Umweltbundesamt - International Conference:
Elements of a Greenhouse Gas Neutral Society
Berlin, 10.10.2013

Power-to-Gas (P2G®): Technology and System Operation Results

Michael Specht, Ulrich Zuberbühler

ZSW – Center for Solar Energy and Hydrogen Research, Stuttgart

in Co-operation with

ETOGAS smart energy conversion formerly known as SOLARFUEL

Agenda:
Power-to-Gas (P2G®) - Technology and System Operation Results

Goal

Principle of P2G®-Process

Layout / Construction / Experimental Results / Development Status

25kW$_{el}$-, 250kW$_{el}$-, 6000kW$_{el}$-Plant

Facts / Frame Conditions (CO_2 Resources, Economics)

Conclusion

Power-to-Gas (P2G®): Key Thesis

- Chemical energy carriers are needed for future energy supply in electricity, heat, mobility, and long term energy storage market!

→ There is no alternative to (electricity-based) chemical energy carriers (eFuels)!

Power-to-Gas (P2G®): Main Goals

- Equalization of fluctuating supply of renewable energy
- Energy storage > 1 week / seasonal storage
- Fuel for sustainable mobility (“Energiewende” in mobility sector)
- Convergence of electricity grid, gas grid and mobility sector
- Reduction of agricultural area for energy plants

Energy Consumption and Storage Capacity in Germany (2012)

		Electricity	Natural gas	Liquid fuels[1)]
Consumption	[TWh/a]	595	909	711
Average power	[GW]	70	100[2)]	80
Storage capacity	[TWh]	0.04[3)]	217[4)]	250[5)]
Calculated operating range of installed storage capacity[6)]	[h]	0,6	2000	3000

1) Petrol, diesel, kerosene; final energy consumption
2) Seasonally fluctuating
3) Pumped hydro storage
4) 48 underground gas storage facilities [Landesamt für Bergbau, Energie und Geologie (LBEG), Hannover]
5) Provisioning of petrol, diesel, kerosene and heating oil
6) Related to average power

- Installed PV power 32.6 GW / installed wind power 31.2 GW

→ Required storage capacity for electricity grid in DE: **tens of TWh** !
→ Required fuel demand for mobility: **hundreds of TWh/a** !

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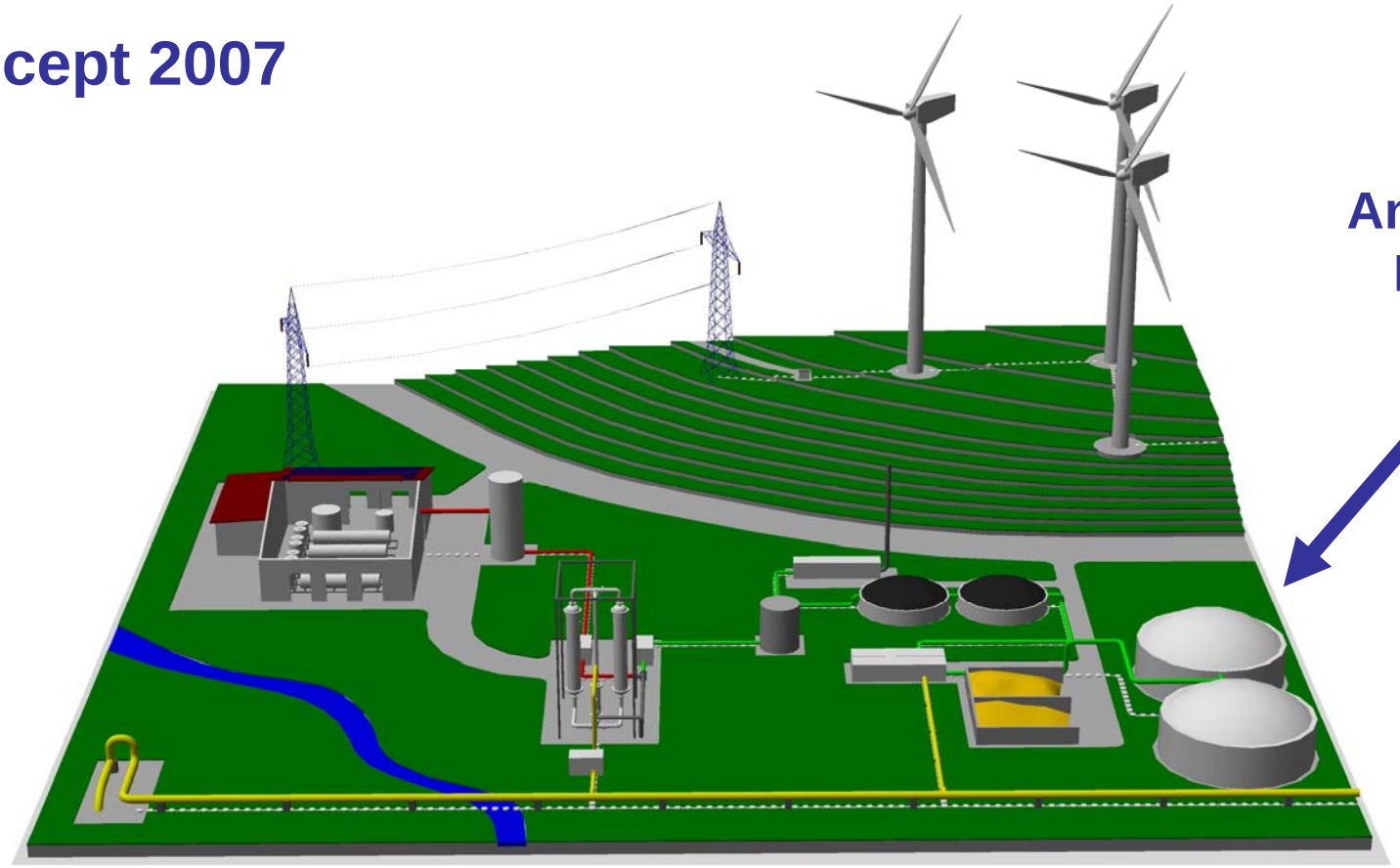
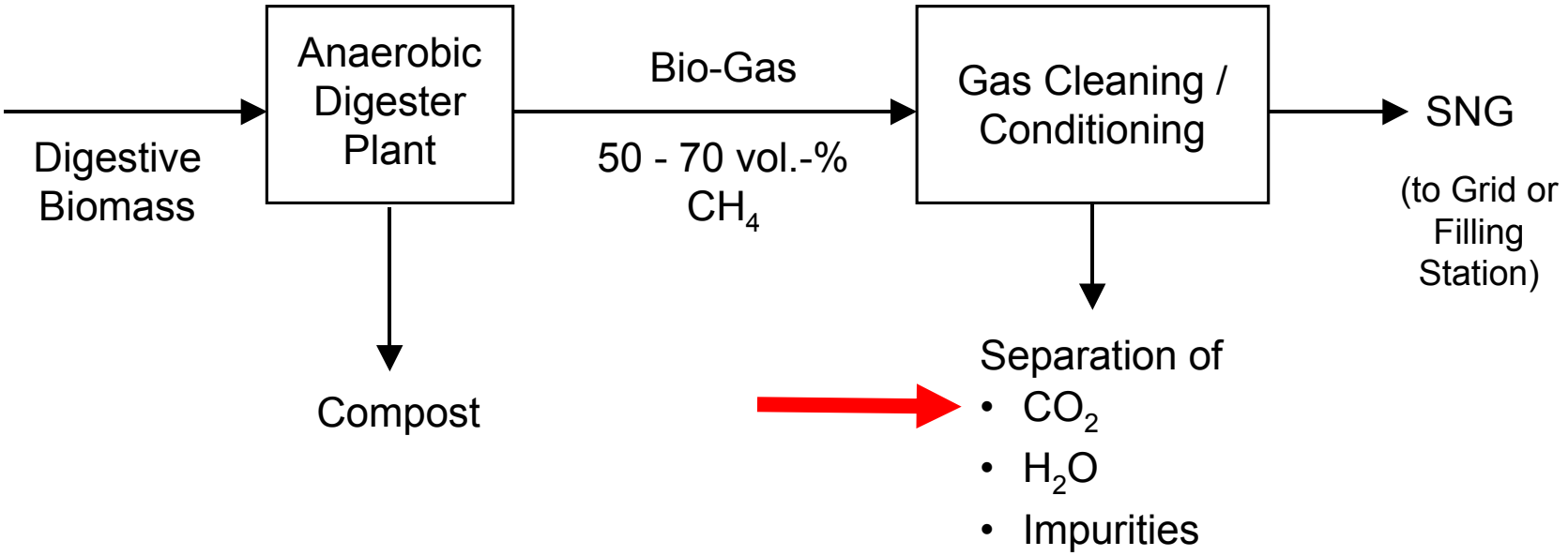
Principle of P2G®: Coupling of Electrolysis, CO_2-Source, Methanisation, and Gas Feed-in

