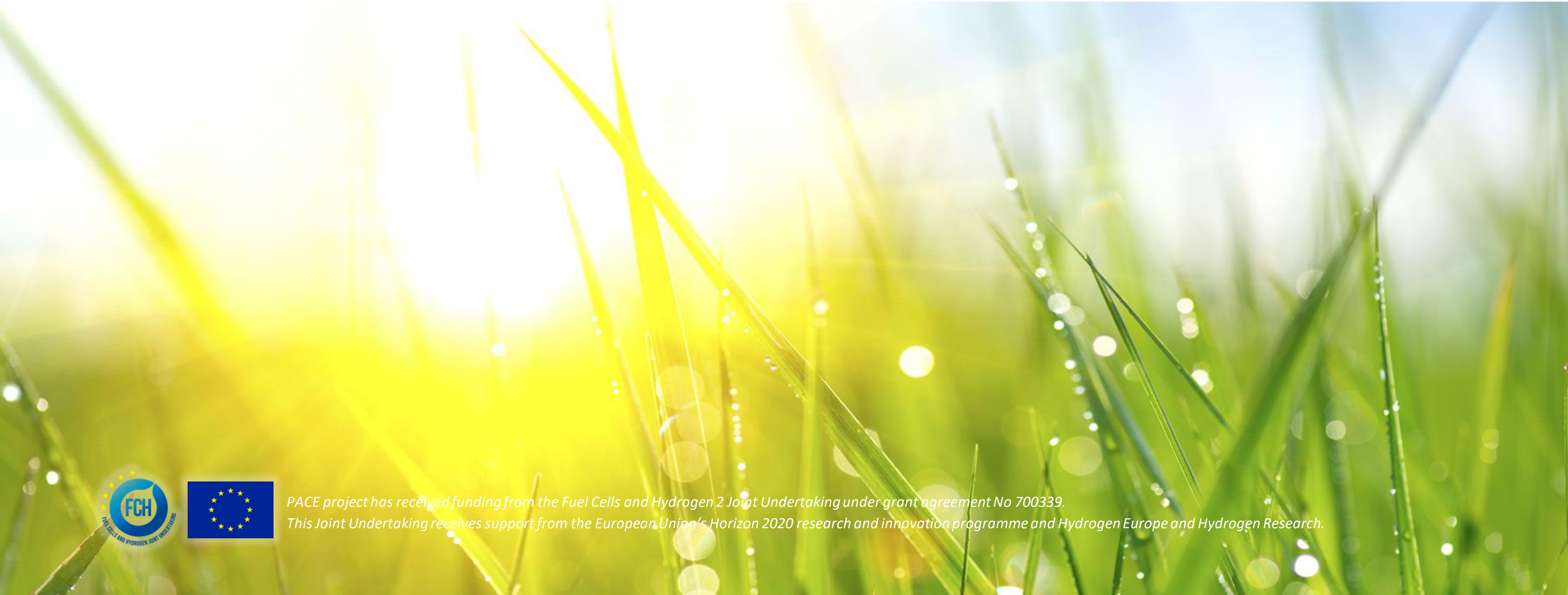
PACE

Pathway to a Competitive European
Fuel Cell micro-CHP Market

Fuel Cell Combined Heat and Power for Specialialised Trade – Training Documents

Module 1: Basics



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The PACE Project

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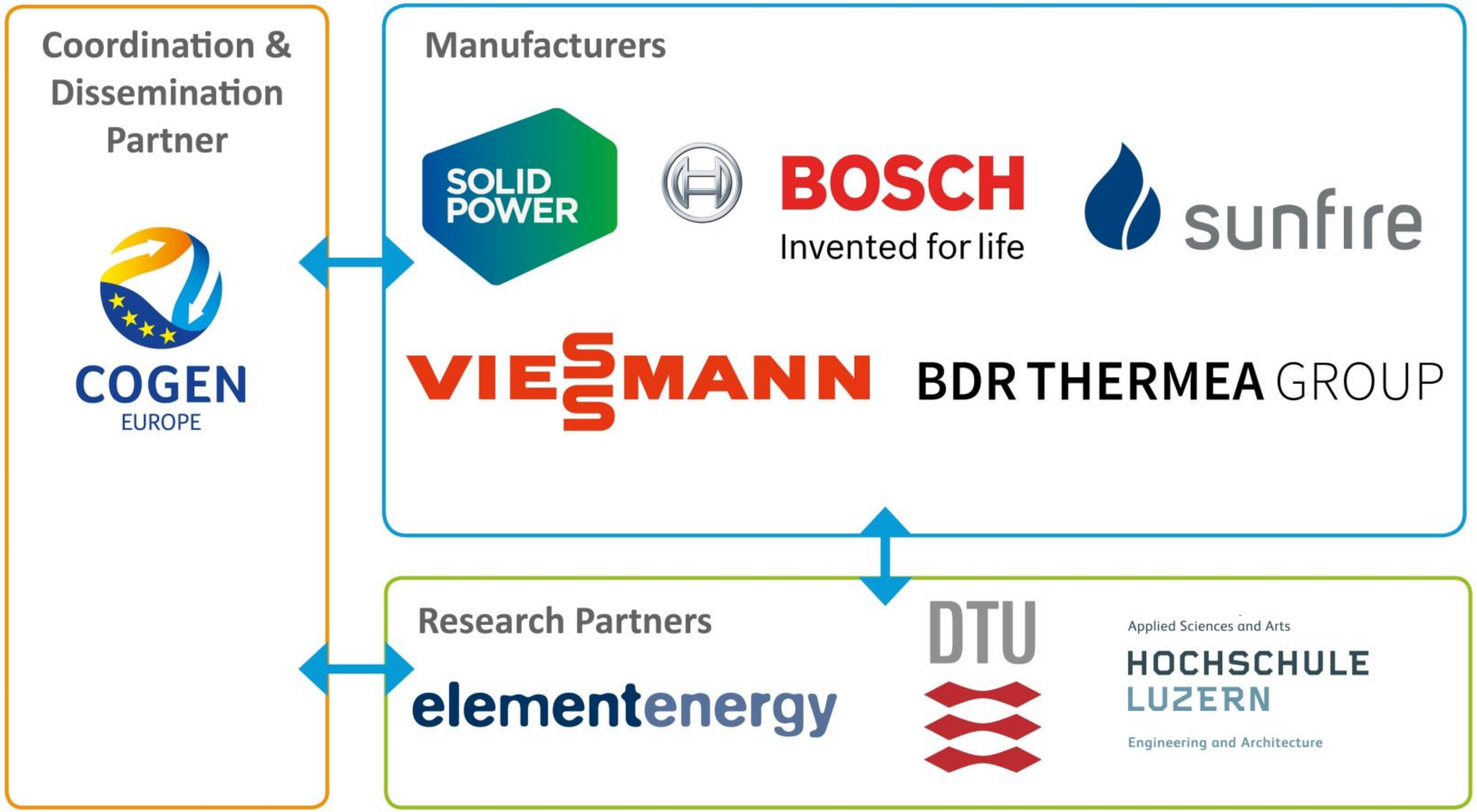

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Introduction

Module 1: Basics

- The purpose of these training modules is to provide a general overview of the potential of Fuel Cell micro-Combined Heat and Power (FC mCHP) units as part of the future of European domestic energy.
- Each module in turn will focus upon a different aspect of FC mCHP units, with the aim to provide a working knowledge of the considerations installers working with this technology will need to make.
- Specific material for each FC mCHP product can be obtained from each unit manufacturer, who also offer specific training on their units.
- These materials have been based upon material developed during the Callux project (2008-2016). Consequently, thanks go to NOW GmbH for permitting the use of this material:

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List of Abbreviations

Module 1: Basics

- CHP – Combined Heat and Power (also known as Cogeneration)
- mCHP – Micro Combined Heat and Power Unit
- FC – Fuel cell
- FCH JU – Fuel Cells and Hydrogen Joint Undertaking
- GDL – Gas Diffusion Layers
- kW – Kilowatt
- kWh – Kilowatt Hour
- MW – Megawatt
- PEMFC – Proton-Exchange Membrane Fuel Cell
- SOFC – Solid Oxide Fuel Cell
- VPP – Virtual Power Plant

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Contents

Module 1: Basics

I. Basics

I 1. Cogeneration (CHP)

Definition

Source: WBZU, ZSW, Callux / ModernLearning GmbH

Definitions of terms:
“Combined heat and power generation is the simultaneous conversion of fuel into electrical energy and useful heat in a stationary technical plant”
(Germany’s Combined Heat and Power Act, 2016)

I. Basics

I 1. Cogeneration (CHP)

The energetic advantage of combined heat and power generation:

