

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

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

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ZSW – Center for Solar Energy and Hydrogen Research, Stuttgart
in Co-operation with

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 (CO₂ 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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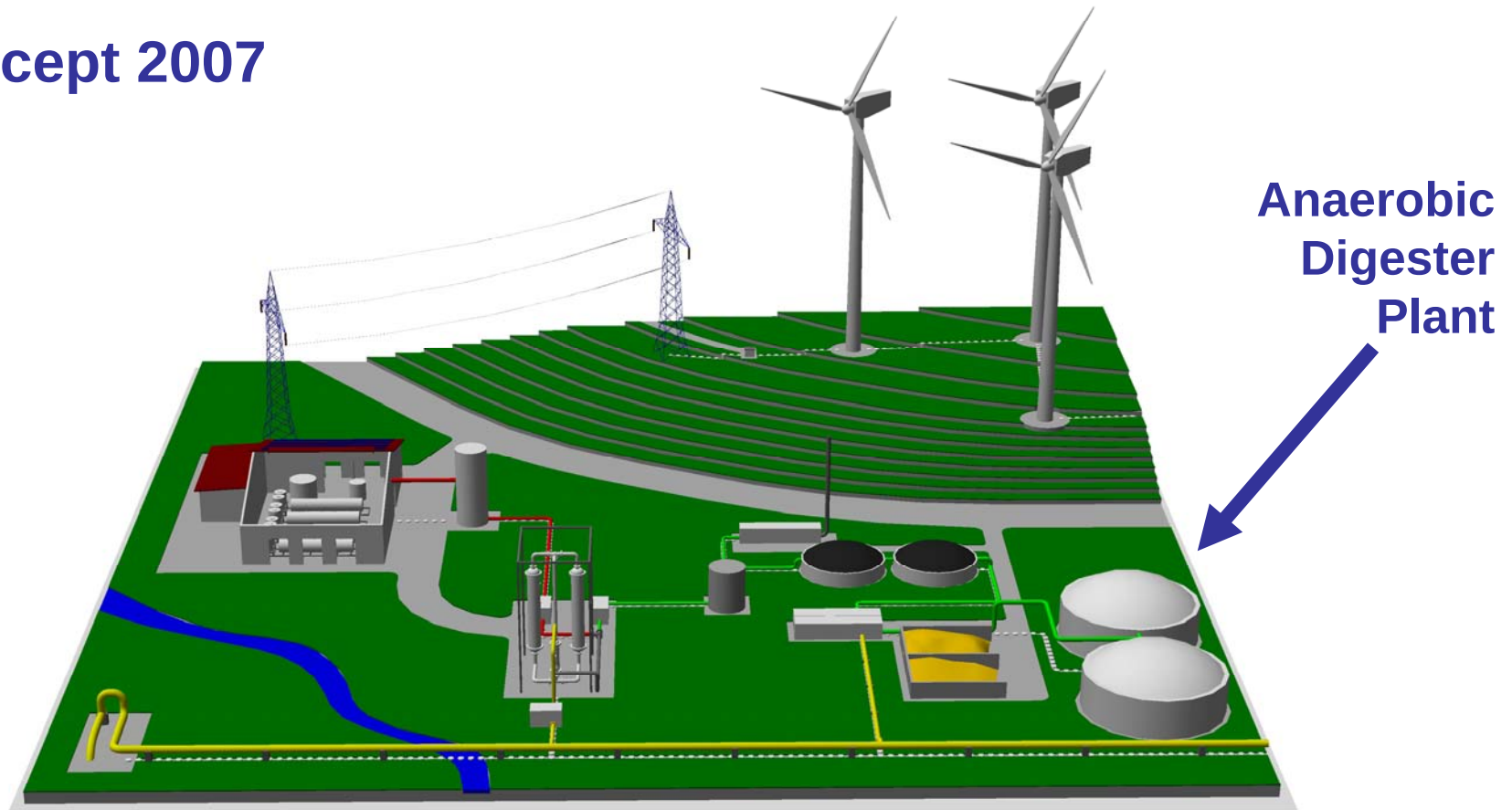
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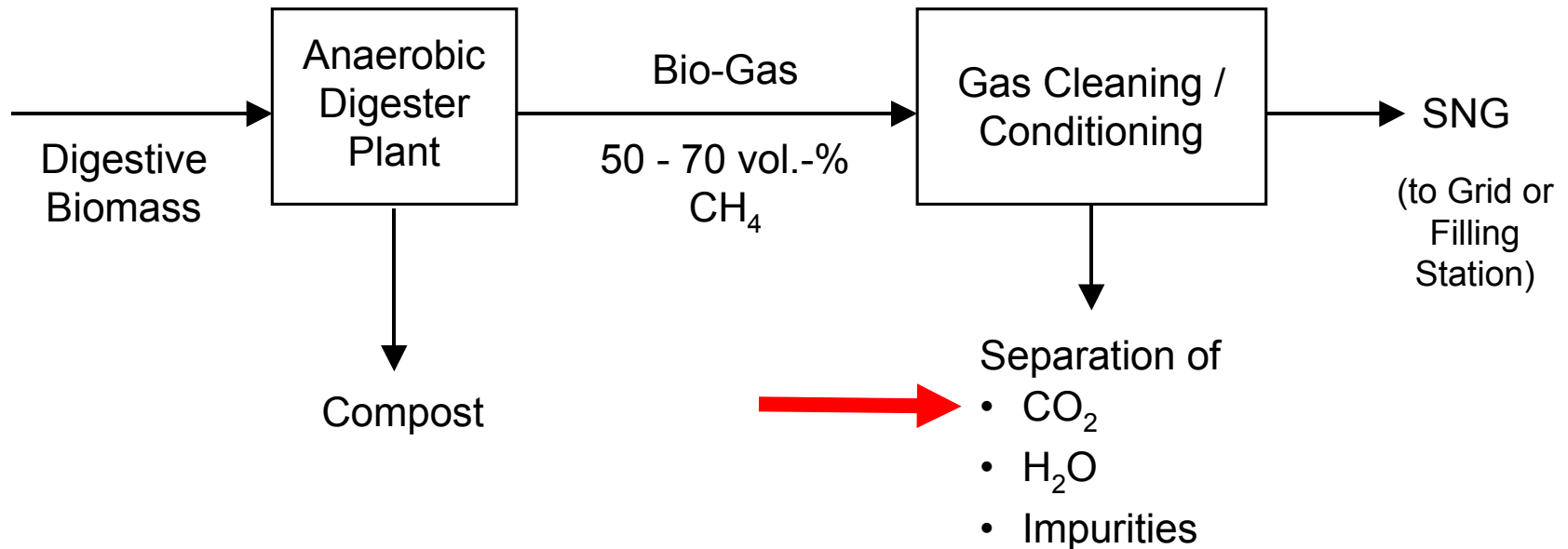


Principle of P2G[®]: Coupling of Electrolysis, CO₂-Source, Methanisation, and Gas Feed-in