Concept 2007



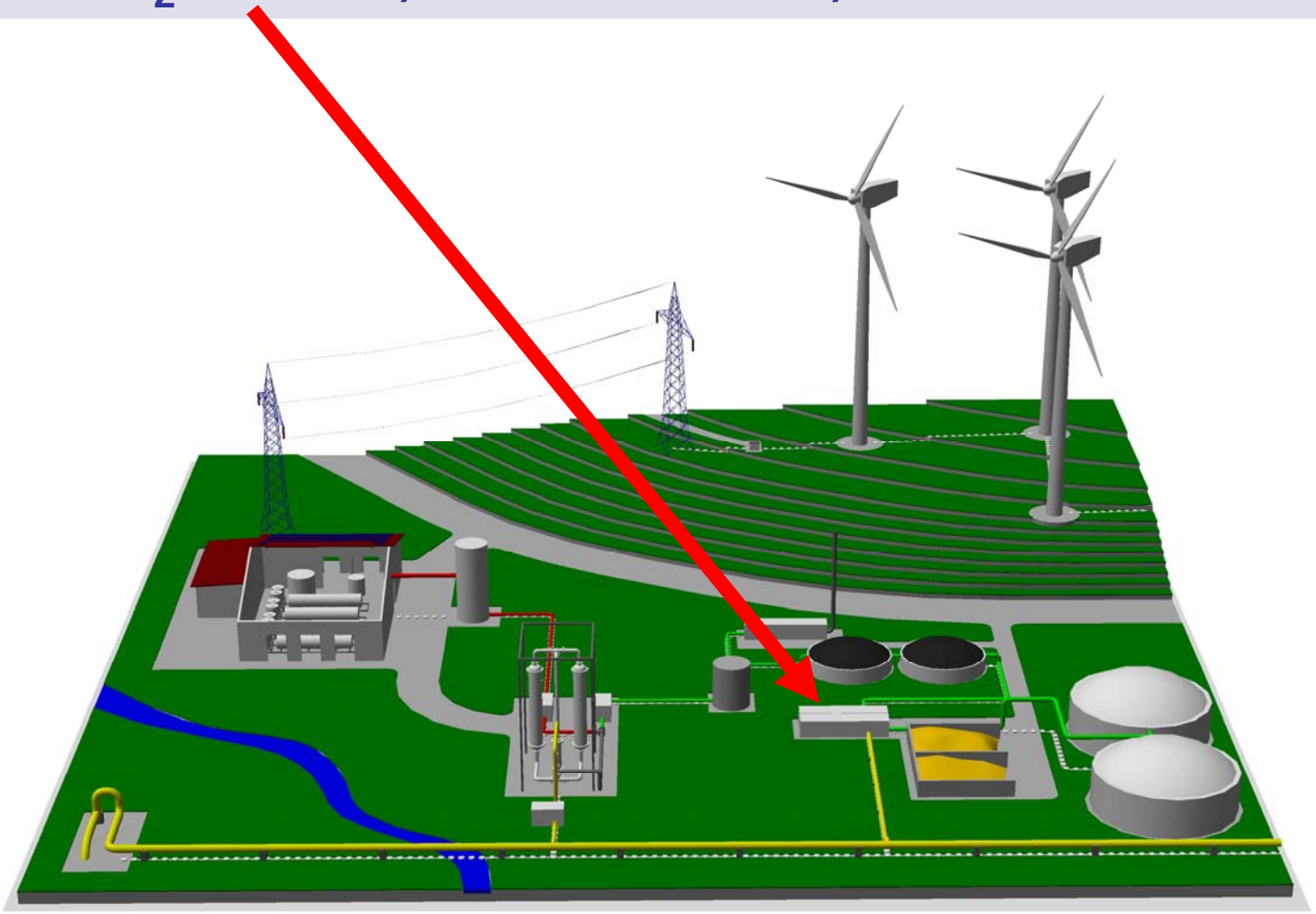
Anaerobic Digester Plant

(Digestive) Biomass → SNG: State-of-the-Art – Technology / CO_2 Source for P2G®



SNG: Substitute Natural Gas

Principle of P2G®: Coupling of Electrolysis, CO_2-Source, Methanisation, and Gas Feed-in



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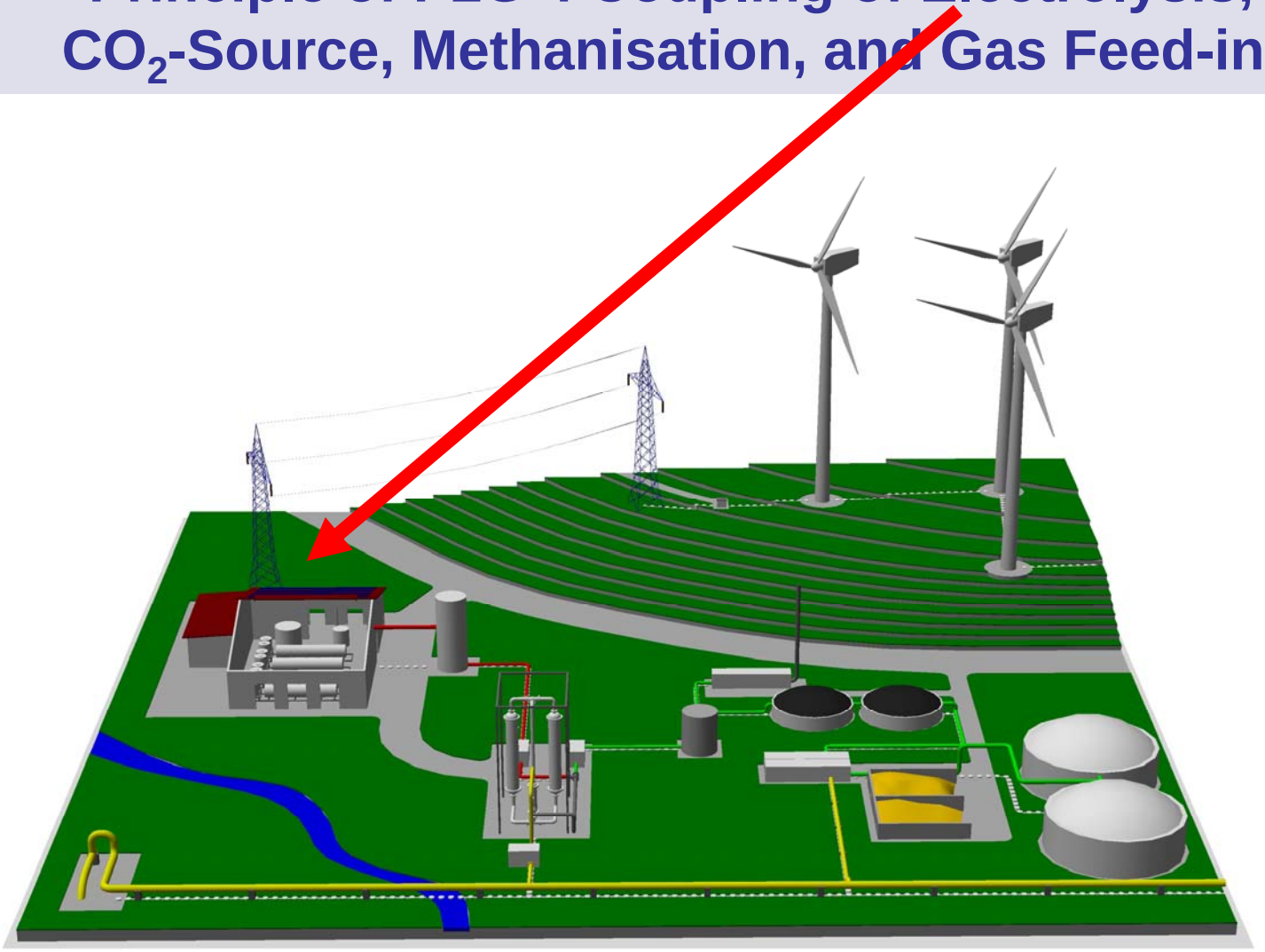

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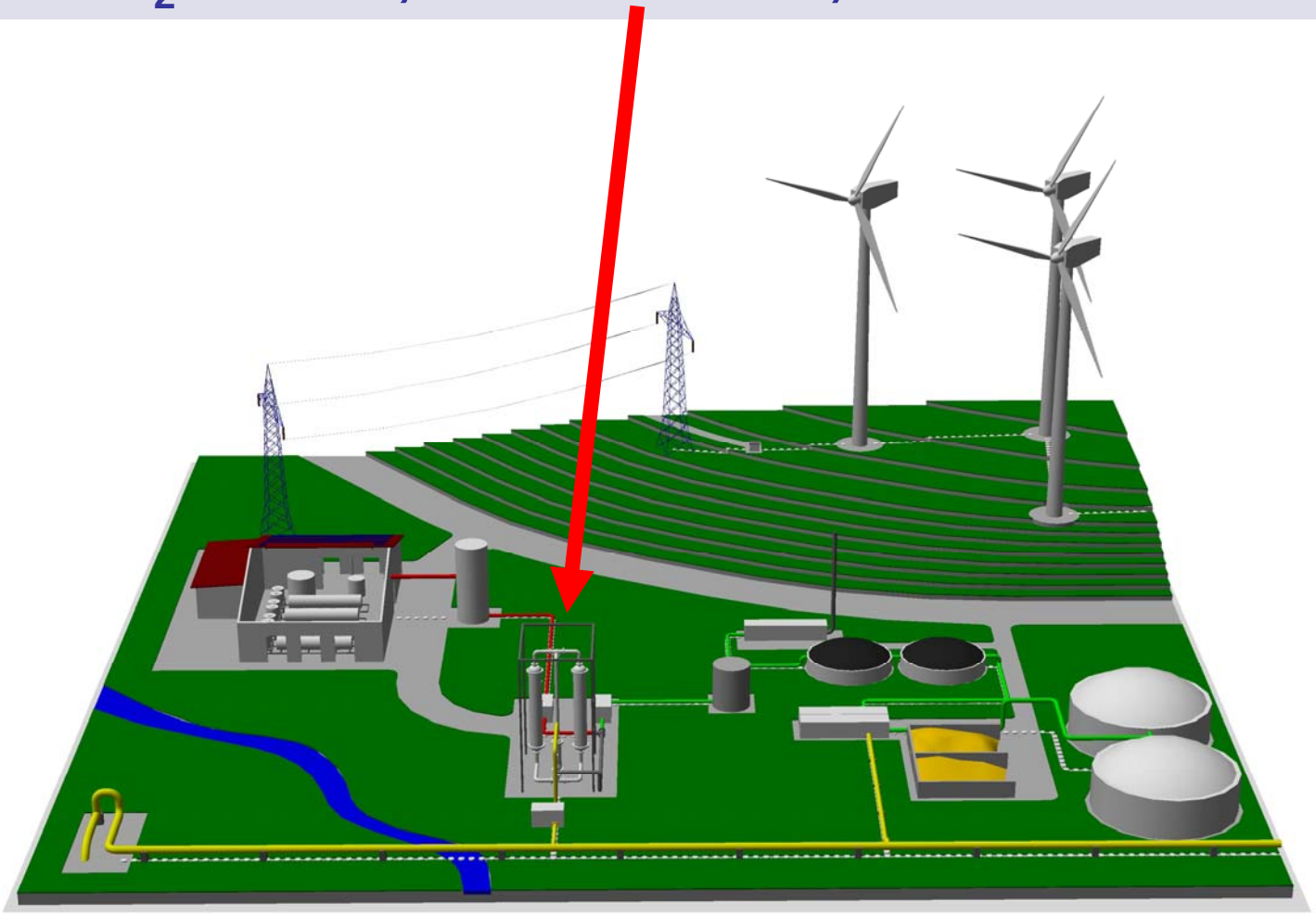

