- External speakers e.g. from the EU, DOE, Japan, Korea etc.
- Collect the data and information and elaborate a "map" or a kind of a portfolio (technology, focus, subsidies, periods, results, changes etc.)
- Focus only on stationary mid- sized and large fuel cells or similar work in subtask 1 (small stationary fuel cells)?

Example:
Self-Generation Incentive Program California
http://energycenter.org/index.php/incentive-programs/self-generation-incentive-program
2013 Self-Generation Incentive Program (SGIP), February 2013, California Center for Sustainable Energy (CCSE)

Technology Type	Incentive ($/W)
Renewable and Waste Energy Recovery	
Wind Turbine	$1.19
Waste Heat to Power	$1.19
Pressure Reduction Turbine	$1.19
Non-Renewable Conventional CHP	
Internal Combustion Engine - CHP	$0.48
Microturbine - CHP	$0.48
Gas Turbine - CHP	$0.48
Emerging Technologies	
Advanced Energy Storage[2]	$1.80
Biogas [3]	$1.80
Fuel Cell - CHP or Electric-Only	$2.03

Fig. 11 Incentives for differen power generation technologies (CCSE 2013)

Appendix 1

Questionnaire 1
Follow up of fuel cells technology status

Focus

- **Mid- and large -scale fuel cells : 50, 200, 1000, 1000 + [kW]**
- All kind of fuel cells i.e. AFC, PEFC, PAFC, MCFC, SOFC
- Demonstration project means: Complete system (plant) is installed and working; realistic circumstances
- All kind of fuels, a variety of fuels is favourable
- Only plants in operation since 2008 and newer
- Pilot-, demonstration and commercial
- Answers concerning your country

Answers from

Name: affiliation: country:

Questions (-> only for fuel cells > 50 kW!)

1 Research & Development

(type of research company: university (U), gov. research institute (G), industry (I))

name of organisation	type	topic/ competence	fuel cell type

2 General status of large fuel cell applications in your country

Total MW installed/ in operation

MW		Year	

Shares (from total MW in %)

AFC	PEFC	PAFC	MCFC	SOFC

3 Manufacturer (in your country)

	Manufacturer 1	**Manufacturer 2**	**Manufacturer 3**
company			
established			
technology			
products			
stack manufacturer			
total systems sold (MW); worldwide			
total systems *in operation* 2012 (MW)			

4 *Examples and Experience (Pilot & Demonstration, Commercial)*

P&D: *first of this type, precommercial, price non competitive, need of financial support (subsidies) limited lifetime, maintenance by manufacturer*

Commercial: *serial production, (near) competitive price, competitive maintenance cost*

Criteria	**Example 1**	**Example 2**	**Example 3**
Basic information			
type of application (P&D, Commercial):			
type of fuel cell			
rated el. power (kW)			
rated el. efficiency			
fuel			
used for (back up, off grid, grid connected, premium power, chp, remote area, etc.)			
estimated lifetime			
warranty			
Location and involved companies			
location			
start of operation			
manufacturer			
customer (who bought the fuel cell			
operator/ maintenance			
end user (user of electricity, heat)			
Commercial information			
total investment			
subsidies (amount)			
subsidies from			
maintenance cost (cts/kWh_{el})			
price of natural gas (cts/kWh)			
price of electricity (cts/kWh)			
Rückliefertarif			
Experience			
date			
operational hours			
average power output			
produced electricity			
average electrical efficiency			
average overall efficiency (el, heat)			
degradation (V/1000 h)			
Remarks			

Please copy this page for more examples!

5 *Progress in the last 10 years (year = put into operation)*

2002

manufacturer	type	el. power kW	el. efficiency %	degradation V/1000 h	achieved lifetime hours

2007

manufacturer	type	el. power kW	el. efficiency %	degradation V/1000 h	achieved lifetime hours

2012

manufacturer	type	el. power kW	el. efficiency %	degradation V/1000 h	achieved lifetime hours

Comments

Appendix 2

Questionnaire 2
Efficiency and Differences

Focus

- ➢ As we have seen in subtask 1 /Annex 19, the most important advantage of fuel cells is/should be high electric efficiency
- ➢ What is efficiency in power generation
- ➢ How do we (stationary fuel cells) measure it, what is included, what not (natural gas input, net power to the grid')
- ➢ How do we compare electric efficiency to other technologies
- ➢ Which are the competing technologies?
- ➢ Influence of the losses in the power and the gas grid?
- ➢ Are there any standards?
- ➢ And, don't forget the thermal efficiency (overall efficiency)

Answers from		
Name:	affiliation:	country:

Introduction

Wikipedia: Energy conversion efficiency

Energy conversion efficiency is not defined uniquely, but instead depends on the usefulness of the output. All or part of the heat produced from burning a fuel may become rejected waste heat if, for example, work is the desired output from a thermodynamic cycle.

$$\eta = \frac{P_{\text{out}}}{P_{\text{in}}}$$

- **Electrical efficiency**, useful power output per electrical power consumed;
- **Mechanical efficiency,** where one form of mechanical energy (e.g. potential energy of water) is converted to mechanical energy (work);
- **Thermal efficiency or Fuel efficiency**, useful heat and/or work output per input energy such as the fuel consumed;
- **'Total efficiency', e.g., for cogeneration,** useful electric power and heat output per fuel energy consumed. Same as the thermal efficiency.