Concept 2007

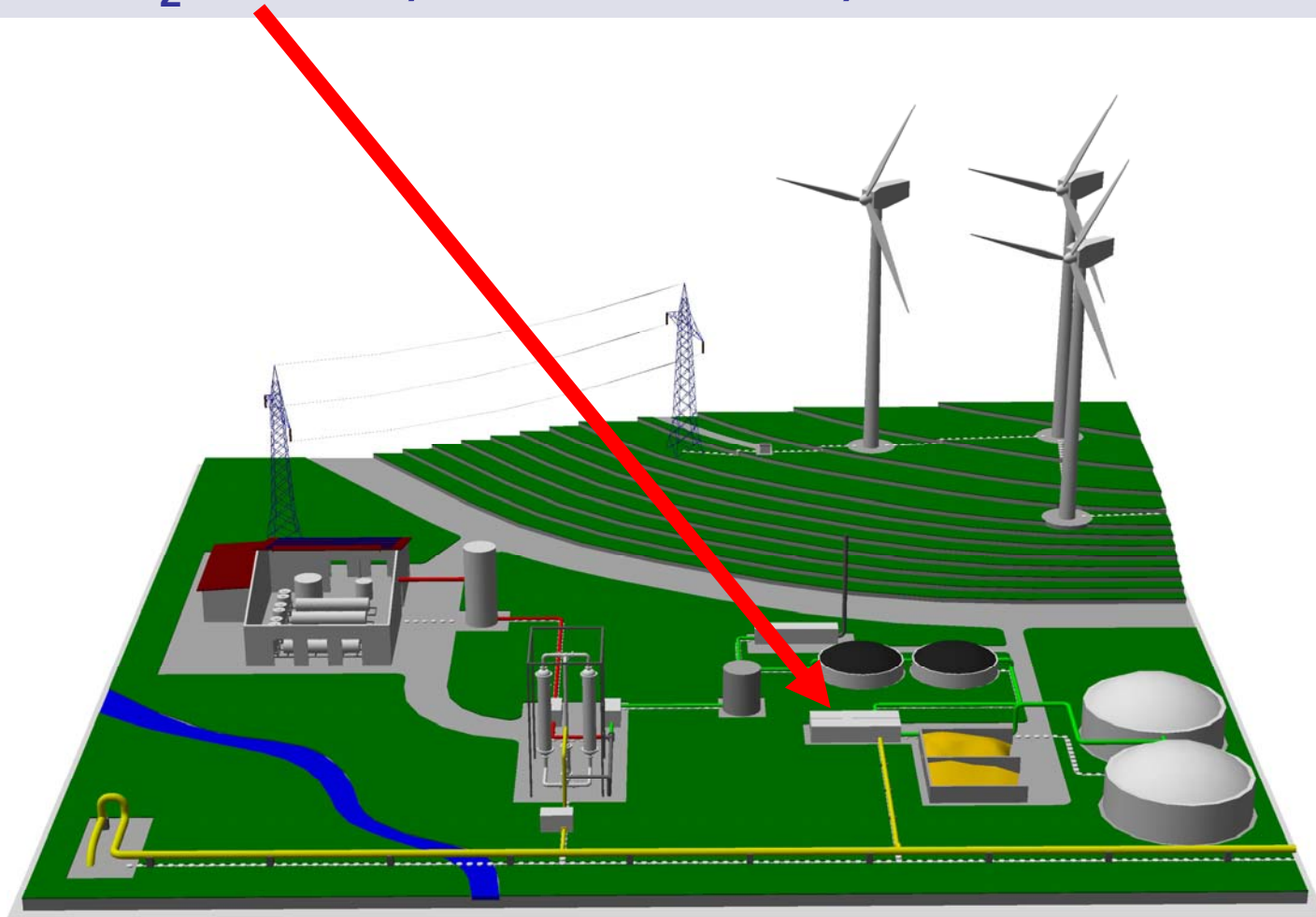


(Digestive) Biomass → SNG: State-of-the-Art – Technology / CO₂ Source for P2G®

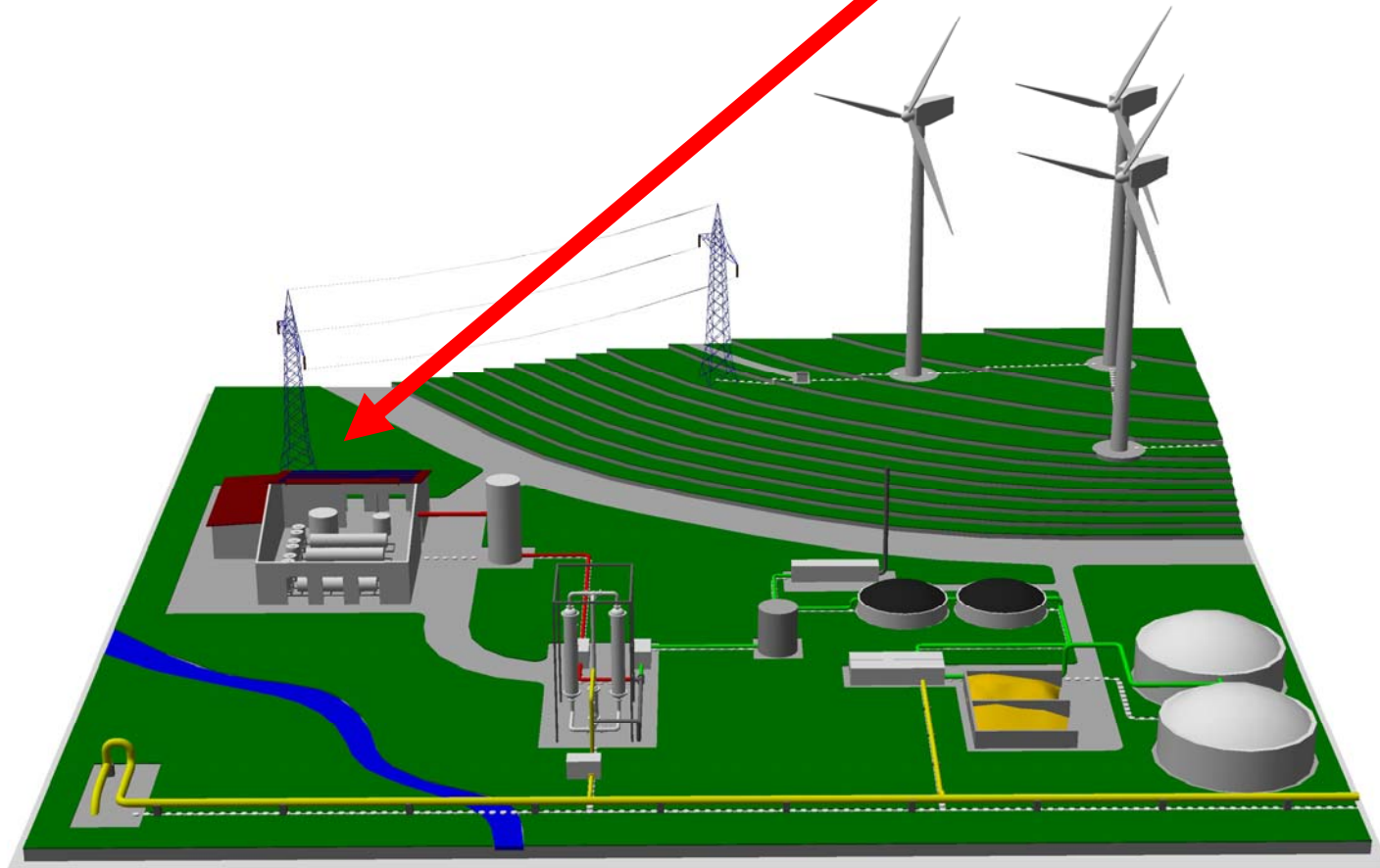


SNG: Substitute Natural Gas

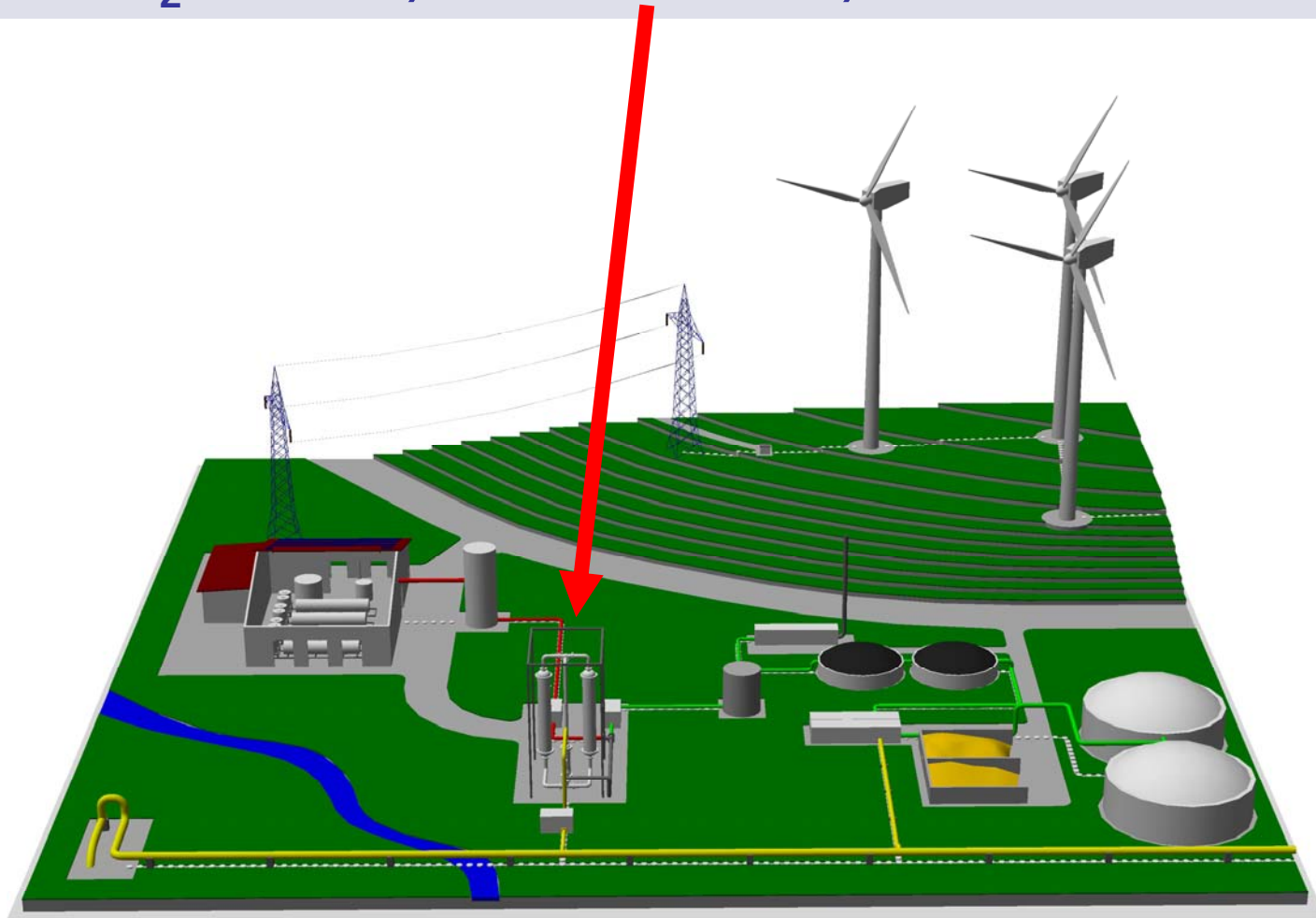
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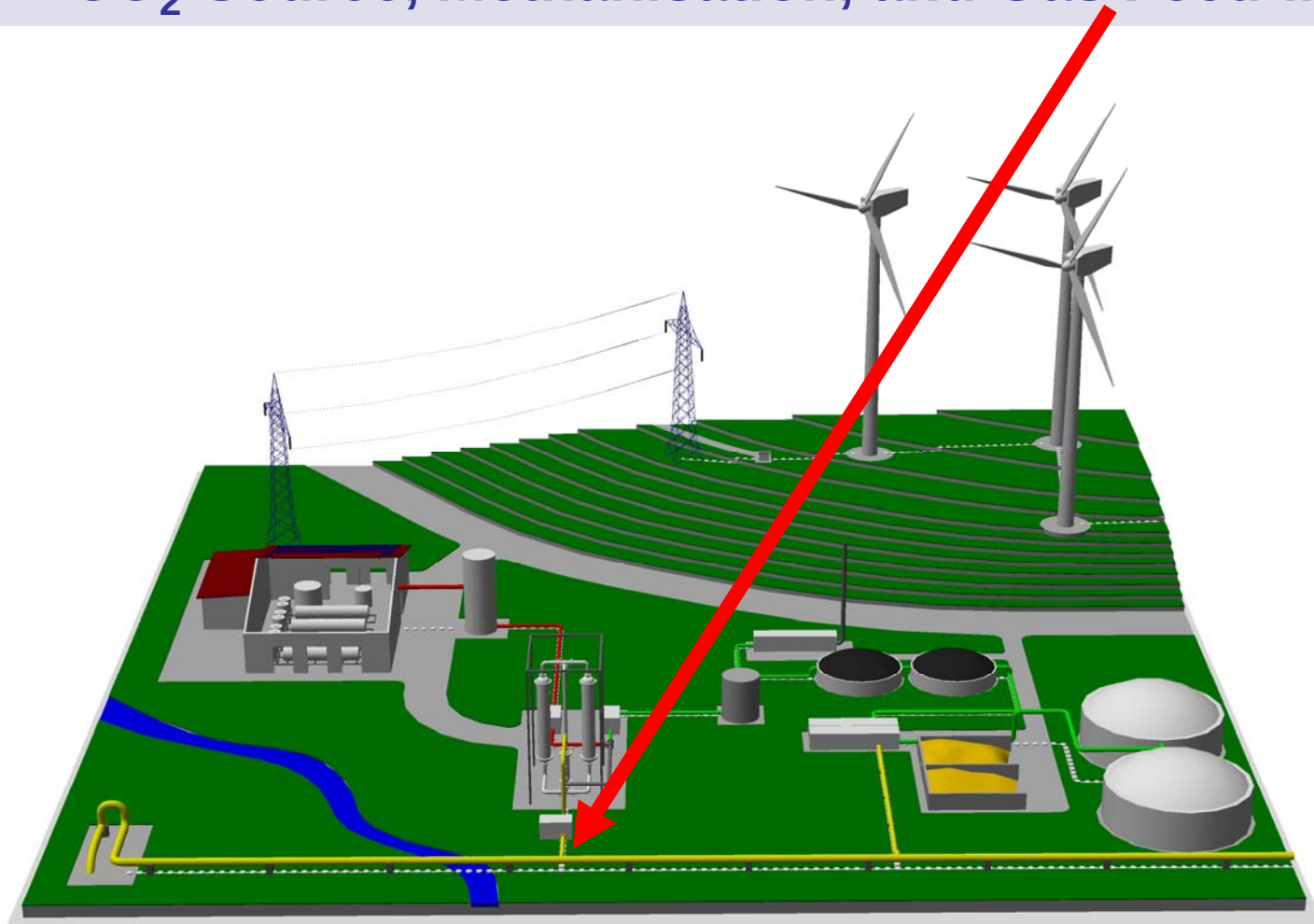
