HyCentA – 10 Years of Hydrogen Success Story

Assoc.Prof. DI Dr. Manfred Klell
HyCentA, A3PS, Vienna 9th November 2015

1. Spatenstich 2005 03 11

Eröffnung 2005 10 11

Hydrogen Center Austria

HyCentA HYDROGEN CENTER AUSTRIA

First Austrian research center for hydrogen with test stands and filling facility since 2005

TU Graz FVT MAGNA OMV

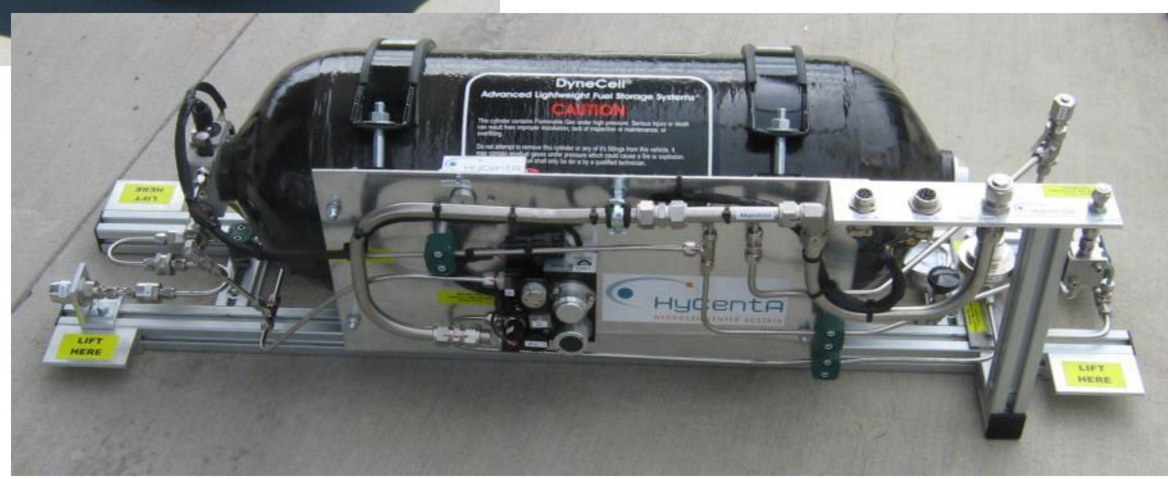
Activities

- Customer-specific test setups with electronic process control
- Conception of hydrogen-pressure systems for stationary and mobile applications
- Thermodynamic analysis of processes and systems
- Economical and ecological analysis
- Expertise in questions of safety, standards and regulations
- Scientific research, lecturing and publications

Habilitationskolloquium 2010 12 13

H2 slush 2010 / 2013

AVL FCC 2010 08 84



Fuel Cell Commuter for World Exhibition Shanghai 2013

200 bar CGH2

Project HYCAR 1

Multi-Flex-Fuel vehicle prototype with combustion engine for operation with natural gas / hydrogen / gasoline

„Mixtures of Hydrogen and Methane in the Internal Combustion Engine – Synergies, Potential and Regulations“.

International Journal of Hydrogen Energy, Vol. 37, S. 11531 – 11540, 2012

Wiener Motorensymposium 2010 04 30

Lecturing and Publications

- Austrian hydrogen conference
  2005, 2007, 2009, 2012

- Lecture at TU Graz:
  Hydrogen in Energy
  and Vehicle Technology

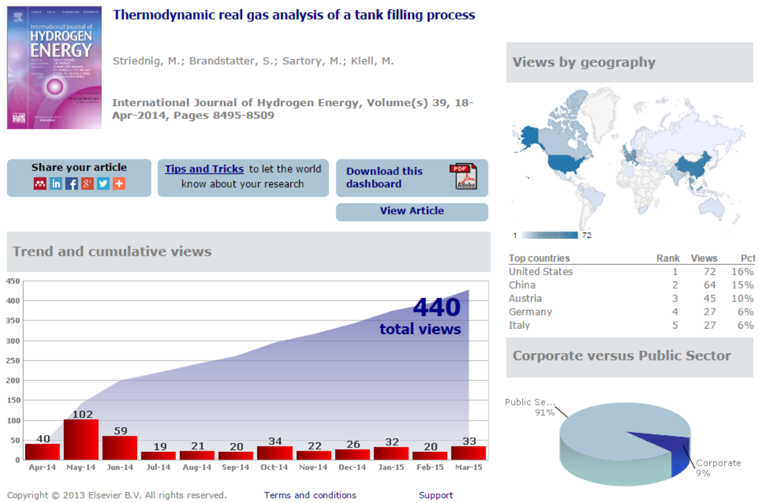
- Habilitation in
  applied thermodynamics:
  Klell:
  Thermodynamik des Wasserstoffs,
  TU Graz 2010

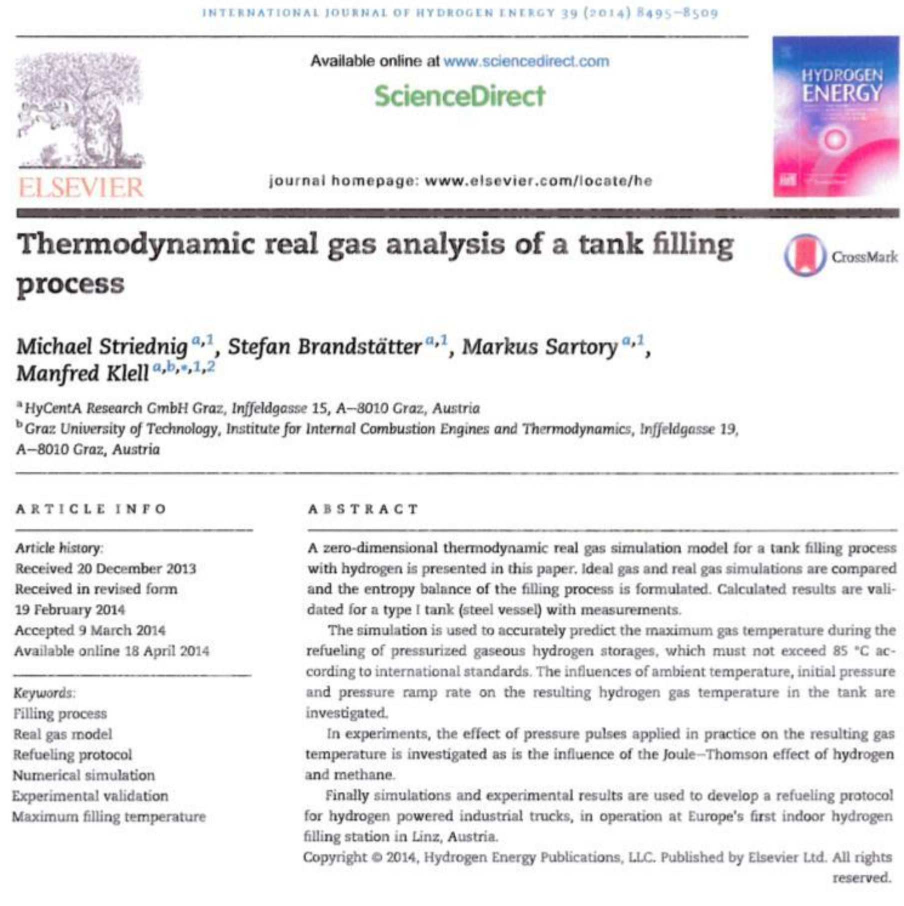
- Studybook 2012: Eichlseder/Klell:
  Wasserstoff in der Fahrzeugtechnik
  Erzeugung, Speicherung, Anwendung
  Springer Vieweg, 3. Auflage

Scientific Publication

- **International Journal of Hydrogen Energy: IJHE 39 (2014) S. 8495 – 8509:**

Real Gas Analysis of a Tank Filling Process





INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 39 (2014) 8495–8509

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Thermodynamic real gas analysis of a tank filling process

CrossMark

Michael Striednig[a,1], *Stefan Brandstätter*[a,1], *Markus Sartory*[a,1], *Manfred Klell*[a,b,*,1,2]

[a] *HyCentA Research GmbH Graz, Inffeldgasse 15, A–8010 Graz, Austria*

[b] *Graz University of Technology, Institute for Internal Combustion Engines and Thermodynamics, Inffeldgasse 19, A–8010 Graz, Austria*

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Refueling protocol
Numerical simulation
Experimental validation
Maximum filling temperature