Wikipedia: Electrical efficiency

The **efficiency** of an entity (a device, component, or system) in electronics and electrical engineering is defined as useful power output divided by the total electrical power consumed (a fractional expression), typically denoted by the Greek letter small Eta (η).

World Energy Council: Fuel Cell Efficiency

Efficiency figures can be defined in many ways, conventionally they are based upon the maximum energy you could obtain from a fuel by burning it, called the heating or calorific value (HV or CV). In a fuel cell, the energy available is called the Gibbs energy, and represents the maximum amount of electricity that can be gained from the cell. The Gibbs energy is smaller than the calorific value. Fuel cell efficiencies related to Gibbs energies are nearly always 100%, so efficiency is normally defined as the electrical energy extracted divided by the calorific value of the fuel. This enables fuel cells to be compared directly to combustion-based processes, but places an upper limit on fuel cell efficiencies due to the chemical properties of the fuel. A hydrogen fuel cell operating at 25°C has a maximum theoretical efficiency of 83%, even though the fuel cell is extracting all the electrical energy possible. This compares to a maximum theoretical efficiency in a combustion engine at 500°C of 58% (assuming heat rejection at 50°C).

In a perfect system, the efficiency of a fuel cell would decrease with increasing temperature, as the Gibbs energy decreases with higher temperatures. However in practice there are efficiency drops at low temperature, and so the change in Gibbs energy is not significant. High temperature (800-1000°C) fuel cells can be used with a turbine to produce electricity from the waste heat. It is in this application where the really high efficiency figures (near 80%) could be realised, and heat could still be provided for district heating. However low temperature fuel cells, or those not operated with a turbine to recover waste heat, are still more efficient than existing technologies.

Example of energy conversion efficiency

Conversion process	Energy efficiency
Electricity generation	
Gas turbine	up to 40%
Gas turbine plus steam turbine (combined cycle)	up to 60%
Water turbine	up to 90% (practically achieved)
Wind turbine	up to 59% (theoretical limit)
Solar cell	6–40% (technology dependent, 15% most often, 85–90% theoretical limit)
Fuel cell	up to 85%
World Electricity generation 2008	Gross output 39%, Net output 33%.[1]
Engine/Motor	
Combustion engine	10–50%[2]
Electric motors	70–99.99% (above 200W); 50–90% (between 10–200W); 30–60% (small ones < 10W)
Natural process	
Photosynthesis	up to 6% [3]
Muscle	14–27%

source: Wikipedia

Fuel heating values and efficiency
In Europe the usable energy content of fuel is typically calculated using the lower heating value (LHV) of the fuel, which definition assumes that the water vapor produced during fuel combustion (oxidation), remains gaseous, and is not condensed to liquid water so the latent heat of vaporization of that water is not usable. Using the LHV, a condensing boiler can achieve a "heating efficiency" in excess of 100% (this does not violate the first law of thermodynamics as long as the LHV convention is understood, but does cause confusion). This is because the apparatus recovers part of the heat of vaporization, which is not included in the definition of the lower heating value of fuel. In the U.S. and elsewhere, the higher heating value (HHV) is used, which includes the latent heat for condensing the water vapor, and thus the thermodynamic maximum of 100% efficiency cannot be exceeded with HHV's use.

Energy losses in the power grid
The transmission and distribution or “T&D” system, then, includes everything between a generation plant and an end-use site. Along the way, some of the energy supplied by the generator is lost due to the resistance of the wires and equipment that the electricity passes through. Most of this energy is converted to heat. Just how much energy is taken up as losses in the T&D system depends greatly on the physical characteristics of the system in question as well as how it is operated. Generally speaking, T&D losses between 6% and 8% are considered normal. *(ABB 2007)*

Electricity Distribution Efficiency
Distribution Loss Factors (DLF)
The resistance of the cables conducting the current flow between the generating plant and the end user's premises cause further efficiency losses due to the Joule heating (I2R Losses) of the interconnecting power cables. There are two major influencing factors.
Location
The resistance of the cables increases with distance so that losses are typically 5% for supplies to urban locations close to the power source but as high as 10% to 20% for remote rural locations. The overall average for the USA is 7% to 8%.
Voltage
Since Joule heating losses are proportional to the square of the current, distribution losses can be reduced by transmitting the power with as low a current as possible by using higher transmission voltages. The upper voltage limit is set by the breakdown of the air insulation between the power cables and the earth, or more likely across the insulators suspending the cables from the transmission pylons (towers).
With high voltage transmission systems there are also additional, though minor, copper and iron losses in the transformers, stepping up the voltage at the generating station and stepping it down again at the point of consumption, due to the resistance of the windings and the hysteresis and eddy current losses in the transformer cores.
(www.mpoweuk.com)

Questions

Please send me links, studies, data to the following questions!

