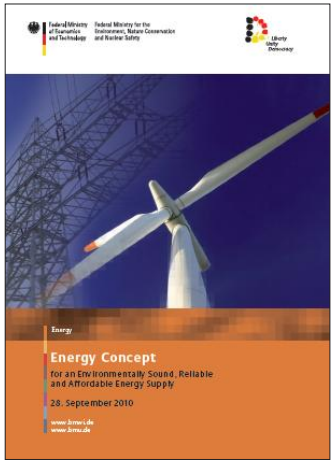
Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

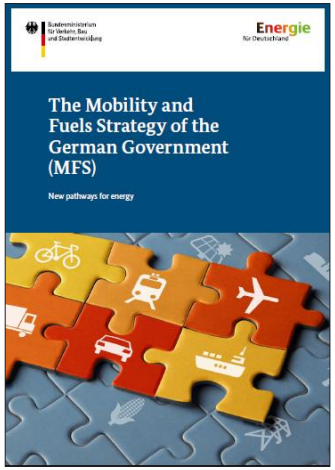
Overview of Fuel Cell and Hydrogen Developments in Germany

5th IPHE H2igher Educational Rounds | Rome, Italy | 01.12.2014

Dr. Klaus Bonhoff | Managing Director (Chair)
National Organisation Hydrogen and Fuel Cell Technology (NOW)

Policy Goals in Germany for Renewable Energies in the Energy System and for Road Transport





Energy Concept (2010)

reduce <u>overall</u> GHG emissions (vs. 1990):
40% by 2020 ➔ 80%-95% by 2050

increase share of renewables in final energy consumption:
18% by 2020 ➔ 60% by 2050

reduce primary energy consumption:
20% by 2020 ➔ 50% by 2050

reduce final energy consumption of <u>transport</u> (vs. 2005):
10% by 2020 ➔ 40% by 2050

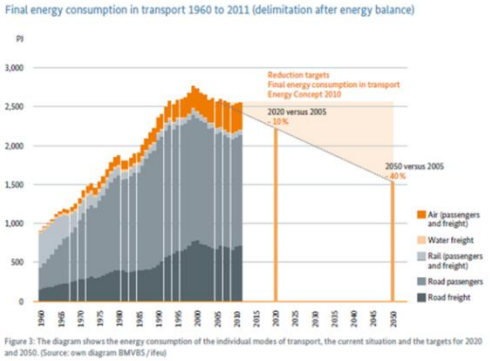
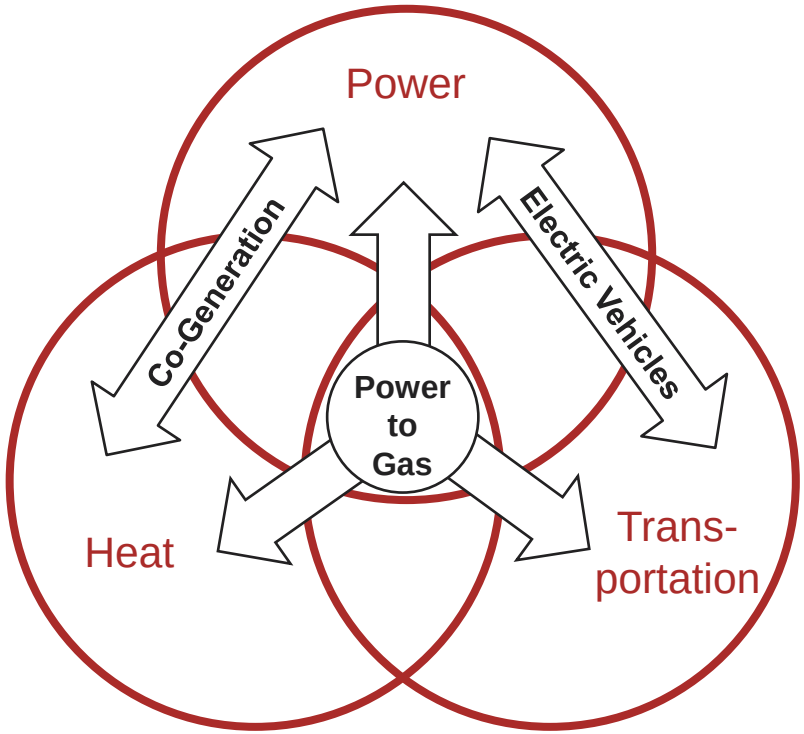


Figure 3: The diagram shows the energy consumption of the individual modes of transport, the current situation and the targets for 2020 and 2050. (Source: own diagram BMVBS / ifeu)

Linking the Energy Sectors



Key Measures:

- Security of Energy Supply
- Energy Efficiency
- Renewable Energies

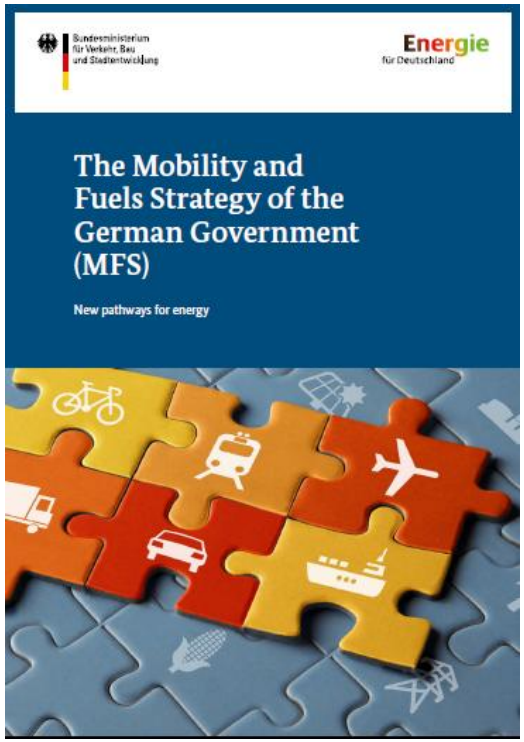
Fuel Cell Vehicles (cars and busses) and Hydrogen Stations

Political Framework for the Transport Sector

- Share of transport in final energy consumption nearly 30%
- Tripling of energy consumption in transport since 1960, even five-fold increase in road traffic

- Goals of the German Energy Concept (2010) for Transport:
  - -10 % until 2020 of energy consumption
  - -40 % until 2050 of energy consumption (vs. 2005)

The Mobility and Fuels Strategy of the German Government outlines the way how to achieve these objectives



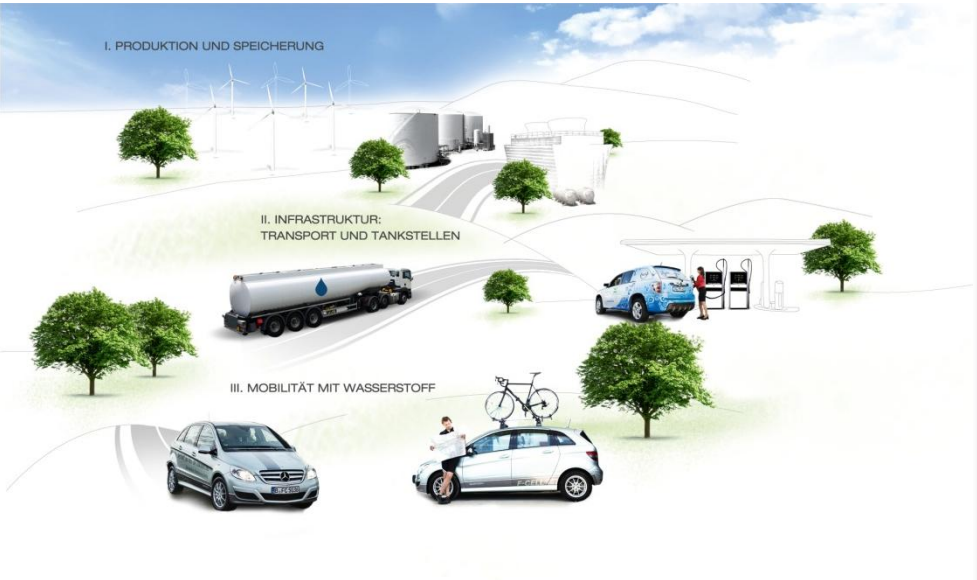
➔ **Electrification of the drive train (BEV's and FCEV's) is a key issue to reach the targets**

➔ **Targets only achievable with PtG-H2 and PtG-Methane**

➔ **Further increase of renewable energies beyond current planning is needed**

➔ **Large scale storage for hydrogen is inevitable**

The Clean Energy Partnership



AIR LIQUIDE · BMW Group · BVG
DAIMLER · EnBW · Ford
GM · Opel · HOCHBAHN · HONDA The Power of Dreams
HYUNDAI · Linde · SIEMENS
Shell · TOTAL · TOYOTA
SSB · VATTENFALL · VOLKSWAGEN AKTIENGESELLSCHAFT

funded by: Federal Ministry of Transport and Digital Infrastructure
coordinated by: NOW