ABSTRACT

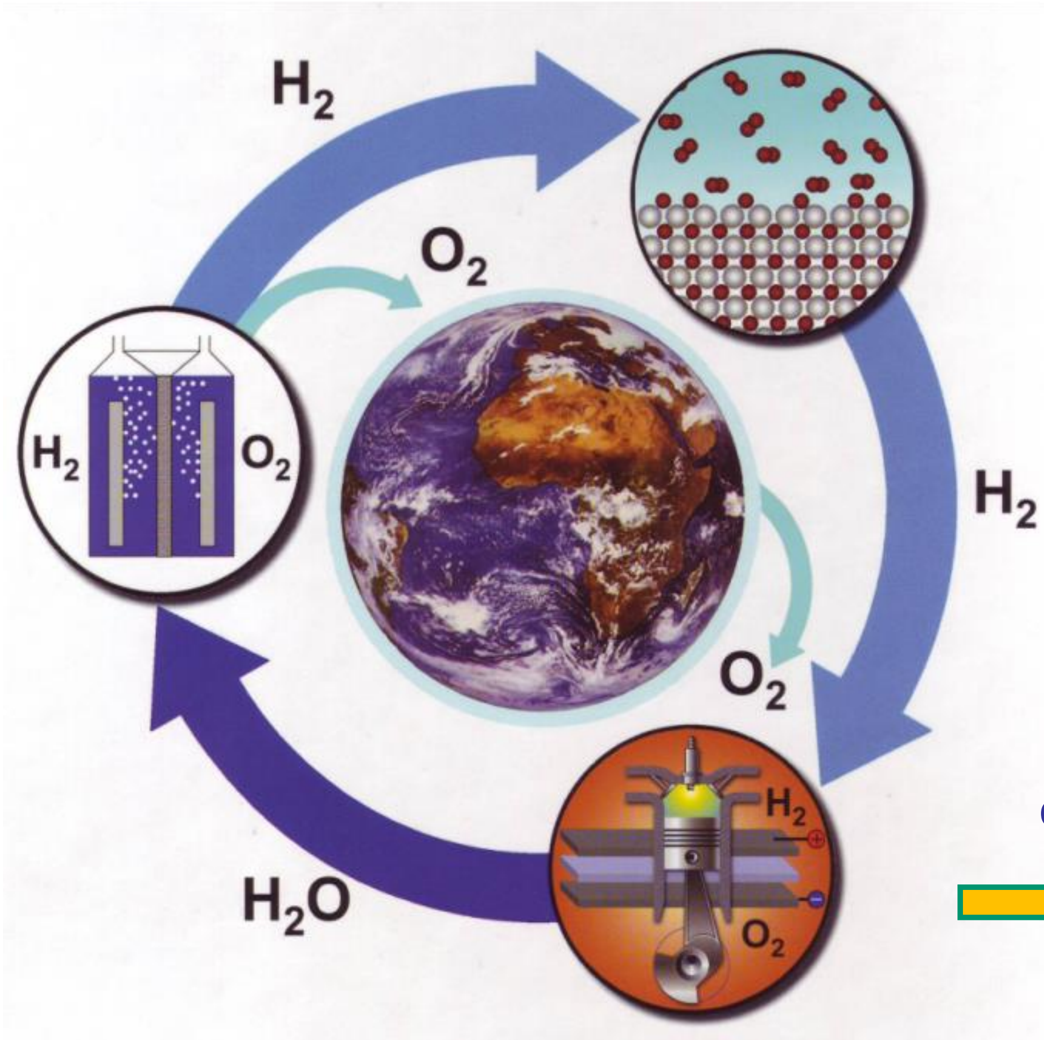
A zero-dimensional thermodynamic real gas simulation model for a tank filling process with hydrogen is presented in this paper. Ideal gas and real gas simulations are compared and the entropy balance of the filling process is formulated. Calculated results are validated for a type I tank (steel vessel) with measurements.

The simulation is used to accurately predict the maximum gas temperature during the refueling of pressurized gaseous hydrogen storages, which must not exceed 85 °C according to international standards. The influences of ambient temperature, initial pressure and pressure ramp rate on the resulting hydrogen gas temperature in the tank are investigated.

In experiments, the effect of pressure pulses applied in practice on the resulting gas temperature is investigated as is the influence of the Joule–Thomson effect of hydrogen and methane.

Finally simulations and experimental results are used to develop a refueling protocol for hydrogen powered industrial trucks, in operation at Europe's first indoor hydrogen filling station in Linz, Austria.

Vision of Hydrogen Economy



CO_2-free closed loop energy cycle

renewable energy

electricity

Source: Züttel 2008

Carbon-free energy



primary energy:

renewable
sun,
wind,
hydropower

energy carrier:

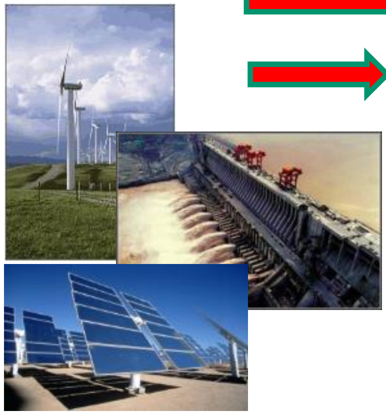
electricity &
hydrogen

distribution & storage:

power grid
natural gas grid and storages

useful energy:

transport
household
industry



power to hydrogen




electric machines & engines



FC, ICE, turbines

Carbon-free mobility

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electricity

short driving range,
slow refuelling

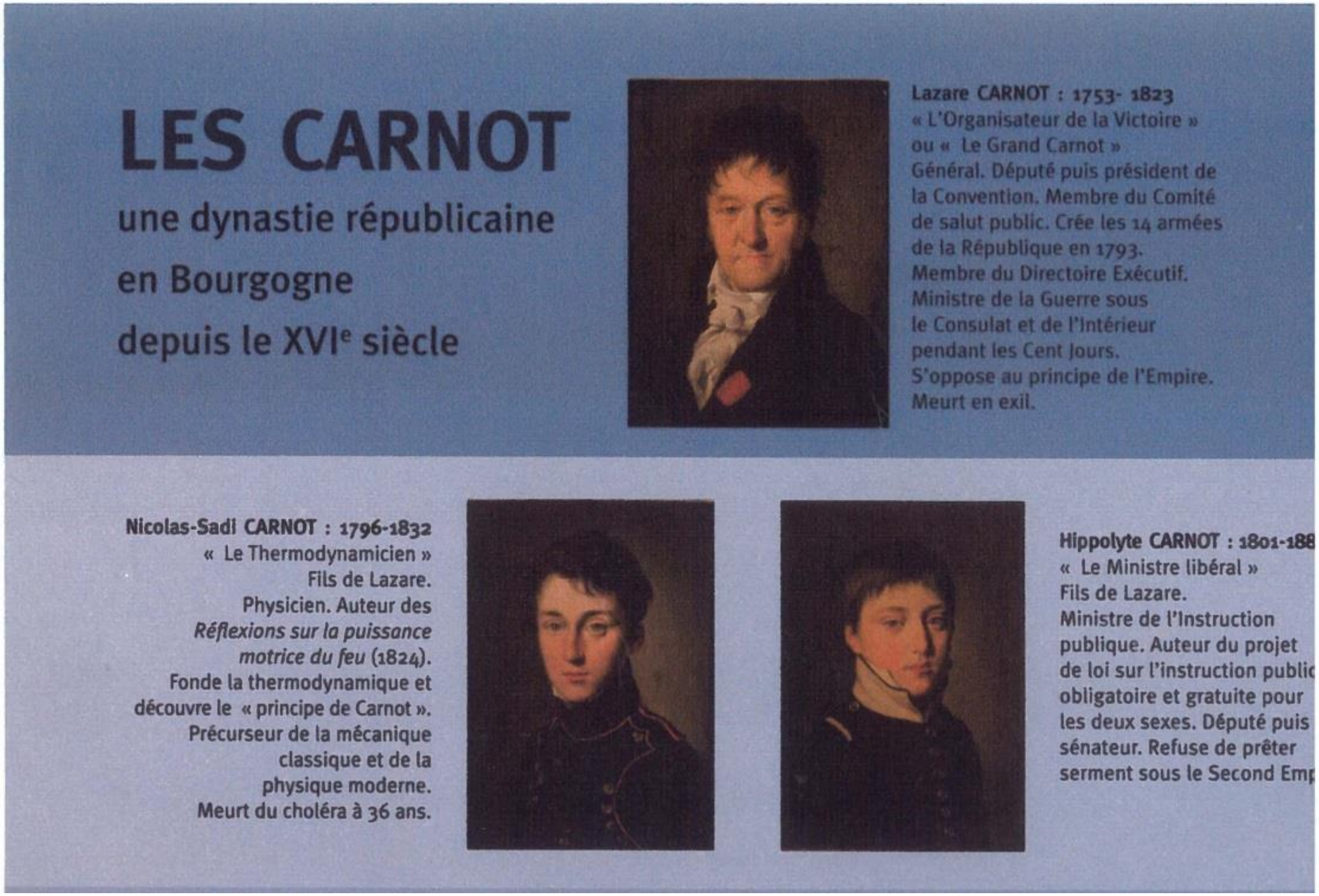
hydrogen

long driving range,
fast refuelling

Carnot Cycle

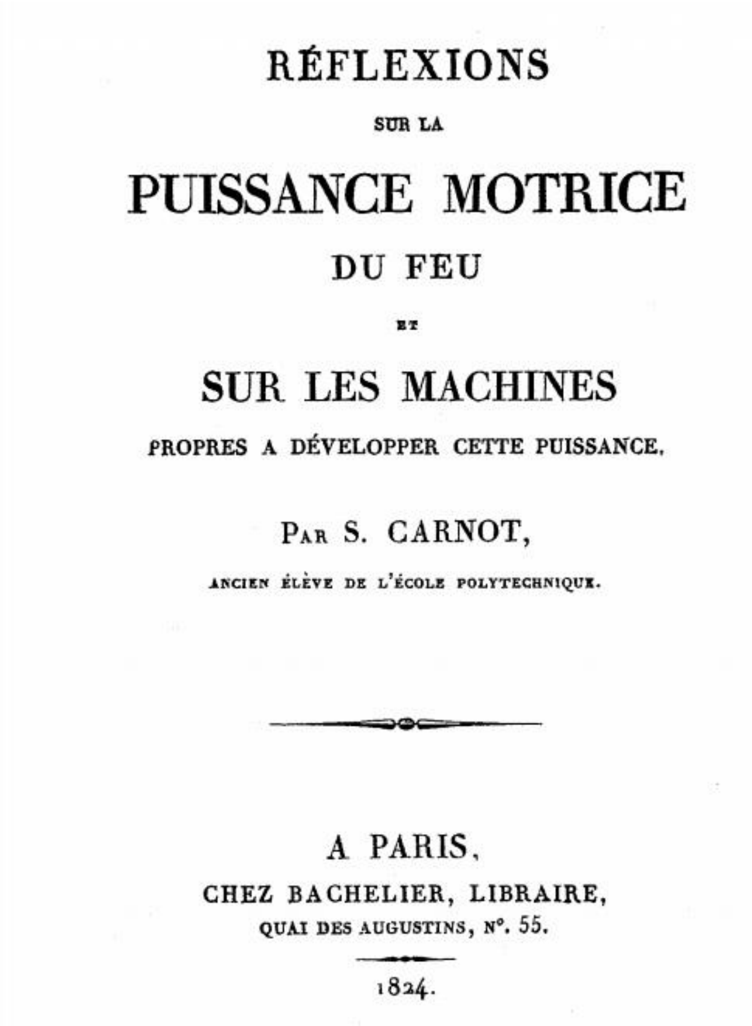
Chateau de La Rochepot, 12. Jhdt.

Carnot Cycle



Famille Carnot

Carnot Cycle



RÉFLEXIONS

SUR LA

PUISSANCE MOTRICE

DU FEU

ET

SUR LES MACHINES

PROPRES A DÉVELOPPER CETTE PUISSANCE.

PAR S. CARNOT,

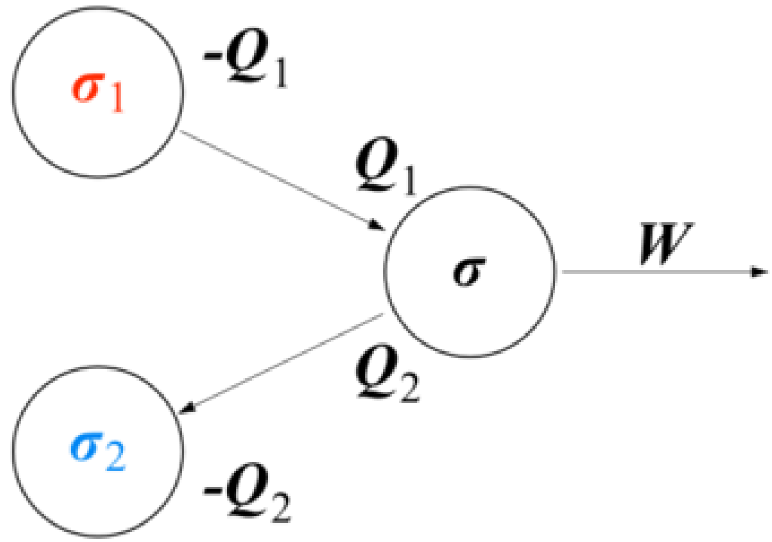
ANCIEN ÉLÈVE DE L'ÉCOLE POLYTECHNIQUE.

A PARIS,

CHEZ BACHELIER, LIBRAIRE,

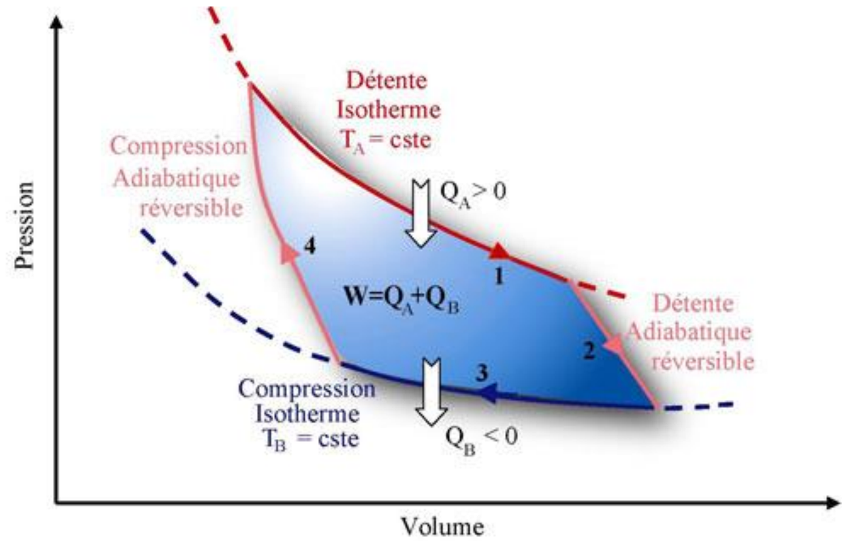
QUAI DES AUGUSTINS, N°. 55.

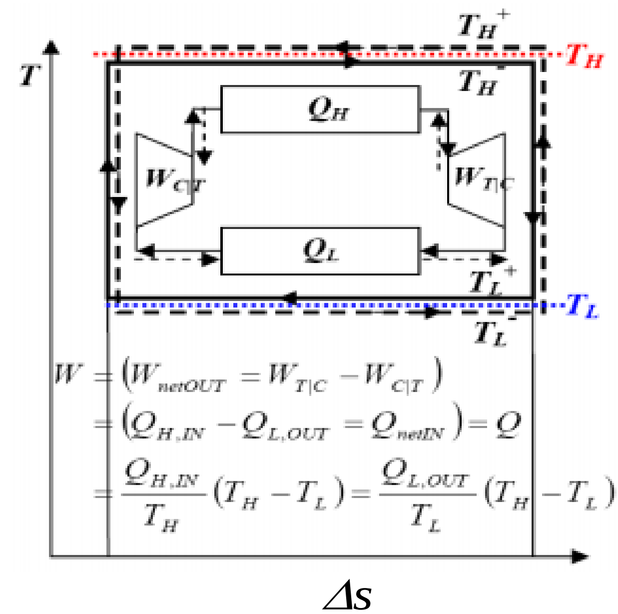
1824.



Une machine thermique (ici un moteur) est un système (σ) qui peut effectuer un nombre indéfini de cycles, échangeant, au cours d'un cycle, une quantité de chaleur Q_1 avec une source chaude (σ_1, à la température T_1) et une quantité de chaleur Q_2 avec source froide σ_2 (à la température T_2), et un travail W avec le milieu extérieur.

