Chemische Speicher

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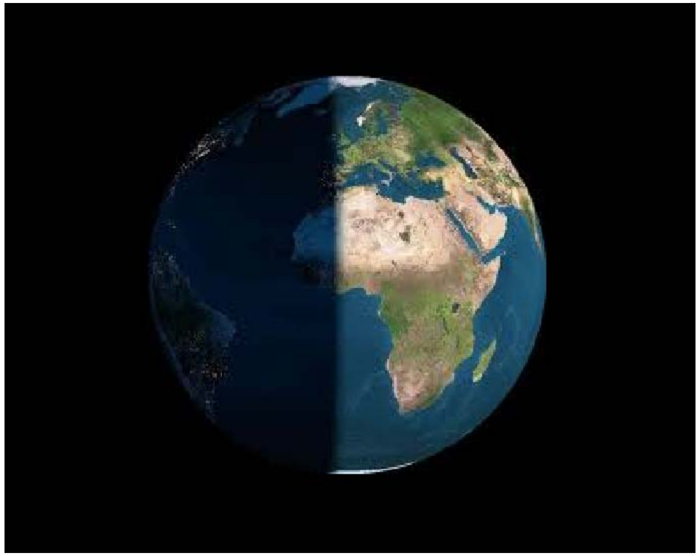
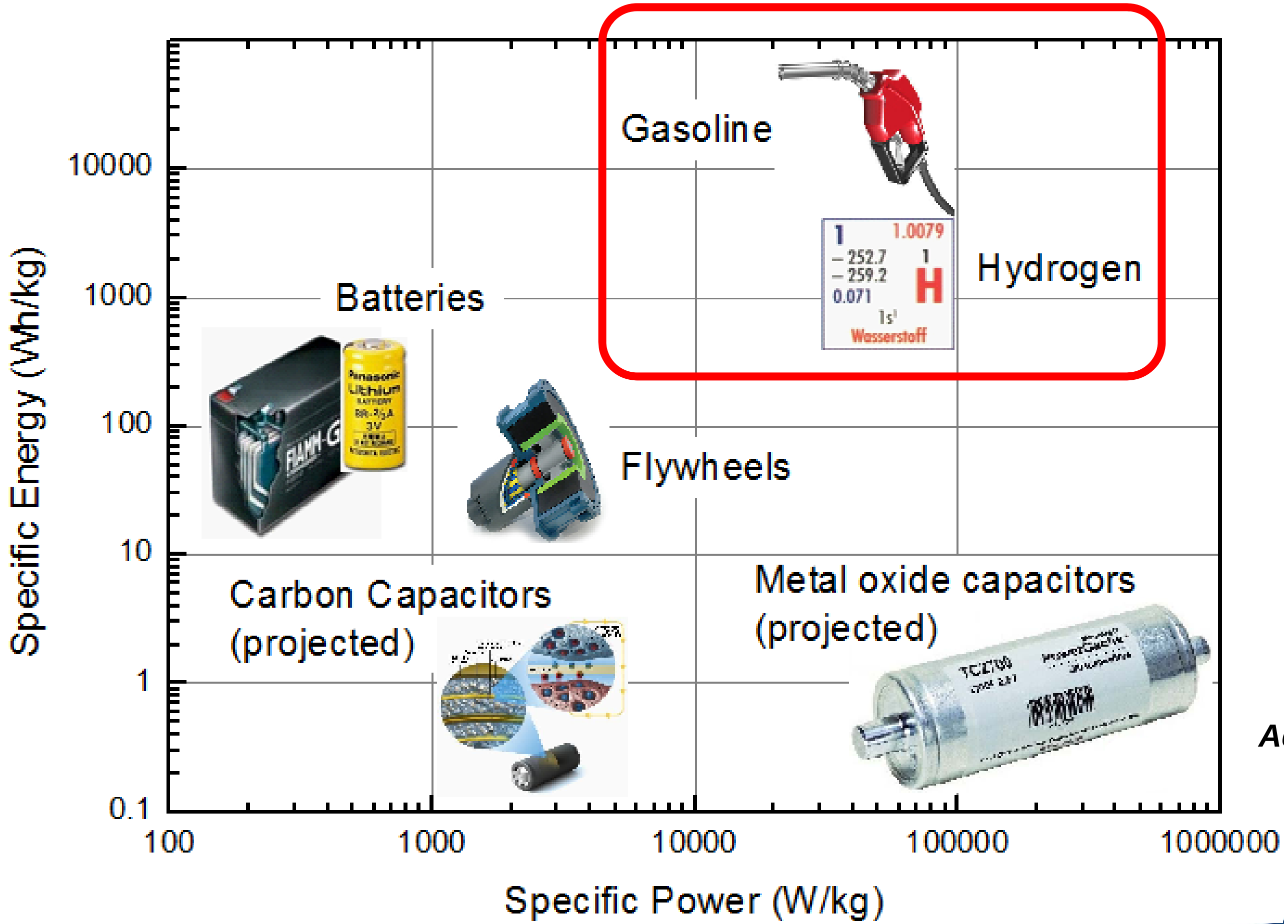


The problem:

- The electricity grid cannot deal with massive, long-lasting fluctuations in supply
- Renewable energy is often generated at a different place than where it is needed most