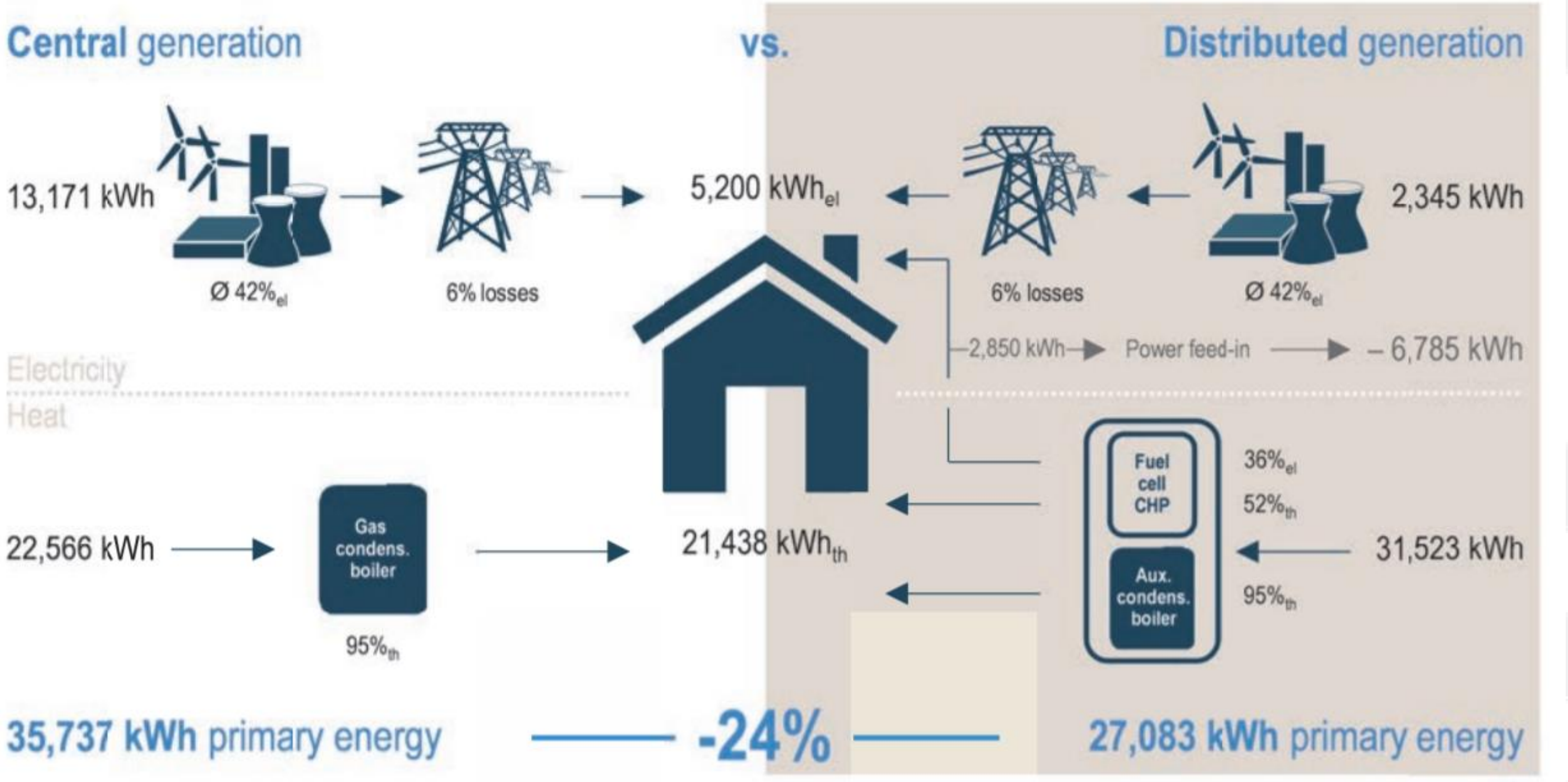


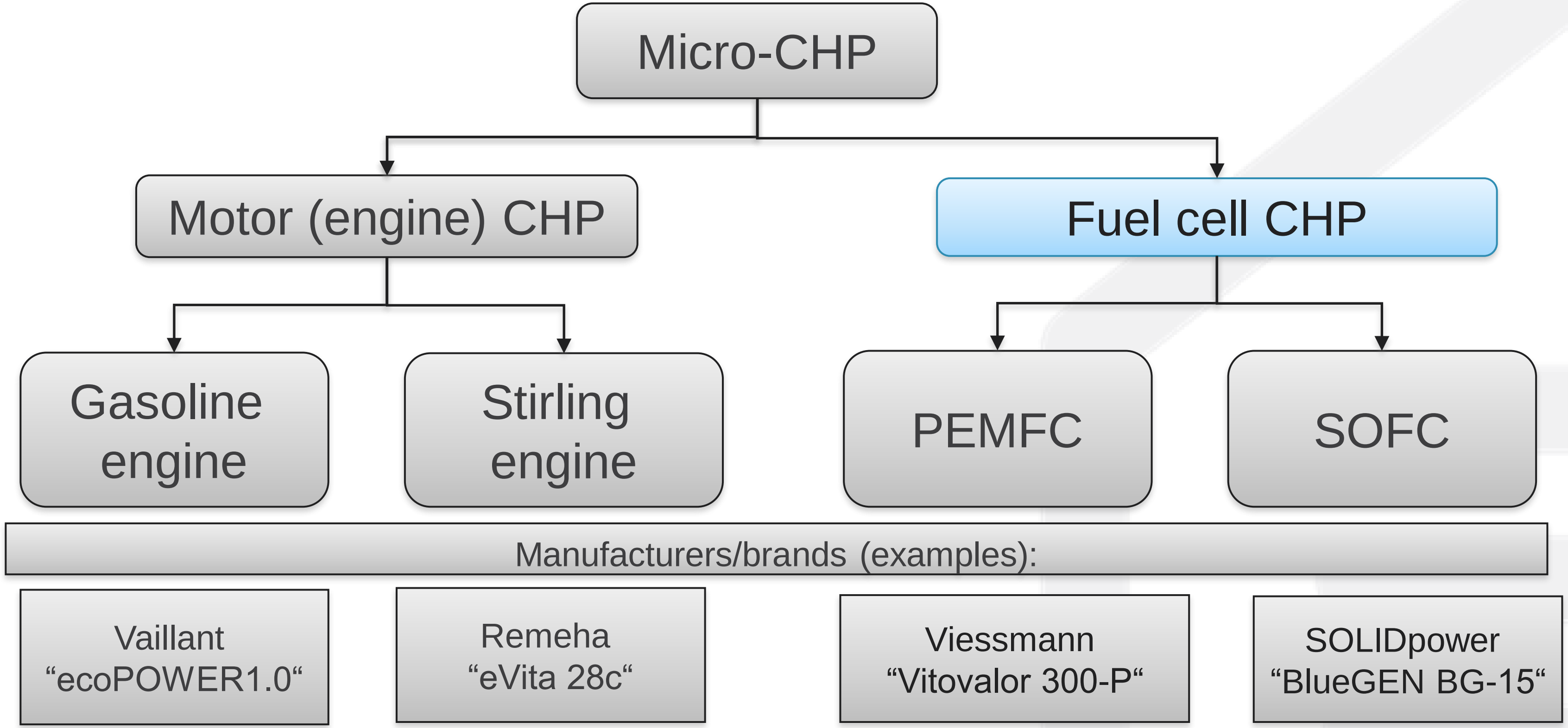
Figure Source: “Advancing Europe’s Energy Systems: stationary fuel cells in distributed generation” (FCH JU, 2015)

Classification

Designation	Range of application	Technology used	Electric power	Possible fuels*
Large CHP plants / combined heat and power plants	Decentralised in large residential complexes, hospitals, industry and commerce	Internal combustion engine, gas turbine	up to several MW	natural gas, heating oil EL, coal, landfill, sewage, biogas
small-scale cogeneration	Decentralised in apartment buildings, housing estates, industry and commerce	Combustion engine, gas turbine, fuel cell (up to 1 MW)	up to 2.000 kW	Natural gas, EL heating oil, landfill, sewage, biogas, hydrogen
Mid-scale CHP	decentralised in apartment buildings, industry and commerce	Combustion engine, Stirling engine, fuel cell	Up to 50 kW	natural gas, EL heating oil, biogas, hydrogen
Mini-CHP	decentralised in apartment buildings, industry and commerce	Internal combustion engine, Stirling engine, steam expansion engine, fuel cell	Up to 15 kW	natural gas, liquid gas, EL heating oil, biogas, hydrogen
Micro-CHP	decentralised in detached and semi-detached houses	Internal combustion engine, Stirling engine, steam expansion engine, fuel cell	Up to 5 kW	natural gas, liquid gas, EL heating oil, biogas, wood pellets, hydrogen

*Depending on the technology used

Product types Micro-CHP (output < 2 kWel):



Micro-CHP

Motor (engine) CHP

Fuel cell CHP

Gasoline engine

Stirling engine

PEMFC

SOFC

Manufacturers/brands (examples):

Vaillant “ecoPOWER1.0“	Remeha “eVita 28c“	Viessmann “Vitovalor 300-P“	SOLIDpower “BlueGEN BG-15“

Properties Micro-CHP (power < 5 kW_{el}):

	Engine (combustion)	Stirling (engine)	PEMFC*	SOFC**
Electrical Output	from 1 kW	from 1 kW	from 0.3 kW	from 0.7 kW
Thermal Output	from 2.5 kW	from 3 kW	from 0.7 kW	from 0.6 kW
Sensitivity to maintenance	many moving parts	fewer moving parts, external combustion	only fans, pumps contain moving parts	only fans, pumps contain moving parts
Electrical Efficiency	ca. 20 - 30 %	ca. 10 - 15%	37 %	33 – 63 %
Modulation Capability	good	good, but slower	good	design dependent

*Proton Exchange Membrane Fuel Cell
**Solid Oxide Fuel Cell

History:

Source: engl. Wikipedia

Birth of the fuel cell

- 1839: Discovery of the FC by Sir W. Grove

Source: NASA, public

Renaissance of the FC - Space Travel

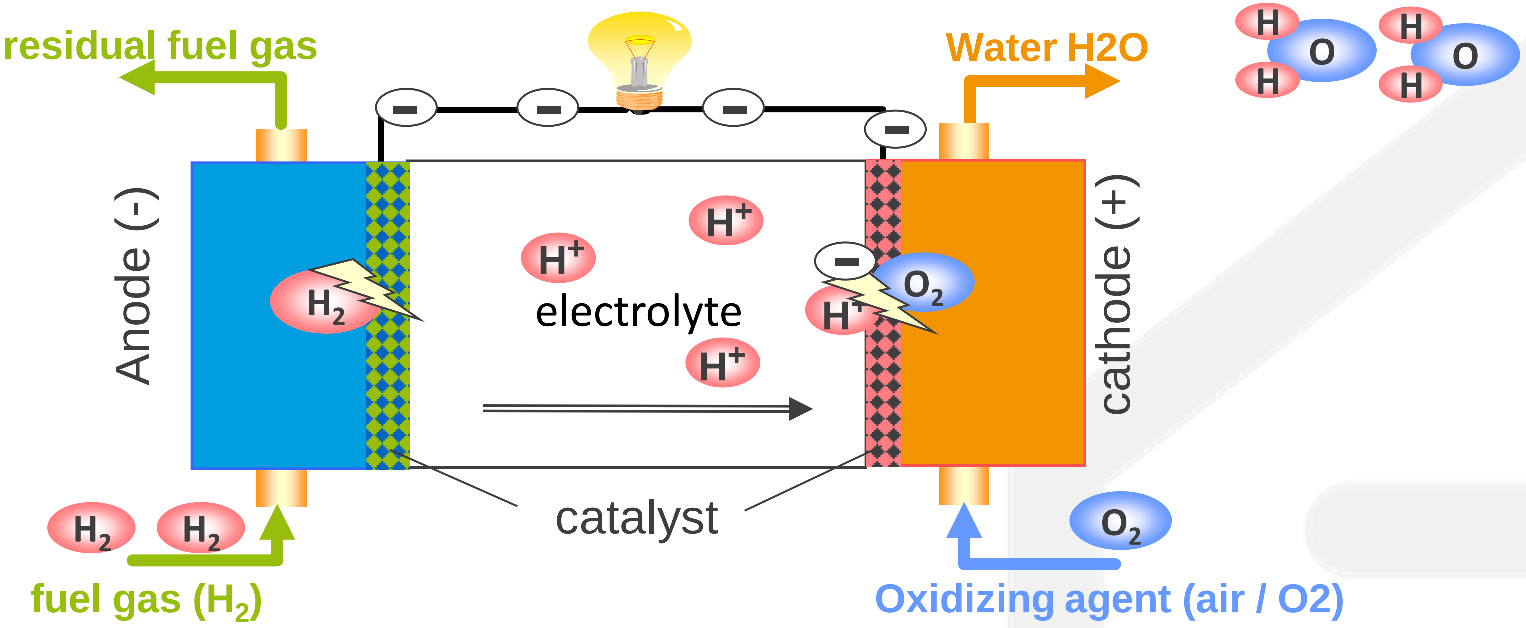
- 60s: Development and deployment of the Apollo program
- 80s : Development and deployment for space shuttle program

Early markets

- ca. 1990: rediscovery of the FC
- Approx. 2000: Prototypes and pre-series production
- Currently: commercially available products
- Advances in (subsidised) market uptake particularly in Japan (ca. 400,000 units installed) and in Germany and Belgium

Examples of model mCHP units
Source: PACE

Functional principle of a FC using the example of a PEMFC:



$2\ H_2 \rightarrow$

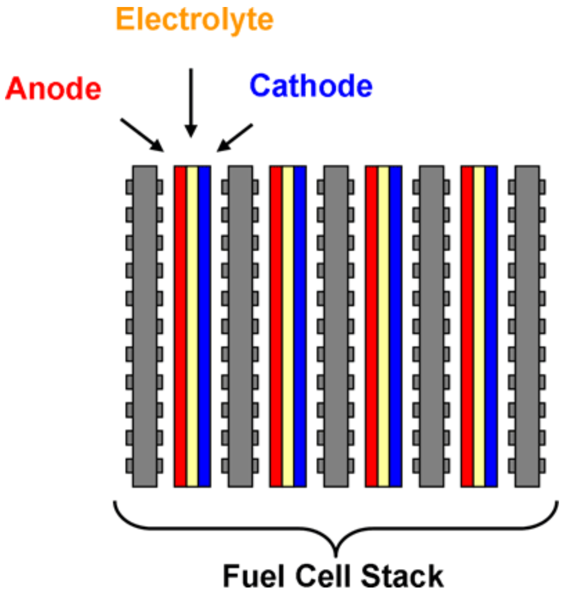
Anode	**diaphragm**	**Cathode**
$2H_2 \rightarrow 4H^+ + 4e^-$	$\xrightarrow{4H^+}$	$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

$\leftarrow O_2$

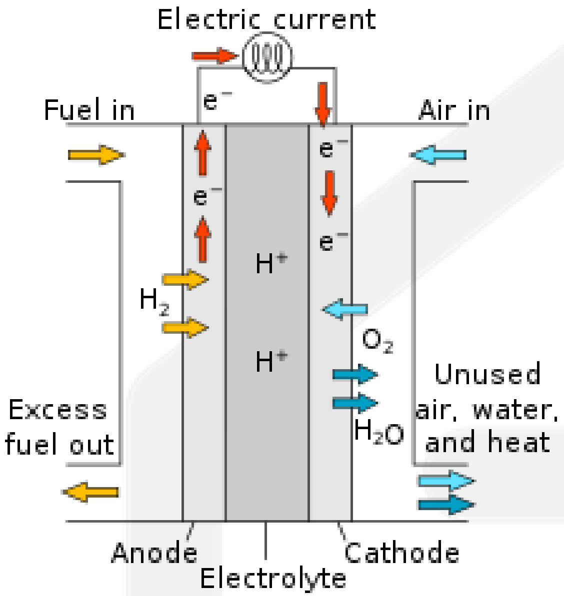
$\rightarrow 2\ H_2O$

Source: WBZU

Construction of a stack of several fuel cells:



Source: Sigma Aldrich



Source: Wikipedia

If several individual cells are connected in series, this is referred to as a fuel cell stack. The voltages of the individual cells add up to the total voltage.

Stack Build-Up

1. Electrolyte (membrane)

   Provides ion transport and separates anode and cathode.

2. Electrodes

   This is where the electrochemical reactions take place.

3. Exchange membrane

   Electrode membrane: "heart" of the fuel cell.

4. Gas diffusion layers (GDL)

   Are necessary for the supply and distribution of the reaction gases.

5. Bipolar plates

   Fine channels in the plates ensure the supply and distribution of hydrogen and oxygen.
   They also serve as "electron collectors".

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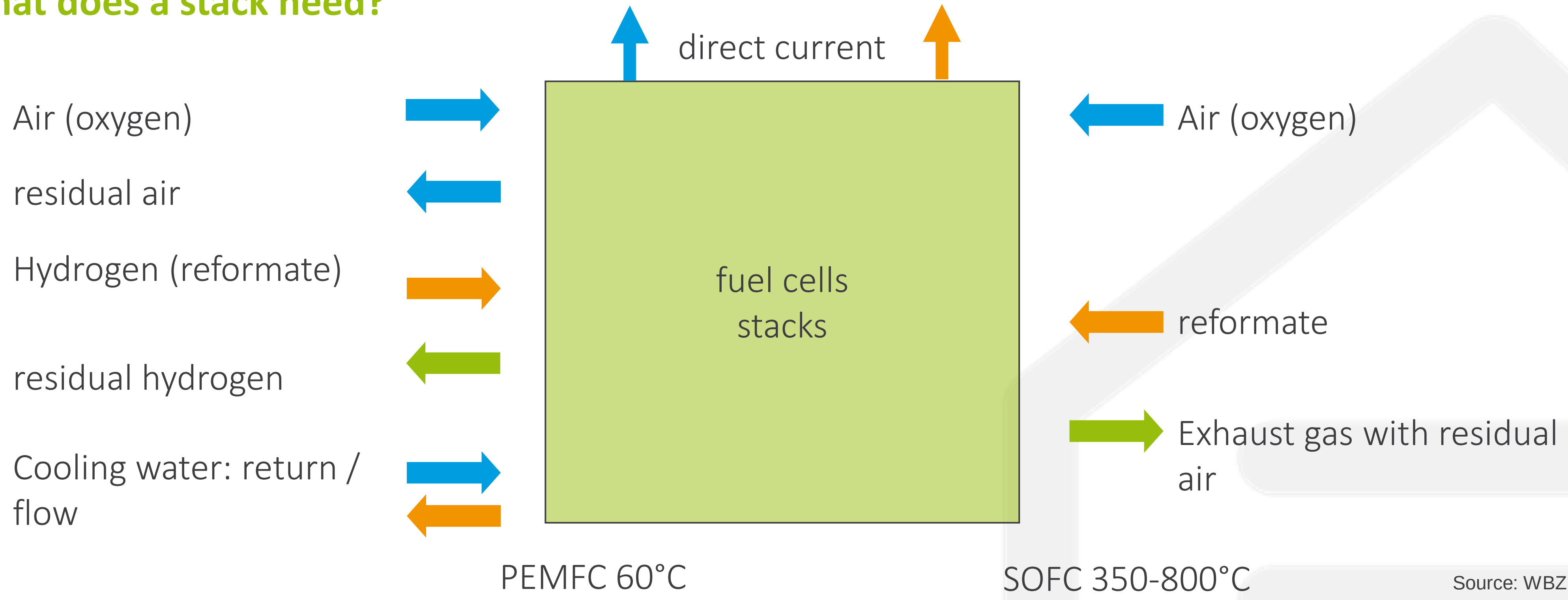
I. Basics

I 2. Fuel Cell (FC)

What does a stack need?



direct current

Air (oxygen)

residual air

Hydrogen (reformate)

residual hydrogen

Cooling water: return / flow

fuel cells stacks

Air (oxygen)

reformate

Exhaust gas with residual air

PEMFC 60°C

SOFC 350-800°C

Source: WBZU

SOFCs cannot be cooled with water. Instead, the heat is discharged through exhaust gas with residual air. This discharge is mostly used to heat the incoming air and gas, and to feed the gas-reforming process to create H_2 and CH_4.