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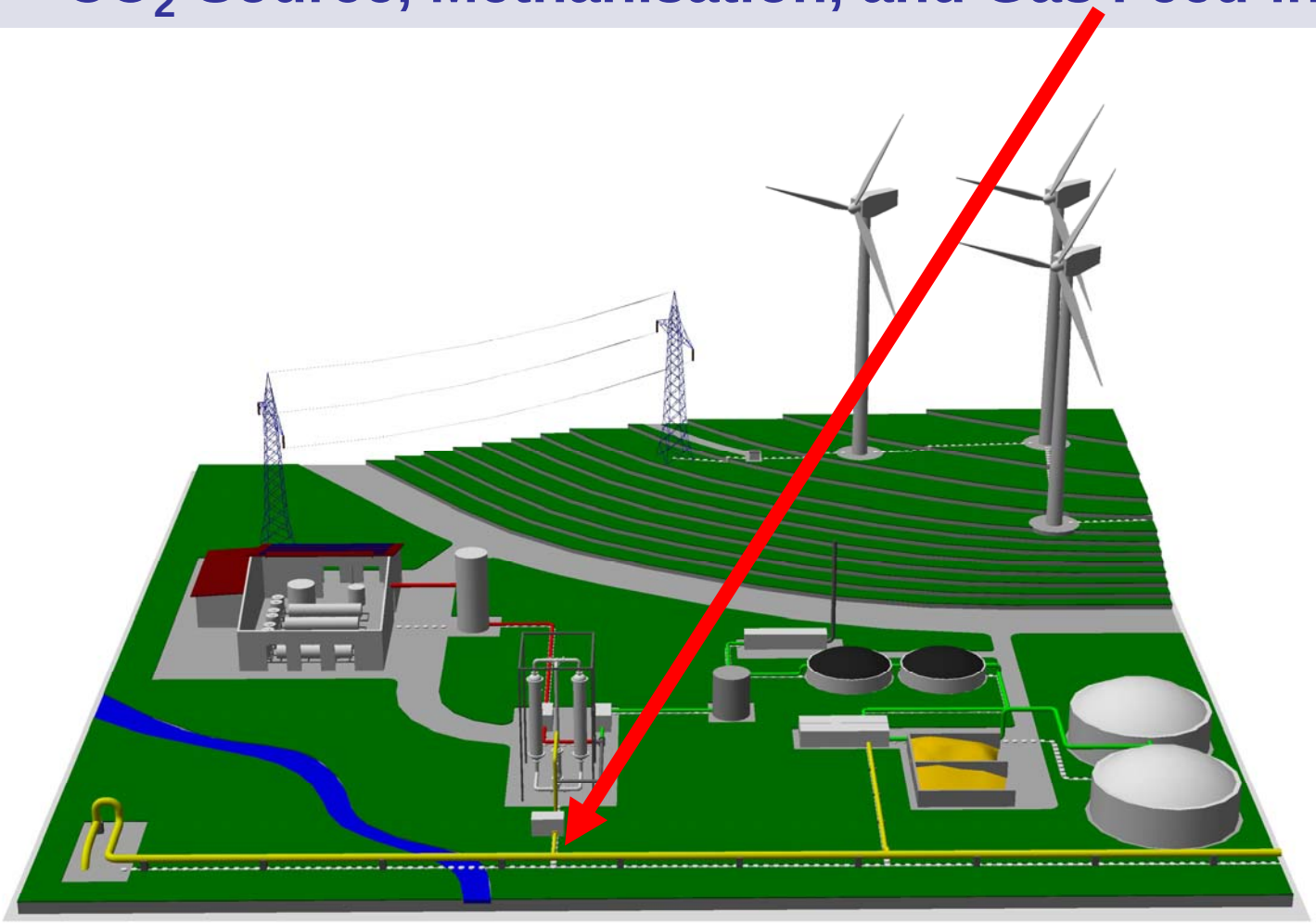
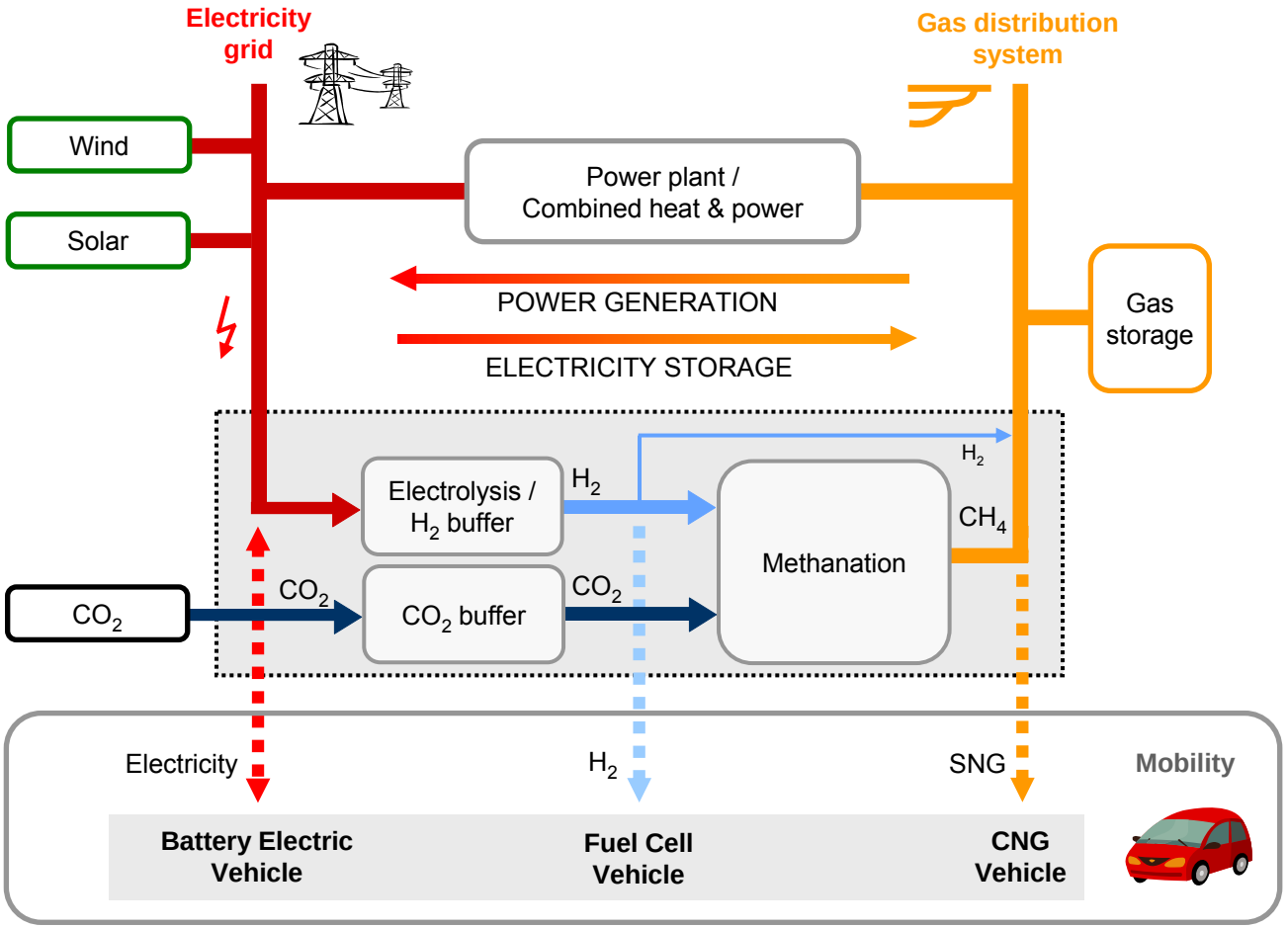
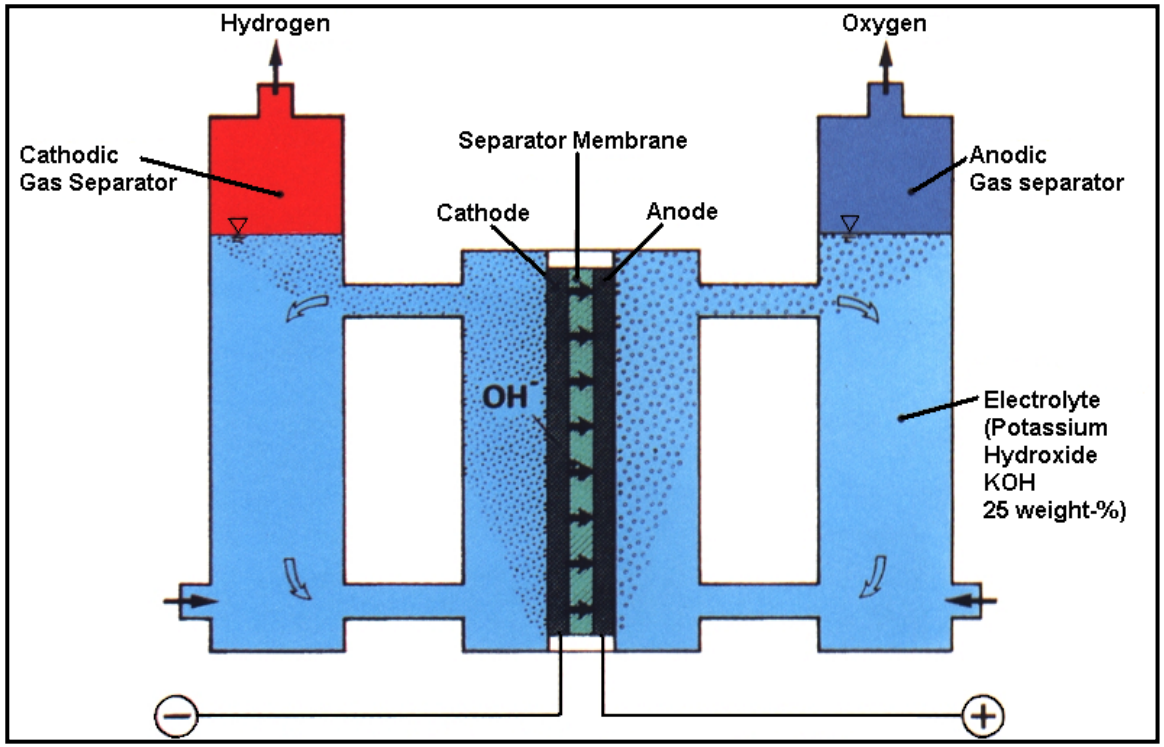