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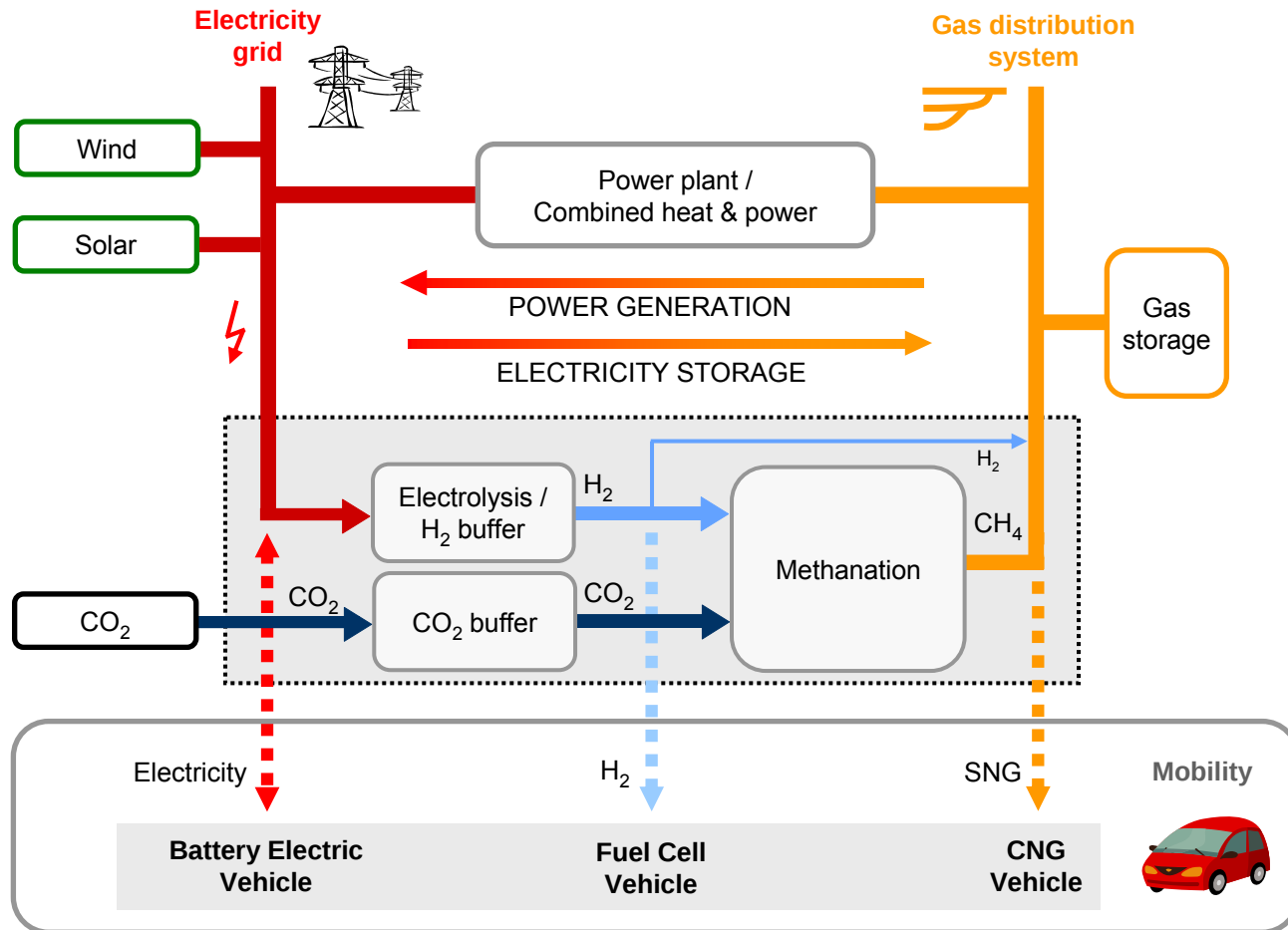
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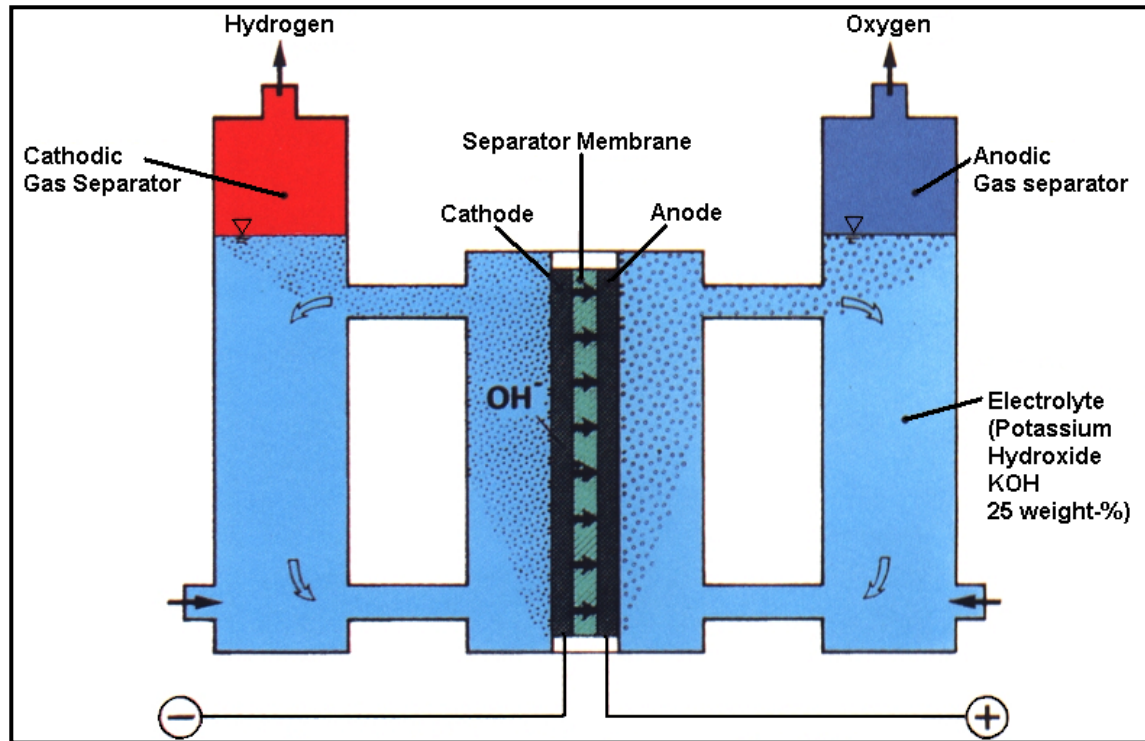
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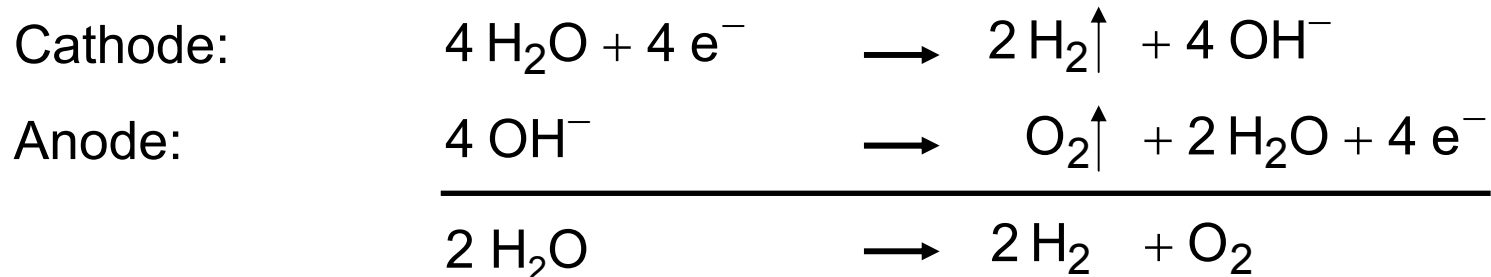
Concept of Power-to-Gas (P2G[®]): Convergence of Electricity Grid, Gas Grid and Mobility Sector