1 Definitions/ Standards for fuel cells

a. Fuel Cell Community
b. National standardization organisations (ASME, DIN)
c. Industry standardization

2 Definitions/ Standards for competing technology

a. National standardization organisations (ASME, DIN)
b. Industry standardization (manufacturers of power generation devices)
c. Organisations of the power industry

3 Losses of the power grid

Studies/Data from your country?

4 Losses of the gas grid

Studies/Data from your country?

Appendix 3

Questionnaire 3
Differences between governmental support programs

Focus

- Governmental support programs for R&D and P&D can help to develop and implement new technologies
- In the different member countries of the IEA the governmental support programs for fuel cells are different
- Within the EU we have country specific programs and joint programs (EU FP etc.)
- For the developer of a new and world wide distributed technology it is quiet difficult to focus their research work
- What are the main differences between the gov. programs

Answers from
Name: affiliation: country:

Questions

1 Research & Development (large fuel cell > 50 kW!)

Please describe and fill in!
Please add columns for more programs, institutes

Fuel cell research programs

	Program 1	Program 2
supported technology		
topic, aim		
duration of program		
funds		
support of (national, industrial) research		
support from (EU, State, Federal State, Utilities, Industry, others)		

Supported federal (national, public) research institute/ university

	Institute 1	Institute 2
name		
kind of institute		
supported technology		
topic, aim		
duration of support		
supported from (EU, State, Federal State)		
funds/ amount		
share of total cost		
other grants		

2 Pilot & Demonstration (large fuel cell > 50 kW!)

Please describe and fill in!

	State EU	Federal State County	Utility (electricity, n. gas)	others
funding special FC-P&D-programs				
funding within climate change or renewable energy programs				
funding within general energy-programs				
legislation				
tax reduction (condition)				
special gas price (condition)				
special price for electricity (condition)				
others				

Comments:

3 "Commercial" (large fuel cell > 50 kW!)

What is your understanding of "commercial" fuel cell power plants?
Please describe:

	State	Federal State County	Utility (electricity, n. gas)	others
funding special FC-P&D-programs				
funding within climate change or renewable energy programs				
funding within gen-eral energy-pro-grams				
legislation				
tax reduction (condition)				
special gas price (condition)				
special price for electricity (condition)				
others				

Comments:

Appendix 4

Annual Report of US Department of Energy

Table 7: Summary of FuelCell Energy U.S. Projects 2010		
Location	**Capacity**	**Notes**
San Diego, CA	2.8 MW	Will use wastewater treatment biogas
San Diego, CA	1.4 MW	Will use wastewater treatment biogas
Point Loma, CA	300 kW	Will use wastewater treatment biogas
San Jose, CA	1.4 MW	Will use biogas
Rancho, CA	1.4 MW	Will power a pumping station
Riverside County, CA	600 kW	Will use biogas
Chino, CA	2.8 MW	Will use biogas
Tulare, CA	300 kW	Fourth fuel cell brings plant's total to 1 MW
French Camp, CA	1.4 MW	Will utilize renewable biogas generated from chicken waste
Hayward Hills, CA	1.4 MW	Utility-owned at CSU-East Bay
San Francisco, CA	1.4 MW	Utility-owned at San Francisco State University
Long Beach, CA	1.4 MW	Utility-owned at CSU-Long Beach
San Bernardino, CA	1.4 MW	Utility-owned at CSU-San Bernadino
Dublin, CA	300 kW	U.S. Army Camp Parks Reserve Forces Training Area
South Windsor, CT	300 kW	Frozen food processing facility
Groton, CT	600 kW	U.S. Naval Submarine base

Table 8: Summary of UTC Power U.S. Projects 2010		
Location	**Capacity**	**Notes**
San Jose, CA	400 kW	CHP, providing 90 percent of grocery store electricity
San Diego, CA	400 kW	CHP, providing 90 percent of grocery store electricity
New Haven, CT	400 kW	Fuel cell will power to two schools
Torrington, CT	400 kW	CHP, providing 94 percent of grocery store electricity and 70 percent of its space heating requirements
New Haven, CT	400 kW	CHP, providing nearly all of the electricity for apartments, stores and common areas and hot water for a swimming pool
White Plains, NY	200 kW	CHP, providing 20 percent of the building's electricity
New York, NY	2.4 MW	Six fuel cells (out of 12) delivered to World Trade Center site
Sturtevant, WI	400 kW	Main headquarters

Appendix 5

Brennstoffzellen-Pilotanlage Grünau (Zürich)

Medienorientierung vom 29. November 2010

Anfang November 2010 hatten die Elektrizitätswerke Zürich (EWZ) in der Heizzentrale der Wohnüberbauung Grünau in Zürich-Altstetten eine grössere Brennstoffzellenanlage in Betrieb genommen. Anlässlich der Medienorientierung vom 29. November 2010 informierten Stadtrat A. Türler, EWZ-Direktor C. Ammann sowie Direktor der Erdgas Zürich AG, K. Lüscher, über die Projektentwicklung und ihre Zielsetzungen. Die Orientierung fand in der Heizzentrale Grünau statt und die Anlage konnte besichtigt werden.