Concept of Power-to-Gas (P2G®): Convergence of Electricity Grid, Gas Grid and Mobility Sector



Power-to-Gas (P2G®) Core Process: Hydrogen Generation by Alkaline Electrolysis



Example: Alkaline Electrolysis

Cathode: $4\,H_2O + 4\,e^- \longrightarrow 2\,H_2\uparrow + 4\,OH^-$

Anode: $4\,OH^- \longrightarrow O_2\uparrow + 2\,H_2O + 4\,e^-$

$2\,H_2O \longrightarrow 2\,H_2 + O_2$

Power-to-Gas (P2G®) Core Process: Methanisation of CO_x

Methanisation:

$3\ H_2 + CO \rightleftharpoons CH_4 + H_2O$ $\quad \Delta H_R^0 = -206{,}4$ kJ/mol

$4\ H_2 + CO_2 \rightleftharpoons CH_4 + 2\ H_2O$ $\quad \Delta H_R^0 = -164{,}9$ kJ/mol

Shift- Reaction:

$H_2O + CO \rightleftharpoons H_2 + CO_2$ $\quad \Delta H_R^0 = -41{,}5$ kJ/mol

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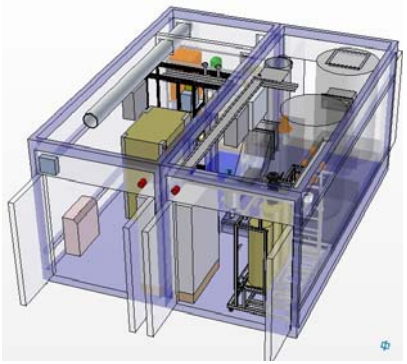
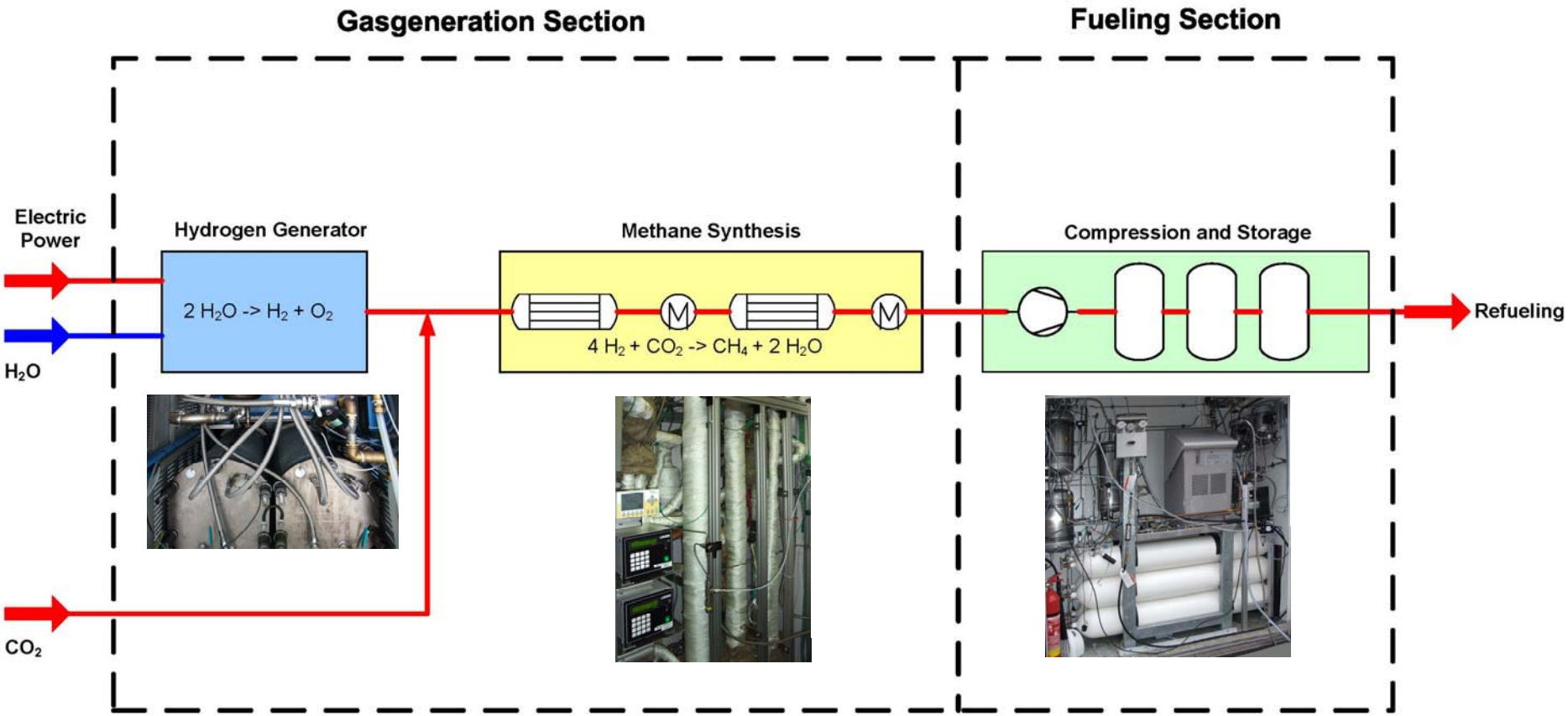
Power-to-Gas (P2G®)

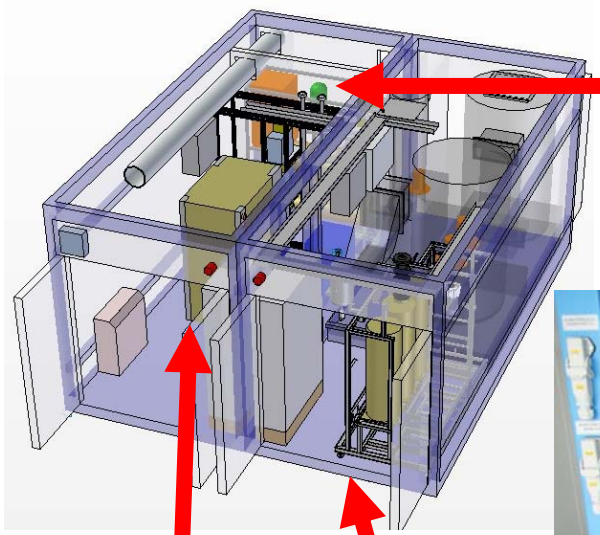
25 kW_e plant



Power-to-Gas - Technology:
Principle Process Flow Sheet of 25kW$_{el}$-P2G®-Plant



25kW$_{el}$-P2G®-Plant: Technical Realisation for SolarFuel Company in 2009



CH_4-Filling station
ca. 15 kg, 200 bar

CO_2-
Recovery

Electrolyser

ETOGAS
smart energy conversion

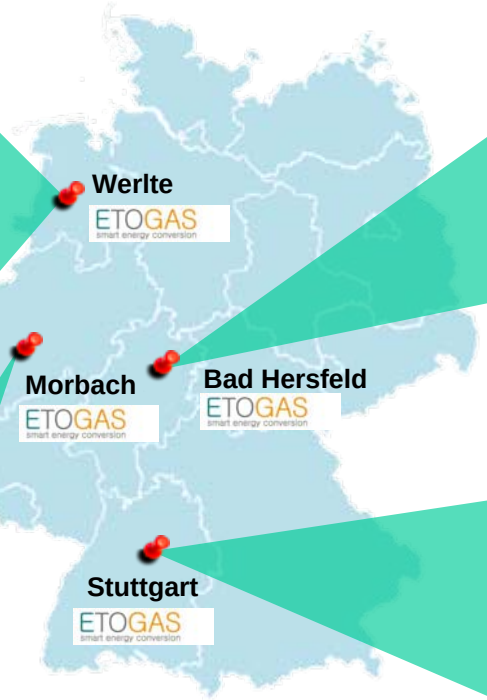
ZSW

25kW$_{el}$-P2G® - Container: Operation with CO_2 and at Biogas Plants with Biogas and PSA Off-Gas