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I. Basics

I 2. Fuel Cell (FC)

Fuel cell types

Source: WBZU, ZSW, Callux

	AFC	PEFC/PEM* DMFC	PAFC	MCFC	SOFC*
Designation	Alkaline FC	Polymer electrolyte / direct methanol FC	Phosphoric acid FC	molten carbonate FC	Solid oxide FC
Temperature	low	<100°C	→	up to 800°C	high
Catalyst Material	noble	Platinum	←	Metals	less noble
Gas Requirement	ultrapure	4-5.0 H_2	→	C_nH_m	less pure
Cell Efficiency	low	40-50%	→	50-60%	high
System Complexity	high	Reformer	←	Internal Reformer	low
Start-Up-Time	low	Seconds	→	Hours	high
Dynamism	high		←		low

*PEM and SOFC sutiable for use in fuel cell heaters

Examples of fuel cell types in domestic energy supply

PEMFC

Proton Exchange Membrane Fuel Cell

- Low temperature FC
- Natural gas operation with external gas treatment
- Catalyst material: Platinum
- Lower cell efficiency
- Quick start up time (0.5-1hr)

SOFC

Solid Oxide Fuel Cell

- High temperature FC
- Natural gas operation with internal gas treatment
- Catalyst material: Nickel
- Higher cell efficiency
- Longer start up time

Case study of a German house

- Detached house, inhabited by 4 persons
- Year of construction 1953, 2010 modernized

- Heated surface: 101 m²
- Heat requirement: 18,000 kWh_{th}:
  - 15,600 kWh heating,
  - 2,400 kWh hot water
- Power requirement: 3,500 kWh_{el}

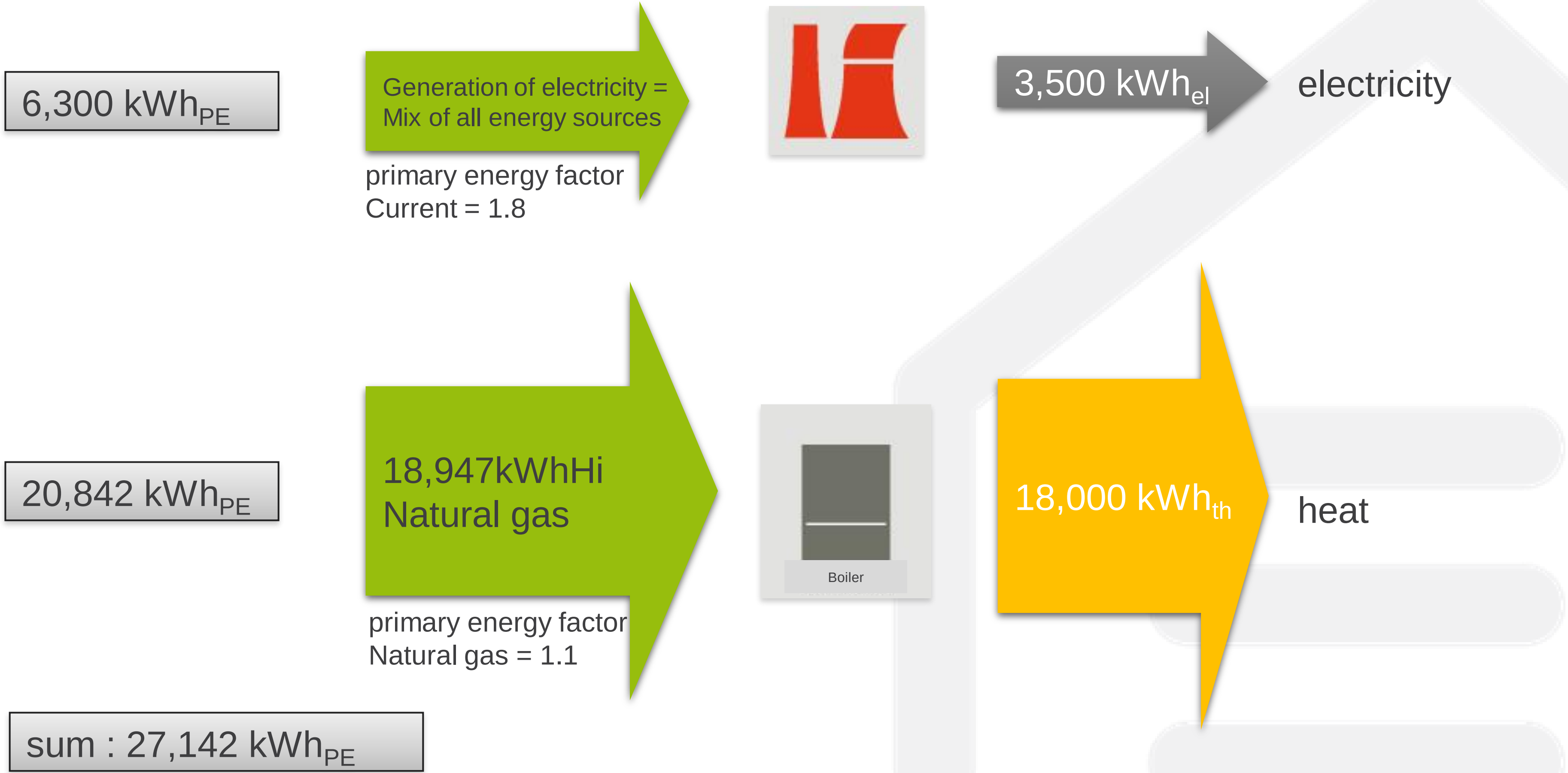
- Fuel cell heater (FC CHP)
  - Electrical power: 1,0 kW_{el},
  - Thermal capacity: 1,8 kW_{th}

- Auxiliary heater
  - Thermal power max. 20 kW_{th}

Source: Callux

Whilst this example shows a typical example in which PEM fuel cells are suitable, another typical scenario which exists is a new build (highly insulated) house with a heat pump that is fed by an electricity-led (SOFC) FC mCHP. This mix of technology provides very large primary energy savings.