Carnot Cycle

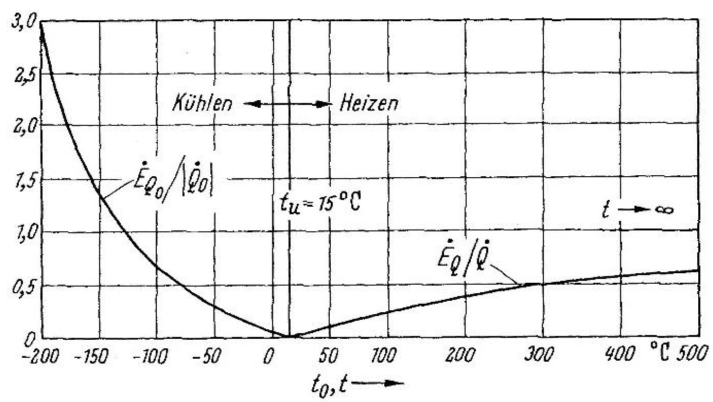




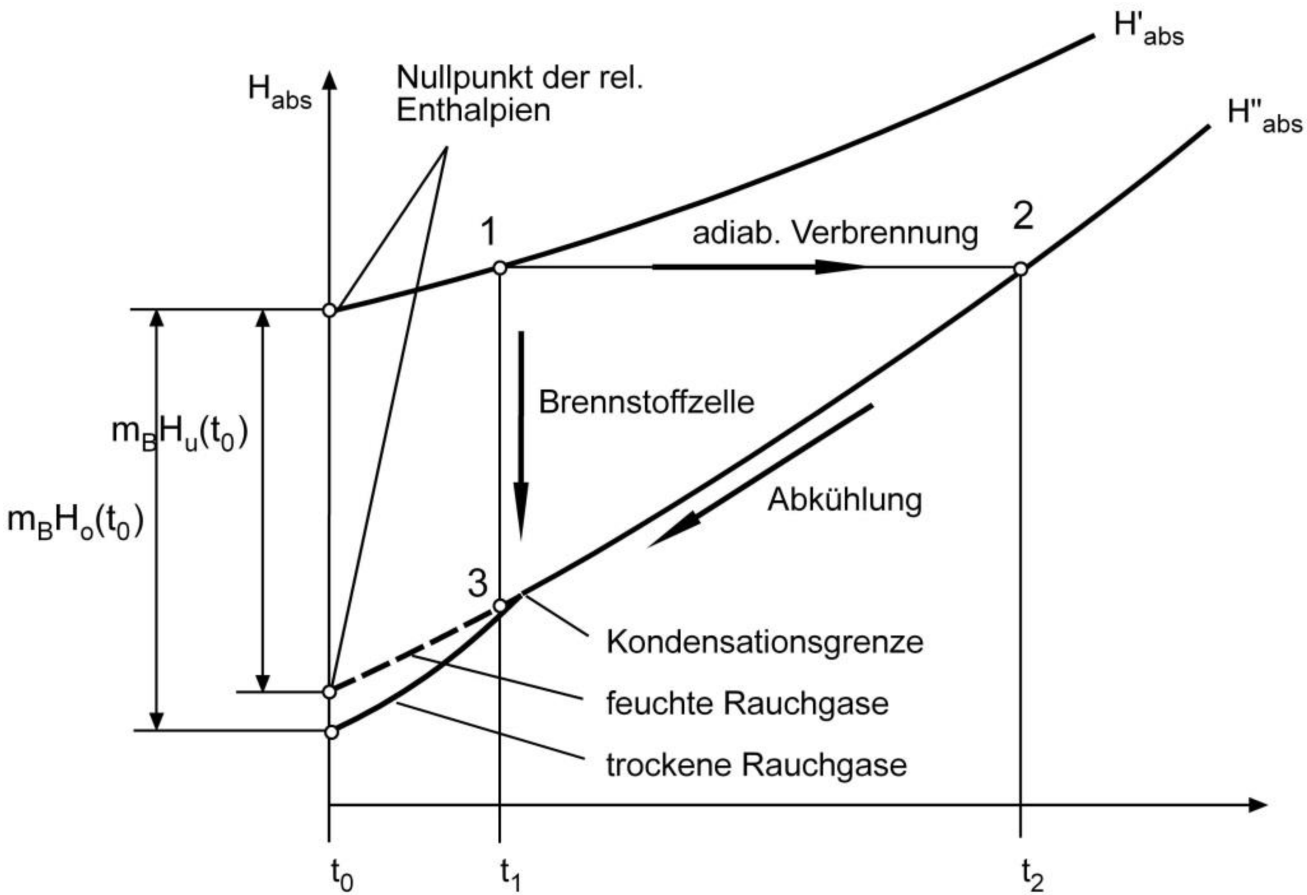
maximal possible efficiency of the conversion of heat into energy:
Carnot-Efficiency

$$\eta_C = \frac{w_{ab}}{q_{zu}} = \frac{q_{zu} - q_{ab}}{q_{zu}} = 1 - \frac{T_{ab}}{T_{zu}}$$

$$Ex_Q = Q\left(1 - \frac{T_u}{T}\right) = Q\,\eta_C$$



Combustion



123: combustion engine: conversion of chemical inner energy into heat into mechanical energy

13: fuel cell: conversion of chemical inner energy into electric energy

Efficiency

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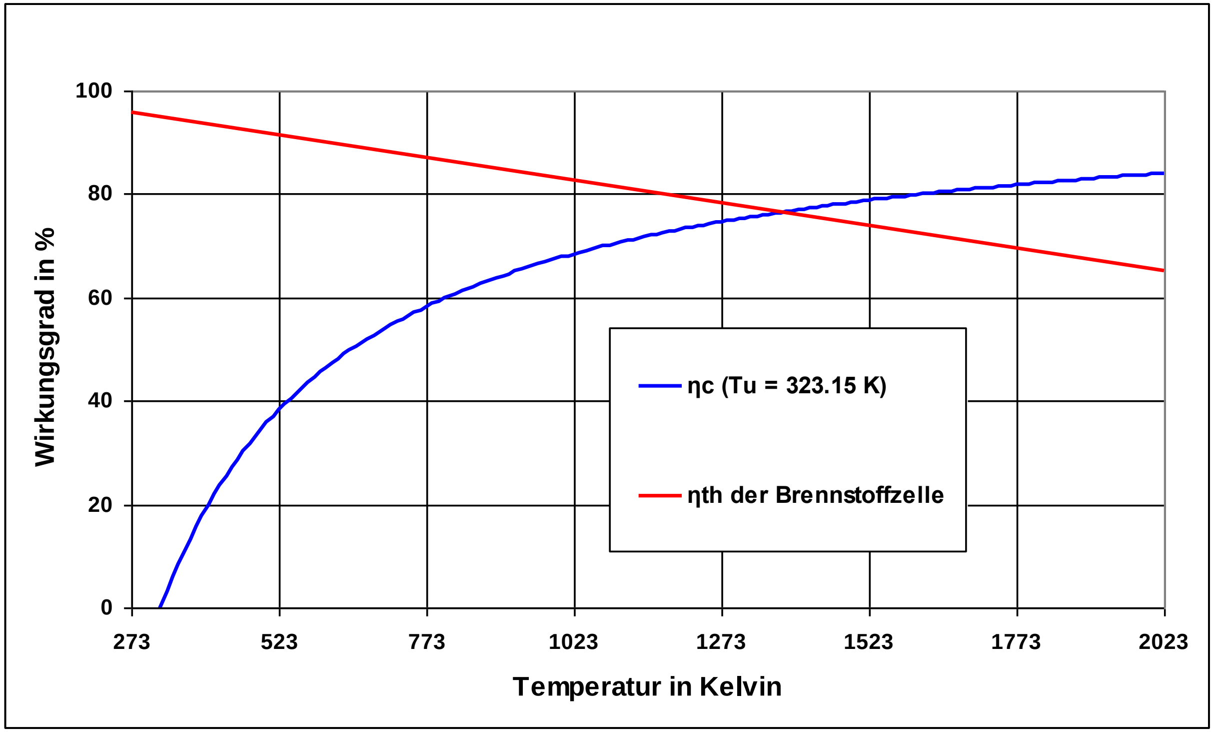
The conversion of heat into mechanical work is limited by the **Carnot efficiency**, the efficiency of a fuel cell is **free enthalpy divided by enthalpy**.