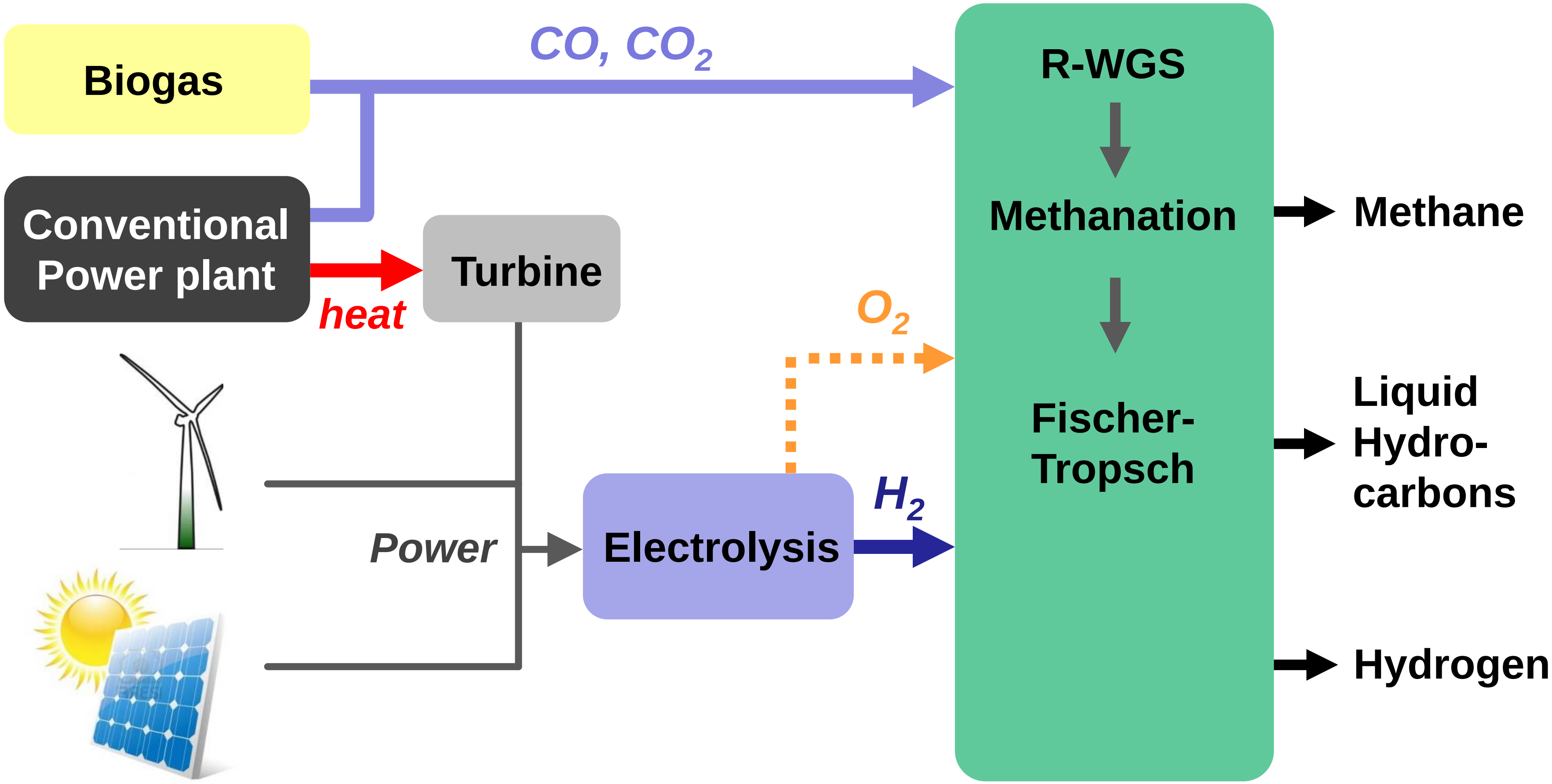
Need for large-scale energy storage solution

For energy storage on a Gigawatt-hour scale, chemical fuels are difficult to beat



Adapted from NREL, USA

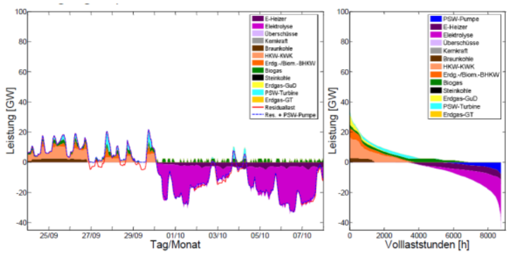
Power-to-Gas


Biogas
CO, CO_2
Conventional Power plant
heat
Turbine
Power
Electrolysis
O_2
H_2
R-WGS
Methanation
Fischer-Tropsch
Methane
Liquid Hydro-carbons
Hydrogen

Für IWES ist Power-to-Gas-Technologie zentraler Bestandteil chemischer Speicher – Forschungsschwerpunkt in energiewirtschaftlicher System- und Anlagenebene

Fraunhofer IWES | Forschungsaktivitäten zu chemischen Speichern | **Power-to-Gas-Technologie** (H_2 und CH_4)

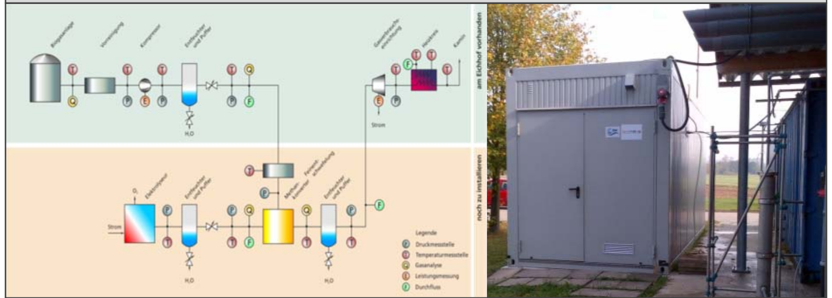
Energiewirtschaft und Systemanalyse



a) Exemplarischer Verlauf über zwei Wochen | b) Jahresdauerlinie

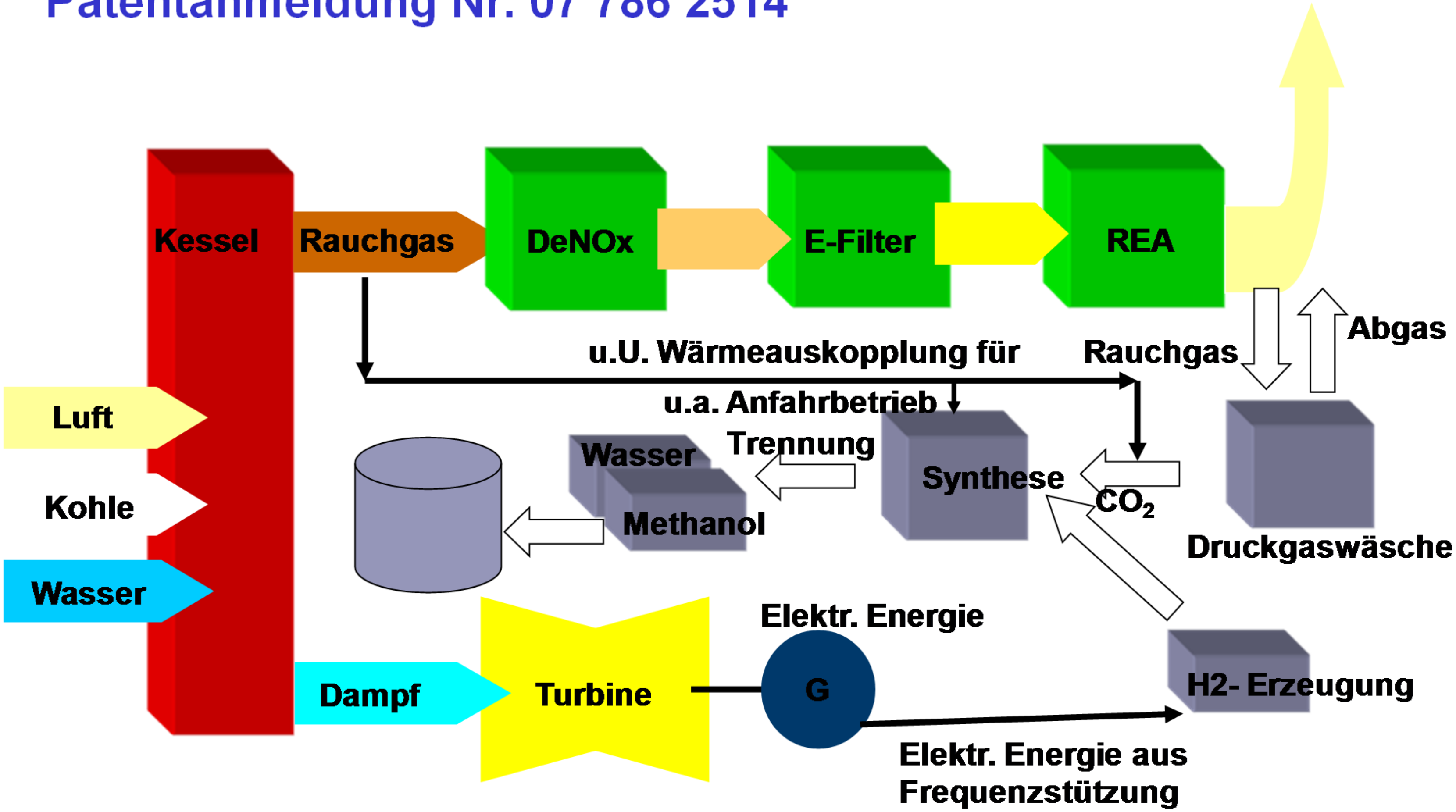
- Technologiebewertung von Power-to-Gas und anderen Speichertechnologien in zukünftigen Energieversorgungssystemen mithilfe europäischer Kraftwerks- u. Speichereinsatzplanung
- räumlich und zeitlich optimaler Power-to-Gas-Einsatz
- sektorübergreifende Analyse der Power-to-Gas-Technologie, d. h. insbesondere Nutzung im Verkehrs- und Wärmesektor
- konvergente Nutzung von Strom- und Gasnetzen