Primary energy use (typical German house) – separate generation



6,300 kWh$_{PE}$

Generation of electricity =
Mix of all energy sources

primary energy factor
Current = 1.8

3,500 kWh$_{el}$

electricity

20,842 kWh$_{PE}$

18,947kWhHi
Natural gas

primary energy factor
Natural gas = 1.1

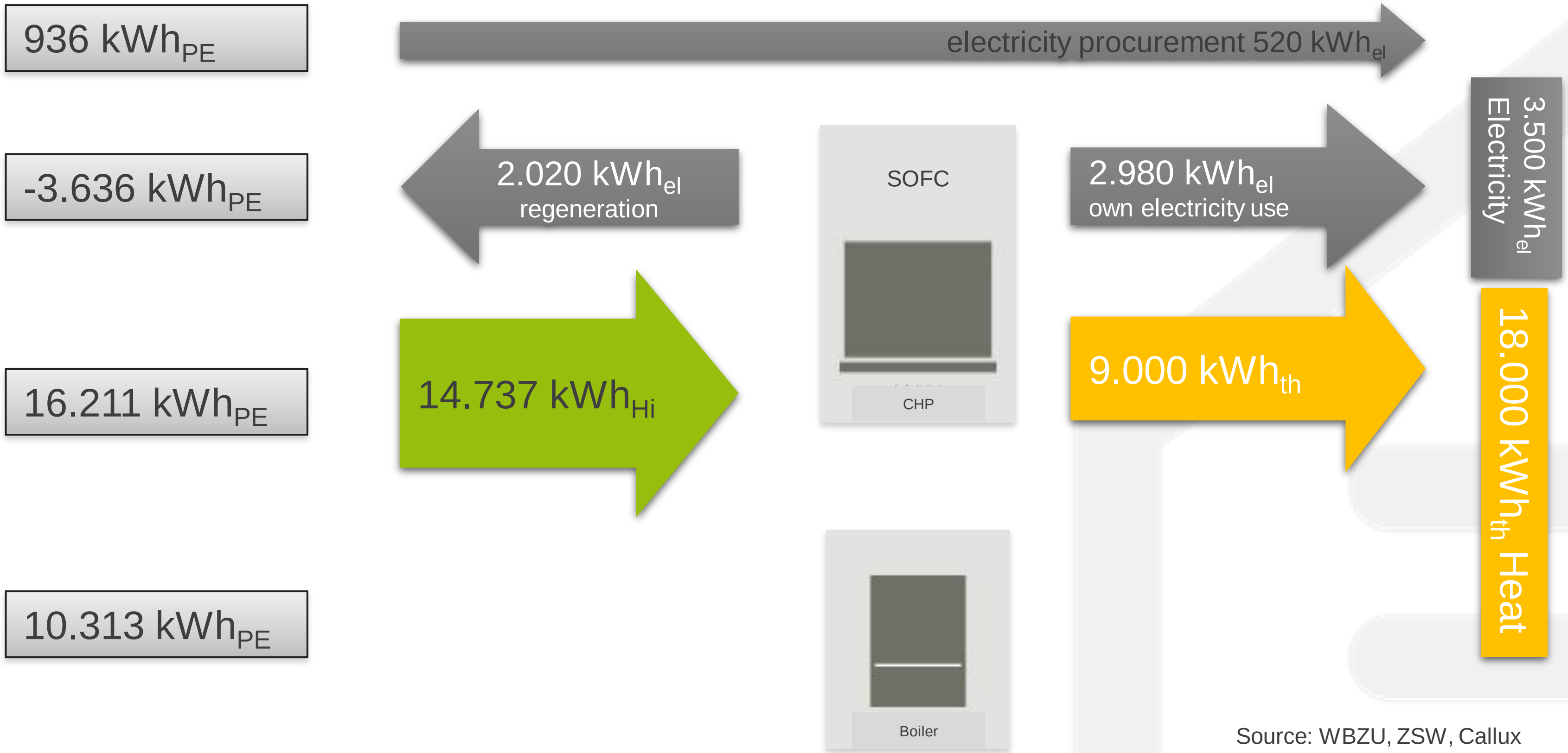
18,000 kWh$_{th}$

heat

sum : 27,142 kWh$_{PE}$

Source: WBZU, ZSW, Callux

Primary energy use – coupled generation



936 kWh_{PE}

electricity procurement 520 kWh_{el}

-3.636 kWh_{PE}

2.020 kWh_{el}
regeneration

SOFC

CHP

2.980 kWh_{el}
own electricity use

3.500 kWh_{el} Electricity

16.211 kWh_{PE}

14.737 kWh_{Hi}

9.000 kWh_{th}

18.000 kWh_{th} Heat

10.313 kWh_{PE}

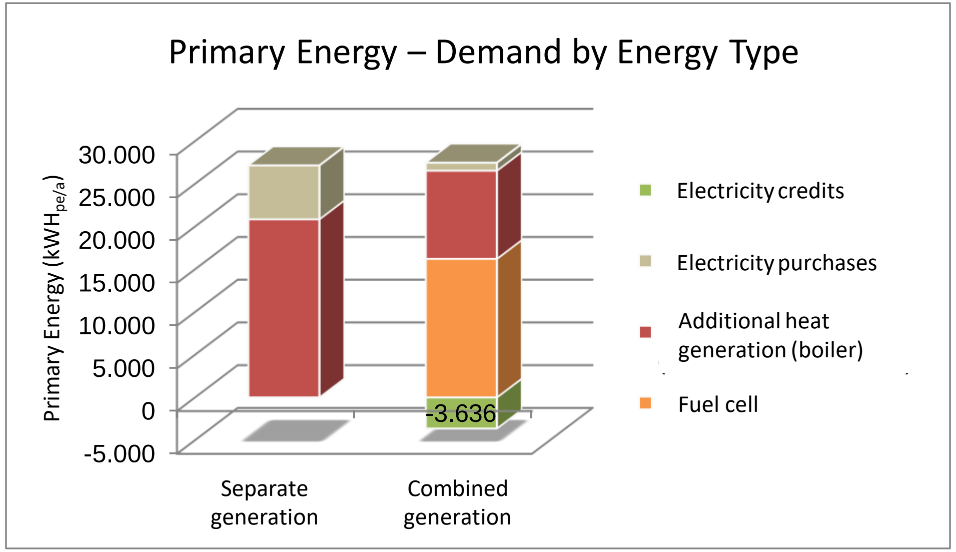
Boiler

Sum: 23.824 kWh_{PE}

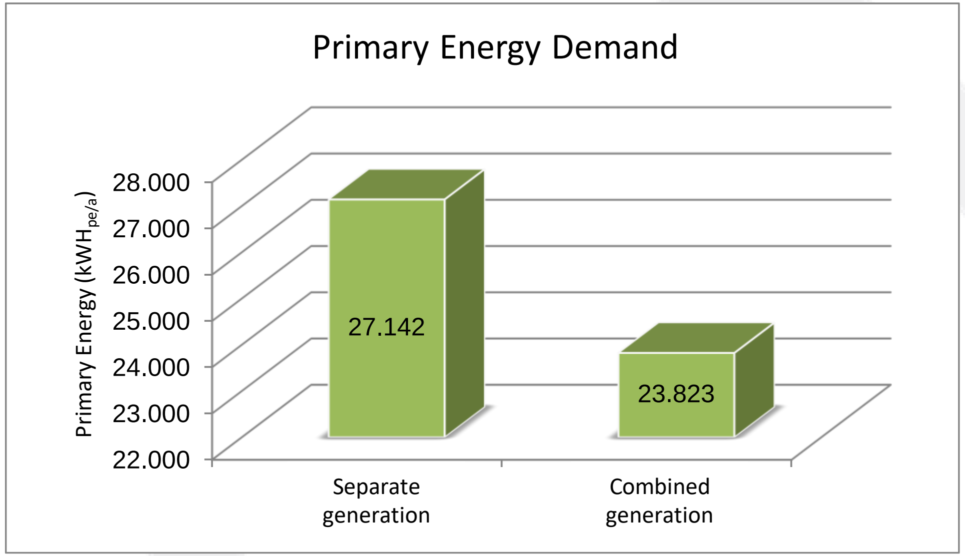
Source: WBZU, ZSW, Callux

Overall primary energy is reduced thanks to a reduction in the required natural gas and because electricity is being fed into the grid

Comparison of Separate and Combined Generation



Source: Gertec GmbH



Source: Gertec GmbH

The energetic advantage is approx. 12 % (with a running time of 5,000 full usage hours per year).

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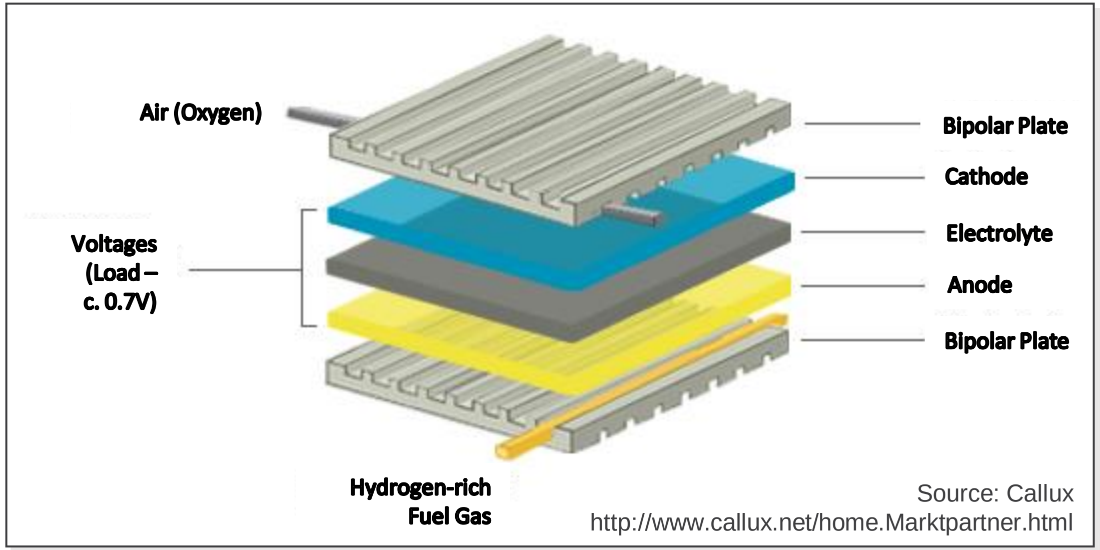
Module 1: Basics

Fuel Cell CHP

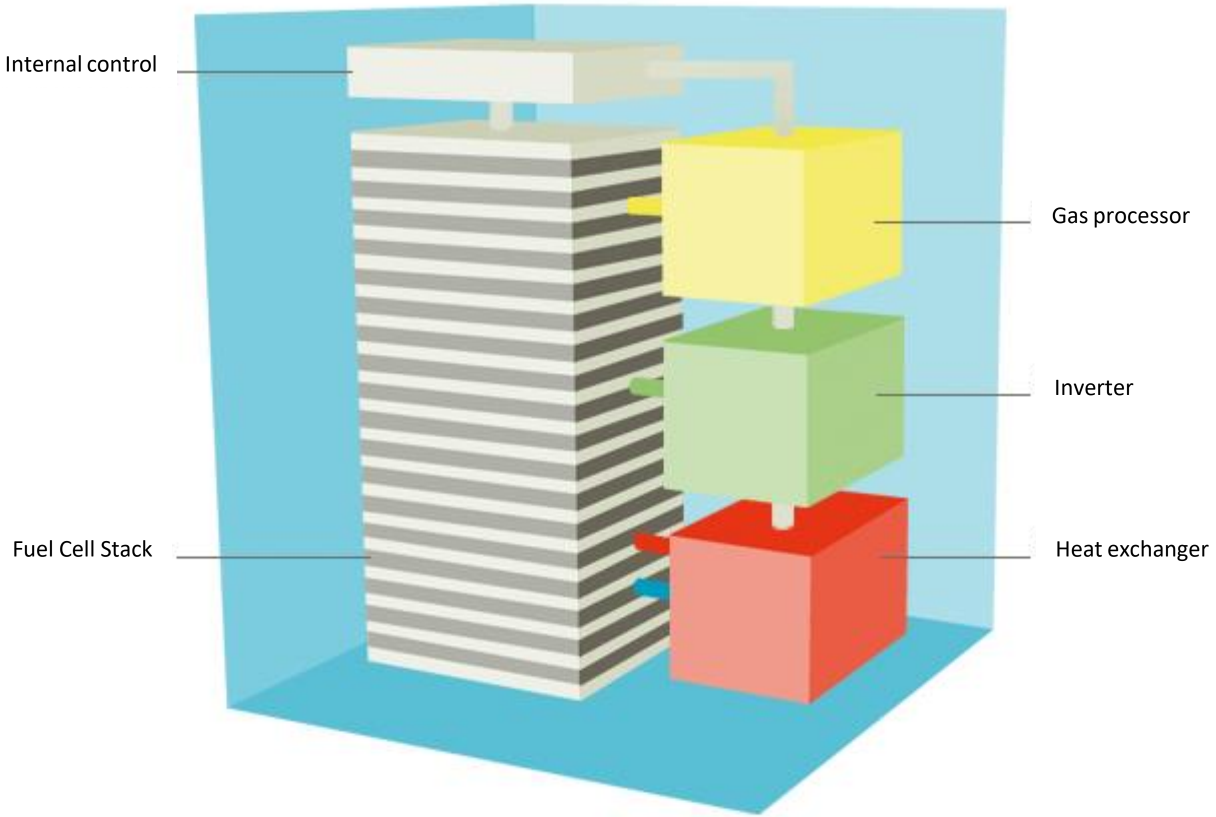


Source: Callux
http://www.callux.net/home.Marktpartner.html

FC with bipolar plate
(eg. PEMFC)

Stationary fuel cell are micro-cogeneration systems. They run on hydrogen, which can be produced from natural gas or biogas, and convert the energy used directly into electricity and heat by electrochemical means.