Beta-Plant

2011

2011



2012

2009

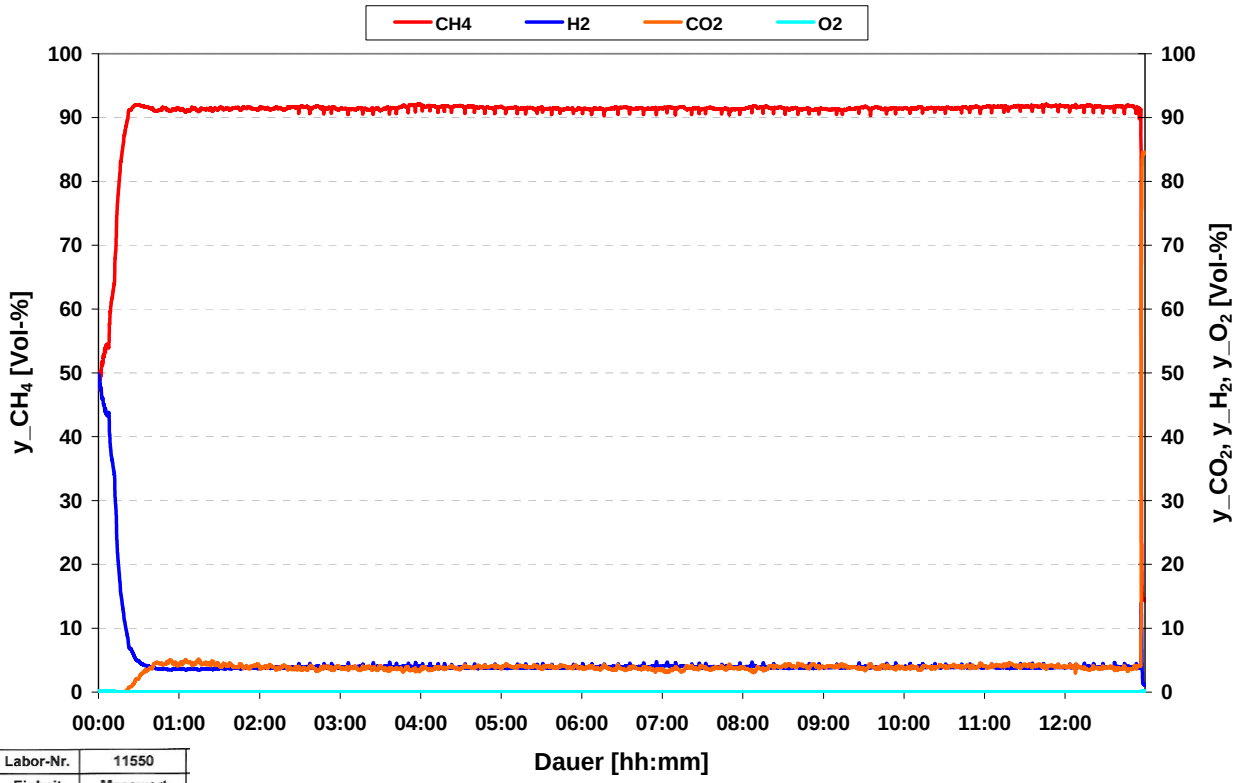
Source: ETOGAS (formerly known as SolarFuel)

ETOGAS smart energy conversion

ZSW

25kW$_{el}$-P2G® – Container (25 kW$_e$): Operation with Off-Gas at Werlte Biogas Plant

Measurement of Gas Composition: Source ZSW



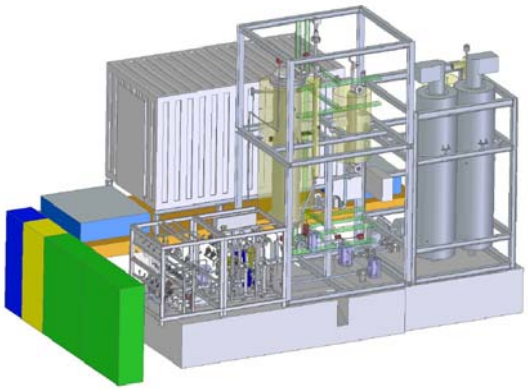
02.02.2011
Grave, EWE ENERGIE AG
Gasprobe
Produktgas SolarFuel vom 02.02.2011
Biogasaufbereitungsanlage Werlte

Laborleistungen	Analyse - Verfahren	Labor-Nr. Einheit	11550 Messwert
Gasanalyse I			
Wasserstoff	Differenz rechnerisch zu 100%	Mol.-%	4,2439
Sauerstoff	DIN EN ISO 6974-6	Mol.-%	0,0202
Stickstoff	DIN EN ISO 6974-6	Mol.-%	1,0502
Methan	DIN EN ISO 6974-6	Mol.-%	91,0622
Kohlenstoffdioxid	DIN EN ISO 6974-6	Mol.-%	3,6235
Gasanalyse III Sonstige			
Wassergehalt	in Anl. an DIN ISO 10101-3 (Karl-Fischer Titration)	mg/m³	76

Gasanalysis: Source EWE AG

Power-to-Gas (P2G®)

250 kW_e plant



Goals of the Ongoing 250kW$_{el}$-P2G®-Project (1)

- Further development of P2G® technology
- Process optimisation
  (efficiency, dynamics, ….)
- Scalability of methanisation reactor
- Transfer of operating data: 250 kW → 6 MW
- Transition to commercialization
- Start of operation: end of 2012

Co-operation partners of ZSW:

ETOGAS smart energy conversion

Fraunhofer IWES

Electrolysis Stacks for 250 kW$_e$ System

Installation of 250kW$_{el}$-P2G®-Plant at Gas Storage Area in Stuttgart-Vaihingen

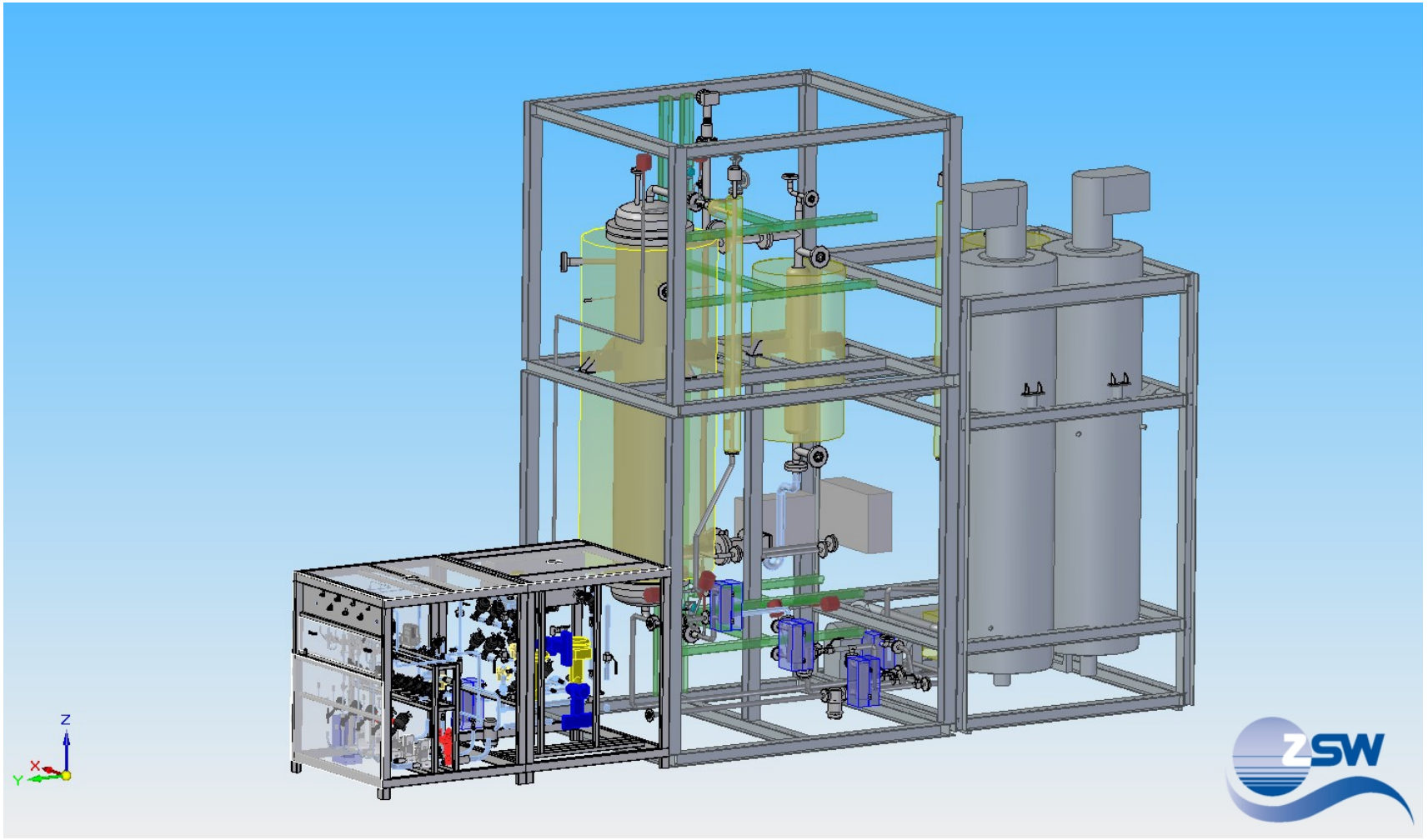
Electrolysis

Methanisation

Inauguration:
30.10.2012

ZSW
P2G®
Plant
Facility

250kW$_{el}$-P2G®: Plant Design



250kW$_{el}$-P2G®: Plant Construction

Public Fund:

Bundesministerium
für Umwelt, Naturschutz
und Reaktorsicherheit

250kW$_{el}$-P2G®: Plant Completion

Public Fund:
Bundesministerium
für Umwelt, Naturschutz
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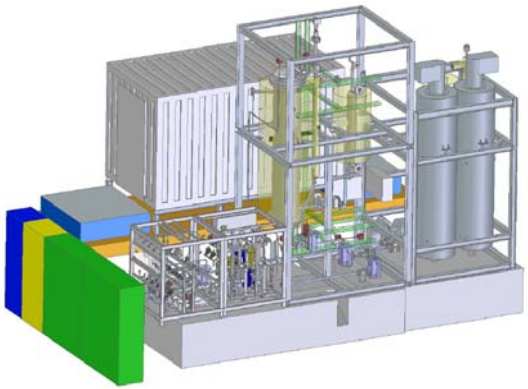
Power-to-Gas (P2G®)