$$\eta_C = 1 - \frac{T_u}{T_o}$$

$$\eta_{th} = \frac{\Delta G}{\Delta H}$$



Principle Electrolysis

Electricity is used to split water into hydrogen and oxygen. Using electricity from regenerative sources, this method is CO_2-free, costs are high, efficiency up to 70 %.

$$H_2O\ (l) \rightarrow H_2\ (g) + \tfrac{1}{2}\ O_2\ (g) \qquad \Delta_R H = 286\ \text{kJ/mol}$$

cathode (–):

$4\ H_2O \rightarrow 2\ H_3O^+ + 2\ OH^-$

dissociation of water

$2\ H_3O^+ + 2\ e^- \rightarrow H_2 + 2\ H_2O$

reduction (acceptance of electrons)

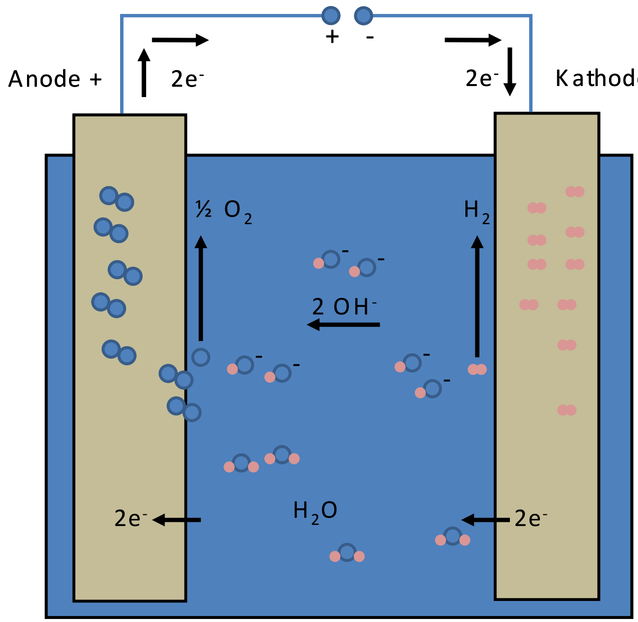
net reaction:

$2\ H_2O\ (l) + 2\ e^- \rightarrow H_2\ (g) + 2\ OH^-\ (aq)$

anode (+):

$2\ OH^-\ (aq) \rightarrow H_2O\ (l) + \tfrac{1}{2}\ O_2\ (g) + 2\ e^-$

oxidation (donation of electrons)



$2\ OH^- \rightarrow H_2O + \tfrac{1}{2}\ O_2 + 2\ e^-$ $\qquad$ $2\ H_2O + 2\ e^- \rightarrow H_2 + 2\ OH^-$

Principle Fuel Cell

The combination of hydrogen and oxygen yields electricity.

$$H_2\,(g) + ½\,O_2\,(g) \rightarrow H_2O\,(l) \qquad \Delta_R H = -\,286\ \text{kJ/mol}$$

anode (–):

H_2 (g) + 2 OH^- (aq) → 2 H_2O (l) + 2 e^-

oxidation (donation of electrons)

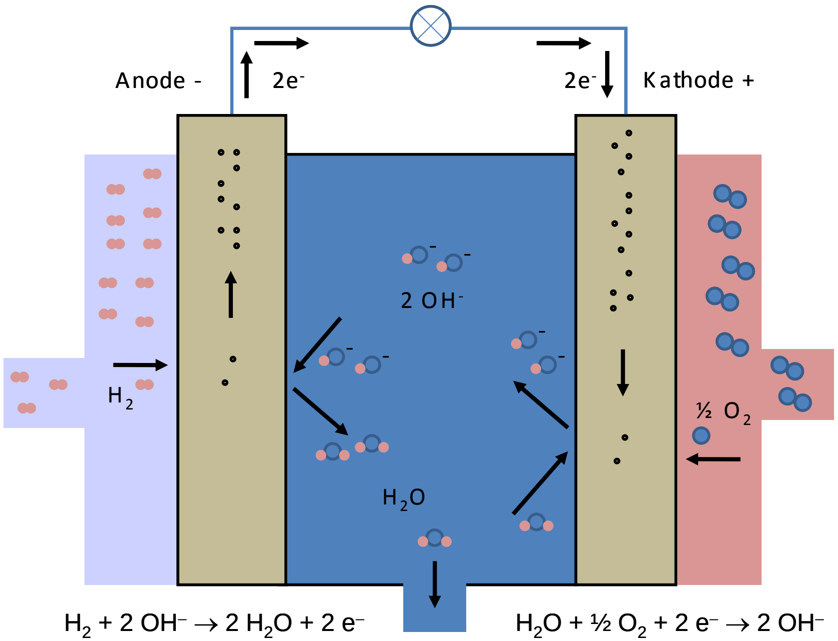
cathode (+):

H_2O (l) + ½ O_2 (g) + 2 e^- → 2 OH^- (aq)

reduction (acceptance of electrons)

As the voltage of a fuel cell is low, many cells have to be combined to form a stack.

$$E^0 = -\frac{\Delta_R H_m^0}{z \cdot F} = -\frac{-286 \cdot 10^3\,\text{J/mol}}{2 \cdot 96485\,\text{As/mol}} = 1{,}48\text{V}$$



New Projects from 2010

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HYDROGEN CENTER AUSTRIA

TU Graz FVT MAGNA OMV

Project E-LOG BioFleet I & II 2010 – 2016

Austrian flagship project

- Replacement of industrial truck batteries by fuel cell-range extender and H2-high pressure tank
- H2 is produced and compressed onsite by decentralized reforming of bio-methane
- European's first hydrogen-indoor refueling
- Energy Globe Award Feuer 2014


JOANNEUM RESEARCH OMV Fronius Linde Material Handling Linde DB SCHENKER powered by klima+energie fonds

Project E-LOG BioFleet I & II
2010 – 2016

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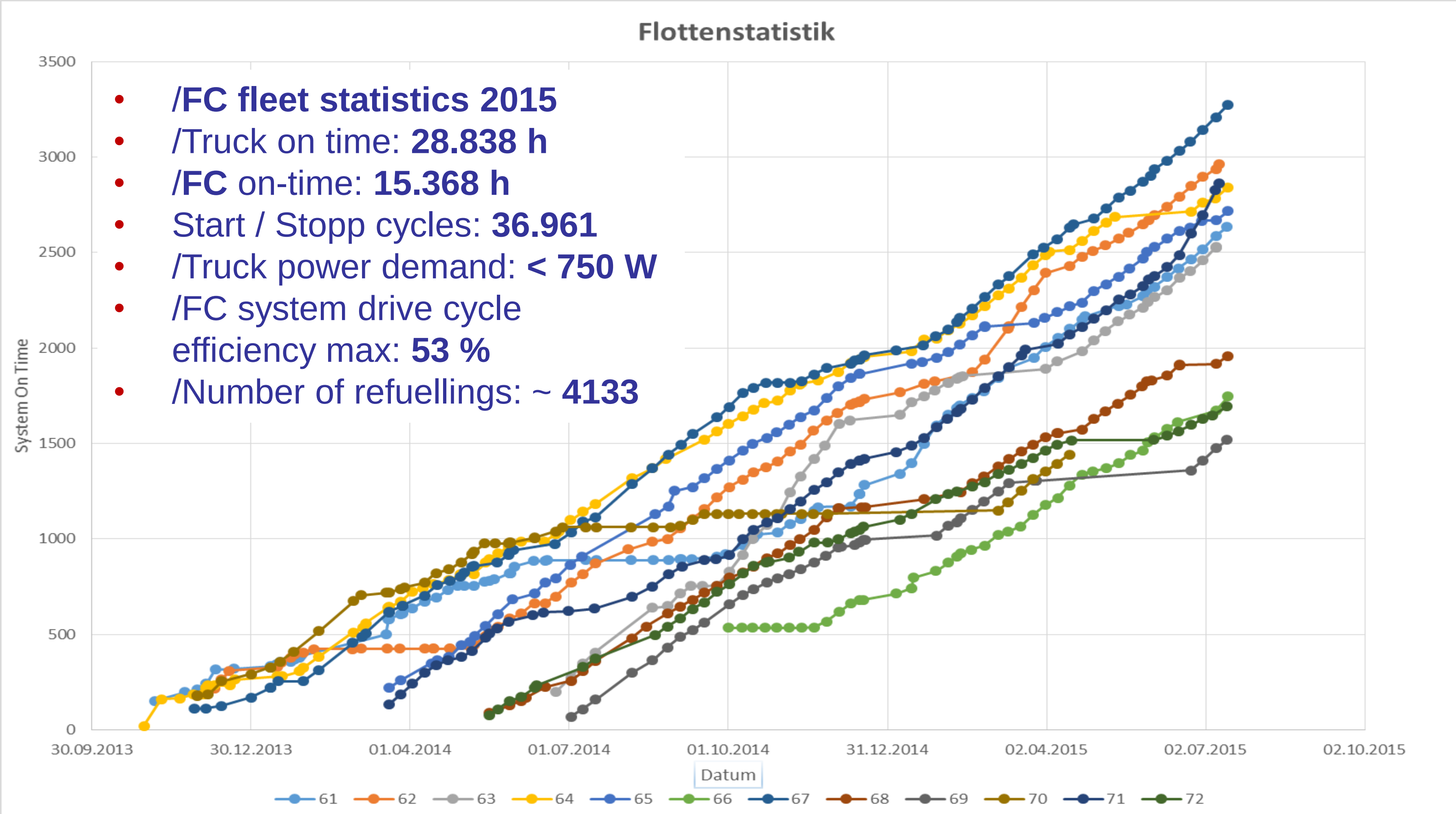
- **/FC fleet statistics 2015**
- /Truck on time: **28.838 h**
- **/FC** on-time: **15.368 h**
- Start / Stopp cycles: **36.961**
- /Truck power demand: **< 750 W**
- /FC system drive cycle efficiency max: **53 %**
- /Number of refuellings: ~ **4133**