Schematic Representation of a FC CHP

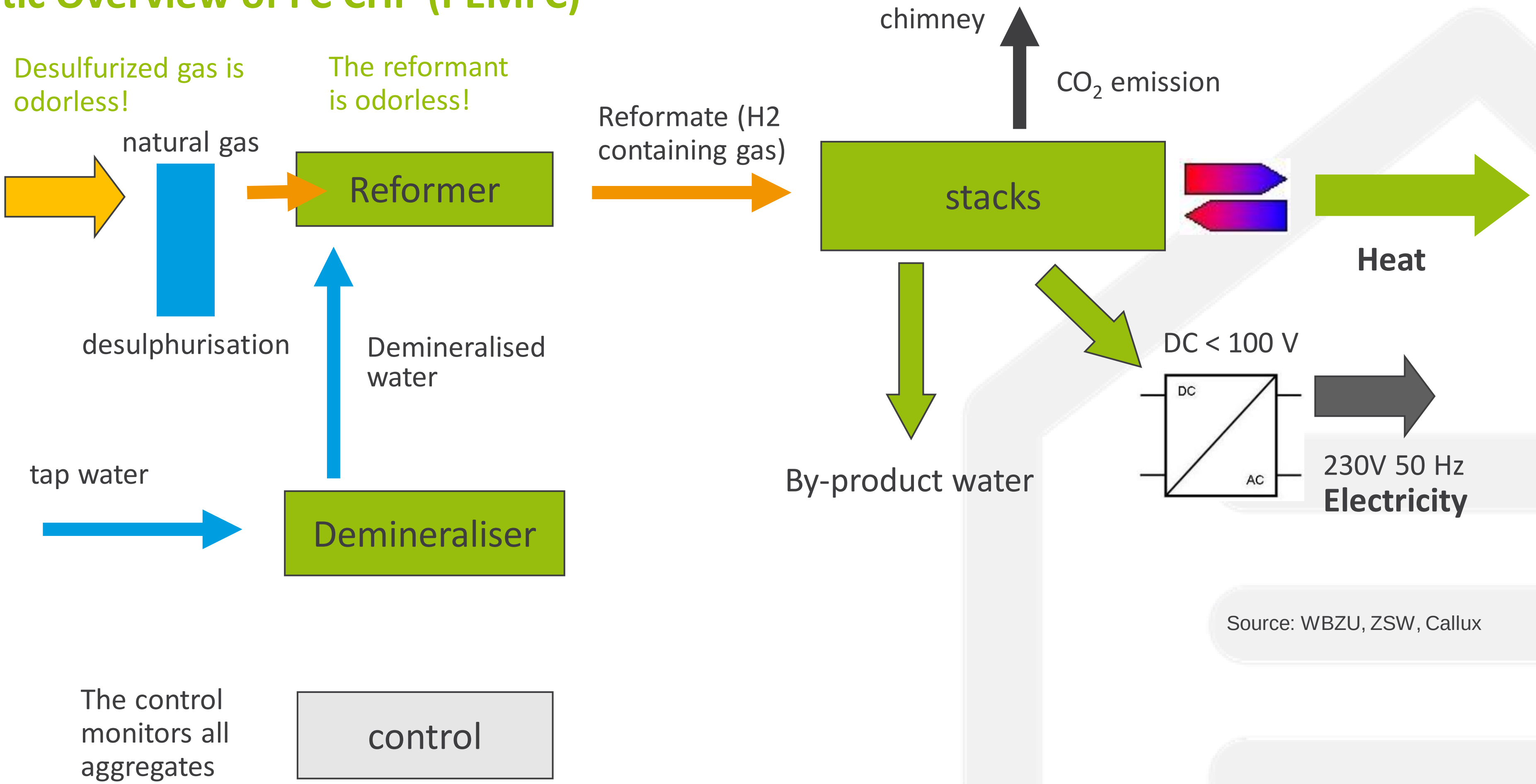


Source: Callux http://www.callux.net/home.Marktpartner.html

II. The Fuel Cell CHP

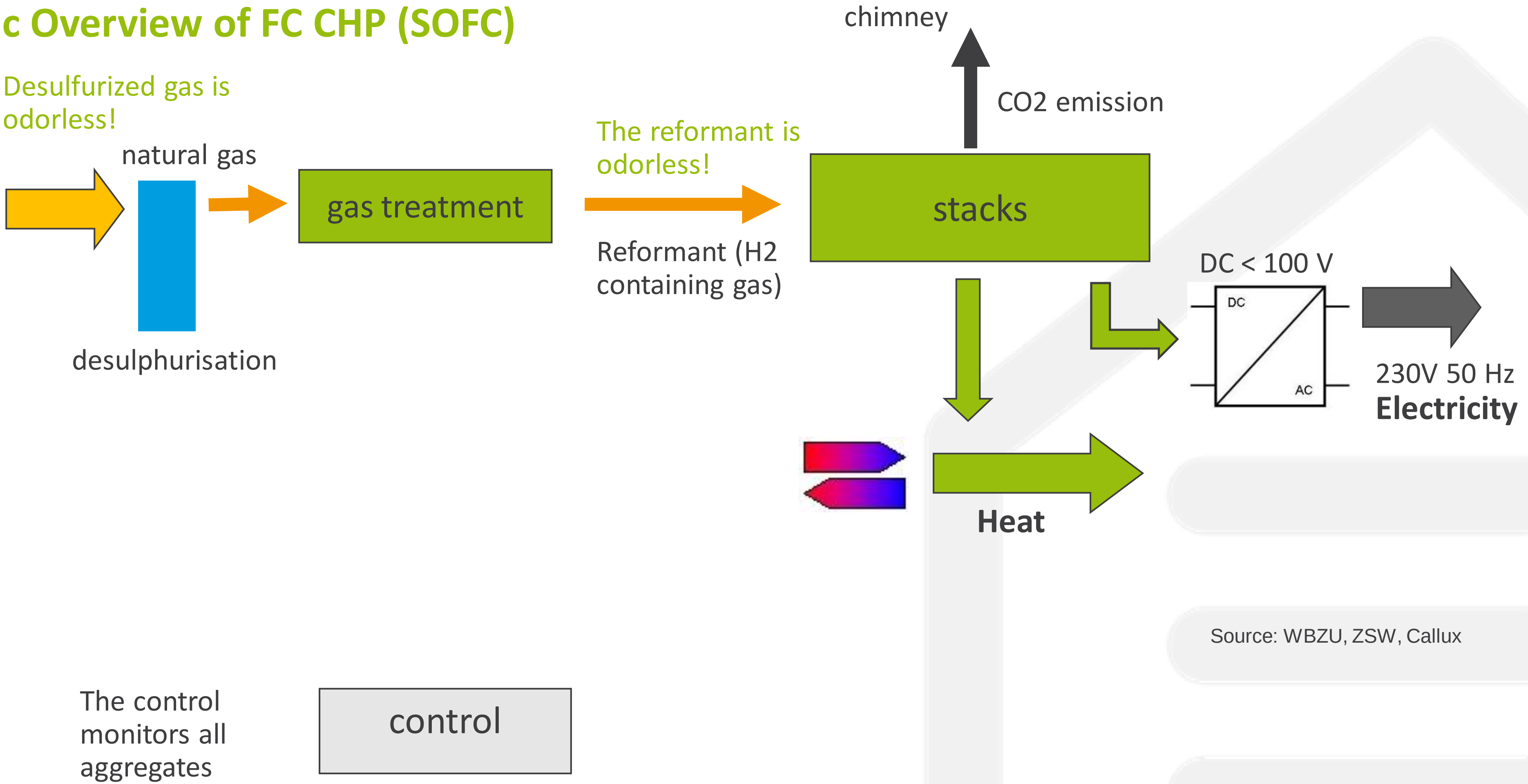
II 1. General

Schematic Overview of FC CHP (PEMFC)



Source: WBZU, ZSW, Callux

Schematic Overview of FC CHP (SOFC)



chimney

CO2 emission

Desulfurized gas is odorless!

natural gas

gas treatment

The reformant is odorless!

stacks

Reformant (H2 containing gas)