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



Example:
Alkaline
Electrolysis



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

Methanisation:



$$\Delta H_{\text{R}}^0 = -206,4 \text{ kJ/mol}$$



$$\Delta H_{\text{R}}^0 = -164,9 \text{ kJ/mol}$$

Shift- Reaction:



$$\Delta H_{\text{R}}^0 = -41,5 \text{ kJ/mol}$$



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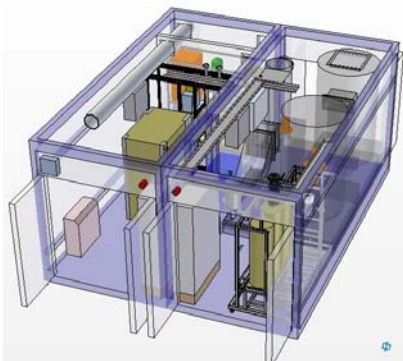
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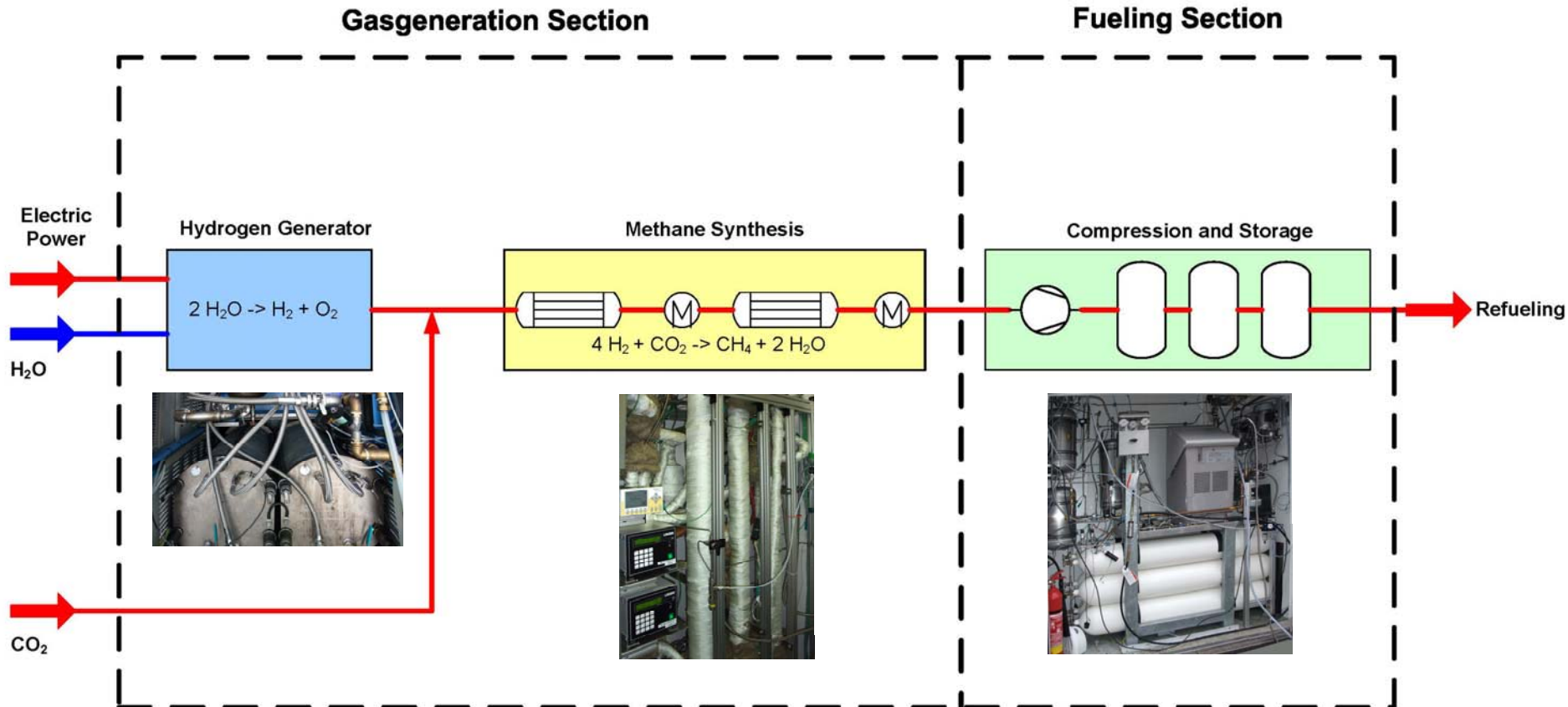


Power-to-Gas (P2G[®])