Brennstoffzelle

- Schmelzkarbonat-Brennstoffzelle (MCFC) von MTU Onsite Energy (Hot Modul). Es handelt sich um das ältere Modell mit dem Stack des US-Hersteller Fuel Cell Energy.
- Elektrische Leistung: 230 kW; el. Wirkungsgrad: 42 %
- Thermische Leistung: 170 kW; Gesamtwirkungsgrad: 80 %
- Arbeitstemperatur 650 °C, Abgastemperatur 400 °C
- Erwartete Jahresproduktion: 1680 MWh Strom
- Abwärme genutzt für Beheizung Überbauung Grünau; Strom wird ins Netz der EWZ eingespeist.
- Investitionen: 4.74 Mio. CHF (Kredit); davon Beitrag von 1.5 Mio. CHF von Erdgas Zürich.
- Die Wärme wird zu den gleichen Kosten, wie sie ab den Heizkesseln entstehen, ans Wärmenetz verkauft. Die resultierenden Kosten für den Strom betragen 40 - 50 Rp/kWh.
- Nutzungsdauer: Geplant sind 12 Jahre Betrieb mit mehreren Stacks

Ziele der EWZ und der Erdgas Zürich

- Erfahrung mit der neuen Technologie sammeln
- Aktives Fördern und Realisieren von Technologien zur dezentralen Stromerzeugung
- Einsetzen einer Stromerzeugungstechnologie mit deutlich höherem elektrischen Wirkungsgrad (42 %) als konventionelle BHKW's
- Erprobung einer neuen Technologie über eine längere Nutzungsdauer. (Verhalten im Dauerbetrieb)
- Erfahrungen über die Entwicklung der Betriebskosten

Persönlicher Eindruck

Die Anlage ist sehr gut in die bestehende Heizzentrale integriert und qualitativ hochwertig ausgeführt. Es entsteht nicht der Eindruck einer Versuchsanlage. Die Installation war vermutlich aufwendig und beansprucht für die peripheren Komponenten wie Gasreinigung, Hilfsgasstation oder Inverter viel Platz. Für das Einbringen der Anlage musste der Zugang zur Heizzentrale deutlich vergrössert resp. neu erstellt werden.

Aus dem Gespräch mit Frau Feuerstein entnahm ich, dass die Anlage ohne Schwierigkeiten in Betrieb gesetzt werden konnte und seither gut funktioniert. Die erwarteten Betriebsdaten wurden erreicht.

Aus den Referaten zwar zu entnehmen, dass die geringen Schadstoff-Emissionen der MCFC eine wichtige Rolle für den Projektentscheid gespielt haben. So werden die Abgase der Anlage als Abluft bezeichnet. Die CO_2-Emissionen werden als „kleine Mengen CO_2 „ benannt und die Absicht, die Anlage zu einem späteren Zeitpunkt mit CO_2-neutralem Biogas zu betreiben und zu zertifizieren, geäussert. Für den Betrieb mit Biogas - wofür sich die MCFC gut eignet - müsste in unmittelbarer Nähe ein Biogasproduzent vorhanden sein.

Insgesamt ist es m. E. erfreulich, dass ein Schweizer Energieversorger die Brennstoffzellentechnologie als eines der möglichen Energieumwandlungssysteme in der Praxis prüfen will und bereit ist, dafür hohe Investitionen zu tätigen. Es bleibt zu hoffen, dass die Betriebserfahrungen auch Dritten zugänglich sein werden und interessierte Kreise mehr über den Stand der Technik erfahren können.

PS.

Am 29. Dezember 2010 teilte die Tognum AG, welche die Muttergesellschaft der MTU Onsite Energy ist, mit, dass sie die Entwicklung des Hot Moduls (MCFC/Brennstoffzelle) einstellen wird. Verhandlungen mit einem asiatischen Produzenten, der die Herstellung der Anlagen übernehmen sollte, hätten zu keinem Ergebnis geführt. Mit der Einstellung der Brennstoffzellenaktivitäten von MTU Onsite Energy wird vermutlich auch die 12-jährige Nutzung der Anlage von EWZ in Frage gestellt sein. Es ist jedoch zu bemerken, dass die MTU-Brennstoffzellen-Entwicklung schon zahlreiche Eigentümerwechsel überstanden hat und vielleicht auch dieses Mal wieder ein „Retter“ die Abteilung übernimmt.