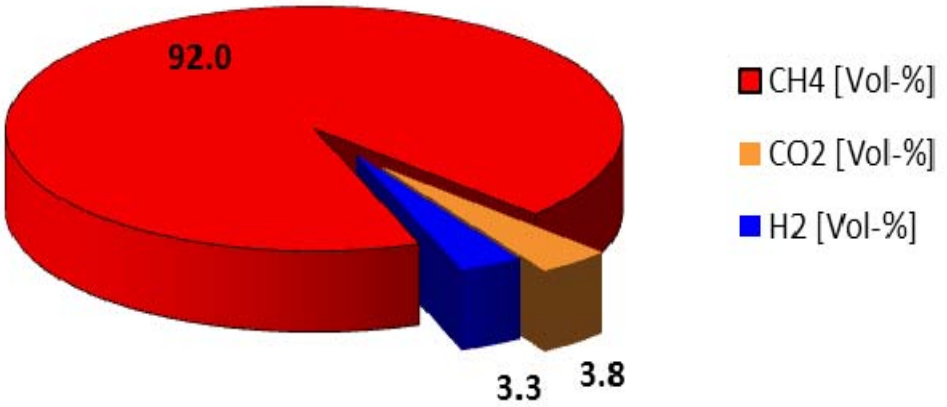
250 kW_e plant:
results



Experimental Methanisation Results with 250 kW_e Plant: Gas Composition with and without Gas Upgrade

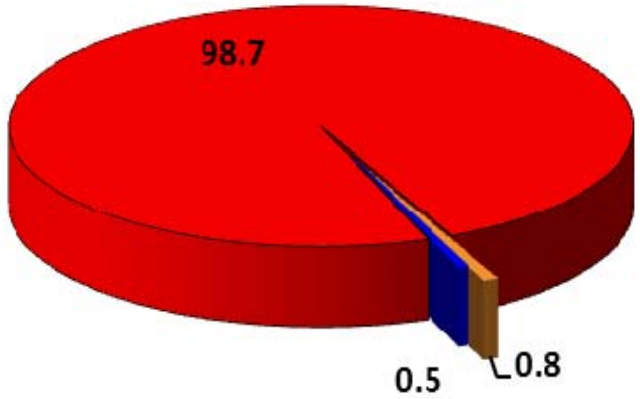
Results: Tube Bundle Reactor + Gas Upgrade via Membrane Technology

Without Gas Upgrade



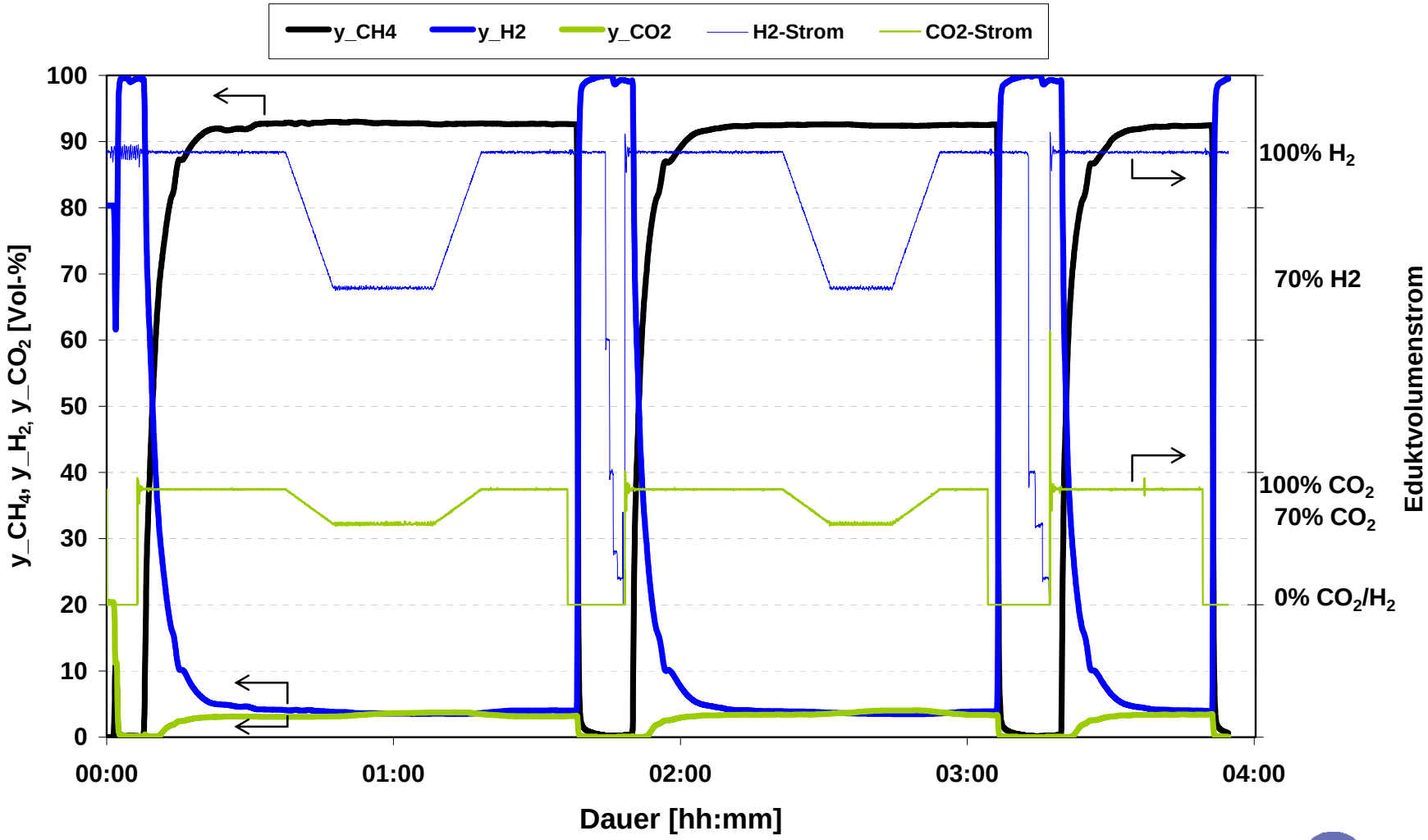
Reaction Parameters:
SV = 1365 1/h
$p_{Methanation}$ = 6 barg

With Gas Upgrade



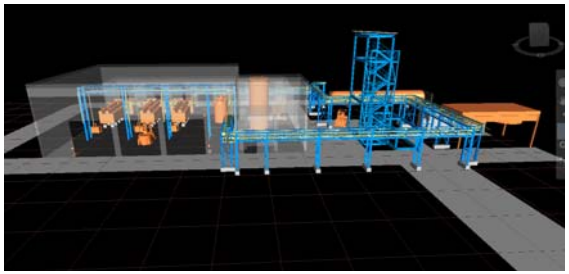
Reaction Parameters:
SV = 1365 1/h
$p_{Methanation}$ = 4 barg
$\Delta p_{Membran\ Unit}$ = 4 bar

Experimental Methanisation Results: Gas Composition at Stand-by/Start-up & Load Change

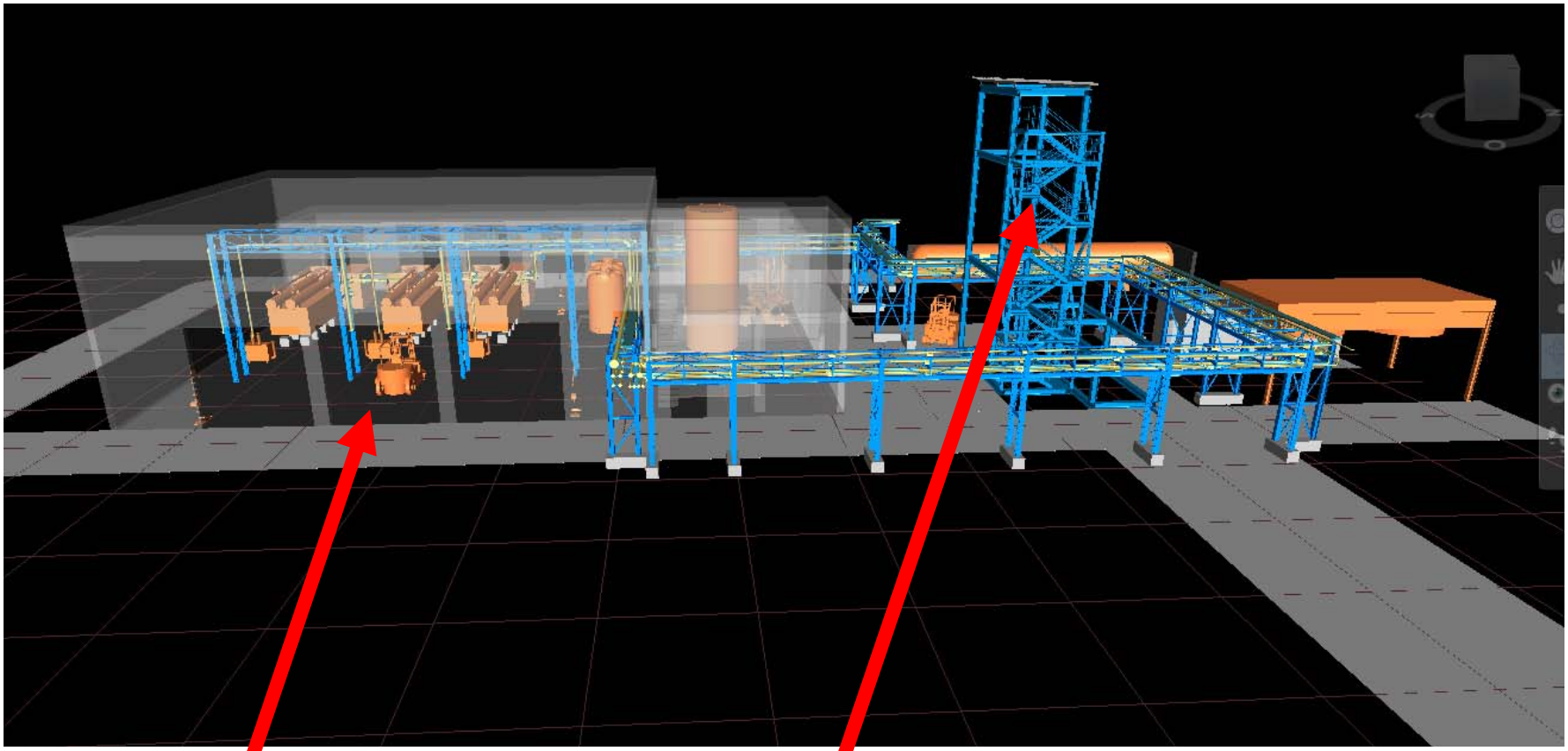


Power-to-Gas (P2G®)