desulphurisation

DC < 100 V

230V 50 Hz
Electricity

Heat

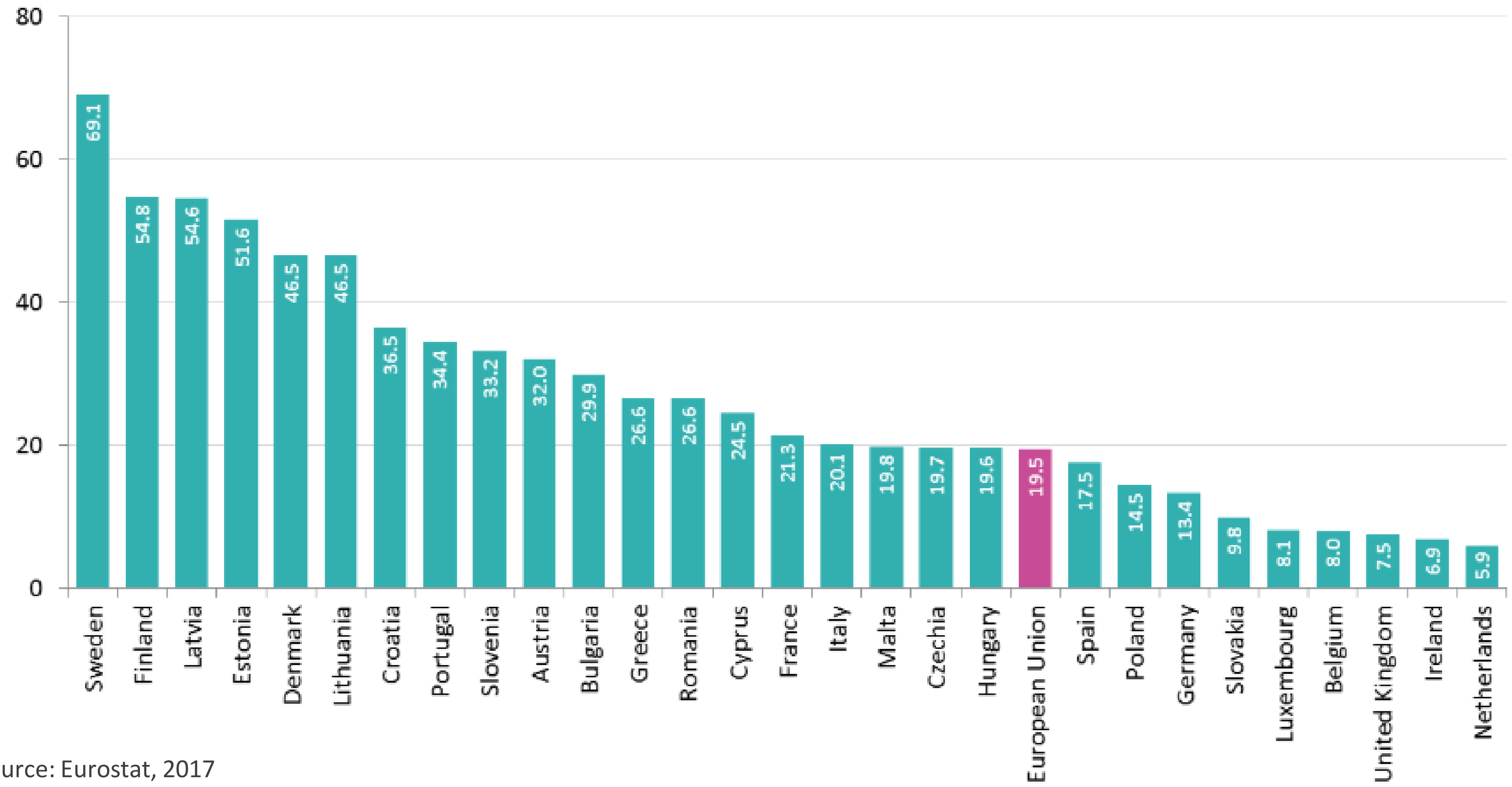
Source: WBZU, ZSW, Callux

The control monitors all aggregates

control

The need to modernise outdated heating technology across EU

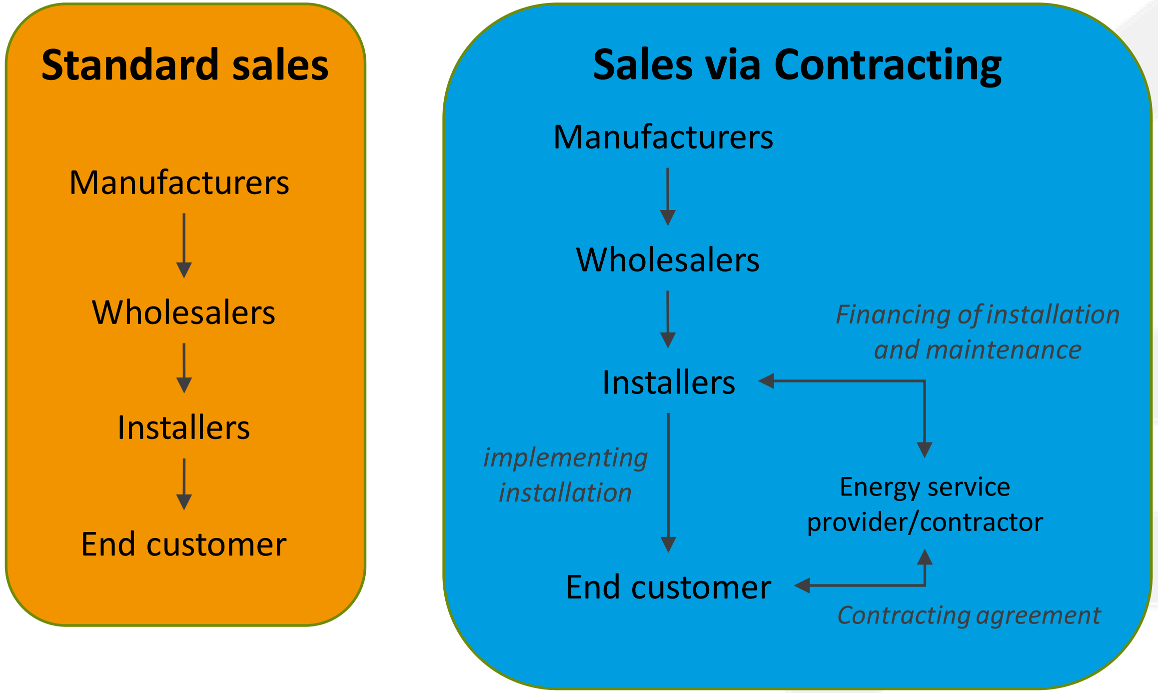
Share of total energy used for heating and cooling coming from renewable sources, 2017
(%)



Source: Eurostat, 2017

New Technology, New Distribution Models

Depending on the manufacturer or sales partner, different sales models are conceivable.



Standard sales

Manufacturers → Wholesalers → Installers → End customer

Sales via Contracting

Manufacturers → Wholesalers → Installers → End customer

implementing installation

Financing of installation and maintenance

Energy service provider/contractor

Contracting agreement

Source: Callux, realisiert von ModernLearning GmbH

General Market Overview (1)

				
Manufacturer	Bosch	SOLIDpower - BlueGEN	SOLIDpower – BlueGEN BG-15	Sunfire
Type	SOFC	HT SOFC	SOFC	SOFC
Electrical Output	0.7 kW	1.5 kW	1.5 kW	0.75 kW
Thermal Output	0.7 kW	0.6 kW	1.0 kW	1.25 kW
Electrical/Thermal Efficiency	45% (2016)	60%/25%	53-57%/40%	38%/50%
Overall efficiency	85%	85%	88-93%	88%
Fuel flexibility	H-gas, L-gas, Green-Gas (methane)	H-gas, L-gas, Green-Gas (methane)	I2H, I2E	LPG, Natural gas
Stack Lifetime	90,000 hours (2016)	60,000 hours	40,000 hours	-
System Life	10 years	15 years	Min 10 years	Min 10 years

General Market Overview (2)

			
Manufacturer	BDR Thermea	Viesmann – Vitovalor 300-P	Viessmann SOFC (Galileo succesor)
Type	PEMFC	PEMFC	SOFC
Electrical Output	0.75 kW	0.75 kW	1.0 kW
Thermal Output	1.1 kW	1.0 kW	1.25 kW
Electrical/Thermal Efficiency	37%/55%	35-40%/53%	40%/50%
Overall efficiency	92%	90%	90%
Fuel flexibility	Natural gas (E/LL)	Natural gas (E/LL)	Natural gas (E/LL)
Stack Lifetime	80,000 hours	80,000 hours	Over 35,000 hours
System Life	Up to 20 years	More than 10 years	More than 10 years

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Module 1: Basics

III. Fuel Cell CHP Consultancy

The Right Technology for the Right Customer

FC CHPs are still expensive and require appropriate consultation with the customer - pay attention to the customer's reaction (e.g. their external impression).

Do not be a salesman, but a consultant – an understanding the customer and their needs (e.g. energy demand, economical use) is the most important factor. The goal is to find the best solution.

The starting point is the technical feasibility and wishes/perceptions of the customer. The basis for this is competence and trust.

By asking the right questions (instead of explanations), consultants can optimally adjust to the customer. The advantages of this technique are:

- The customer's wishes and ideas become clear
- Customers feel they are taken seriously and in are good hands - creates trust
- With casual questions, important keywords can be brought into play

III. Fuel Cell CHP Consultancy

Listening and (re)acting competently

Consultations are dialogues! Interested parties want to exchange ideas.

Interested customers are usually already well informed before a consultation. Nevertheless they often have incorrect assumptions. These are to be corrected based on the context and using best judgement.

The art of the consultation consists of:

- responding flexibly to ideas and using emotions positively,
- correcting any false assumptions convincingly (not offensively),
- making complex facts easy to understand.

III. Fuel Cell CHP Consultancy

III 1. Goals, methods and processes

Multi-stage consulting processes are crucial

1. Clarification of key points
- Technical and structural framework conditions
- Customer's ideas
- Financability / estimation of investment costs / sales models

2. Planning
- Develop concrete plans
- Create a quote
- Create profitability calculations

3. Order placement

III. Fuel Cell CHP Consultancy

The (formal) counselling interview

The (formal) consultation takes place at the customer's request and should be well prepared.

Part of the preparation:

- Make an appointment (allow enough time (1.5 - 2 h)),
- Ask customers to have electricity and gas bills for the last 2-3 years ready at hand,
- Review existing customer data, if applicable, and
- Make notes for preliminary talks.

Checklist:

- business card, camera, notepad, pencil
- Checklist for on-site inspection
- FC CHP documents, product brochures
- Notebook with animations/calculation program if necessary
- Meter or hand laser length measuring device.

III. Fuel Cell CHP Consultancy

III 1. Goals, methods and processes

The (informal) consultation – using customer contact proactively

- Informal consultations are discussions on specialist topics that can take place anytime and anywhere - are potential "door openers”
- Actively use this non-binding discussion to give food for thought or tips "in confidence" (e.g. for service activities)
- For this, every employee of your company should:
  - Know the most important arguments, performance data and general conditions required for FC CHP
  - Be able to respond competently to requests (and do so)
  - Point out FC CHPs to customers as an option
- Use easily understandable terms, e.g. electricity-generating heating, micro or mini power station

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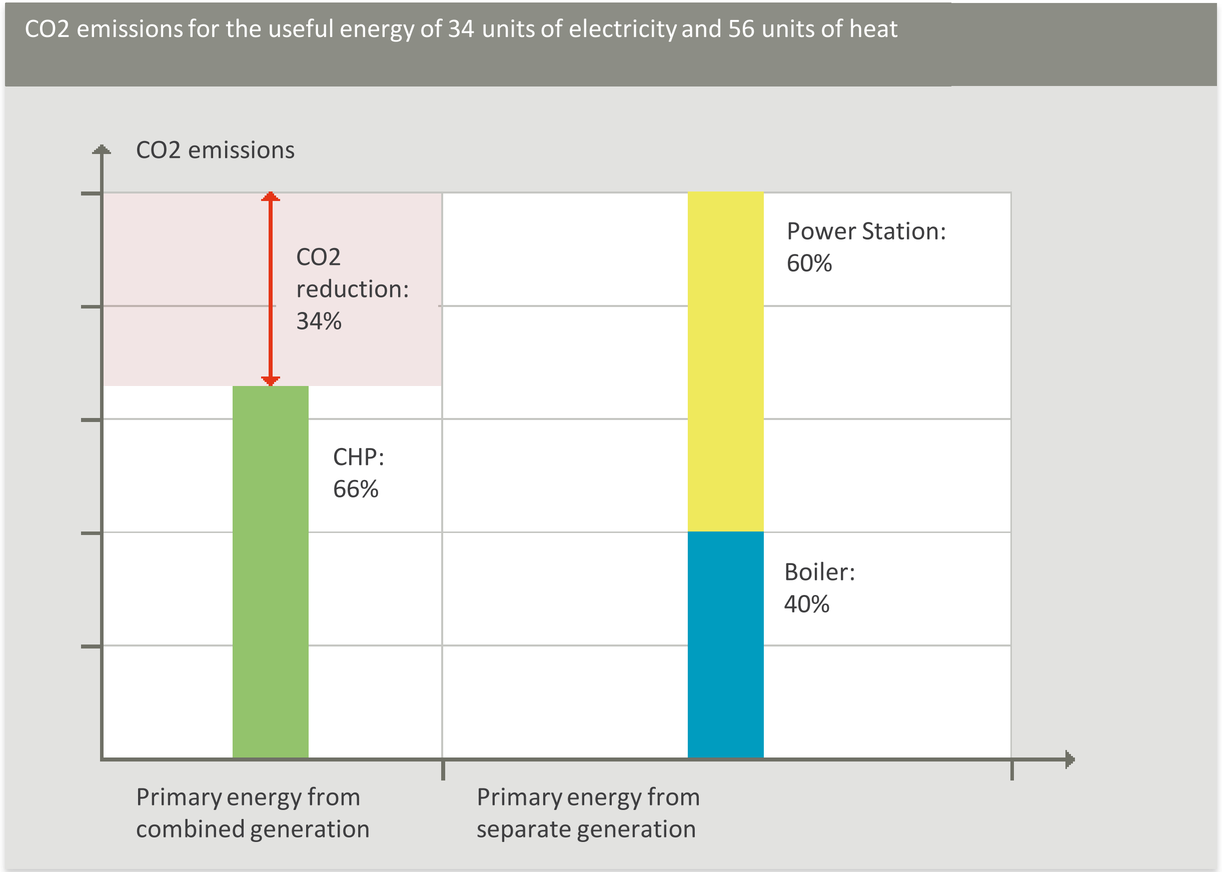
Module 1: Basics