The CEP fleet of vehicles

Opel HydroGen4

Toyota FCHV-adv

Audi Q5 HFC

Hyundai ix35 Fuel Cell

Honda FCX Clarity

Ford Focus Fuel Cell

Mercedes-Benz B-Class F-CELL

VW Tiguan HyMotion

Hochbahn Mercedes-Benz
Citaro FuelCELL-Hybrid

SSB Mercedes-Benz
Citaro FuelCELL-Hybrid

BVG buses
MAN Lion's City

funded by: Federal Ministry of Transport and Digital Infrastructure
coordinated by: NOW

Clean Energy Partnership (CEP) Fact and Figures – Status Quo

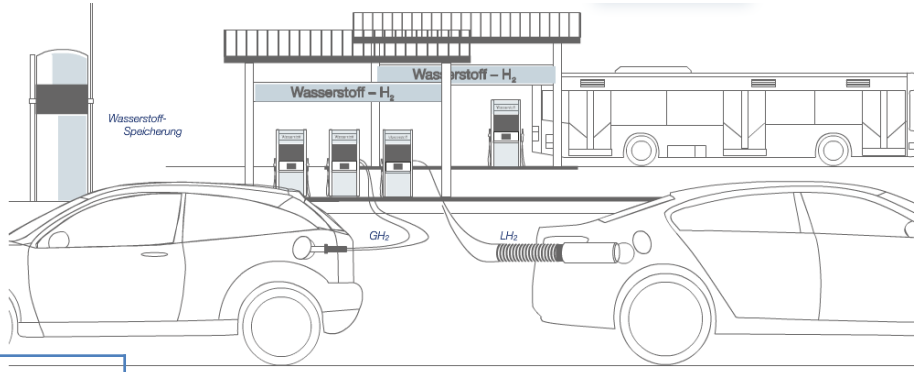
Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

Number of vehicles in the CEP regions

	Cars						Buses		
	BE	HH	BW	HS	NRW	**Total**	BE	HH	BW
CEP II	45	2				**47**	14	6	
2012 Q1	46	14	13	10	2	**85**	4	4	2
2014 Q4 (planned)	≥56	≥20	≥20	≥15	≥3	**≥130**	4	6	5

Kilometres driven (by cars)

CEP since 2005	**2.603,000 km**
2010	181,000 km
2013	708,000 km

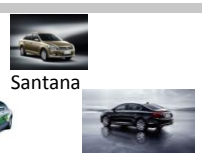


Fillings

	Cars		Buses	
	Number	**Volume of H_2**	**Number**	**Volume of H_2**
2010	1,300	3,300 kg	1,600	24,000 kg
2011	1,900	3,800 kg	1,700	29,000 kg
2013		6,669 kg		27,996 kg

Fuel Cell Vehicles (FCV)

series production vehicles
commercial introduction
commercial introduction announced


Santana


750fc

950


Tucson


ix35 Fuel Cell


Opel Zafira


HydroGEN4


Focus


Explorer


xTerra FCEV


X-Trail FCEV


TeRRa SUV


FCX


FCX Concept 2005


Clarity


FCHV 3


FCHV 4


FCHV 5


Toyota FCV


Necar 1


Necar 2


Necar 3


Necar 4


Necar 5


A-Klasse F-CELL


B-Klasse F-CELL


Tiguan


Caddy


Audi Q5

Pre-commercial / prototype vehicles and fleets | 2013 | 2014 | 2015 | 2016 | 2017

Fuel Cell Electric Vehicles
Los Angeles Motor Show 2014

Green Car Reports 17.11.2014

2016 Toyota Mirai Priced At $57,500, With $499 Monthly Lease

Hybrid Cars 18.11.2014

Toyota Mirai FCV First Drive Impressions

The Toyota Mirai drives essentially like a normal car.

Autocar 19.11.2014

Hydrogen-powered Audi A7 h-tron concept could make production

Automobil-Produktion 18.11.2014

Audi zeigt Konzeptfahrzeug mit Brennstoffzellentechnik

Los Angeles Times 19.11.2014

Carmakers prepare to shift to hydrogen fuel cells

Heise Online 18.11.2014

Toyotas Serien-Brennstoffzellenauto: Mirai kommt früher als geplant

Green Car Reports 18.11.2014

Toyota FCV Mirai launches in LA; initial TFCS specs; $57,500 or $499 lease; leaning on Prius analogy

We are just at the starting point. Today is not the day of completion and perfection. We will continue our efforts with fresh devotion. Mirai contains two innovations: innovation for mobility, and innovation to realize a hydrogen based society.

Prius means "go before," and for nearly twenty years, Prius paved the way by demonstrating to mainstream buyers that the future in mobility would include electric motors. But "the future" that Prius went before will be the car we will talk about today: the Toyota Mirai hydrogen fuel cell electric vehicle. ... The gas-electric hybrid technology in the first Prius blazed a new trail, that many critics said could not be blazed. The hydrogen fuel cell technology in the new Mirai will do the same.

—Takeshi Uchiyamada, Chairman of Board, Toyota Motor Corporation

Golem 20.11.2014

"Mit dem Concept Car H-Tron zeigen wir, dass wir die Brennstoffzellentechnologie beherrschen. Sobald Markt und Infrastruktur es rechtfertigen, können wir in den Serienprozess einsteigen," sagte Audi-Vorstand Ulrich Hackenberg.

Autocar 17.11.2014

BMW plans new hydrogen-fuelled i5

Environment & Energy News 19.11.2014

Three major automakers, Hyundai Motor Co., Toyota Motor Corp. and Honda Motor Co., have announced they will launch commercial FCVs during the next year. Several others plan to release vehicles before the end of the decade.

Bild 19.11.2014

Los Angeles – **Mal so richtig Dampf ablasen würde vielen gut tun. Der VW Passat „HyMotion" macht es bereits. Er fährt mit Brennstoffzelle: eine Auto-Zukunftsvision, in der es keinen Smog und Lärm mehr gibt.**

Green Car Reports 20.11.2014

Volkswagen Group shows 3 hydrogen fuel cell concepts at LA Show: Audi A7 Sportback h-tron; Golf Sportwagen HyMotion; Passat HyMotion

Autocar 19.11.2014

Volkswagen Group unveils hydrogen-powered Golf Estate and Passat

German car giant showcases its hydrogen fuel cell technology with a brace of concepts at the Los Angeles motor show

The information daily 19.11.2014

Hydrogen powered cars are here but building the infrastructure is key

Green Car Reports 20.11.2014

Honda to provide $13.8M to FirstElement Fuel to support build out of California hydrogen refueling infrastructure

Green Car Reports 17.11.2014

DOE reports progress on development of hydrogen storage technologies

Green Car Reports 17.11.2014

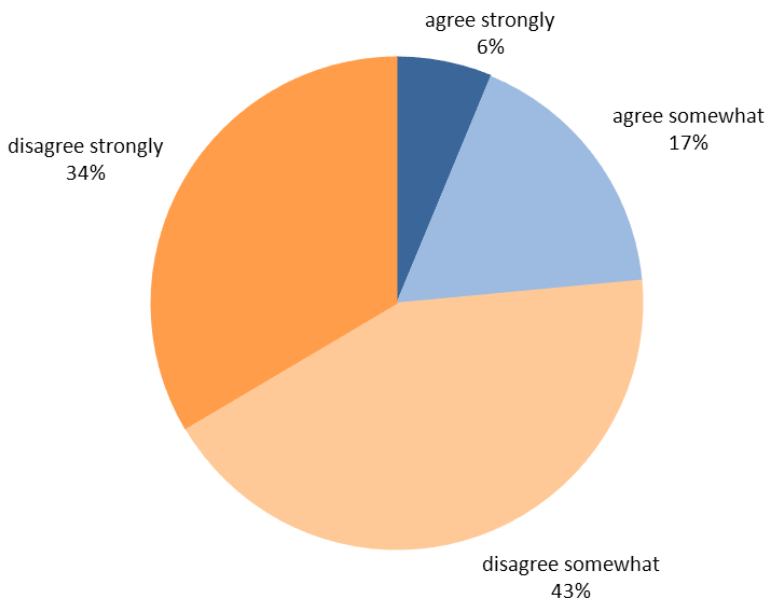
Honda FCV Concept makes world debut in Japan; Power Exporter concept