Anlagentechnik



- Direktmethanisierung als direkte Kopplung von Biogasanlagen und der Power-to-Gas-Technologie
- Einbindungskonzepte, Entschwefelung, Sicherheitsmaßnahmen
- Versuchsanlagen am IWES-Standort Eichhof
- CO_2-Bedarf der Power-to-Gas-Anlagen und nutzbare CO_2-Potenziale

Blockschema der Abgasreinigung und der Methanolgewinnung im konventionellen, fossil befeuerten Kraftwerk; Europäische Patentanmeldung Nr. 07 786 2514



Synthetic Liquid Hydrocarbons

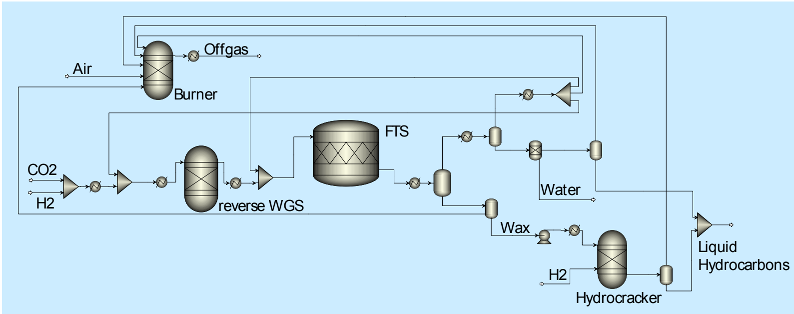
HGF Energy-Alliance ***SynKWS***

Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

CVT Chemical Engineering — Universität Stuttgart Germany

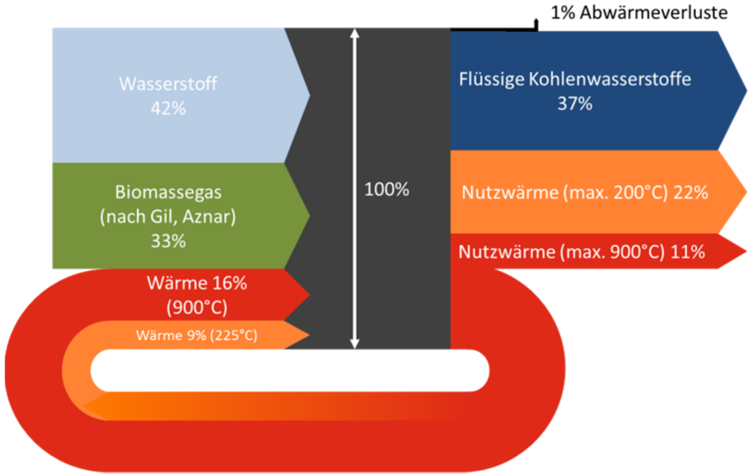
Process Concept

- Primary Renewable Energy Sources: Solar, Wind, Biomass
- Chemical Conversion via Electrolysis, Gasification, Fischer-Tropsch-Synthesis
- Synthesis of tailored hydrocarbons as chemical storage for centralized and decentralized applications (power generation, transportation fuels etc.)