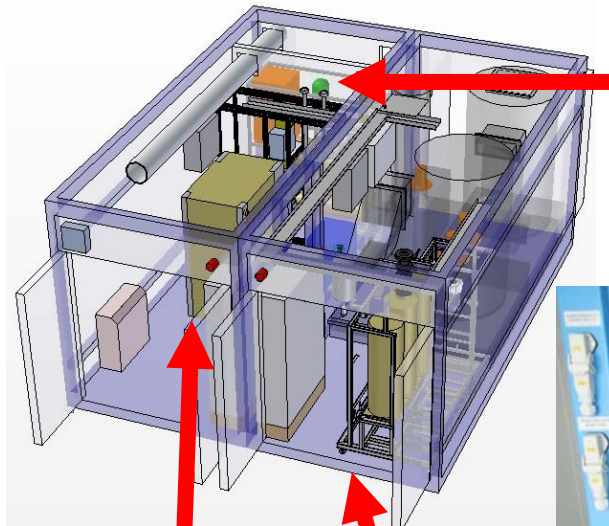
25 kW_e plant



Power-to-Gas - Technology: Principle Process Flow Sheet of 25kW_{el}-P2G[®]-Plant



25kW_{el}-P2G[®]-Plant: Technical Realisation for SolarFuel Company in 2009



CH₄-Filling station
ca. 15 kg, 200 bar

CO₂-
Recovery

Electrolyser



25kW_{el}-P2G[®] - Container: Operation with CO₂ and at Biogas Plants with Biogas and PSA Off-Gas

Beta-Plant



2011



2011



2012



Source: IWES/Mahler

2009

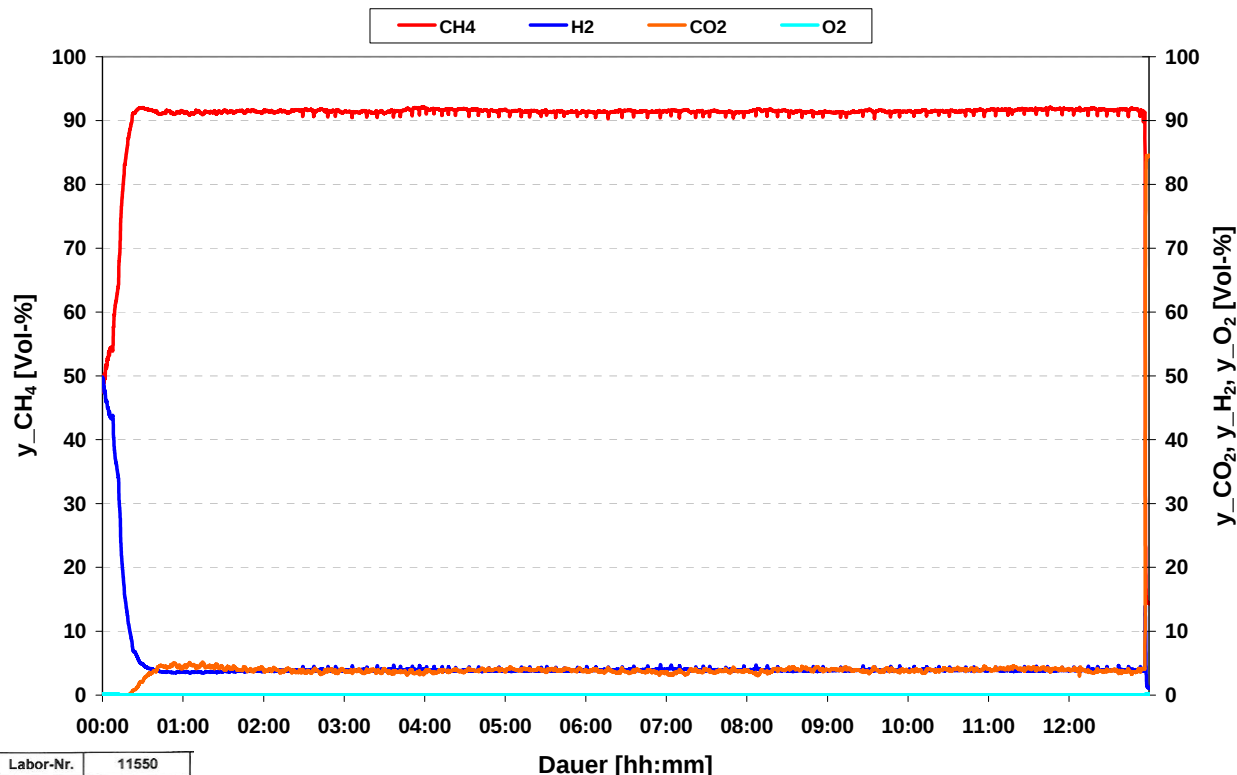


Source: ETOGAS (formerly known as SolarFuel)

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



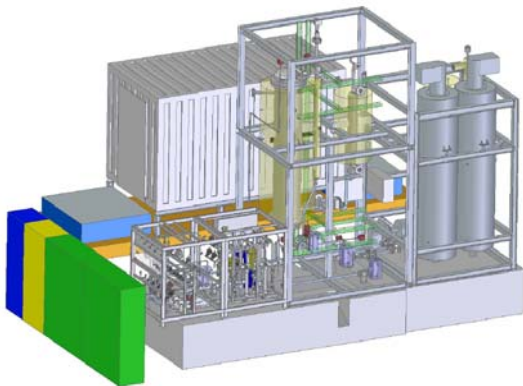
	Analyse - Verfahren	Labor-Nr.	11550
Laborleistungen		Einheit	Messwert
Gasanalyse I			
Wasserstoff	Differenz rechnerisch zu 100%	Mol.-%	4,2439
Sauerstoff	DIN EN ISO 6974-6	Mol.-%	0,0202
Stickstoff	DIN EN ISO 6974-6	Mol.-%	1,0502
Methan	DIN EN ISO 6974-6	Mol.-%	91,0622
Kohlenstoffdioxid	DIN EN ISO 6974-6	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



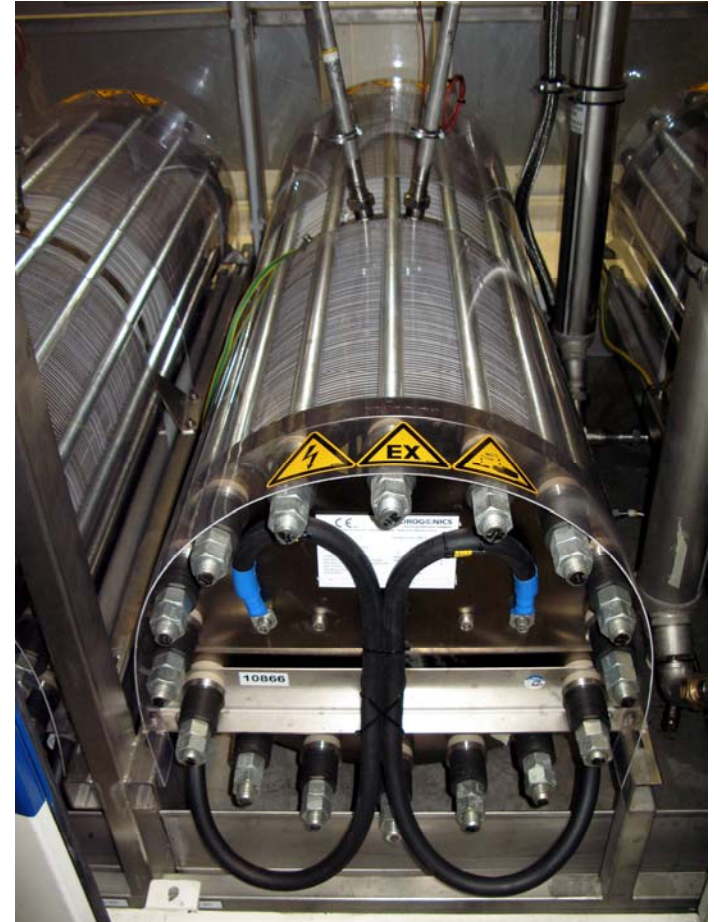
Goals of the Ongoing 250kW_{el}-P2G[®]-Project (1)