JOANNEUM RESEARCH | OMV | Fronius | Linde Material Handling | DB SCHENKER | powered by klima+ energie fonds

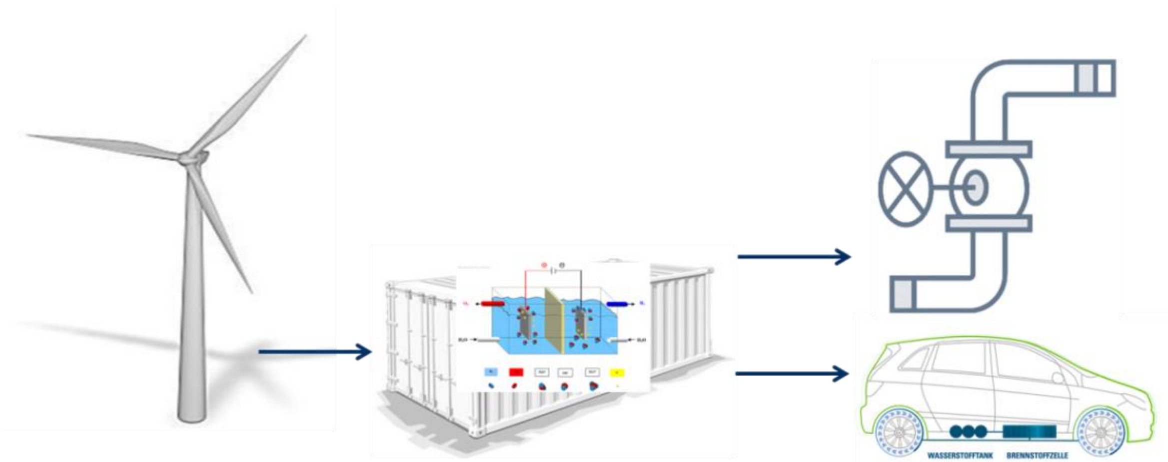
Project Wind2Hydrogen
2014 – 2016

HyCentA HYDROGEN CENTER AUSTRIA

Conversion of renewable electricity into hydrogen for storage purposes and transport inside the natural gas grid

- New development of a high pressure PEM-electrolycer
- Construction of a 100-kW-pilot plant
- Operative experiences of a power-to-gas-plant with real-life load cases of renewable energy and the feed-in of H2 into the natural gas grid
- Production of sustainable hydrogen for H2-mobility

Sponsored by resources of the climate and energy fund as part of „ENERGY MISSION AUSTRIA“



OMV · EVN · Fronius · ENERGIE INSTITUT · powered by klima+energie fonds

Project Wind2Hydrogen 2014 – 2016

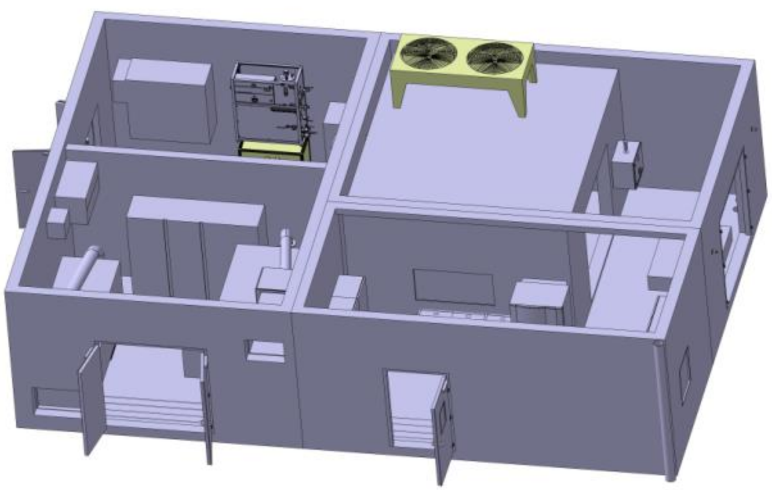
HyCentA HYDROGEN CENTER AUSTRIA

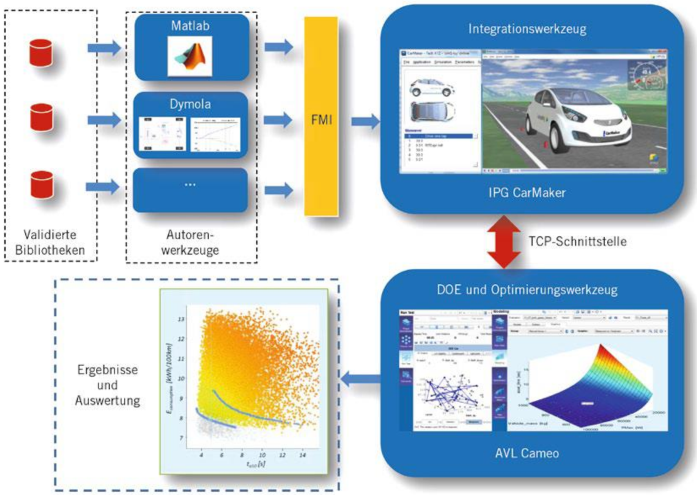
Set up of pilot plant, operation since 08.06.2015, official Opening by Minister Stöger on 19.08.2015

OMV EVN Fronius ENERGIE INSTITUT powered by klima+ energie fonds

Project HIFAI - RSA
2014 – 2017

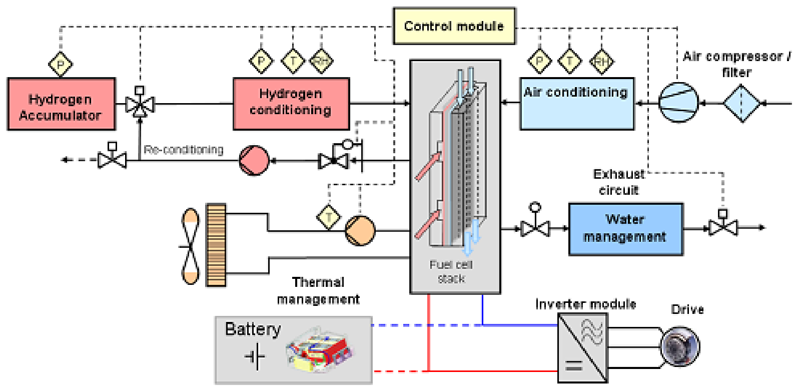
- **System integration test bench for scientific research on 150 kW PEM fuel cell systems**
- **Hardware in the Loop, real time simulation of vehicle, driver and driving cycles**
- **Continuous tool chain for applications of fuel cell systems, from simulation, optimization through to verification on the test bench**