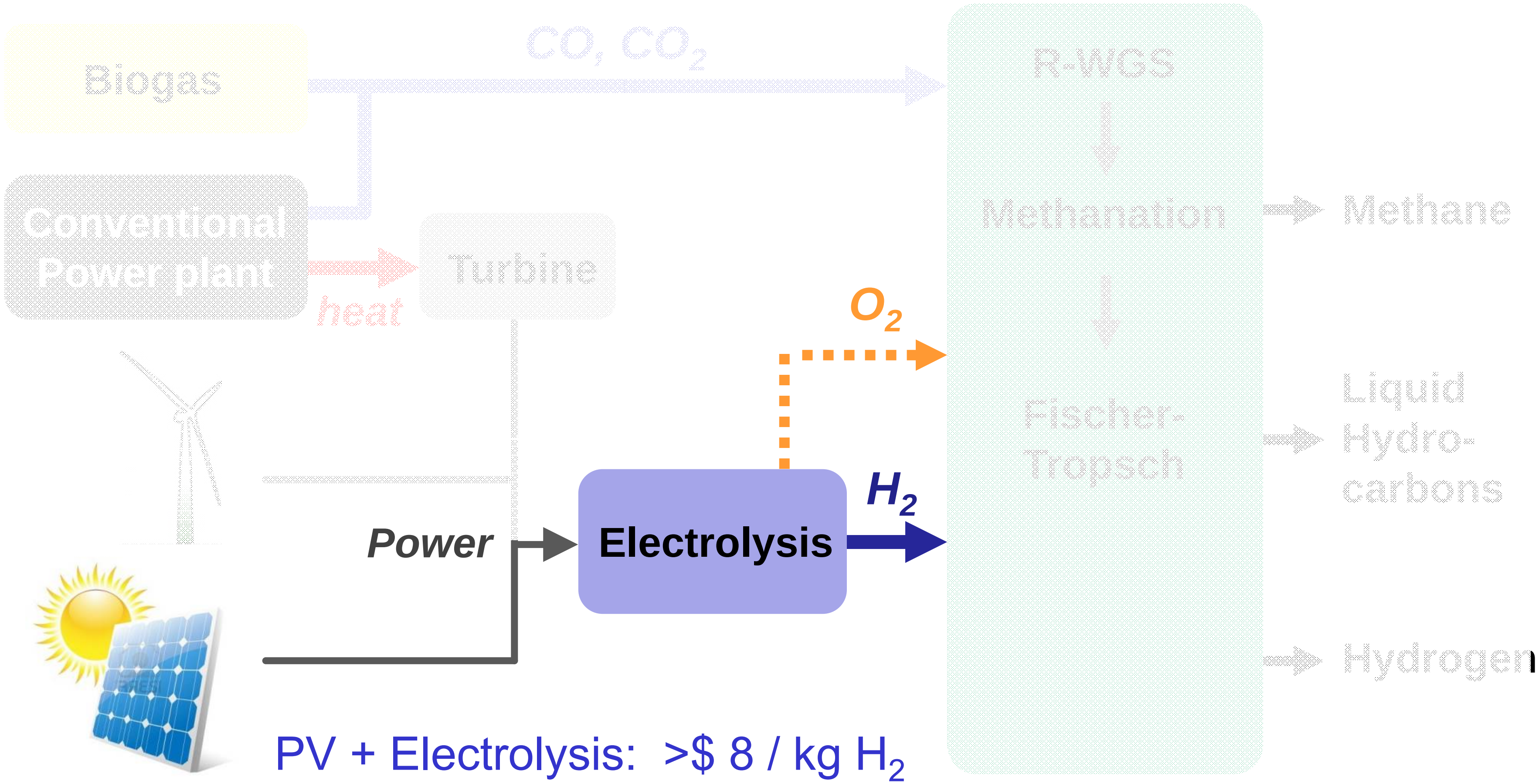


DLR Research Activities

- Systemic evaluation of synthetic hydrocarbons as chemical energy storage
- Process development and techno-economic evaluation
- Evaluation of combustion characteristics