Bilder anlässlich Medieninformation 29.11.10 aufgenommen

	
Fig. 1: *HotModul von MTU Onsite Energy in Heizzentral Grünau (Druckbehälter mit Stack)*	***Fig. 2:*** *Blick vom hinteren Teil mit Gas/ Luft-Zufuhr*

	
Fig. 3: *Gasaufbereitung*	***Fig. 4:*** *Wasseraufbereitung mit Jonentauscher*

Appendix 6

Methods for Calculating Efficiency

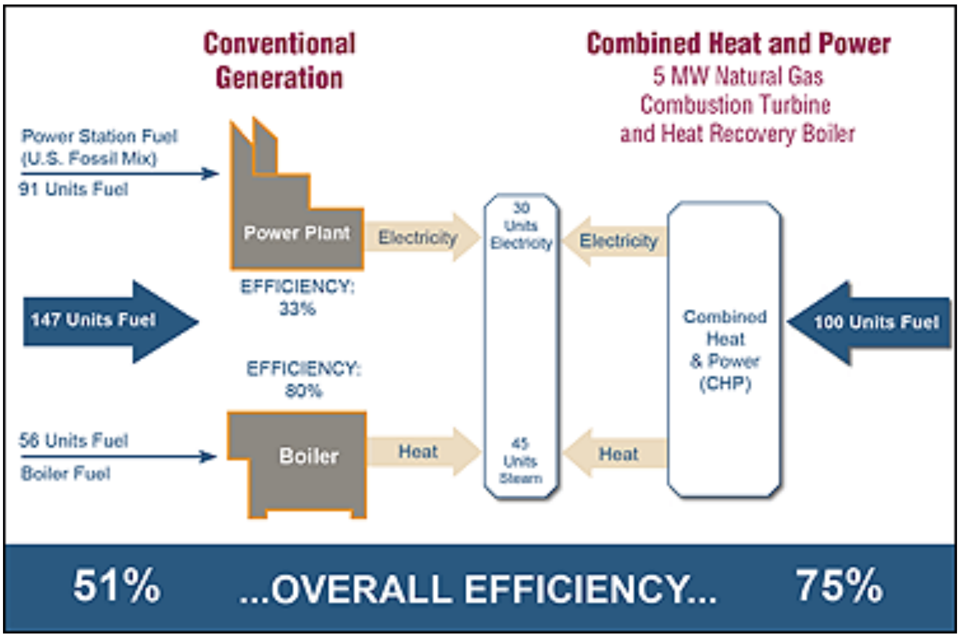
(source: http://www.epa.gov/chp/basic/methods.html#four) EPA United States Environmental Protection Agency)

CHP is an efficient and clean approach to generating power and thermal energy from a single fuel source. CHP is used either to replace or supplement conventional separate heat and power (SHP) (i.e., central station electricity available via the grid and an onsite boiler or heater).

CHP System Efficiency Defined

Every CHP application involves the recovery of otherwise wasted thermal energy to produce additional power or useful thermal energy. Because CHP is highly efficient, it reduces emissions of traditional air pollutants and carbon dioxide, the leading greenhouse gas associated with global climate change.
Efficiency is a prominent metric used to evaluate CHP performance and compare it to SHP. This Web page identifies and describes the two methodologies most commonly used to determine the efficiency of a CHP system: **total system efficiency and effective electric efficiency.**
The illustration below illustrates the potential efficiency gains of CHP when compared to SHP.

Conventional Generation vs. CHP: Overall Efficiency



In this example of a typical CHP system, to produce 75 units of useful energy, the conventional generation or separate heat and power systems use 147 units of energy—91 for electricity production and 56 to produce heat—resulting in an overall efficiency of 51 percent. However, the CHP system needs only 100 units of energy to produce the 75 units of useful energy from a single fuel source, resulting in a total system efficiency of 75 percent.

Key Terms Used in Calculating CHP Efficiency

Calculating a CHP system's efficiency requires an understanding of several key terms, described below.

CHP system. The CHP system includes the unit in which fuel is consumed (e.g. turbine, boiler, engine), the electric generator, and the heat recovery unit that transforms otherwise wasted heat to useable thermal energy.

Total fuel energy input (Q_{FUEL}). The thermal energy associated with the total fuel input. Total fuel input is the sum of all the fuel used by the CHP system. The total fuel energy input is often determined by multiplying the quantity of fuel consumed by the heating value of the fuel. Commonly accepted heating values for natural gas, coal, and diesel fuel are:
1020 Btu per cubic foot of natural gas
10,157 Btu per pound of coal
138,000 Btu per gallon of diesel fuel

Net useful power output (W_E). Net useful power output is the gross power produced by the electric generator minus any parasitic electric losses in other words, the electrical power used to support the CHP system. (An example of a parasitic electric loss is the electricity that may be used to compress the natural gas before the gas can be fired in a turbine.)