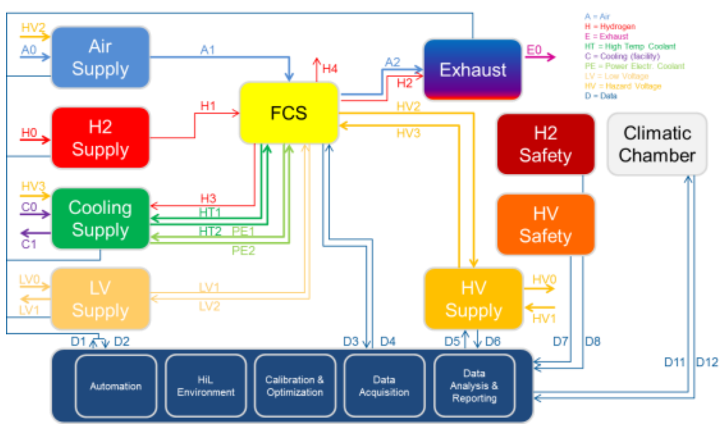




Project HIFAI - RSA
2014 – 2017

- Optimization of energy and thermo management
- Accelerated aging test procedures
- Improved cold start behavior
- System configuration and integration of fuel cell systems for stationary and mobile applications
- Optimization of energy efficiency of the entire system integration test bed

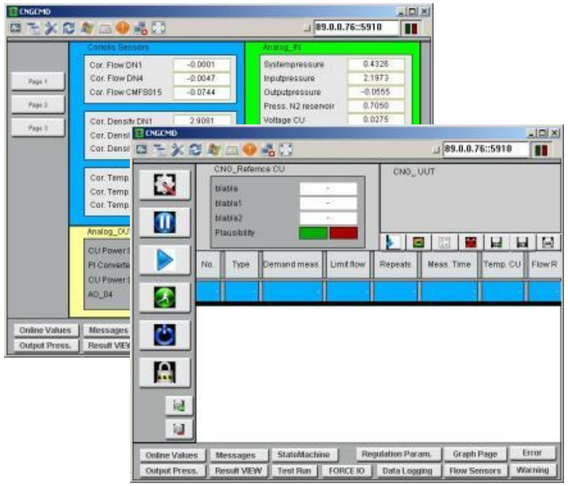


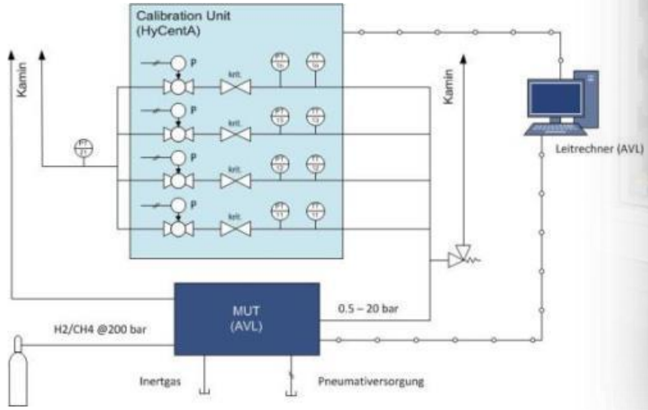


Project FCH Media 2014 – 2016

Research activities on instrumentation and actuation of fuel cell test benches with

- High dynamic **conditioning of hydrogen and air** as well as
- **Dynamic flow measurement** including appropriate calibration techniques.

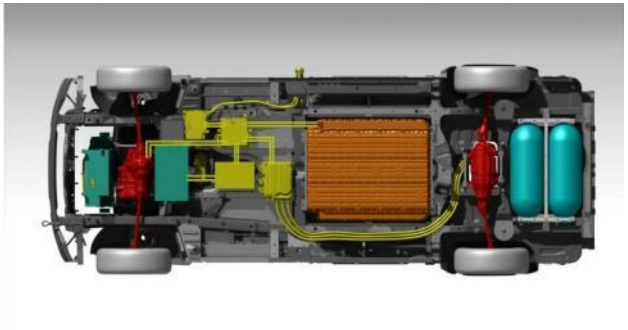




Project FC REEV 2014 – 2016

Fuel Cell Range Extended Electrical Vehicle

Extension of a battery-powered
vehicle
with a
fuel cell system (25 kW)
and a
700 bar hydrogen storage system
for extended driving range (> 400 km)



MAGNA
PM PROTON MOTOR Fuel Cells · Power Systems
IFA Institut für Fahrzeugantriebe & Automobiltechnik
TU WIEN TECHNISCHE UNIVERSITÄT WIEN Vienna University of Technology

Project FCH REFuel 2015 – 2018

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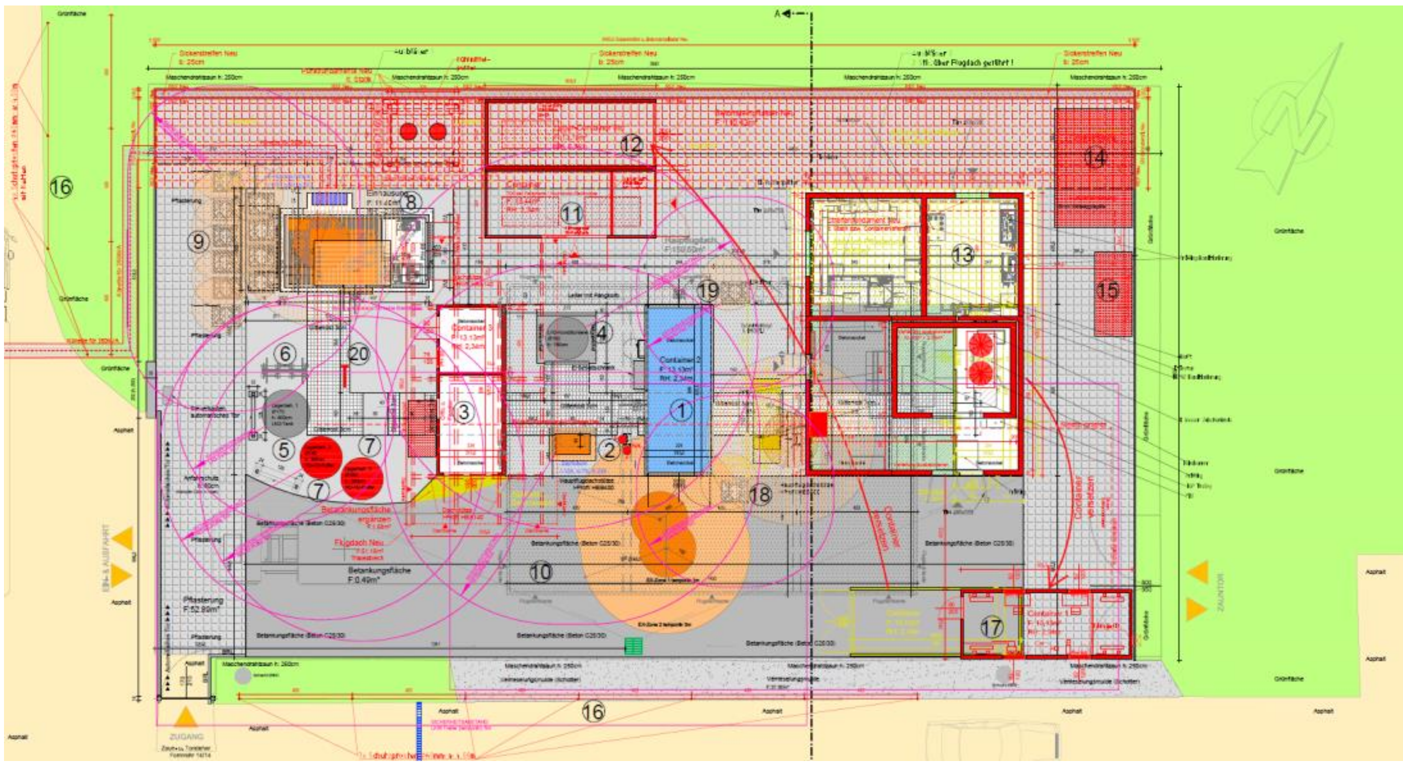
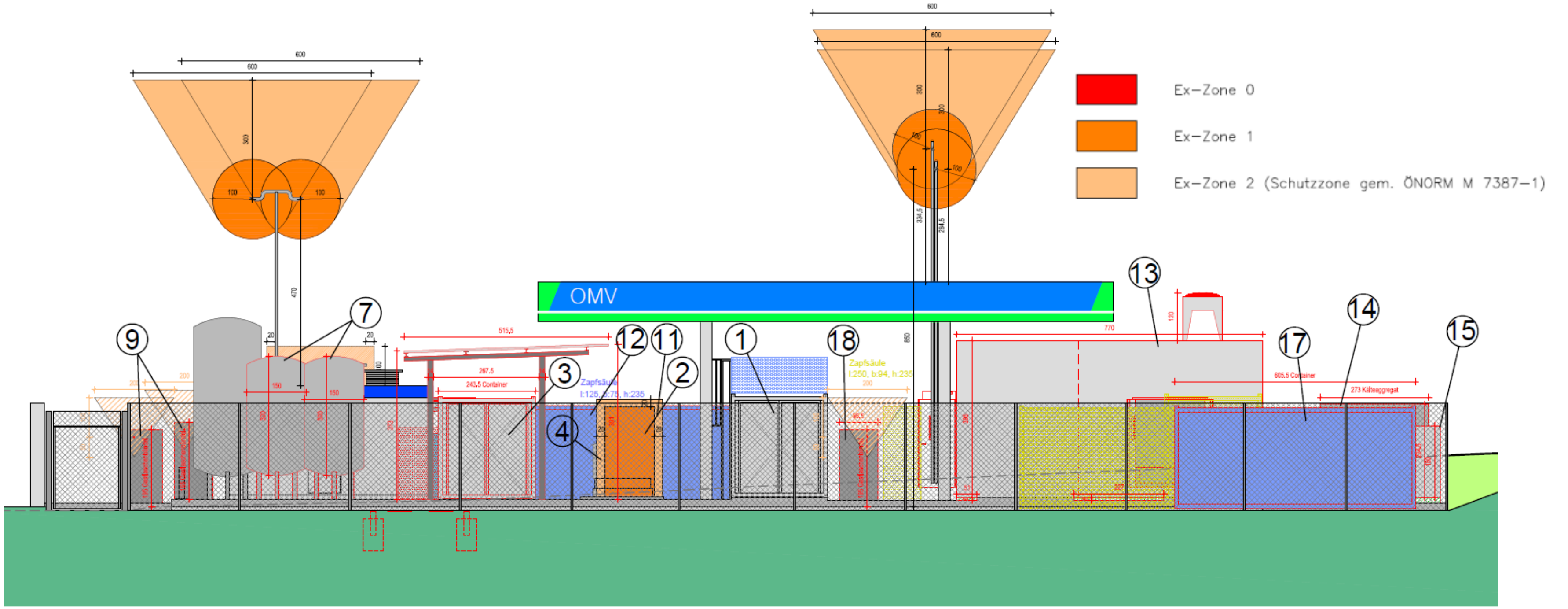
Development of a modular low-cost H2 filling station concept using 350 and 700 bar electrolysis and fuel cell range extender vehicles