- 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



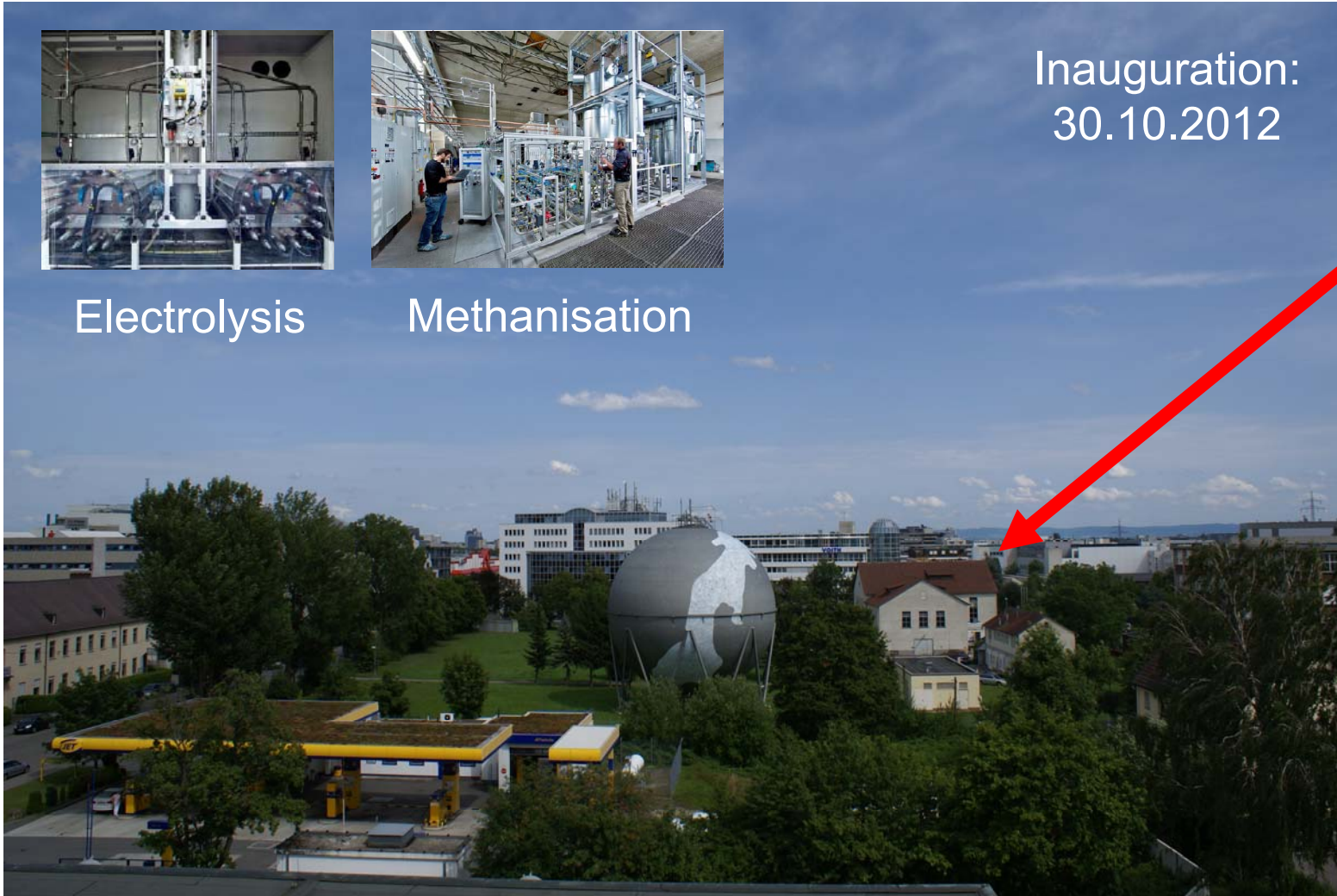
Electrolysis



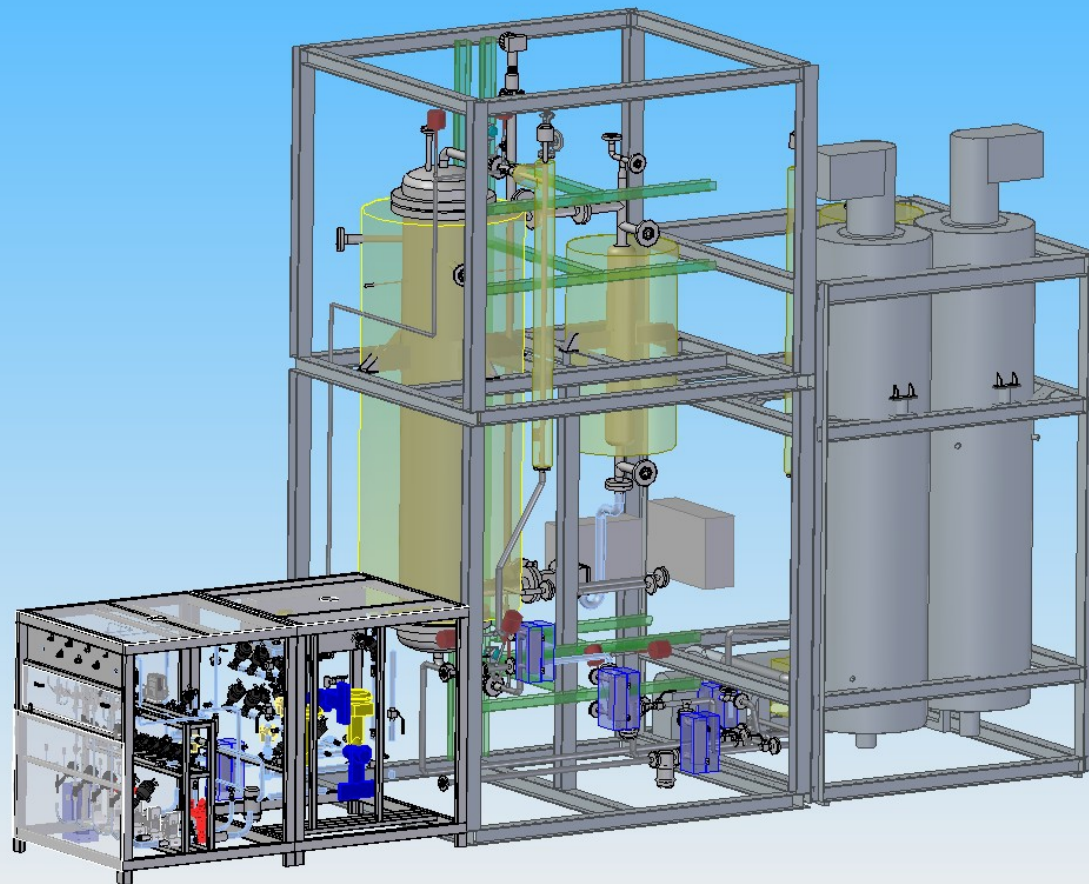
Methanisation

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:

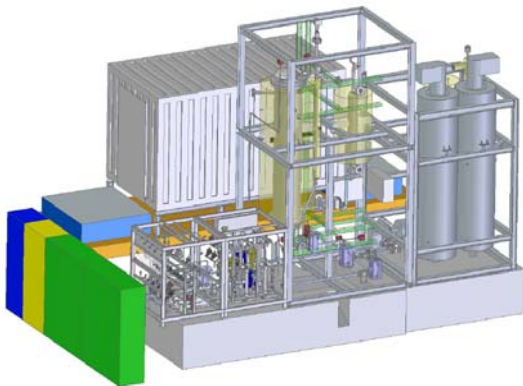


Bundesministerium
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Power-to-Gas (P2G[®])

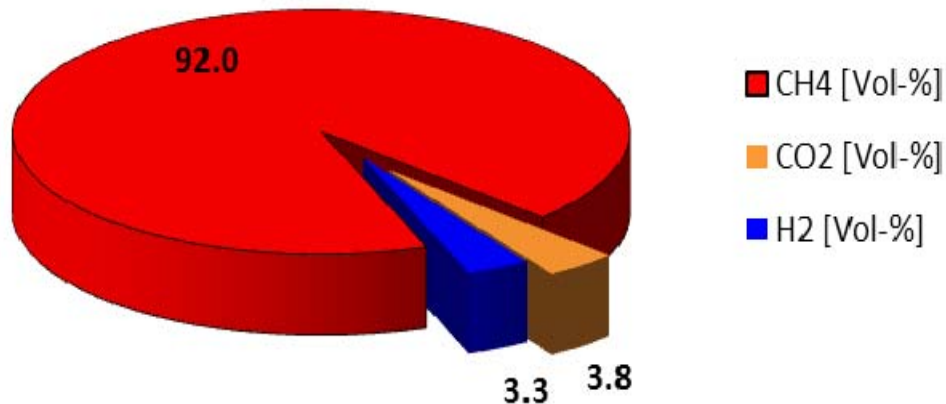
250 kW_e plant:
results



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

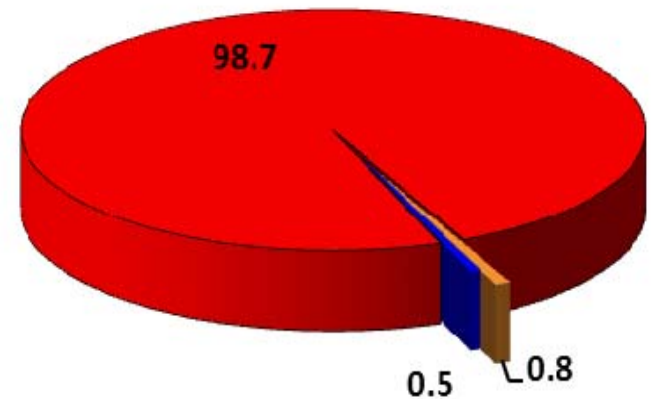


Reaction Parameters:

SV = 1365 1/h

$p_{\text{Methanation}} = 6 \text{ barg}$

With Gas Upgrade



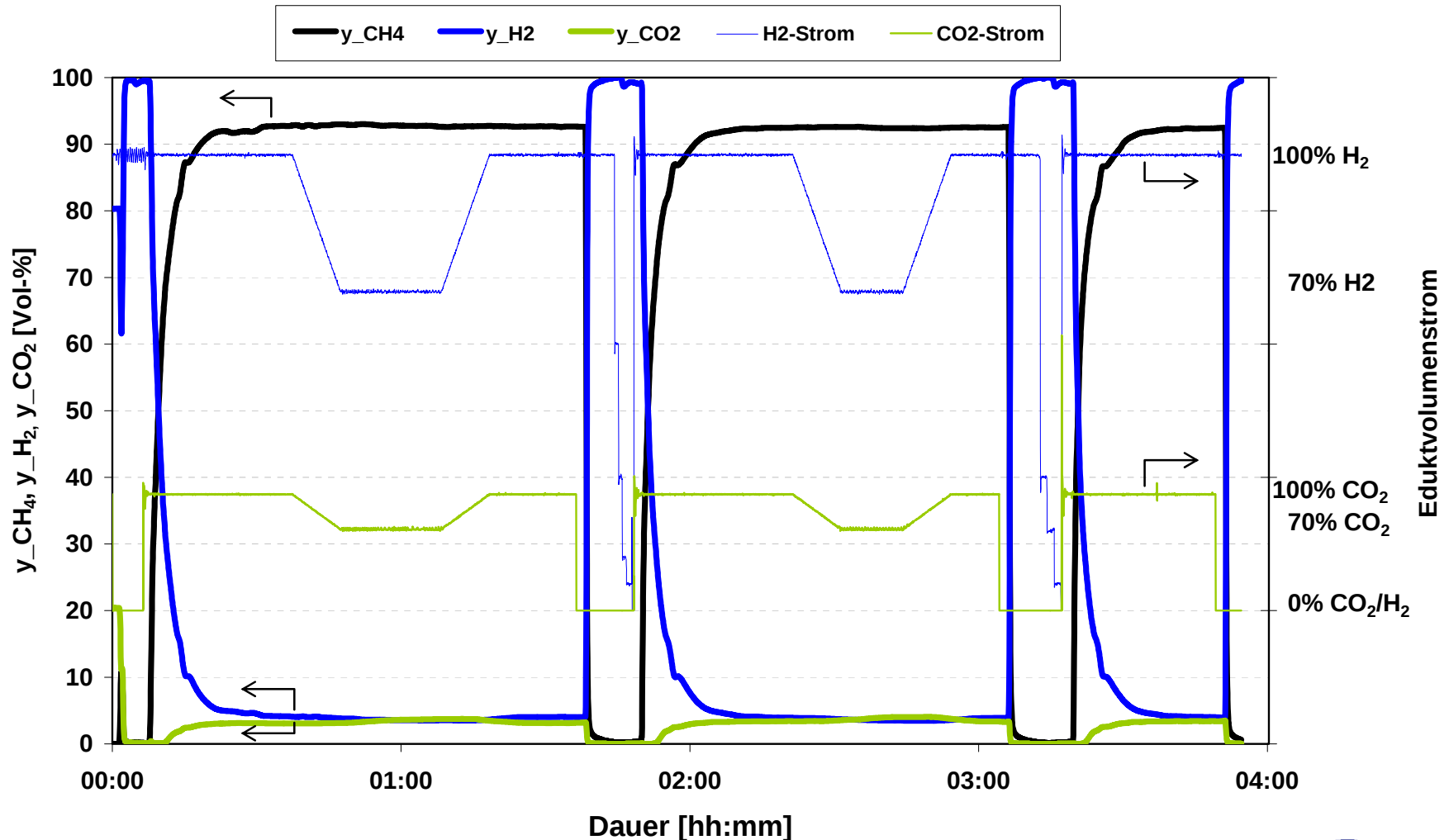
Reaction Parameters:

SV = 1365 1/h

$p_{\text{Methanation}} = 4 \text{ barg}$

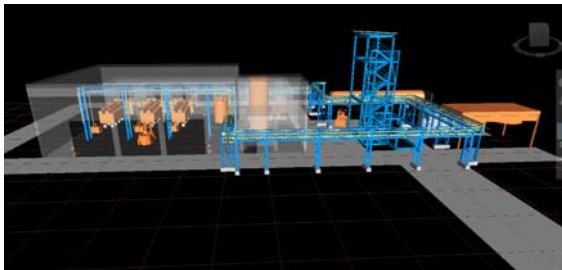
$\Delta p_{\text{Membran Unit}} = 4 \text{ bar}$

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

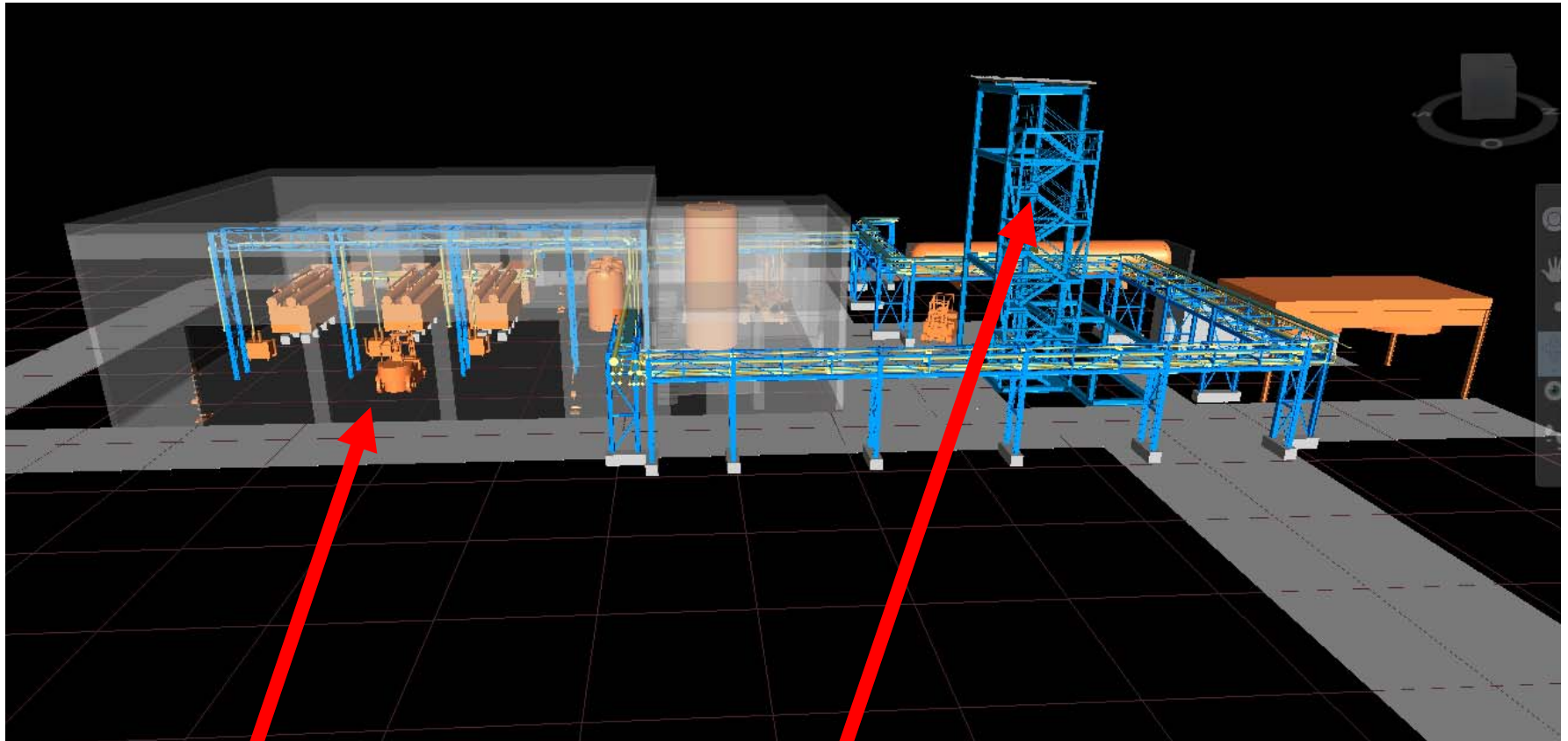


Power-to-Gas (P2G[®])