DGAP Medientreff 19.11.2014

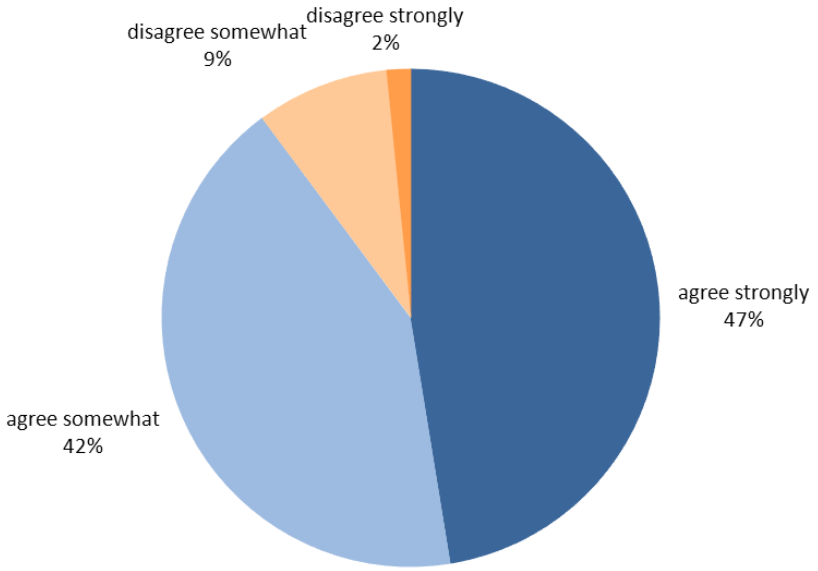
'FirstElement Fuel schafft damit eine der wichtigsten Voraussetzungen für die erfolgreiche Markteinführung von brennstoffzellenbetriebenen Fahrzeugen', sagte Steven Carter, Vice President des Environmental Business Development Office bei Honda. 'Durch diese Zusammenarbeit mit FirstElement wird für unsere Kunden die Betankung brennstoffzellenbetriebener Fahrzeuge ebenso sicher, komfortabel und kundenfreundlich wie die Fahrzeuge selbst sein.'

NOW Study “Hy-Trust”
Evaluation of Hydrogen Safety

Survey 01/2013
I would be more afraid to live next to a hydrogen filling station than an ordinary filling station.



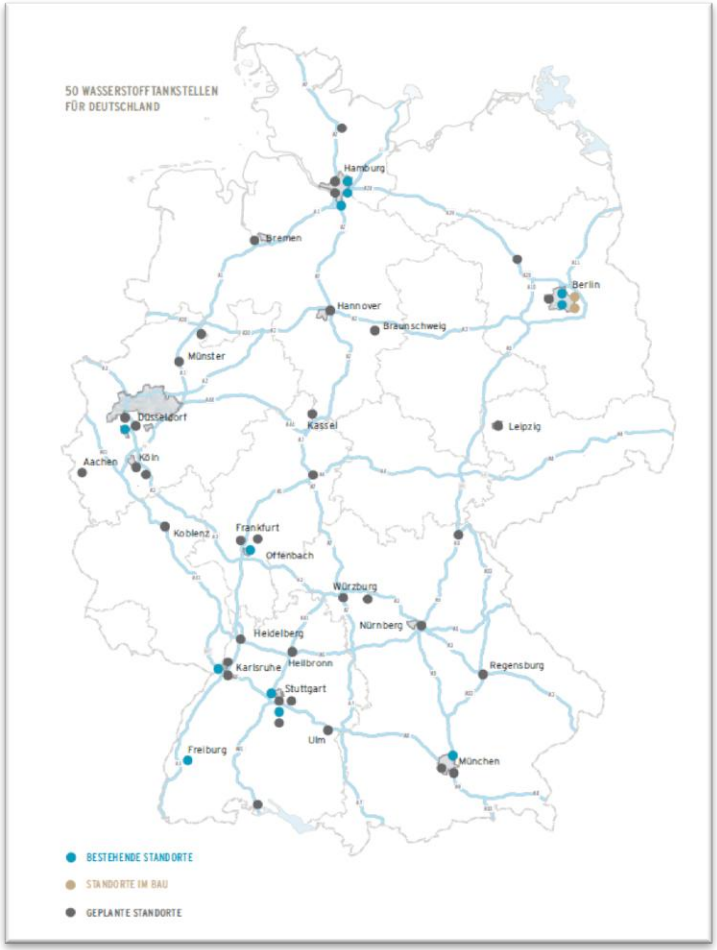
Survey 01/2013
I take it for granted that hydrogen vehicles will be safe once they are officially sold .

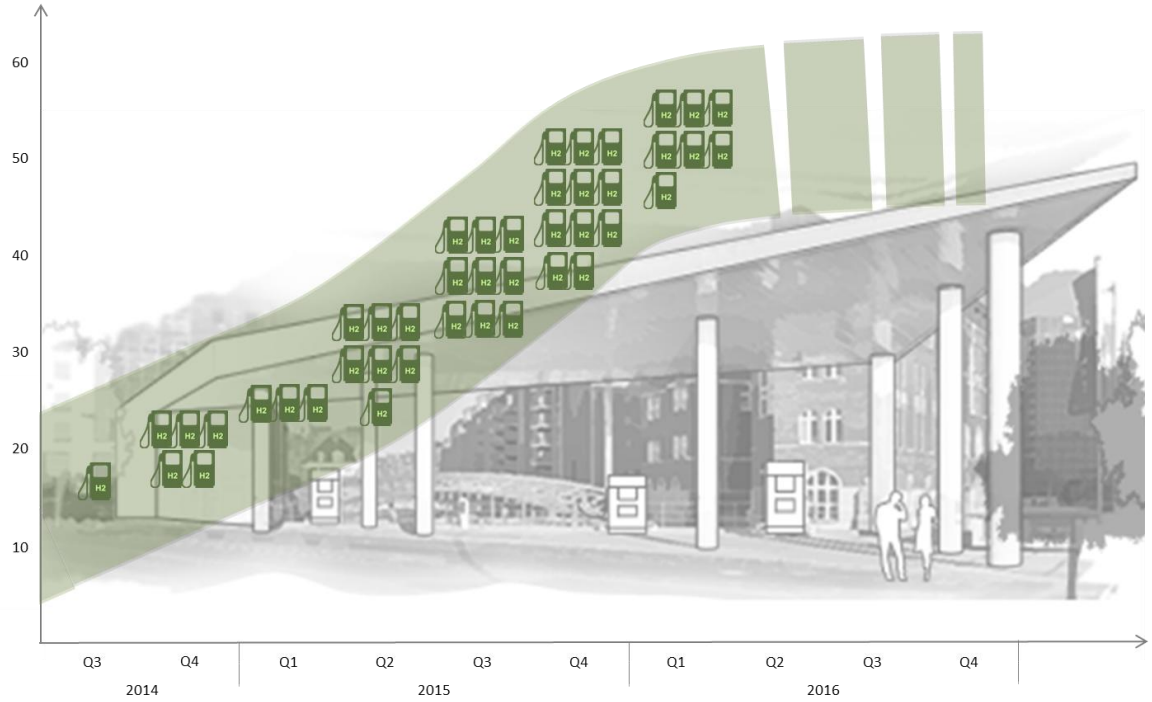


50-Hydrogen-Station Program in Germany

field testing of technical innovations and connecting corridors between metropolitan regions

Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie



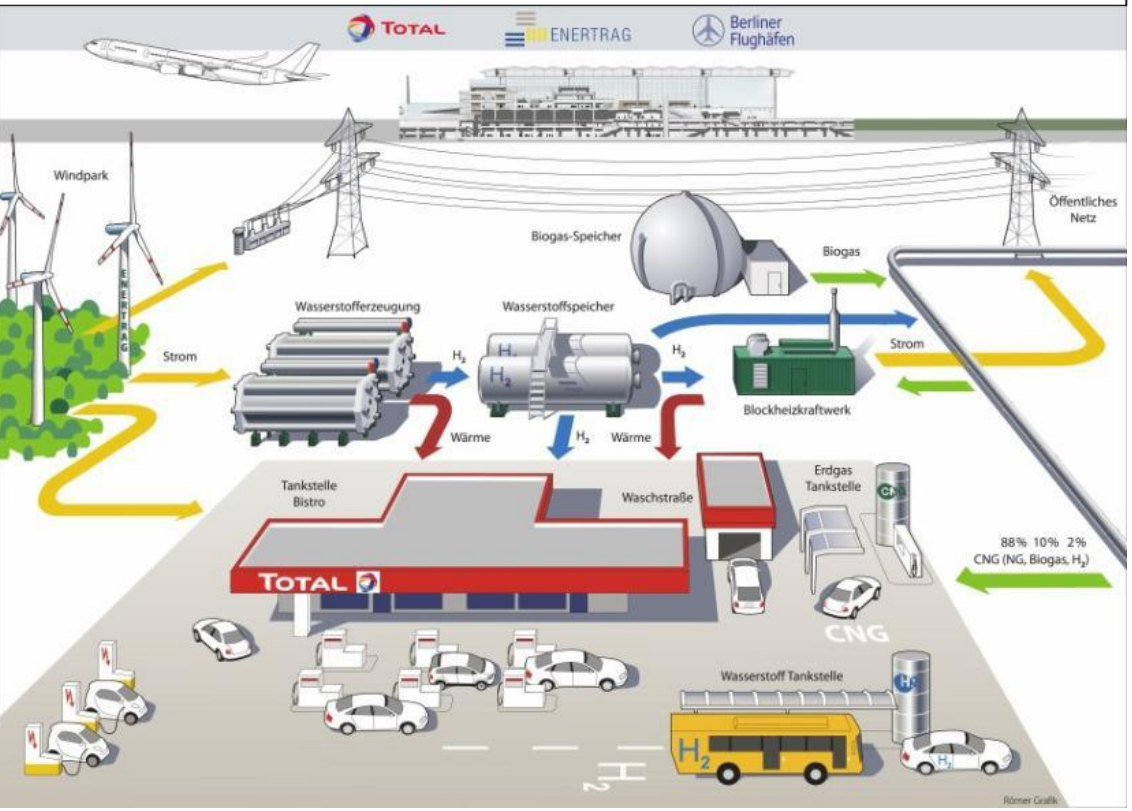


Hydrogen Station Deployment

demonstrating Wind-Hydrogen for transportation

Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

hydrogen as part of an integrated energy system



Total: multi-energy fuelling station

refueling renewable power

Total Refueling Station at Berlin-Schoenefeld

Opening on May 23th, 2014

Implementing the 50-Station-Program in German

Opening ceremony of the Total multi-energy station at
Berlin-Jafféstraße on October 29, 2014

DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the deployment of alternative fuels infrastructure

PRESS
EN

Council of the European Union

PRESS RELEASE
ST 13660/14
PRESSE 487
Brussels, 29 September 2014

Clean fuel infrastructure rules adopted by the Council

The Council today adopted a directive on **building up minimum infrastructure for alternative fuels across the EU** (PE-CONS 79/14; statements: 13267/14 ADD 1).

'Under the directive, each member state has two years to draw up an alternative fuel deployment strategy and send it to the Commission. These strategies or "national policy frameworks" will set out the country's national targets for putting in place new recharge and refuelling points for the different types of "clean fuel", such as electricity, hydrogen and natural gas, as well as relevant supporting actions.'

'The deadlines for having the infrastructure in place range from 2020 to 2030, depending in particular on the type of fuel, vehicle and deployment area. For instance, the directive stipulates that by the end of 2020, member states should install enough recharge and refuelling points so that electric cars and cars using compressed natural gas (CNG) can circulate at least in cities and suburban areas.'

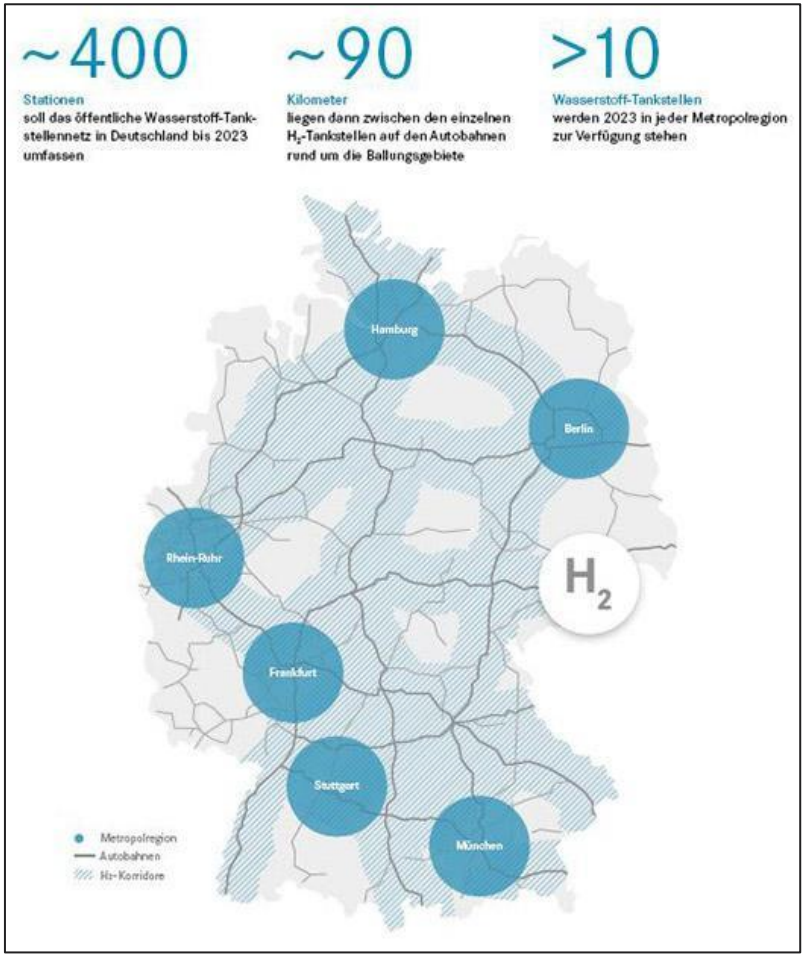
H2-Mobility action plan until 2023

Air Liquide, Daimler, Linde, OMV, Shell and Total agree on an action plan for the construction of a hydrogen refueling network in Germany.

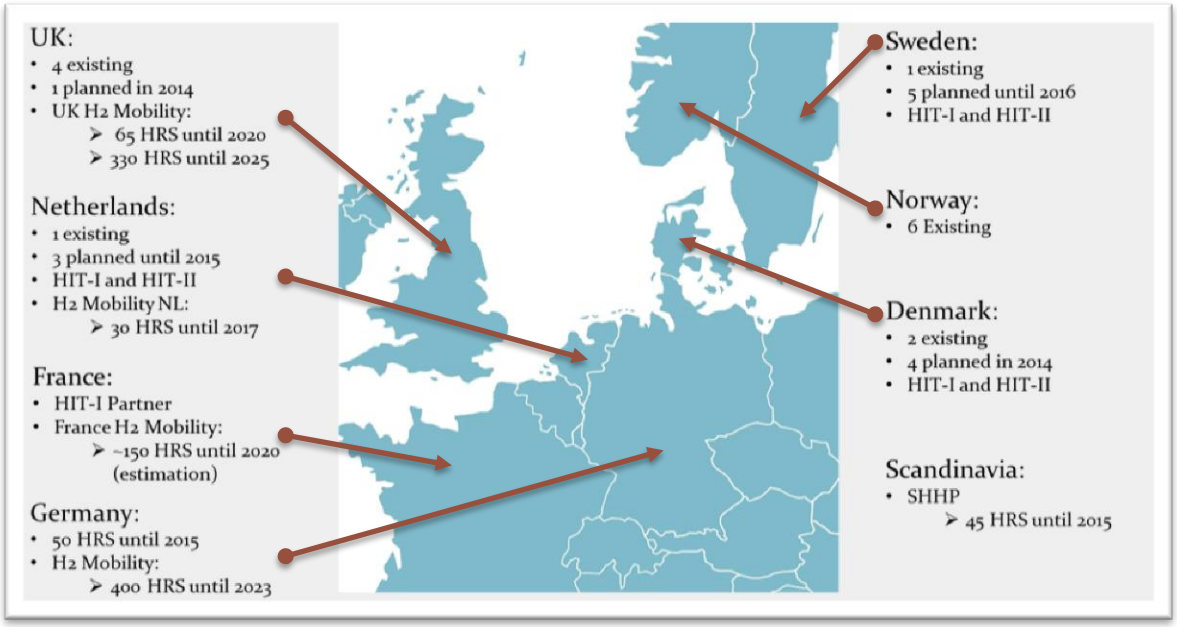
Targets:

- **400 HRS** until **2023** (100 HRS until 2017).
- **350 mio. €** investment.
- Max**. 90 km** distance between two HRS at the motorway.
- **10 HRS** in each metropolitan area.

H_2 Mobility



Development of an Aligned European Hydrogen-Infrastructure Strategy



- Several HRS initiatives and roll-out scenarios throughout Europe are currently in place
- Strong coordination within Europe is needed since:
  - the initiatives are at different development phases
  - there are only limited funding budgets available
  - an aligned strategy increases the political awareness

Hydrogen Production from Renewable Energies

stabilizing the grid in the power sector and providing a renewable fuel to the transportation sector