1. Prüfcontainer
2. Zapfsäule - gasförmig 350 bar / 700 bar
3. Hochdruckkomponentenprüfstand NEU
4. LH2-Konditionierer
5. LN2-Tank flüssig 3 000 Liter
6. N2 Verdampfer
7. ND-H2-Puffer 2 x 5100 Liter NEU
8. H2 Verdichter450 bar NEU
9. Gaselager 1: H2, Erdgas, CH4, H2NG, He NEU
10. Tankbefüllfahrzeug (Zonierung nur im Grundr.)
11. HD-Elektrolyse, HD-Verdicher 950 bar NEU
12. Lagercontainer NEU (Cont. versetzt)
13. Brennstoffzellenprüfstand 150 kW NEU
14. Kälteaggregat NEU
15. Kälteaggregat NEU
16. Schutzpfosten (für Sicherheitsabstand) NEU
17. Bürocontainer NEU (Cont. versetzt)
18. Gaselager 2: H2, Erdgas, CH4, H2NG, N2 NEU
19. Gaselager 3: H2, Erdgas, CH4, H2NG, N2 NEU
20. LH2-Kupplung NEU

- Ex–Zone 0
- Ex–Zone 1
- Ex–Zone 2 (Schutzzone gem. ÖNORM M 7387–1)

Project FCH REFuel 2015 – 2018



ANSICHT SÜD-OST 1 : 100

LEGENDE BAU-UND ANLAGENTEILE

1. Prüfcontainer
2. Zapfsäule - gasförmig 350 bar / 700 bar
3. Hochdruckkomponentenprüfstand NEU
4. LH2-Konditionierer
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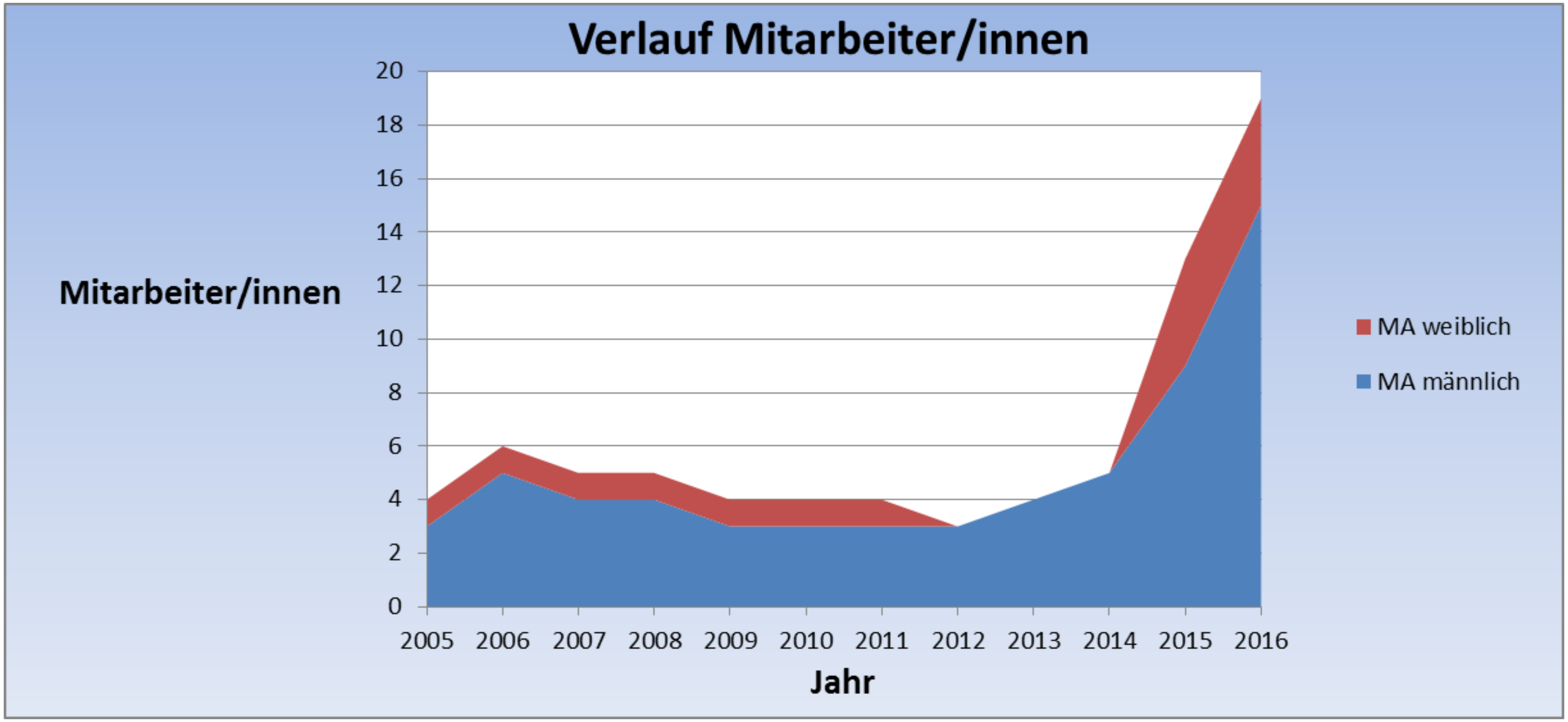
20. LH2-Kupplung NEU

Development Staff



Team

Vision of Hydrogen Economy

Legend:
1. photovoltaic plant, 2. wind power plant, 3. hydropower plant,
4. energy autonomous detached house, 5. municipal storage, 6. pumped-storage power plant,
7. centralized electrolysis and methanisation, 8. hydrogen filling station, 9. gas power plant
10. energy autonomous mobile network transmission station, 11. green intralogistics,
12. natural gas/hydrogen pore storage

www.hycenta.at

Contact:

HyCentA Research GmbH

Assoc.Prof. DI Dr. Manfred Klell (CEO)
Inffeldgasse 15
A-8010 Graz

0316-873-9500

klell@hycenta.at