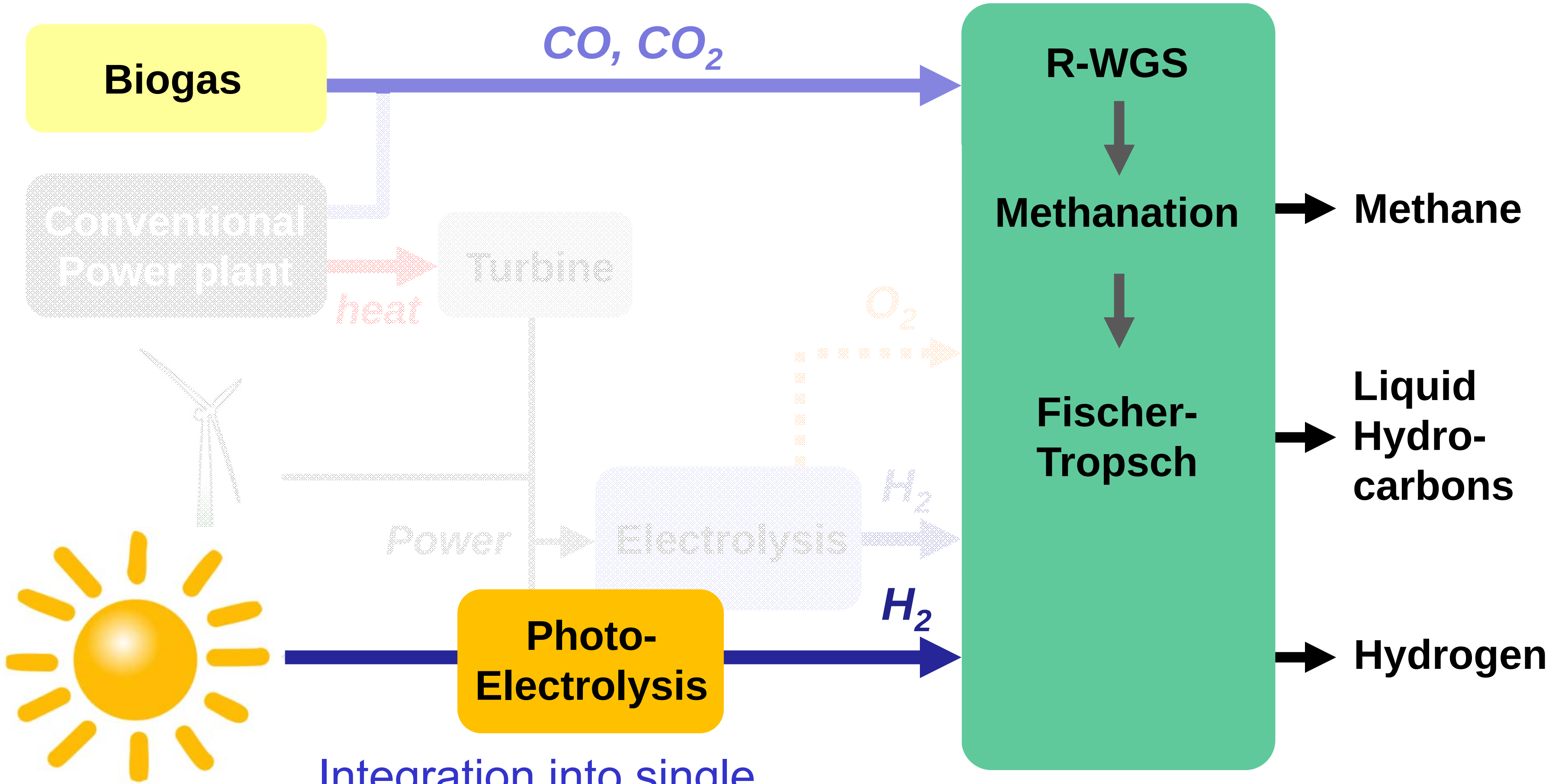
Power-to-Gas



PV + Electrolysis: >$ 8 / kg H_2

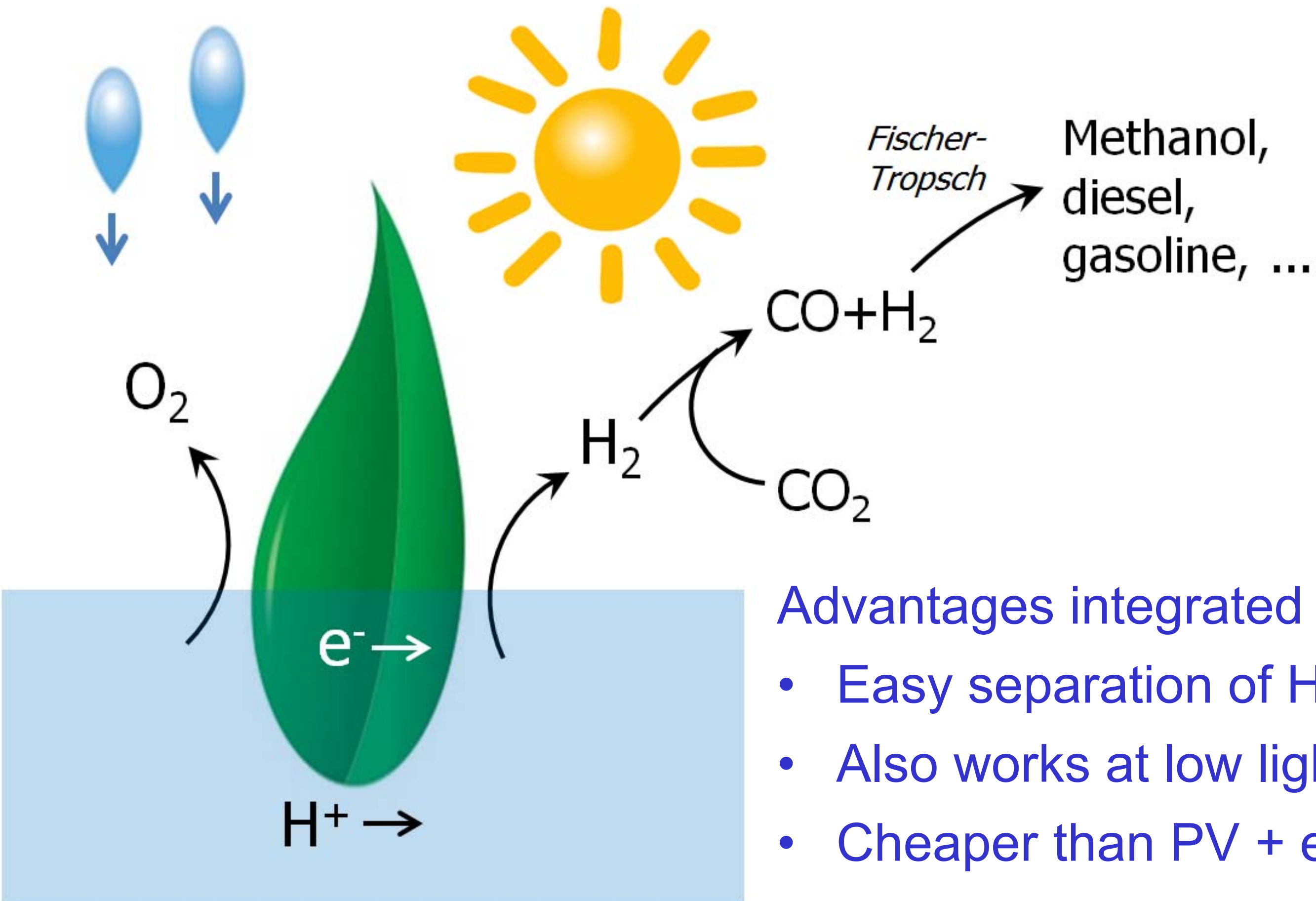
EU (DOE) targets: < 5 €($) / kg H_2

Power-to-Gas and Power-to-Liquid



Integration into single device strongly reduces costs

Towards Solar Fuels: Photoelectrochemical Water Splitting at an Artificial Leaf



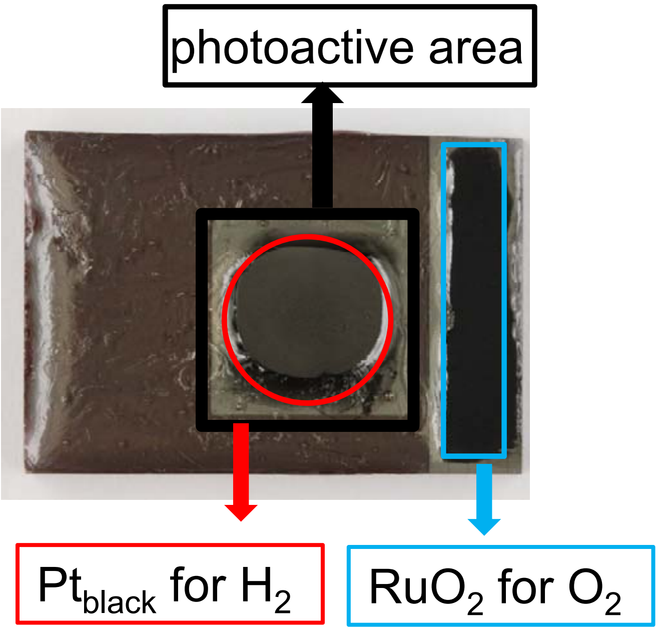
Advantages integrated PEC device:

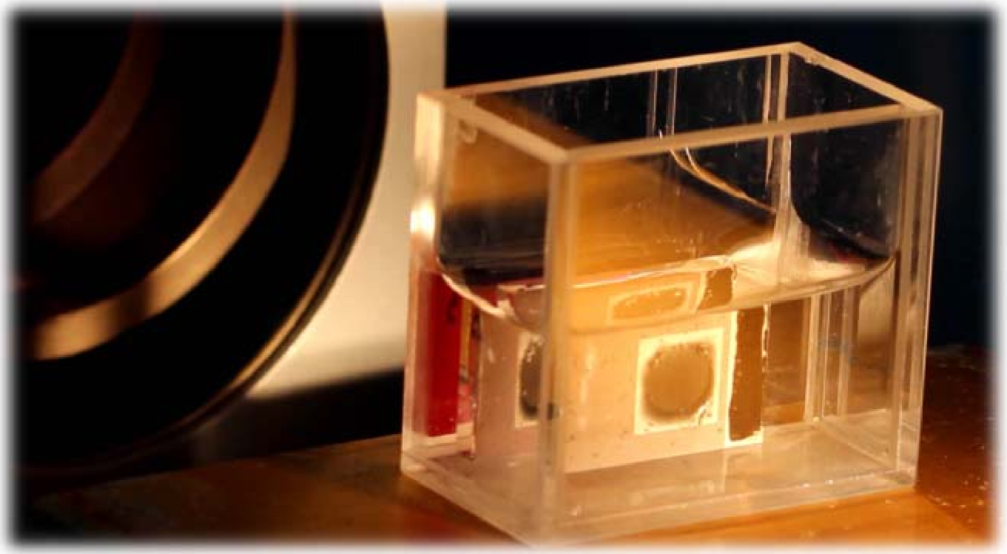
- Easy separation of H_2 and O_2
- Also works at low light intensities
- Cheaper than PV + electrolyzer