Primary energy demand and CO_2 emissions



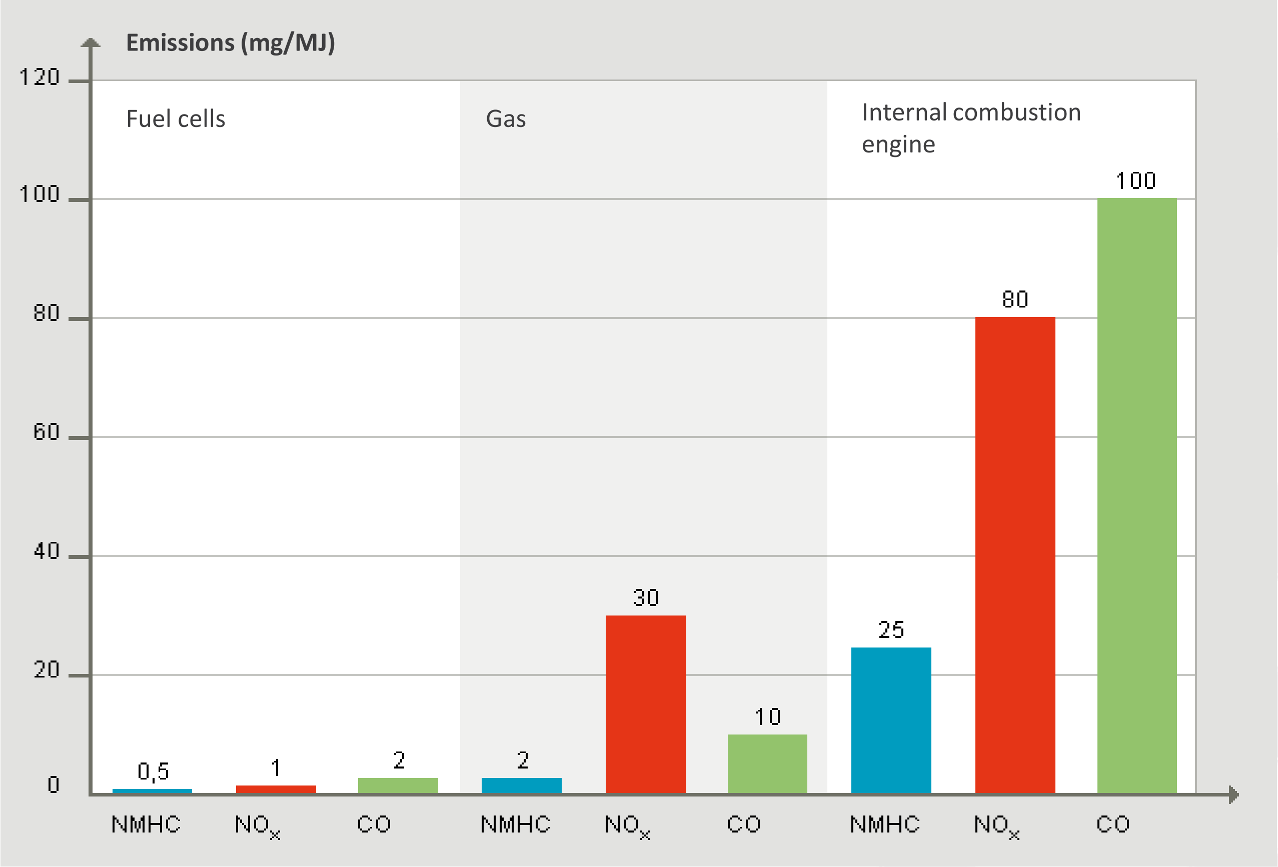
Source: Callux, http://www.callux.net/files/basismodul/start.html

- Whilst this graph shows a typical example, actual CO_2 savings can be larger depending upon the electricity mix in a specific country (e.g. countries with a larger proportion of coal on the electricity grid) and whether the gas feed is fully natural gas or biogas (more biogas = larger CO_2 saving).
- In addition, almost all fuel cell mCHPs are compatible with hydrogen following small adjustments to the units. They are thus potentially carbon neutral.
- The key message: FC mCHPs offer a CO_2 reduction now and a carbon-free future.

IV. Further Topics

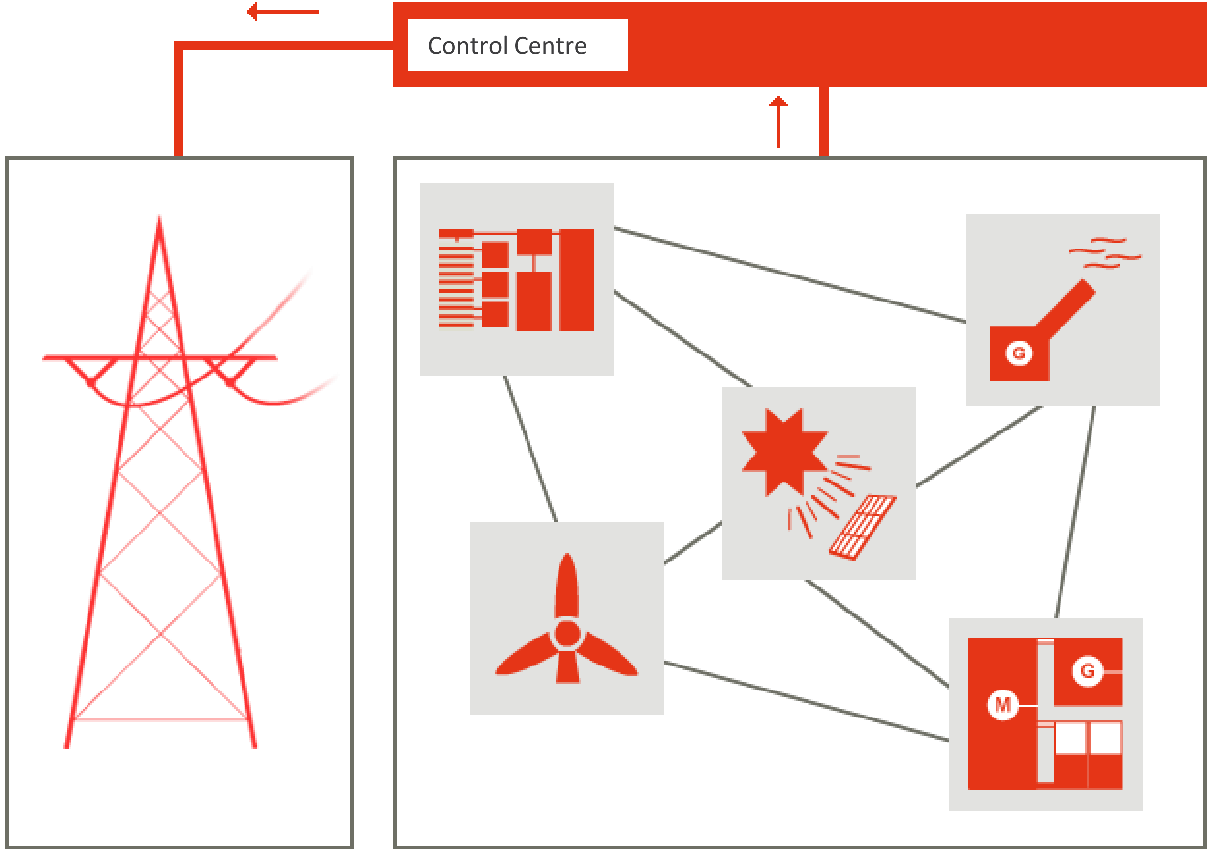
IV 1. CO_2 and Pollutant Emissions

Pollutant emissions



Source: Callux, http://www.callux.net/files/basismodul/start.html

FC CHP in tomorrow's energy system – virtual power plants (VPPs)



Source: Callux, http://www.callux.net/files/basismodul/start.html

Operation

FC CHP are not designed for operation in isolation:

- Current-controlled operation with (subsidised) CHP only permissible if the heat can always also be used.
- Power cannot be regulated to the second.
- Electricity (from the mains) is required to start the FC CHP.
- FC CHP are therefore generally operated in parallel to the mains (although can run “Off grid” on a battery).
- In the event of a mains failure, isolated operation is conceivable for the device alone - for safety reasons, however, a mains disconnection occurs immediately.
- The device itself, however, continues to be supplied with electricity and continues to generate heat, which can also be used.

Safety when using hydrogen

- FC CHP are gas appliances running on gas from the grid (natural gas, liquid gas, biogas, hydrogen gas blends).
- Large quantities of hydrogen are also bound in natural/bio gas: Natural gas group H, for example, consists of 89% methane (CH4).
- In FC CHP only very small amounts of H2 are present (less than 1 litre between reformer and stack)
- The technical processing of H2 has been standard in the industry for many decades.
- H2 is non-toxic and does not harm the environment
- FC CHP naturally meet all safety requirements - just like any other tested gas appliance.

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