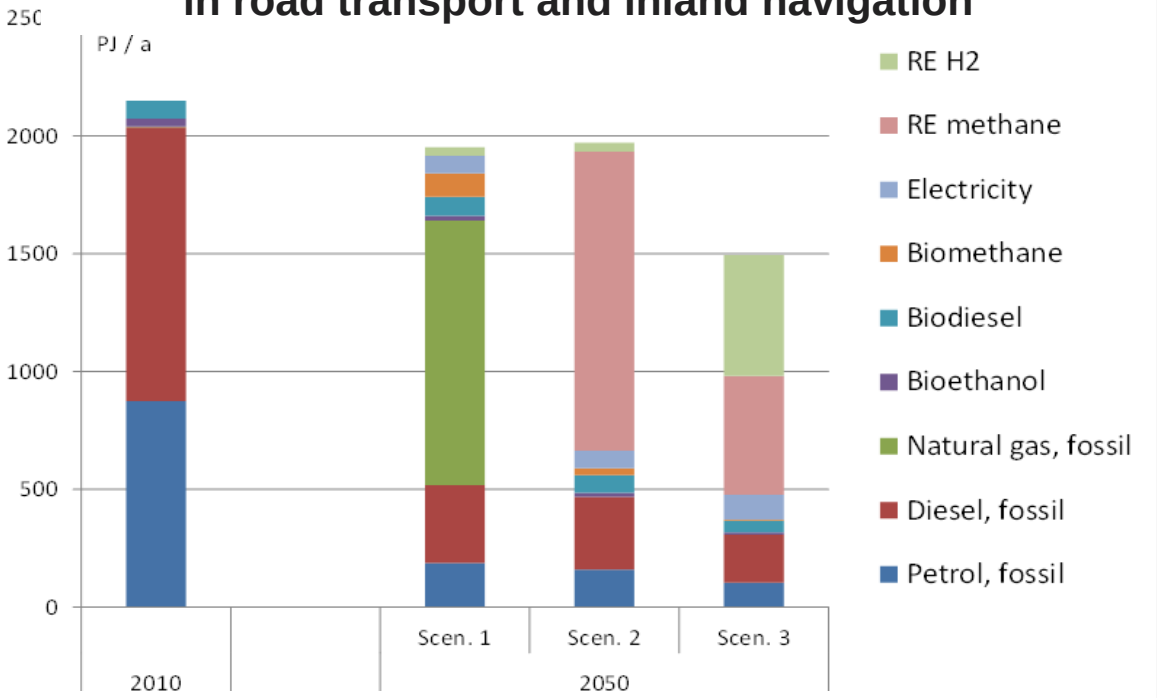
Power-to-Gas Technologies are needed to Reduce Primary Energy Demand in Transportation

Scenarios:

1. high market penetration with methane-operated internal combustion engines, but no PtG;
2. high market penetration with methane-operated internal combustion engines, fuel demand entirely covered with PtG; and
3. considerable shares of both methane-operated internal combustion engines and fuel cell electric engines, fuel demand entirely covered with PtG.

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft | ifeu | ludwig bölkow systemtechnik | DBFZ

Final energy consumption in road transport and inland navigation



Source:
Power-to-Gas (PtG) in transport
Status quo and perspectives for development
Study in the context of the scientific supervision, support and guidance of the BMVBS in the sectors Transport and Mobility with a specific focus on fuels and propulsion technologies, as well as energy and climate , 2014

Substantial reduction of GHG-Emissions in transportation are only achievable with Power-to-Gas including electrification of the drive-train (Batteries and Fuel Cells)

Scenarios:

1. high market penetration with methane-operated internal combustion engines, but no PtG;
2. high market penetration with methane-operated internal combustion engines, fuel demand entirely covered with PtG; and
3. considerable shares of both methane-operated internal combustion engines and fuel cell electric engines, fuel demand entirely covered with PtG.

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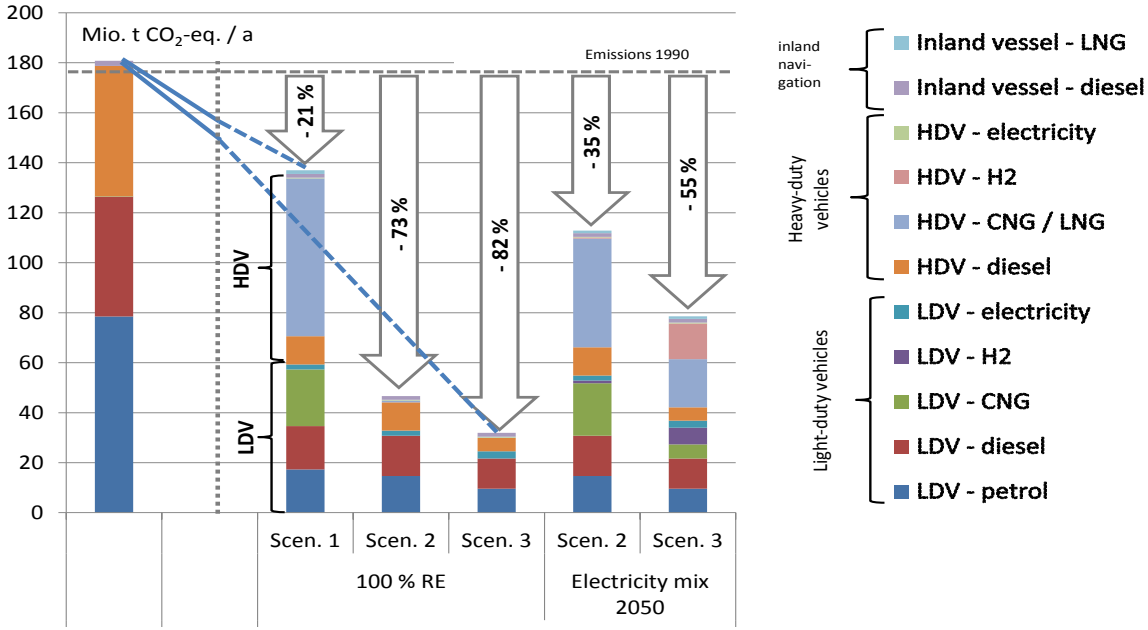
GHG emissions in road transport and inland navigation



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The Overall Power Demand Increases with Power-to-Gas Fuel-Options for the Transportation Sector

Scenarios:

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2. high market penetration with methane-operated internal combustion engines, fuel demand entirely covered with PtG; and
3. considerable shares of both methane-operated internal combustion engines and fuel cell electric engines, fuel demand entirely covered with PtG.

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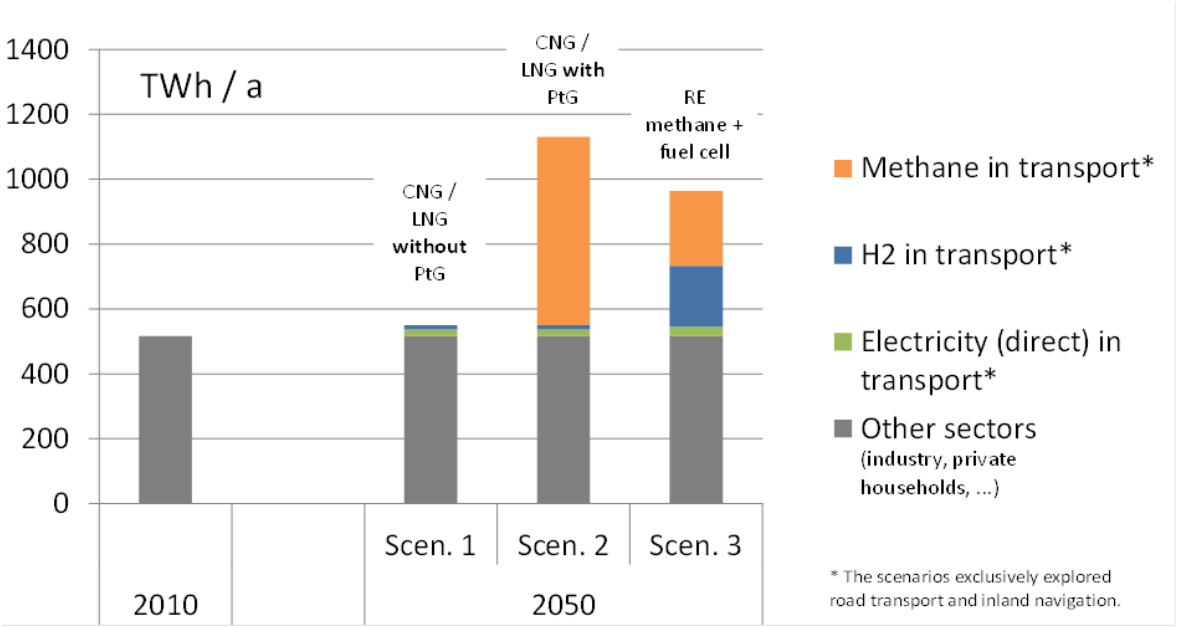
Electricity demand in the scenarios 1–3

(for the demand of the other sectors, the current electricity demand was extrapolated to 2050)