Net useful thermal output (ΣQ_{TH}). Net useful thermal output is equal to the gross useful thermal output of the CHP system minus the thermal input. An example of thermal input is the energy of the condensate return and makeup water fed to a heat recovery steam generator (HRSG). Net useful thermal output represents the otherwise wasted thermal energy that was recovered by the CHP system. Gross useful thermal output is the thermal output of a CHP system utilized by the host facility. The term utilized is important here. Any thermal output that is not used should not be considered. Consider, for example, a CHP system that produces 10,000 pounds of steam per hour, with 90 percent of the steam used for space heating and the remaining 10 percent exhausted in a cooling tower. The energy content of 9,000 pounds of steam per hour is the gross useful thermal output.

Calculating Total System Efficiency

The most commonly used approach to determining a CHP system's efficiency is to calculate total system efficiency. Also known as thermal efficiency, the total system efficiency (η_o) of a CHP system is the sum of the net useful power output (W_E) and net useful thermal outputs (ΣQ_{TH}) divided by the total fuel input (Q_{FUEL}), as shown below:

$$\eta_o = \frac{W_E + \Sigma\, Q_{TH}}{Q_{FUEL}}$$

The calculation of total system efficiency is a simple and useful method that evaluates what is produced (i.e., power and thermal output) compared to what is consumed (i.e., fuel). CHP systems with a relatively high net useful thermal output typically correspond to total system efficiencies in the range of 60 to 85 percent.

Note that this metric does not differentiate between the value of the power output and the thermal output; instead, it treats power output and thermal output as additive properties with the same relative value. In reality and in practice, thermal output and power output are not interchangeable because they cannot be converted easily from one to another. However, typical CHP applications have coincident power and thermal demands that must be met. It is reasonable, therefore, to consider the values of power and thermal output from a CHP system to be equal in many situations.

Calculating Effective Electric Efficiency

Effective electric efficiency calculations allow for a direct comparison of CHP to conventional power generation system performance (e.g., electricity produced from central stations, which is how the majority of electricity is produced in the United States). Effective electric efficiency (ξEE) can be calculated using the equation below, where (WE) is the net useful power output, (ΣQTH) is the sum of the net useful thermal outputs, (QFUEL) is the total fuel input, and ∝ equals the efficiency of the conventional technology that otherwise would be used to produce the useful thermal energy output if the CHP system did not exist:

$$\varepsilon_{EE} = \frac{W_E}{Q_{FUEL} - \Sigma\,(Q_{TH} / \alpha)}$$

For example, if a CHP system is natural gas fired and produces steam, then a represents the efficiency of a conventional natural gas-fired boiler. Typical a values for boilers are: 0.8 for natural gas-fired boiler, 0.75 for a biomass-fired boiler, and 0.83 for a coal-fired boiler.

The calculation of effective electric efficiency is essentially the CHP net electric output divided by the additional fuel the CHP system consumes over and above what would have been used by conventional systems to produce the thermal output for the site. In other words, this metric measures how effectively the CHP system generates power once the thermal demand of a site has been met.

Typical effective electrical efficiencies for combustion turbine-based CHP systems are in the range of 51 to 69 percent. Typical effective electrical efficiencies for reciprocating engine-based CHP systems are in the range of 69 to 84 percent.

Which CHP Efficiency Metric Should You Select?

The selection of an efficiency metric depends on the purpose of calculating CHP efficiency.

If the objective is to compare CHP system energy efficiency to the efficiency of a site's SHP options, then **the total system efficiency metric** may be the right choice. Calculation of SHP efficiency is a weighted average (based on a CHP system's net useful power output and net useful thermal output) of the efficiencies of the SHP production components. The separate power production component is typically 33 percent efficient grid power. The separate heat production component is typically a 75- to 85-percent efficient boiler.

If CHP electrical efficiency is needed for a comparison of CHP to conventional electricity production (i.e., the grid), then the **effective electric efficiency metric** may be the right choice. Effective electric efficiency accounts for the multiple outputs of CHP and allows for a direct comparison of CHP and conventional electricity production by crediting that portion of the CHP system's fuel input allocated to thermal output.

Both the total system and effective electric efficiencies are valid metrics for evaluating CHP system efficiency. They both consider all the outputs of CHP systems and, when used properly, reflect the inherent advantages of CHP. However, since each metric measures a different performance characteristic, use of the two different metrics for a given CHP system produces different values.

For example, consider a gas turbine CHP system that produces steam for space heating with the following characteristics:

Fuel Input (MMBtu/hr)	41
Electric Output (MW)	3.0
Thermal Output (MMBtu/hr)	17.7

Using the total system efficiency metric, the CHP system efficiency is 68 percent (3.0*3.413+17.7)/41).

Using the effective electric efficiency metric, the CHP system efficiency is 54 percent (3.0*3.413)/(41-(17.7/0.8).

This is not a unique example; a CHP system's total system efficiency and effective electric efficiency often differ by 5 to 15 percent.

NOTE: Many CHP systems are designed to meet a host site's unique power and thermal demand characteristics. As a result, a truly accurate measure of a CHP system's efficiency may require additional information and broader examination beyond what is described in this document.