6000 kW_e plant



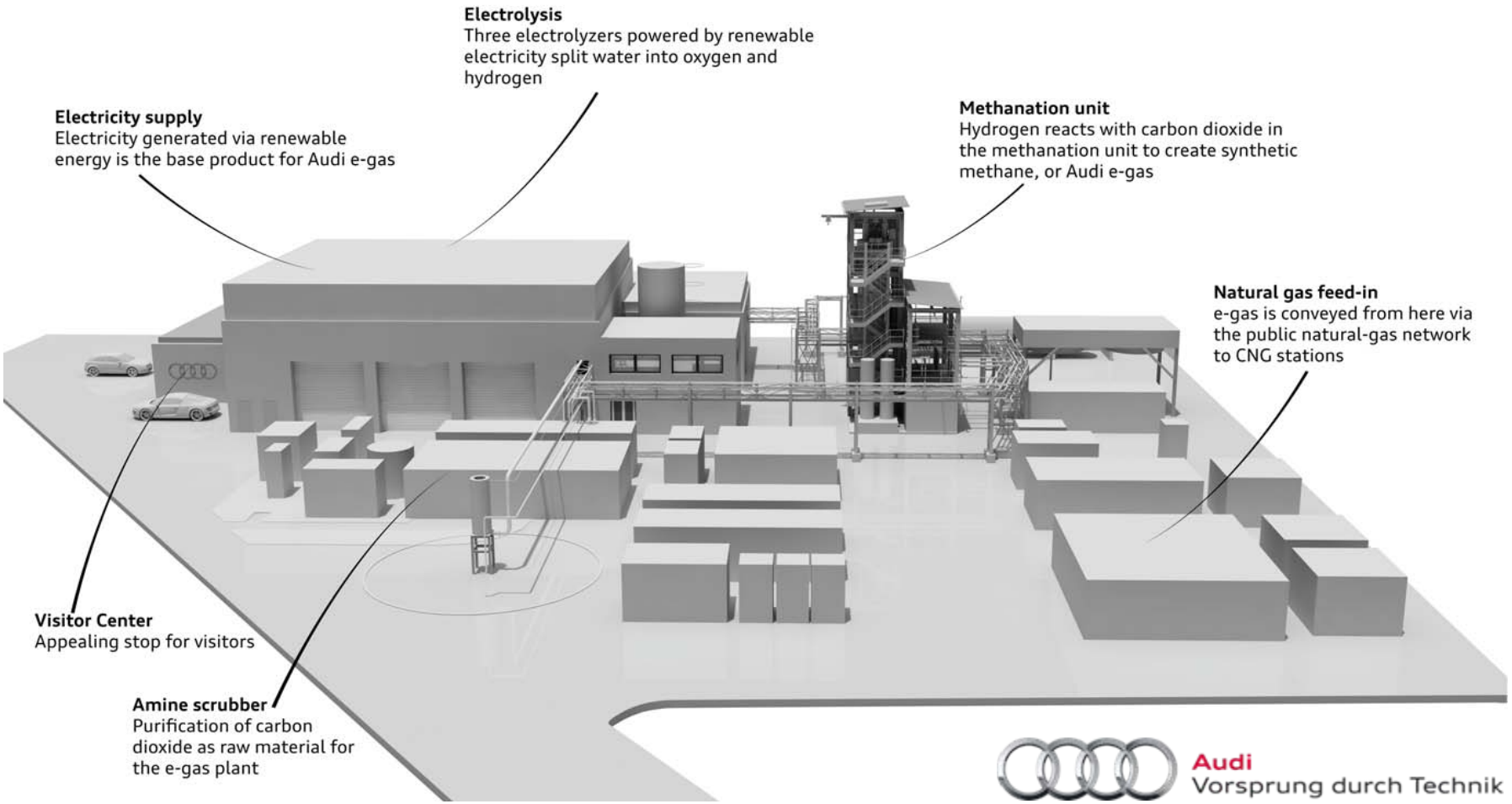
ETOGAS Layout of 6000kW$_{el}$-P2G® - Plant in Werlte (Audi e-gas Project)



Electrolysis

Methanisation

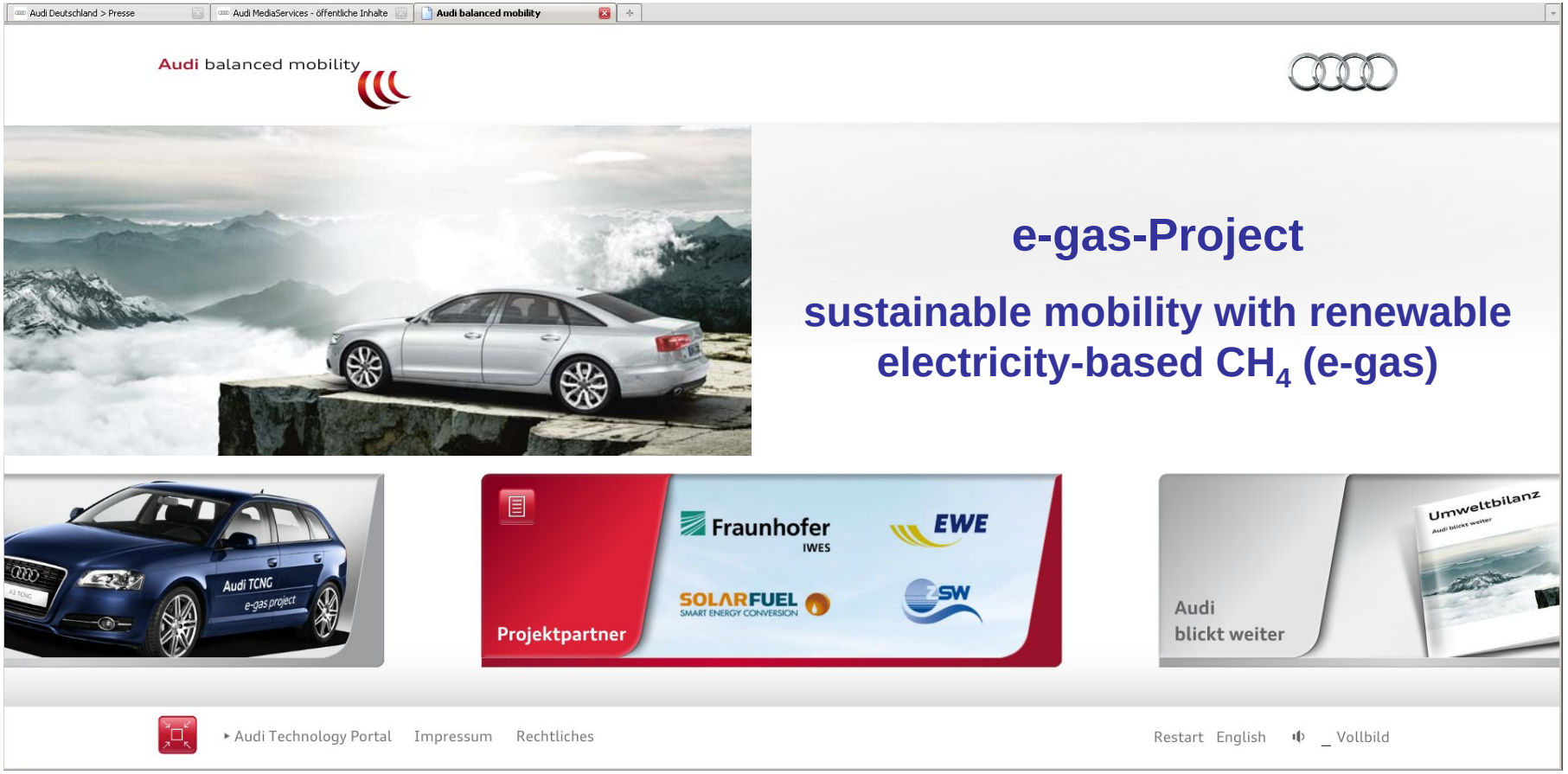
ETOGAS Layout of 6000kW$_{el}$-P2G® - Plant in Werlte (Audi e-gas Project)



Source: www.audi-mediaservices.com

6000kW$_{el}$-P2G® - Plant in Werlte (Audi e-gas Project): Inauguration: 25.06.2013

Sustainable Mobility: 6000kW$_{el}$-P2G® - Plant in Werlte for Fueling Audi Vehicles with e-gas



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Biogenic Carbon Resources for P2G®

Is enough biogenic carbon for P2G® available?

