understanding new energies

H_2 Lab - a Combined Training Platform

Michael Dietrich
Dr. Dmitry Kushnikovskiy
leXsolar GmbH

About us

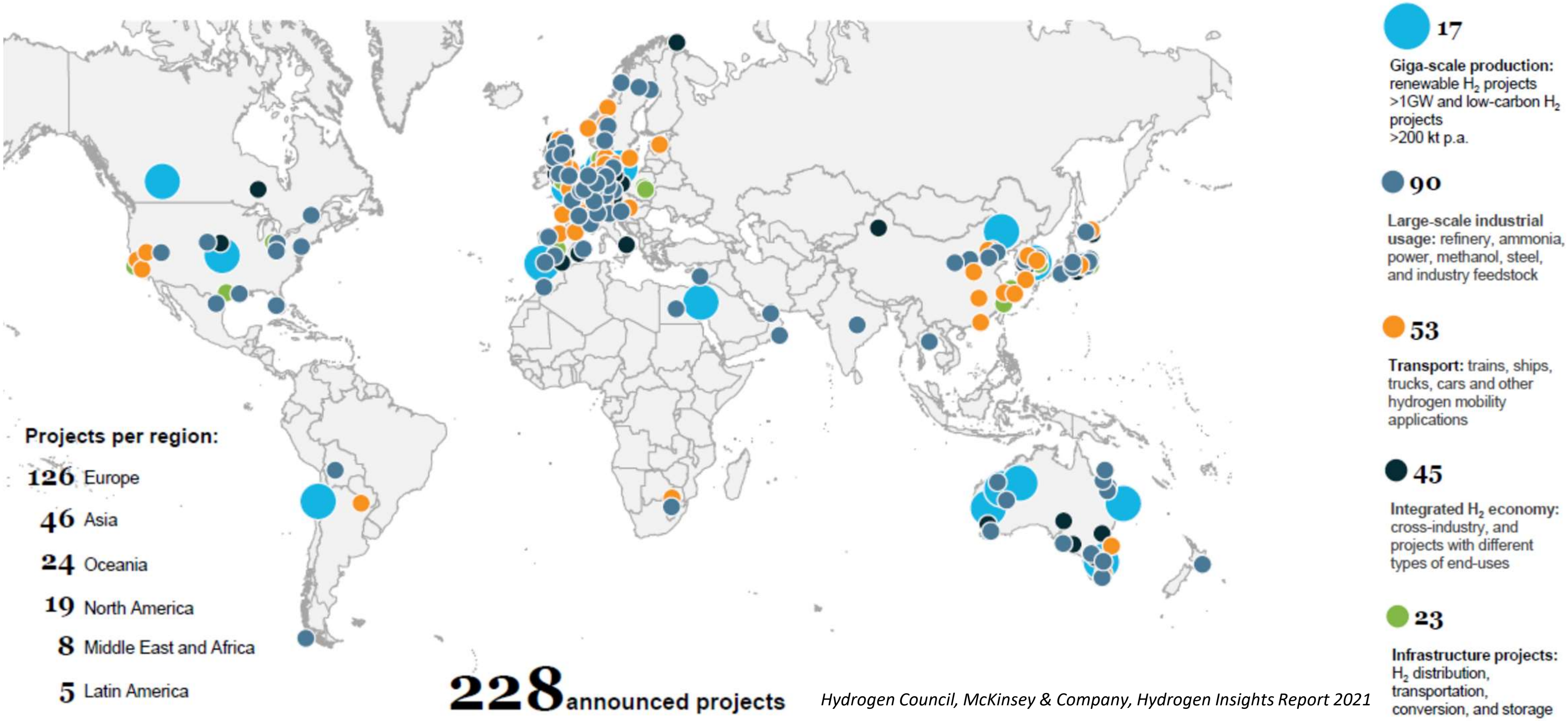
- **Established in 2003 as a spin-off from the Technical university of Dresden/ Germany**
- **Worlddidac Award Winner**
- **One of the leaders in education in renewable energies**
- **Active in 60+ countries with over 50 partners**