International Standards

(source: http://www.fuelcellstandards.com/stationary_apps.html)

Fuel Cell Power Systems - Performance - efficiency, emissions, durability

ASME PTC 50 Performance Test Code for Fuel Cell Power Systems Performance (US and Other Locales)

IEC 62282-3-200 Test Method for the Performance of Stationary Fuel Cell Power Plants (International)

BS EN 62282-3-200:2012 Test Method for the Performance of Stationary Fuel Cell Power Plants (European Union & UK)

JIS C 8802 Test Method for Durability of Phosphoric Acid Fuel Cell Power Facility (Japan)

State of California Regulations Emission Regulations

JIS C 8825 Testing Methods for EMC of Small Polymer Electrolyte Fuel Cell Power Systems (electromagnetic compatibility) (Japan)

JIS C 8824 Testing Methods for Environment of EMC for Polymer Electrolyte Fuel Cell Systems (Japan)

JIS C 8841-3 Small Solid Oxide Fuel Cell Power Systems Part 3: Performance testing methods and environment testing methods (Japan)

Under Development / Proposed

NIST IR 7131 Test Methodology and Performance Rating Standard for Residential Fuel Cell Systems (Proposed US federal regulation)

JIS C 62282-3-2 Test Methods For the Stationary Fuel Cell Power System – Performance (Japan)

IEC 62282-3-201 Small stationary polymer electrolyte fuel cell power system – Performance test method

20090618-T-604 Stationary fuel cell power system - Performance test methods (China)

KS C IEC 62282-3-2 Stationary Fuel Cell Power Systems - Performance (Korea)

CNS xxxxx Stationary Fuel Cell Power Systems – Performance (Taiwan)

Test Method fort he Performance of Stationary Fuel Cell Power Systems
IEC 62282-3-200 = EN 62282-3-200
Elaboratet by the International Electrotechnical Commission

The **International Electrotechnical Commission** (IEC) is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies. (source: http://www.IEC.ch/index.htm)

IEC 62282-3-200 is approved and adopted in many countries such as European Union, UK, Japan, Korea, Taiwan etc.

International Electrotechnical Commission
Test Method for the Performance of Stationary Fuel Cell Power Plants
Published
International & EU

Organization	Technical Committee No. 105 -Fuel Cell Technologies
Identification	Working Group #4 Test Methods For the Fuel Cell Power System - Performance IEC 62282-3-200 (2011-10) EN 62282-3-2:2006
Scope	Describes how to measure the performance of stationary fuel cell power systems for residential, commercial and industrial applications.
Status	Published in 2006 as IEC 62282-3-2 (2006-03). The second edition was harmonized with ASME PTC50 and published in October 2011 as IEC 62282-3-100 Ed.1. Available from www.ansi.org and www.IEC.ch The document has been adopted as a European and UK Standard as BS EN 62282-3-200:2012. Japan, Korea, China and Taiwan are in the process of adoption.
Committee Information	**Chairman** Noboru Hashimoto **Secretariat** Japan **Secretary** Shoko Falvo

source: http://www.fuelcellstandards.com/1.1.4.htm

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IEC 62282-3-200

Edition 1.0 2011-10

INTERNATIONAL STANDARD

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Fuel cell technologies –
Part 3-200: Stationary fuel cell power systems – Performance test methods

Technologies des piles à combustible –
Partie 3-200: Systèmes à piles à combustible stationnaires – Méthodes d'essai des performances

INTERNATIONAL ELECTROTECHNICAL COMMISSION

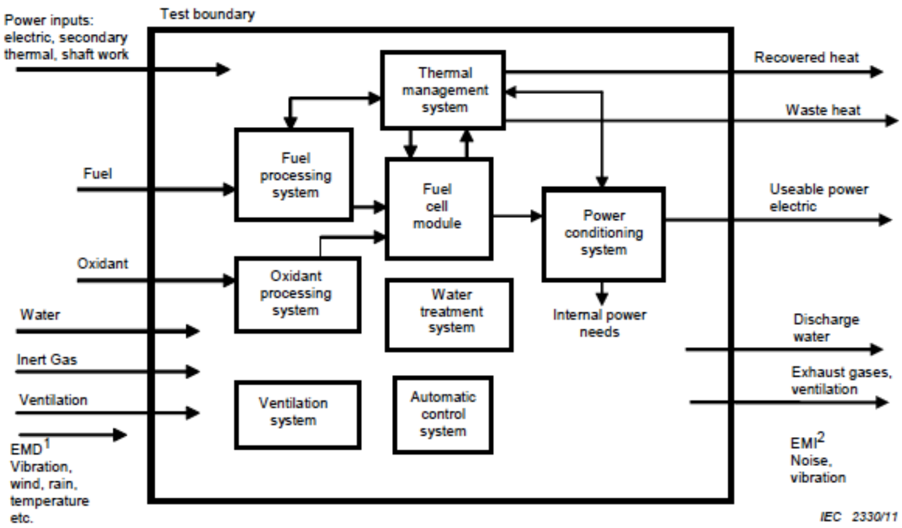
COMMISSION ELECTROTECHNIQUE INTERNATIONALE

PRICE CODE
CODE PRIX XC

ICS 27.070

ISBN 978-2-88912-732-0

System boundaries in IEA 62282-3-200



Key

: **Fuel cell power system** including subsystems. The interface is defined as a conceptual or functional one instead of hardware such as a power package.