An “Artificial Leaf” Based on a Superstrate PV Cell

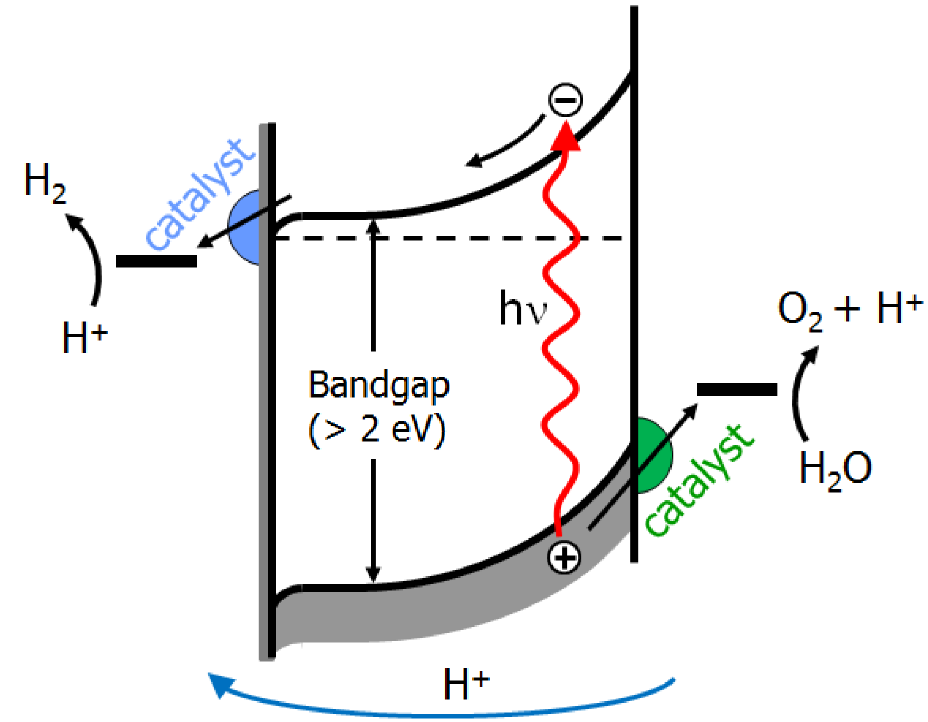
- a-Si/a-Si/μ-Si cell provides ~1.8 V at working point
- PEDOT:PSS ‘glue’ immobilizes the catalysts
- Superstrate design avoid light scattering by bubbles
- Operation close to maximum power point, η = 3.5%
- Less than 10% performance loss in 18 hrs

pvcomB





Chemically-Stable Semiconductors: Metal Oxides



Metal oxide semiconductors

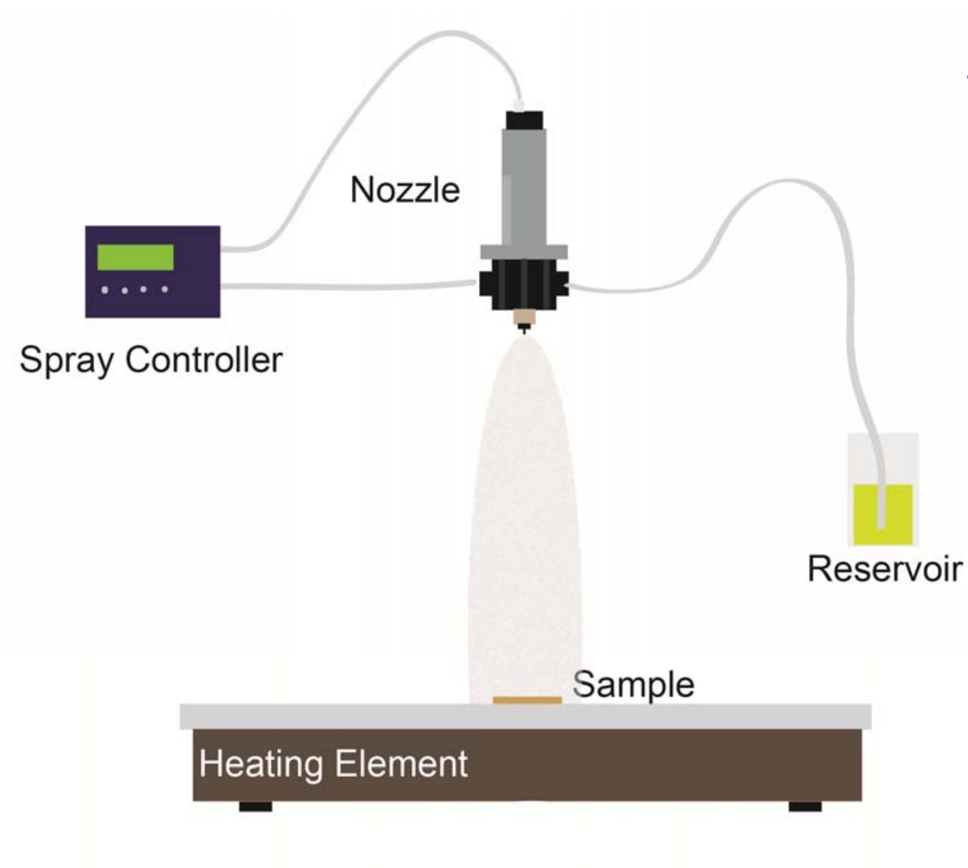
- \+ Bandgap >1.23 V (1.5 – 3 eV)
- \+ Chemically stable
- \+ Easy to make, cheap
- – Poor carrier transport
- – Defects → recombination
- – Slow surface reactions
- – Bad energetics for H_2 evolution

Examples:

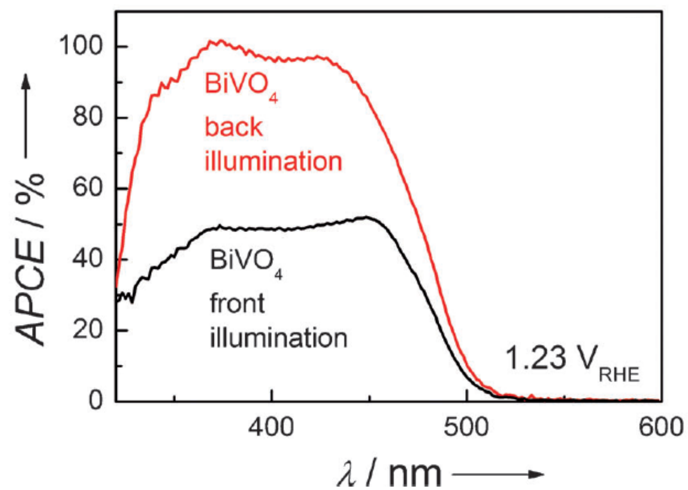
TiO_2, Fe_2O_3, WO_3, Cu_2O

Bismuth Vanadate, $BiVO_4$

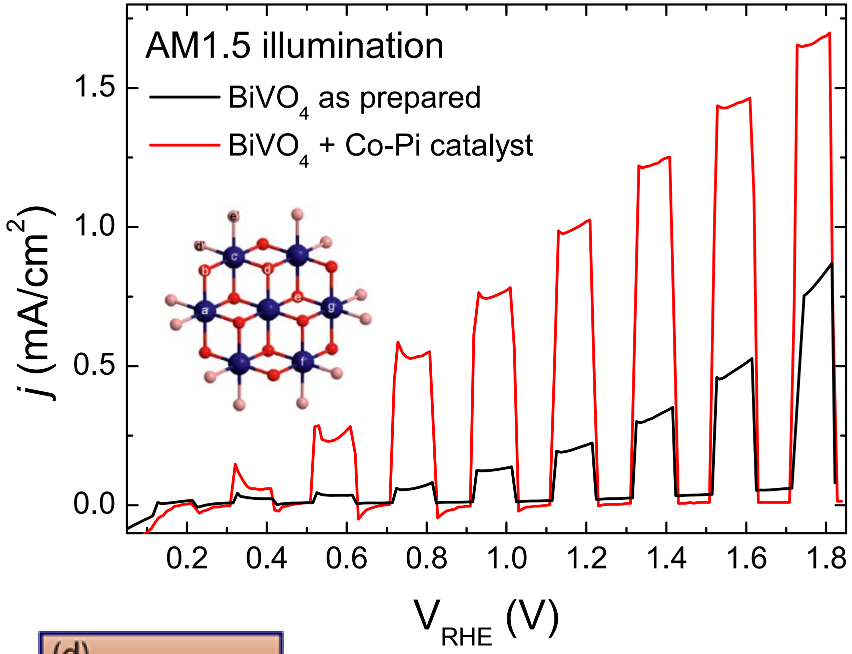
TU Delft

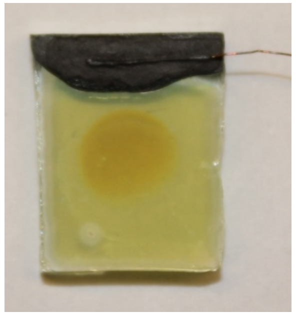


- \+ Bandgap 2.4 eV (η_{theory} = 9.3%)
- – Poor carrier mobility, 0.04 cm^2/Vs)
- \+ Long lifetime, ~40 ns
- \+ Int. QE ~100% at low light intensities
  $\Rightarrow$ almost no recombination!
- – Low QE under 1 sun conditions

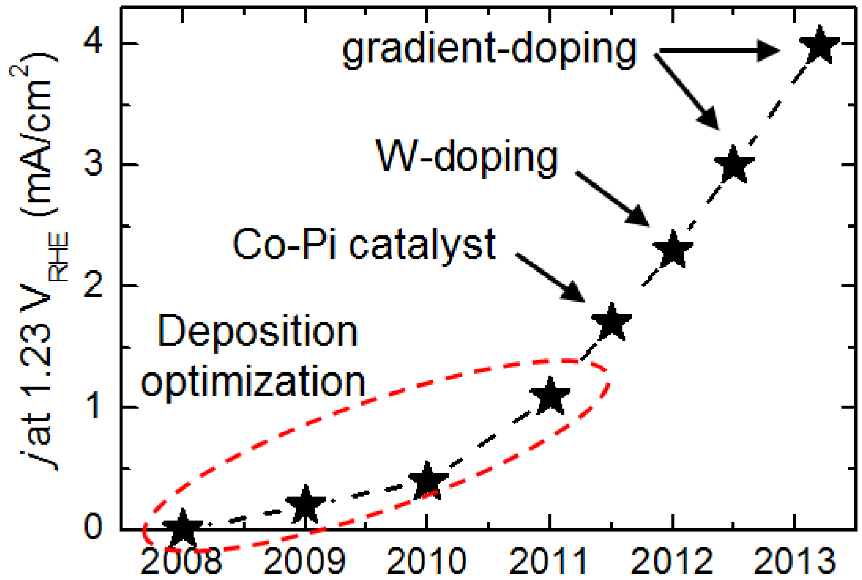


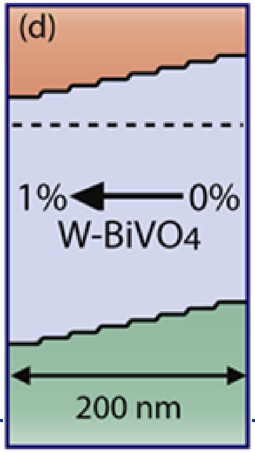
Bismuth Vanadate, $BiVO_4$





$BiVO_4$ film on glass with Co-phosphate catalyst (Co-Pi)