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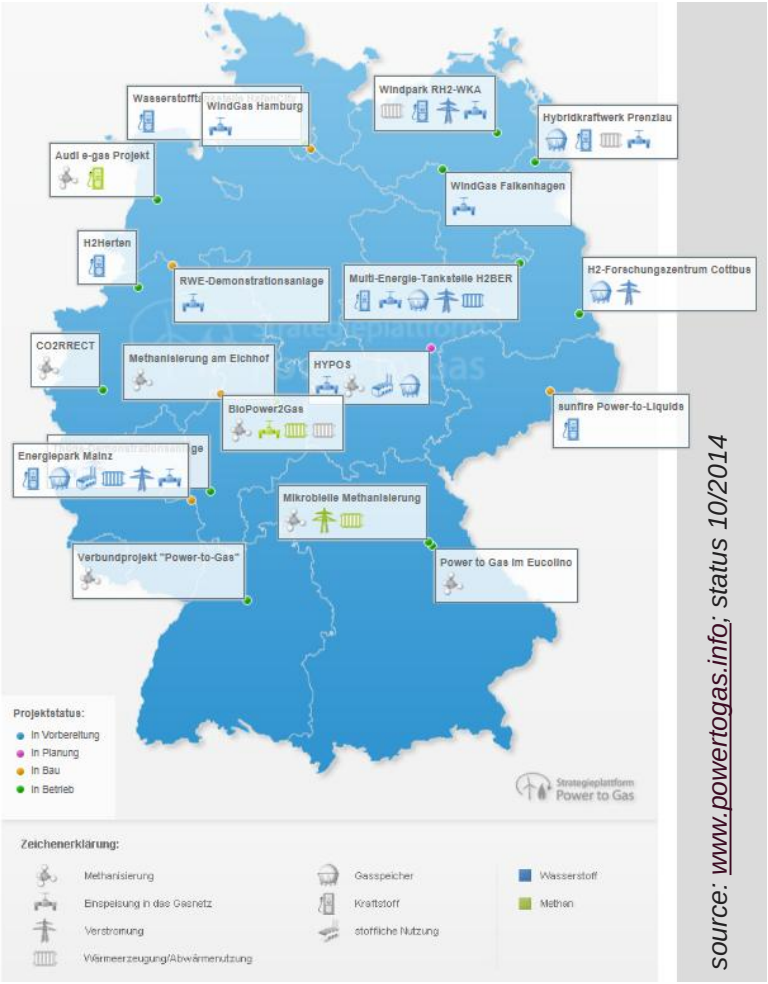
Power-to-Gas

Demonstration Projects in Germany



source: www.powertogas.info; status 10/2014

Wind Hydrogen Project RH$_2$ -WKA

Renewable Hydrogen- Werder/Kessin/Altentreptow

Demonstration of Wind-H$_2$- System

- conception, construction and operation
- electricity supply for wind power plants at times of calm

plant design

ground-breaking ceremony July 2011

start of trial H$_2$-production December 2012

Project „Power-to-Gas for Hamburg“

- 1MW PEM-electrolyzer
- injection of H$_2$ into natural gas grid

ground-breaking ceremony June 2013

Wind-Hydrogen-System at the Energy Park in Mainz

- Project consortium: Stadtwerke Mainz, Siemens, Linde, Hochschule Rhein-Main
- 2 MW PEM electrolyzer
- Large scale ionic compressor
- Multiple uses of hydrogen
- Planned start of operation in 2015

Co-generation with Fuel Cell Systems

efficient decentralized supply of power and heat in homes

Fuel Cell CHP Technology offers Multi-Purpose Solutions

Conversion of fossil power generation system

Grid expansion

Combined Heat & Power-Technology with highest electric efficiency

Opportunities for integration into virtual power networks

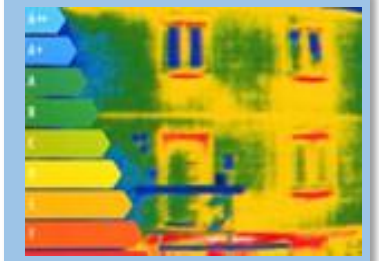
Ease pressure on and help stabilizing electricity grid through de-central operation

Much higher efficiency compared to non-coupled heat and power production

Operation with biogas or SNG

Predestined for flexible use and leveling out fluctuating renewable energies

Expansion of REN



Increases in energy efficiency

Fuel cell CHP appliances offer ideal building blocks for future energy systems due to their efficiency, flexibility and de-central deployability

Lighthouse project CALLUX - overview

Focus:

- **Research and Development**
- **Training (craftsmen)**
- **Operating experience**
- **Market research**
- **Cost reduction**
- **Reliability increase**

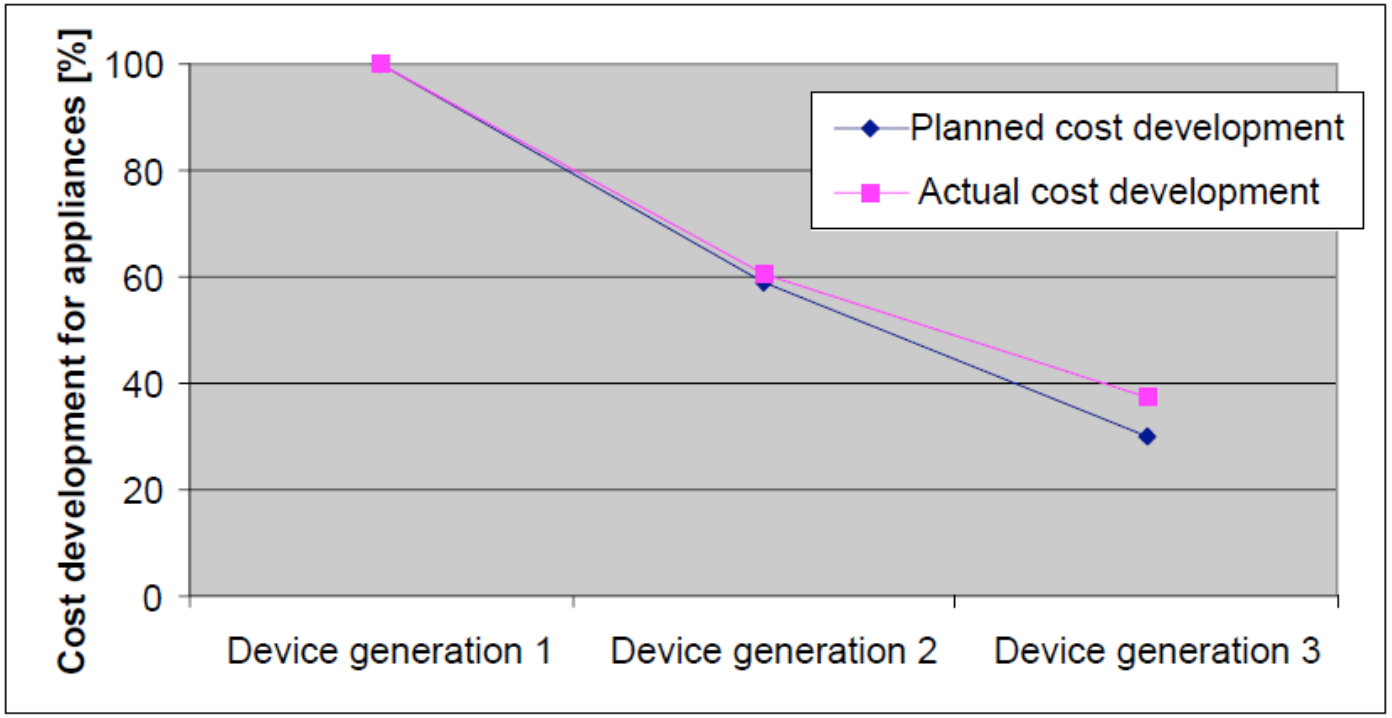
Research & Development → Demonstration / Field Trials / Markt Preparation → Commercial Ramp Up → Mass Market

CALLUX

http://www.callux.net

Cost trend for fuel cell heating appliance (averages of all manufactors)

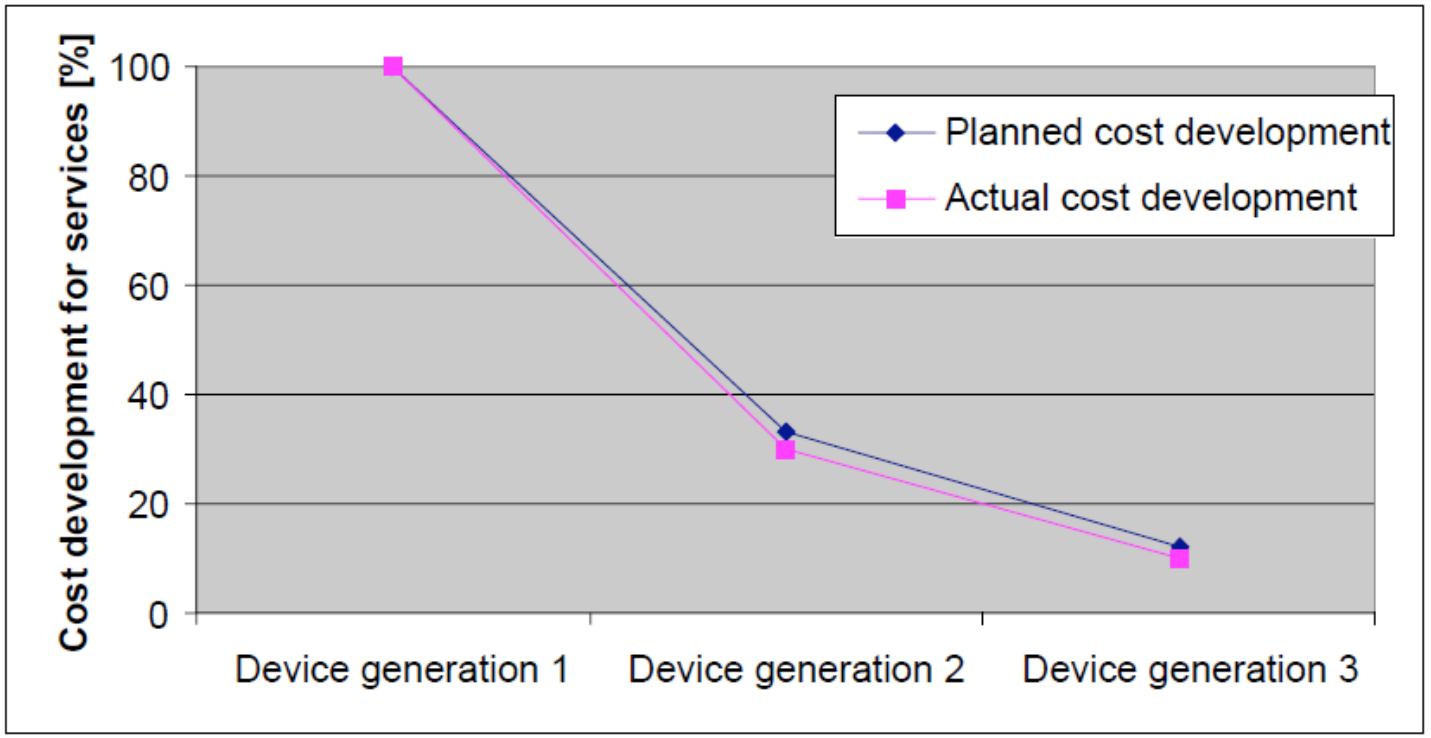
callux
Praxistest Brennstoffzelle fürs Eigenheim
Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie



→Appliance costs were reduced by around 60% over the course of the project.

Cost trend for servicing/replacement parts (averages for all manufactors)

callux
Praxistest Brennstoffzelle fürs Eigenheim
Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie



→Costs for appliance servicing and replacement parts were reduced by around 90% over the course of the project.

Market Research – Consumer Feed-Back

callux
Praxistest Brennstoffzelle fürs Eigenheim
Ein Projekt im Nationalen Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie

Experience with installing and operating the fuel cell heating system

Survey of Callux field test customers in June 2013

Fuel Cell Products
for Residential Combined Heat and Power Supply

								
Hersteller	**Baxi Innotech**	**Buderus**	**Ceramic Fuel Cells**	**Elcore**	**Hexis**	**Junkers**	**Vaillant**	**Viessmann**
Typ	NT-PEM	SOFC	SOFC	HT-PEM	SOFC	SOFC	SOFC	NT-PEM
Leistung (el/th)	1,0/1,87 kW	0,7/0,7 kW	1,5/0,61 kW	0,3/0,6 kW	1,0/1,8 kW	0,7/0,7 kW	1,0/1,4 kW	0,75/1 kW
Thermische Leistung des Zusatzbrenners	3,5-20 kW	14 bzw. 24 kW	extern, individuell wählbar	extern, individuell wählbar	7-21 kW	13,3 bzw. 23 kW	5,8-27 kW	5,5-19 kW
Speicher	extern, individuell wählbar	Warmwasserspeicher 75 l, Pufferspeicher 150 l	extern, individuell wählbar	extern, individuell wählbar	extern, individuell wählbar	Warmwasserspeicher 75 l, Pufferspeicher 150 l	extern, individuell wählbar	Warmwasserspeicher 46 l, Pufferspeicher 170 l
Elektrischer Wirkungsgrad	34 %	45 %	bis zu 60 %	33 %	30-35 %	45 %	38 %	37 %
Gesamt-wirkungsgrad	96 %	90 %	bis zu 85 %	98 %	95 %	90 %	90 %	90 %
Abmessungen in mm	600 x 600 x 1515	600 x 1200 x 1800	660 x 600 x 1100	500 x 500 x 900	580 x 620 x 1650	600 x 1200 x 1800	600 x 625 x 986	1085 x 600 x 1998
Gewicht in kg	ca. 200	280 (SOFC-Modul 115) (Gas-Brennwertmodul 45) (Pufferspeicher 80) (Trinkwasserspeicher 40)	ca. 200	85	210	220	160	290 (Brennstoffzellenmodul 125) (Spitzenlastmodul 165)
Feldtests, Kooperationen, Demonstrations-projekte	Callux (DE), ene.field (EU), eigene Feldtests mit Energieversorgern	ene.field (EU)	verschiedene Kunden z.B. aus der Energiewirtschaft, Kooperation mit Gas- und Wärme-Institut Essen (InnovationCity Ruhr) und Gasversorgern	ene.field (EU), verschiedene Partner aus der Energiewirtschaft und dem Hausbau	Callux (DE), Pharos (CH), ene.field (EU)	ene.field (EU)	Feldtest in Callux (DE), Kleinserie in ene.field (EU)	Januar 2013 Pretest; Juli 2013 bis März 2014 großer Feldtest
Markteinführung	2015	2016	2012	2014	Ende 2013	2016	2016/2017	April 2014

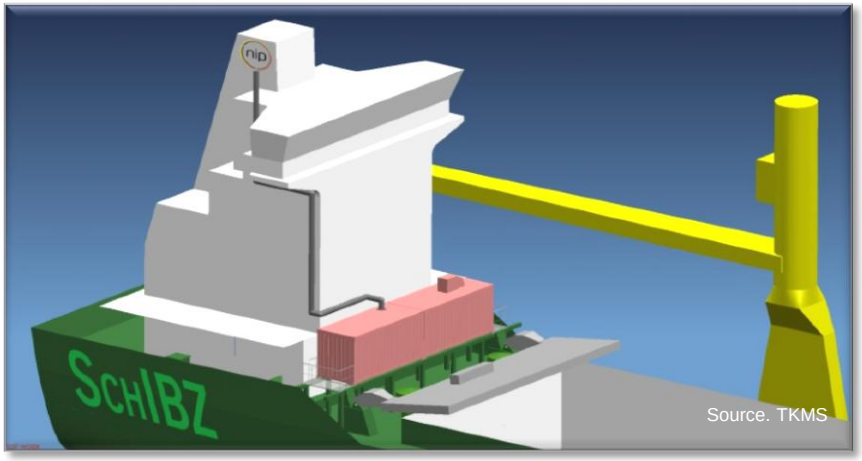
commercial products available

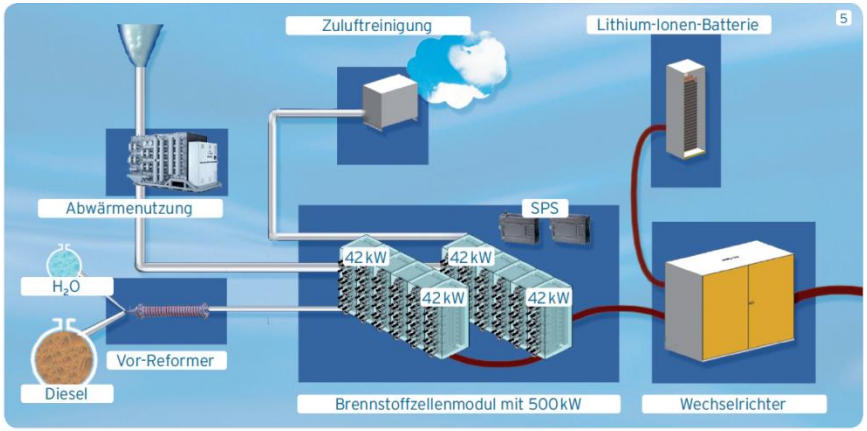
Fuel Cells for Ships

meeting emission targets

SchIBZ

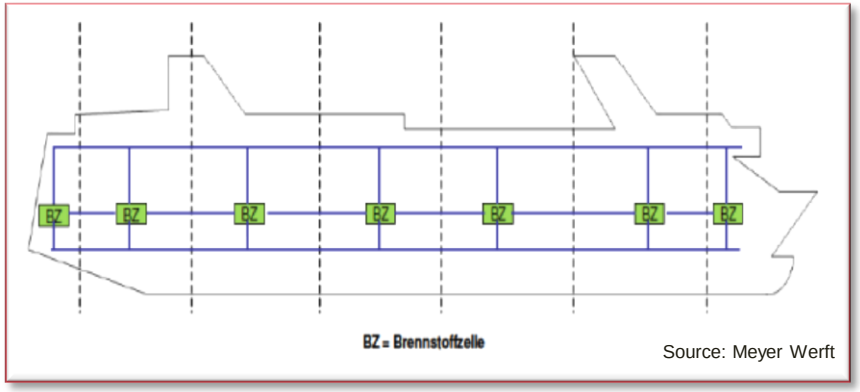
- Im Rahmen des Projekts wird der Einsatz einer Hochtemperaturbrennstoffzelle mit 500 kWel Leistung auf seegängigen Schiffen erprobt
- Mit Dieselöl betriebene SOFC
- (max. 15 ppm S)
- 100 kW Demonstrator ab Sommer 2014
- Installation an Bord ab 2014