: **Subsystems**; fuel cell module, fuel processor, etc. These subsystem configurations depend on the kind of fuel, type of fuel cell or system.

: **The interface points** in the boundary to be measured for calculation data.

ÖVE/ÖNORM EN 62282-3-200 - Brennstoffzellentechnologien - Teil 3-200: Stationäre Brennstoffzellen-Energiesysteme - Leistungskennwerteprüfverfahren (IEC 62282-3-200:2011) (deutsche Fassung)

Ausgabedatum	2012-09-01
Fachnormenausschuß	Komitee E Elektrische Niederspannungsanlagen
Normenart	STANDARD
Norm-Nummer	ÖVE/ÖNORM EN 62282-3-200
Norm-Titel, deutsch	Brennstoffzellentechnologien - Teil 3-200: Stationäre Brennstoffzellen-Energiesysteme - Leistungskennwerteprüfverfahren (IEC 62282-3-200:2011) (deutsche Fassung)
Vorgänger-Norm	ÖVE/ÖNORM EN 62282-3-200 (2010 10 01) ÖVE/ÖNORM EN 62282-3-2 (2007 04 01)
Norm-Titel, englisch	Fuell cell technologies - Part 3-200: Stationary fuel cell power systems - Performance test methods (IEC 62282-3-200:2011) (german version)
Norm-Titel, französisch	Technologies des piles à combustible - Partie 3-200: Systèmes à piles à combustible stationnaires - Méthodes d'essai des performances (CEI 62282-3-200:2011) (version allemande)
gültig ab	2012-09-01
internat. Übereinstimmung	IEC 62282-3-200 (2011 10) , ident EN 62282-3-200 (2012 01) , ident
Originalsprache	de
Preisgruppe	Preisgruppe 24 - Preis incl. 10% Mehrwertsteuer, zuzüglich Versand- und Verpackungsspesen.
Kurzreferat	Diese ÖVE/ÖNORM umfasst die Betriebs- und Umwelt-Aspekte der Leistung von stationären Brennstoffzellen-Energiesystemen. Die Prüfverfahren betreffen folgende Bereiche: - Leistungsabgabe unter spezifizierten Betriebs- und Laständerungsbedingungen; - elektrischer und thermischer Wirkungsgrad unter spezifizierten Betriebsbedingungen; - Umwelteigenschaften z. B. gasförmige Emissionen, Lärm usw. unter spezifizierten Betriebs- und Laständerungsbedingungen. Die Elektromagnetische Verträglichkeit (EMV) wird in dieser Norm nicht behandelt. Dieser Normen-Teil ist ebenfalls nicht anzuwenden auf kleinere stationäre Brennstoffzellen-Energiesysteme mit einer elektrischen Leistungsabgabe von unter 10 kW; diese werden zukünftig in IEC 62282-3-201 behandelt.
Seitenanzahl der Norm	90

source: http://www.bdb.at/Service/NormenDetail?id=442991

ASME PTC 50: Performance Test Code for Fuel Cell Power Systems Performance

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ASME PTC 50 provides guidance for evaluation of fuel cell power systems to determine their power output and efficiency in several ways. Corrections for site conditions and deviations are allowed, but the intent is that any fuel cell power system tested in accordance with ASME PTC 50 can be compared with other rigorous data from other standardized tests of similar scope.

ASME PTC 50 is a rigorous test that can be used to calculate power output, electrical efficiency, heat rate, heat recovery effectiveness, and other factors. ASME PTC 50 applies to all fuel cell power systems regardless of the electrical power output, thermal output, fuel cell type, fuel type, or system application.

The Code addresses combined heat and power systems, that is, the generation of electricity and usable heat at specific thermal conditions. It does not address the performance of specific subsystems
nor does it apply to energy storage systems, such as regenerative fuel cells or batteries. It is not applicable to automotive fuel cells. It also does not address emissions, reliability, safety issues, or
endurance.

It contains methods and procedures for conducting and reporting fuel cell system testing, including instrumentation to be used, testing techniques, and methods for calculating and reporting results. ASME PTC 50 defines the test boundary for fuel and oxidant input, secondary energy input and net electrical and thermal energy output. At these boundaries, it provides procedures for measuring temperature, pressure, input fuel flow and composition, electrical power and thermal output. ASME PTC 50 provides procedures for determination of electrical efficiency or heat rate and overall thermal effectiveness
at rated or any other steady state condition. The Code also provides the method to correct results from the test to reference conditions.

source: ASME, Brochure on PTC 50

Secretary Jack Karian

IEC 62282-6-200 (2007-11): Micro Fuel Cell Power Systems - Performance