6000 kW_e plant



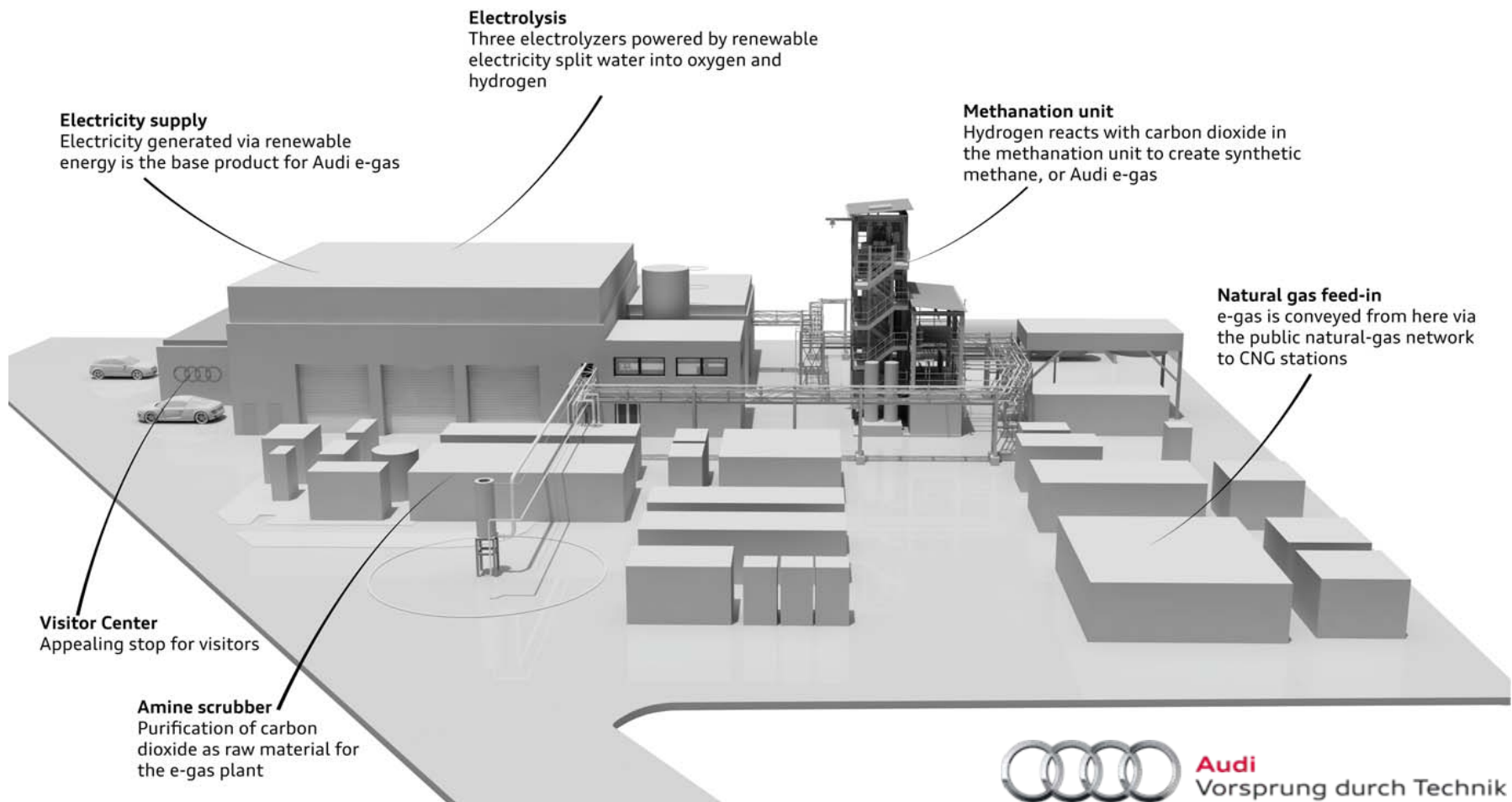
ETOGAS Layout of 6000kW_{el}-P2G[®] - Plant in Werlte (Audi e-gas Project)



Electrolysis

Methanisation

ETOGAS Layout of 6000kW_{el}-P2G[®] - Plant in Werlte (Audi e-gas Project)



Audi
Vorsprung durch Technik

Source: www.audi-mediaservices.com

ETOGAS
smart energy conversion



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

Audi Deutschland > Presse Audi MediaServices - öffentliche Inhalte Audi balanced mobility

Audi balanced mobility



e-gas-Project

sustainable mobility with renewable electricity-based CH₄ (e-gas)



Projektpartner



Audi blickt weiter



Audi Technology Portal Impressum Rechtliches

Restart English _ Vollbild

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Biogenic Carbon Resources for P2G[®]

Is enough biogenic carbon
for P2G[®] available?

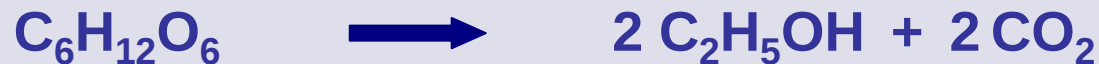


Biogenic CO₂ (CO) Resources: via Anaerobic Digestion, Ethanol Production, Gasification

Anaerobic Digestion:



Ethanol Production:



Thermo-chemical Gasification:



CO₂ / 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

¹⁾ Direct CO₂ recycling:

CCPP/CCU: Combined Cycle Power Plant / Carbon Capture and Utilisation

25 GW, 3000 h/a, η = 50 %, CO₂ retention: 90 %

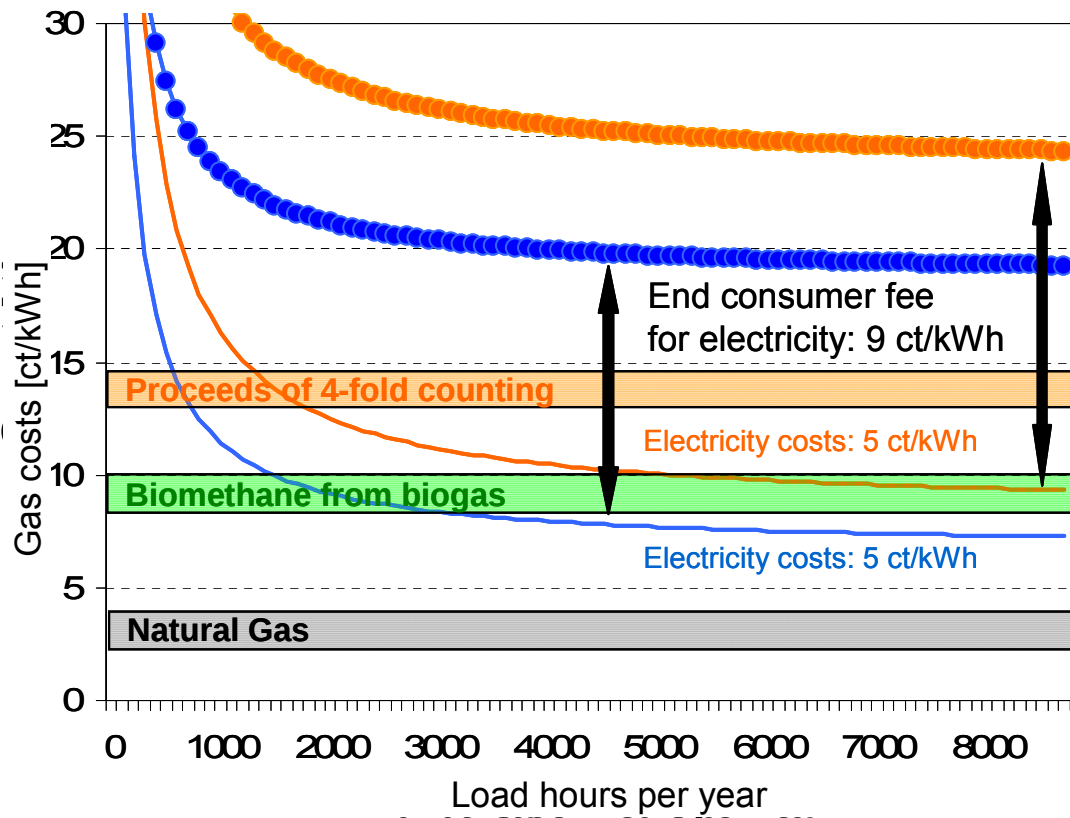
SNG: Substitute Natural Gas

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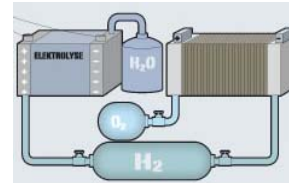
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Options for Long Term (Seasonal) Energy Storage: Chemical Energy Carriers

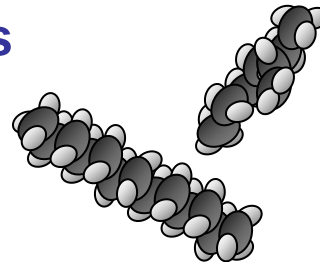
➤ Hydrogen



➤ 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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