Biogenic CO_2 (CO) Resources: via Anaerobic Digestion, Ethanol Production, Gasification

Anaerobic Digestion:

$$C_6H_{12}O_6 \rightarrow 3\,CH_4 + 3\,CO_2$$

Ethanol Production:

$$C_6H_{12}O_6 \rightarrow 2\,C_2H_5OH + 2\,CO_2$$

Thermo-chemical Gasification:

$$\text{Biomass} \rightarrow H_2, CO, CO_2$$

CO_2 / Carbon Potential in Germany for the Production of C-based Fuels

Carbon Resource	CO_2	C	SNG Production Potential
	[t/a]	[t/a]	[TWh_{gas}/a]
Biogas Plants			
CH_4 Gas Share	**$7.3 * 10^6$**	**$2.0 * 10^6$**	**39**
CO_2 Gas Share	**$5.1 * 10^6$**	**$1.4 * 10^6$**	**27**
Energetic Biomass Utilisation in DE today (without Biogas)	**$73 * 10^6$**	**$20 * 10^6$**	**385**
Non-renewable Trash	**$25 * 10^6$**	**$6.8 * 10^6$**	**130**
Cement / Limestone Production	**$17 * 10^6$**	**$4.8 * 10^6$**	**92**
CCPP/CCU [1] (or SOFC/CCU)	**$27 * 10^6$**	**$7.3 * 10^6$**	**135**
Fossile Power Plants	**$309 * 10^6$**	**$84 * 10^6$**	**1618**
CO_2 from Air			**unlimited**

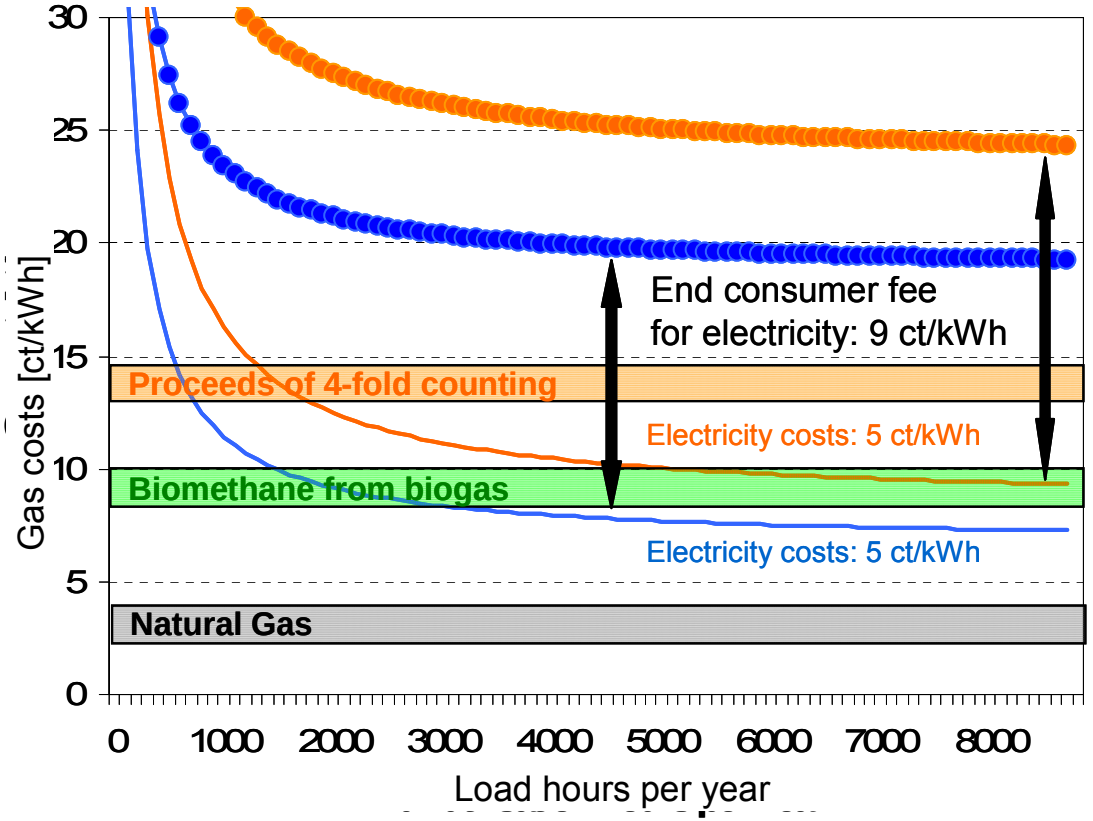
SNG: Substitute Natural Gas

[1] Direct CO_2 recycling:
CCPP/CCU: Combined Cycle Power Plant / Carbon Capture and Utilisation
25 GW, 3000 h/a, η = 50 %, CO_2 retention: 90 %

P2G® - Economics

What are the costs of e-gas?

Cost Estimate of e-gas (Capital and Energy Costs only): Electricity to Gas - Path



Assumptions

- Estimated life: 20 years
- Interest rate: 6% p.a.
- No other operating cost, no cost for methan feed-in etc.

Methan-Path (Status 2020)

- Investment: 1.000 €/kW_{el}
- Efficiency factor electricity to gas: 60%

Hydrogen-Path (Status 2020)

- Investment: 600 €/kW_{el}
- Efficiency factor electricity to gas: 75%

→ Without reduction of the end consumer fee for electricity an economic operation of a P2G plant is not possible!

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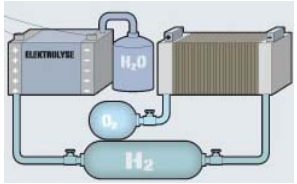
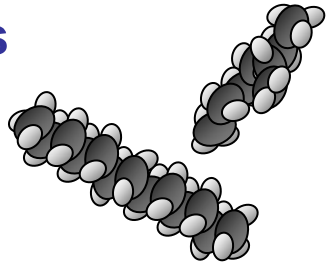
Options for Long Term (Seasonal) Energy Storage: Chemical Energy Carriers

- **Hydrogen**



- **Substitute Natural Gas (SNG)**

- **Liquid Hydrocarbons**



→ Chemical energy carriers are needed for future energy supply in electricity, heat and mobility market!

→ **No alternative for long term energy storage!**

Conclusion:
Advantages of P2G® - Technology

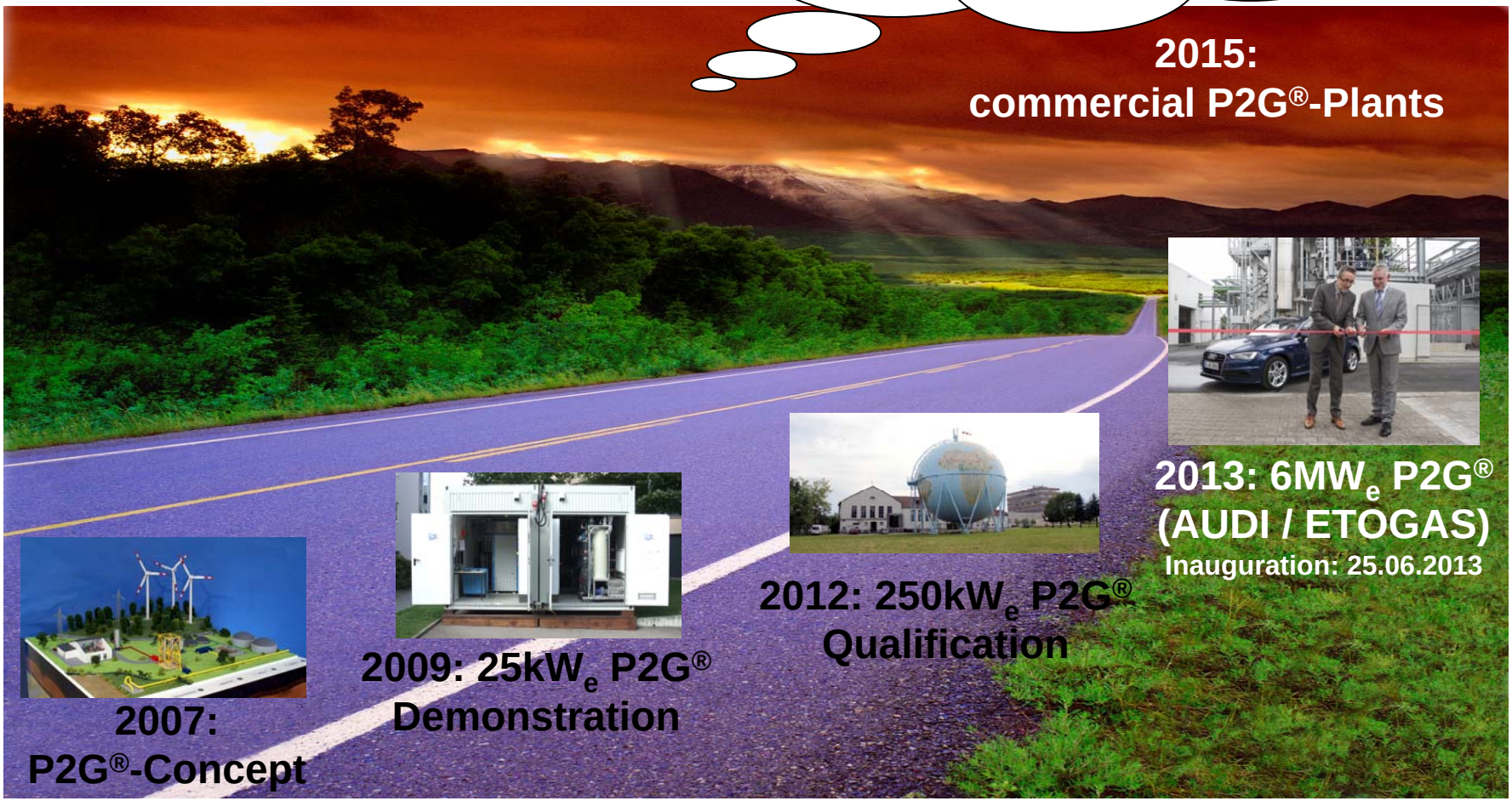
- Inspired by nature: “P2G® = artificial photosynthesis”
- SNG is an ideal chemical storage medium for renewable energy (RE)
- Storage of RE with “unlimited” storage capacity in the gas grid
- Utilisation of existing underground gas storage facilities
- Stabilization of electricity grid (positive and negative control power)

- Merging of the energy sectors “electricity grid”, “gas grid”, and “mobility”

P2G®-ROADMAP


2015:
commercial P2G®-Plants
2013: 6MW$_e$ P2G®
(AUDI / ETOGAS)
Inauguration: 25.06.2013
2012: 250kW$_e$ P2G®
Qualification
2009: 25kW$_e$ P2G®
Demonstration
2007:
P2G®-Concept

Thanks for your kind attention.
An interesting discussion !



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smart energy conversion

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