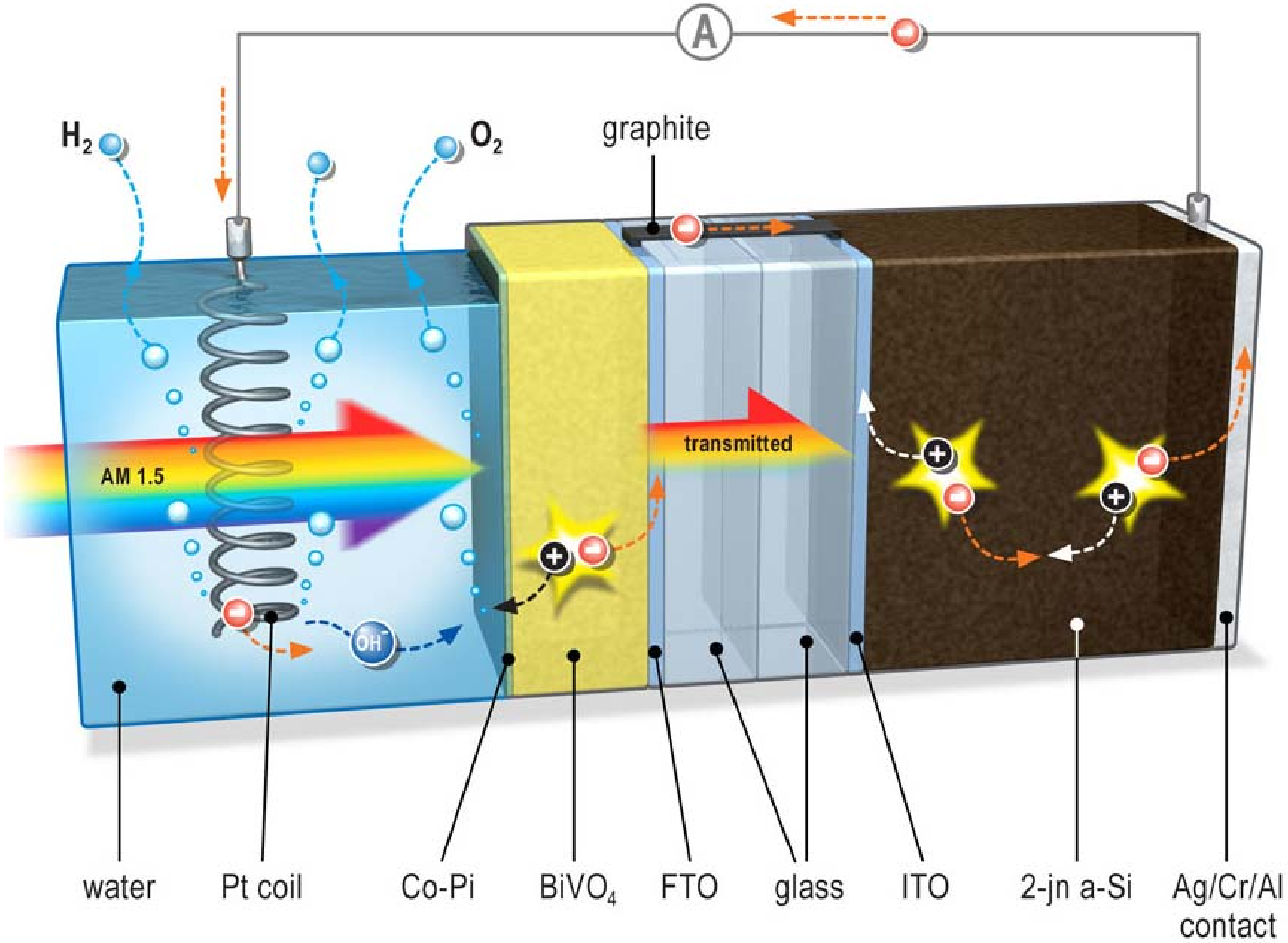




Gradient dopant profile enhances the charge separation

(similar to BSF passivation in photovoltaics)

Hybrid CoPi-W:$BiVO_4$ / 2-jn a-Si Water Splitting Device



TU Delft

F.F. Abdi et al., *Nature Commun.* 4 (2013) 2195

Hybrid CoPi-W:$BiVO_4$ / 2-jn a-Si Water Splitting Device

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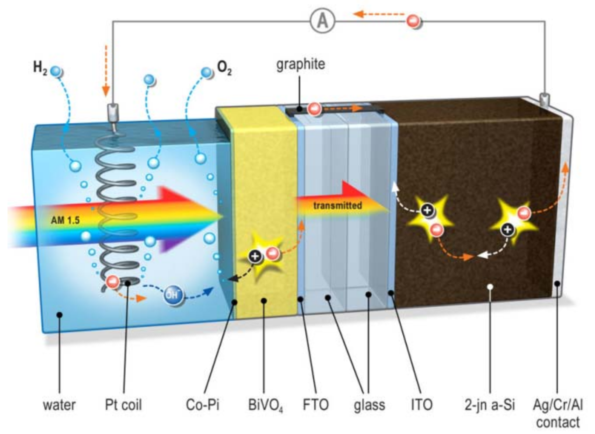

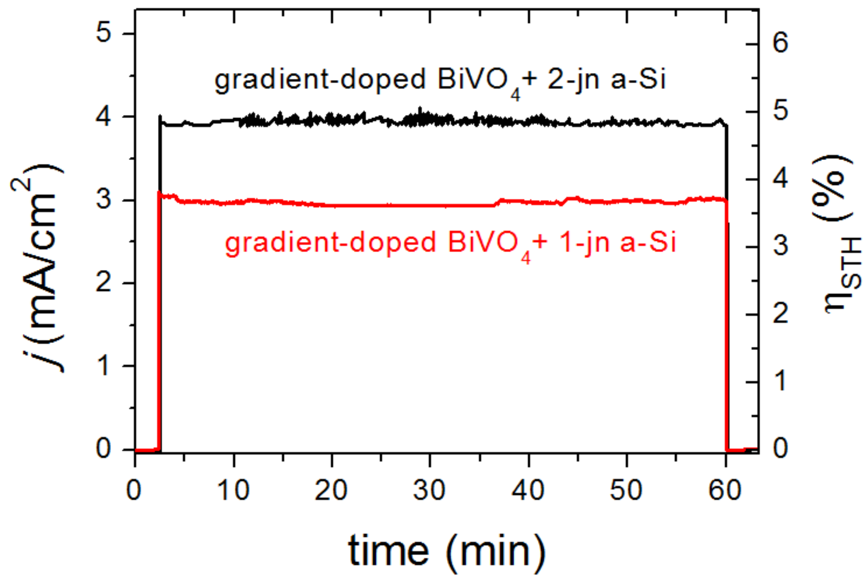

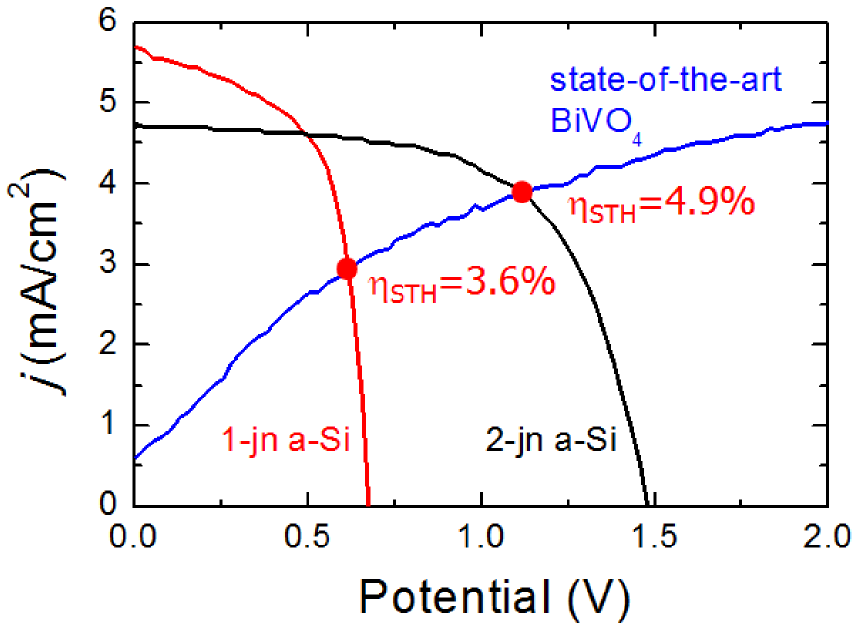

Highest efficiency (4.9%) ever reported for a water splitting device based on a metal oxide semiconductor

Conclusions

- Chemical storage will be an integral part of future energy systems
- Power-to-gas technology is especially important for Germany
- Photoelectrochemical water splitting:
  - Possible alternative for coupled PV / electrolyzer systems, but research is still in an early phase
  - Find new oxides with smaller bandgaps (1.8 – 2.2 eV)
  - Improve understanding of fundamental mechanisms
  - Scale-up to larger areas:
    EU Project PECDEMO with DLR, Evonik, and others
    Aims: 50 cm^2, 8% efficiency, 1000 hours lifetime,
    cost analysis, systems and life-cycle analysis

Vielen Dank für Ihre Aufmerksamkeit!

Fraunhofer IWES

izes gGmbH Institut für ZukunftsEnergieSysteme

DLR

HZB Helmholtz Zentrum Berlin

FVEE ForschungsVerbund Erneuerbare Energien
Renewable Energy Research Association