PaXell

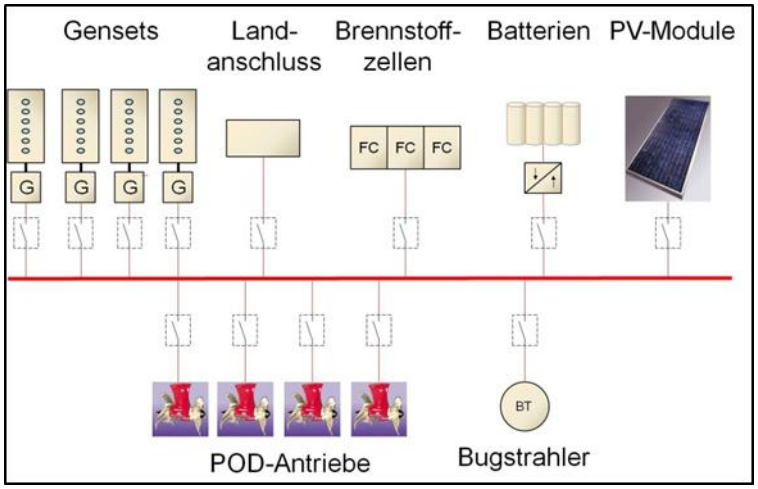
- Im Rahmen des Projekts wird der Einsatz einer Hochtemperaturbrennstoffzelle auf Passagierschiffen erprobt
- HT PEM-Brennstoffzelle
- Dezentrale Stromversorgung
- Energiemodule 250 – 1000 kW
- Einbau an Bord ab 2014



Source: Meyer Werft

RiverCell – in Planung

- **Hybridisierung des Hauptantriebes** mit Verbrennungsmotoren, Brennstoffzellen, Batterien und Photovoltaikmodulen
- Energiebereitstellung für den **Hotelbetrieb** durch Kraft-Wärme-Kälte-Kopplung per Brennstoffzellen
- **Großes Marktpotential** für Flusskreuzfahrtschiffe und Fähren bei künftiger Verschärfung von Emissionsrichtlinien
- Erhebliche **Emissionsreduktion** durch Landstromversorgung **in Häfen** - Liegeplätze in emissionssensiblen Innenstadtbereichen bleiben zugänglich

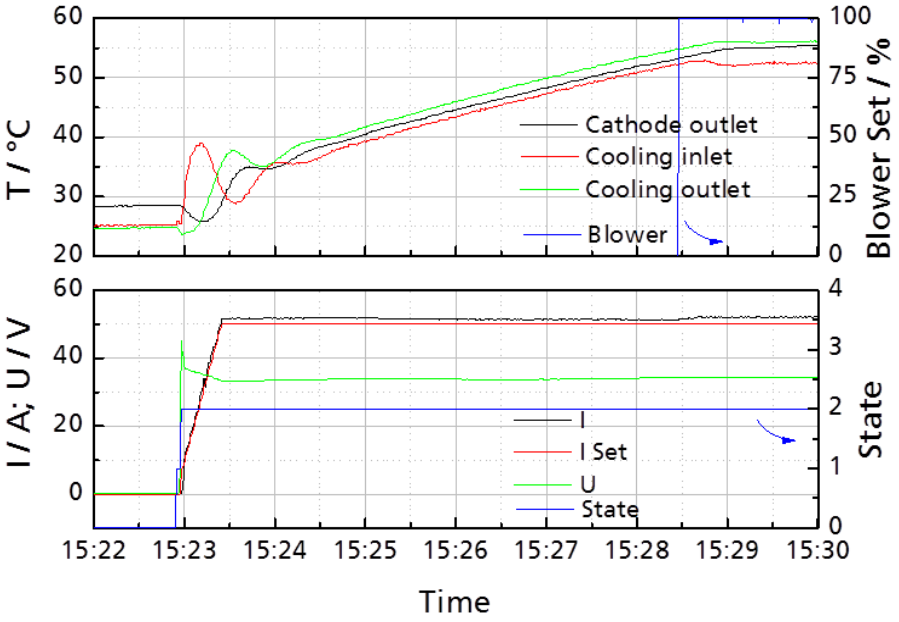


Fuel Cells Systems for Back-up Power and Remote Locations

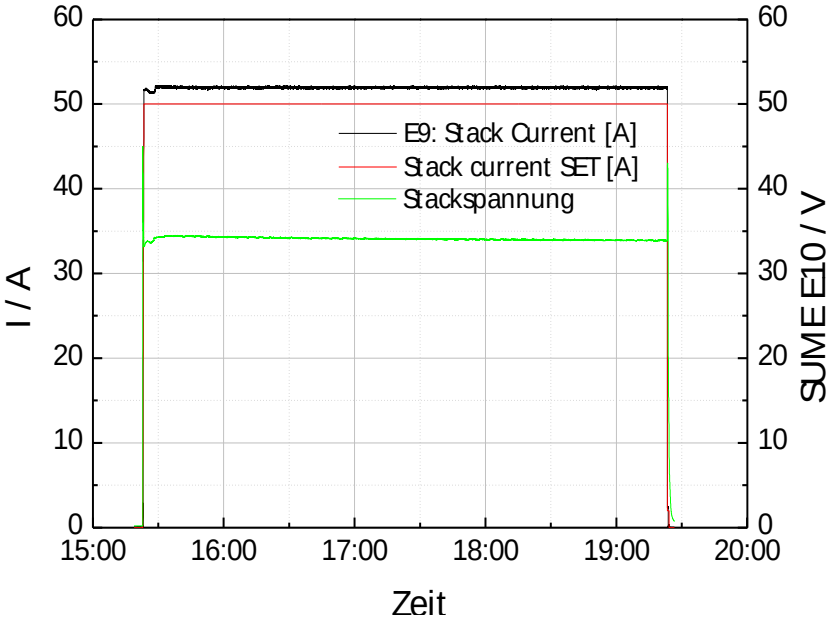
reliable power supply at any time

Fuel Cell Systems for autonomous BOS-Station

clean power net
Brennstoffzellen in Industrie und Business



Start-up Behaviour



Endurance Testing
stable nominal power over 4 hours
(+40 °C und 10% r.H.)

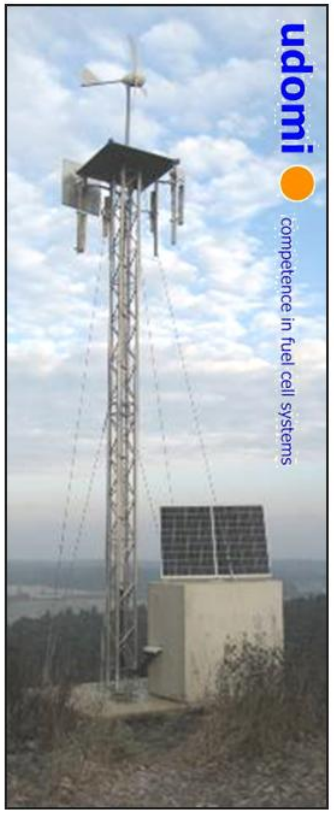
Testing over 100 hrs and 300 start-stopps at extreme climate conditions proves reliability

First DMFC Systems in Telecom Applications

clean power net
Brennstoffzellen in Industrie und Business

120 kWh Energie-speicher, BTS in Italien

Repeater, Norwegen, - -40°C



GSM Repeater, Deutschland

Internet über Funk, Norwegen

Fuel cell powered industrial truck application in the BMW plant Leipzig

Current Status

- Germany's first indoor fueling-station
- Carbon-fiber-body-shop production supply with 5 f-cell forklifts & 6 f-cell tuggers at BMW plant Leipzig
- Guidelines for using f-cell powered industrial trucks
- Evaluation of ecological and economic sustainability in progress

More Information

- www.h2intradrive.de

Hydrogen and Fuel Cell Technologies – Key Pillars for the transformation of the Energy System

market introduction – 2025 perspective of the NOW Advisory Council in 2014

Fuel cells for electric vehicle drives and hydrogen infrastructure for emission-free mobility, with

- more than 500 public hydrogen fuelling stations nationally
- over half a million fuel cell cars on the road
- 1,000 fuel cell buses in line service operation within the public transport system

Hydrogen generation from renewable energies and integration in the energy system as a link between sustainable mobility and energy supply

- 1,500 MW capacity electrolysers for the generation of hydrogen from renewable energies
- definition and implementation of successful business models for power to gas
- development of hydrogen storage mechanisms to store renewable electricity

Fuel cells for stationary energy supply using decentralised co-generation in residential and building supply, industry and a secure power supply for public safety communication systems, telecommunications, etc.

- more than a half a million fuel cell heating appliances in operation
- more than 200 MW fuel cell CHP installations in operation
- more than 100,000 secure power supply installations in place in Germany

State of Equilibrium

stable

unstable

indifferent

Nationale Organisation Wasserstoff- und Brennstoffzellentechnologie

Thank you very much!

download:
www.now-gmbh.de

Dr. Klaus Bonhoff
Managing Director (Chair)

NOW GmbH
National Organization Hydrogen and Fuel Cell Technology