leXsolar areas of expertise

EU Environmental Strategy

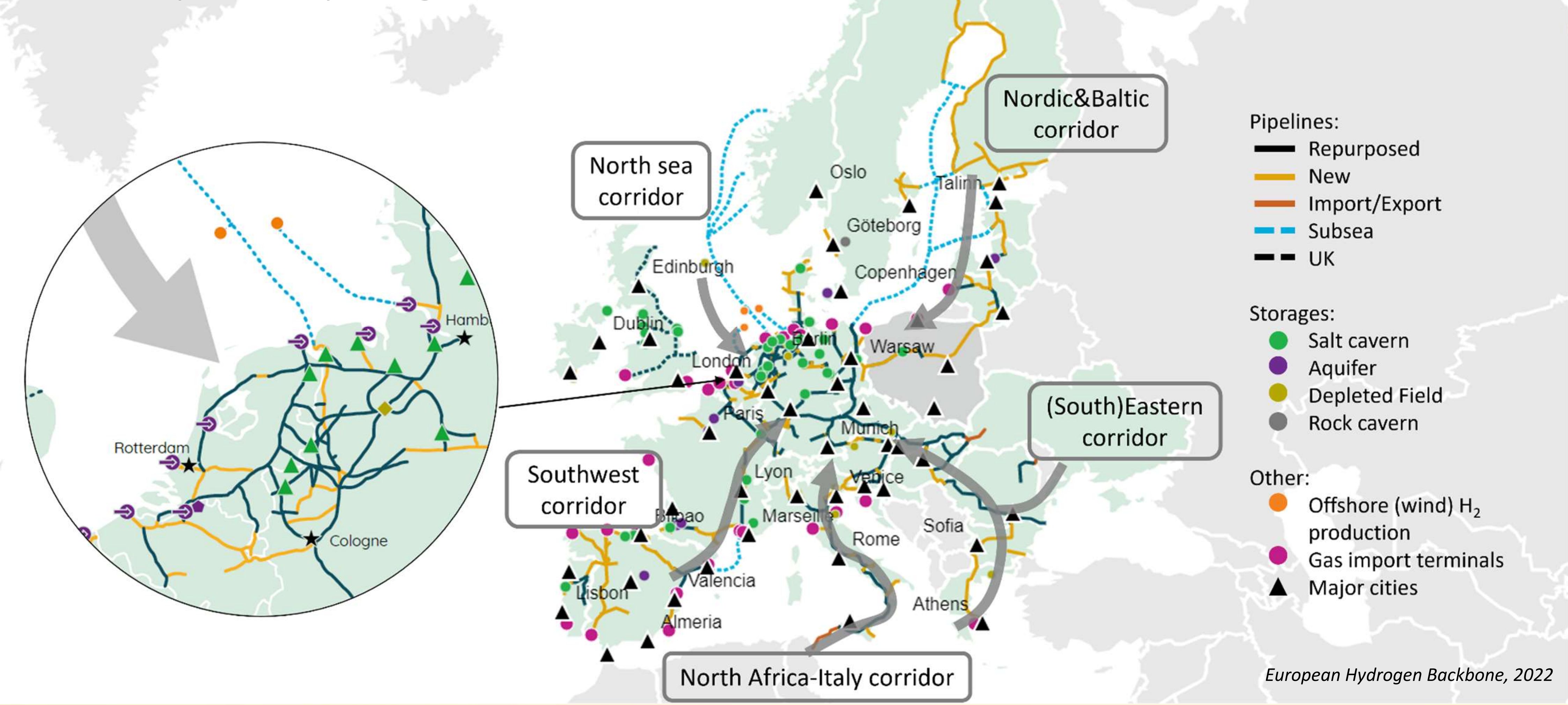
- 55% reduction of emissions from cars by 2030
- Zero emissions from new cars by 2035
- Net zero emissions of greenhouse gases by 2050
- 40% new renewable energy target for 2030
- 160,000 additional green jobs could be created in the construction sector by 2030
- 35 million buildings could be renovated by 2030
- Economic growth decoupled from resource use
- 600 billion euro investments from NextGeneration EU Recovery Plan

Global Hydrogen Projects



Hydrogen Council, McKinsey & Company, Hydrogen Insights Report 2021

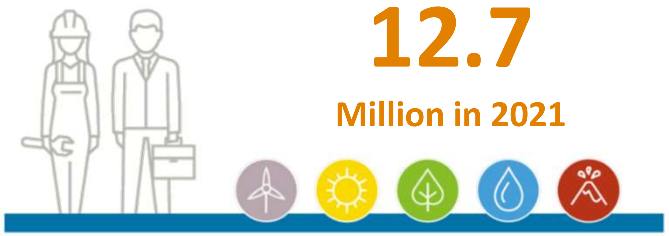
European Hydrogen Backbone Initiative



European Hydrogen Backbone, 2022

Jobs in Renewable Energy Sector

- Doubled since 2011
- Ca. 38 million are expected globally by 2030
- 134 million in the energy sector
- Asia accounted for 63% of total jobs in renewables globally



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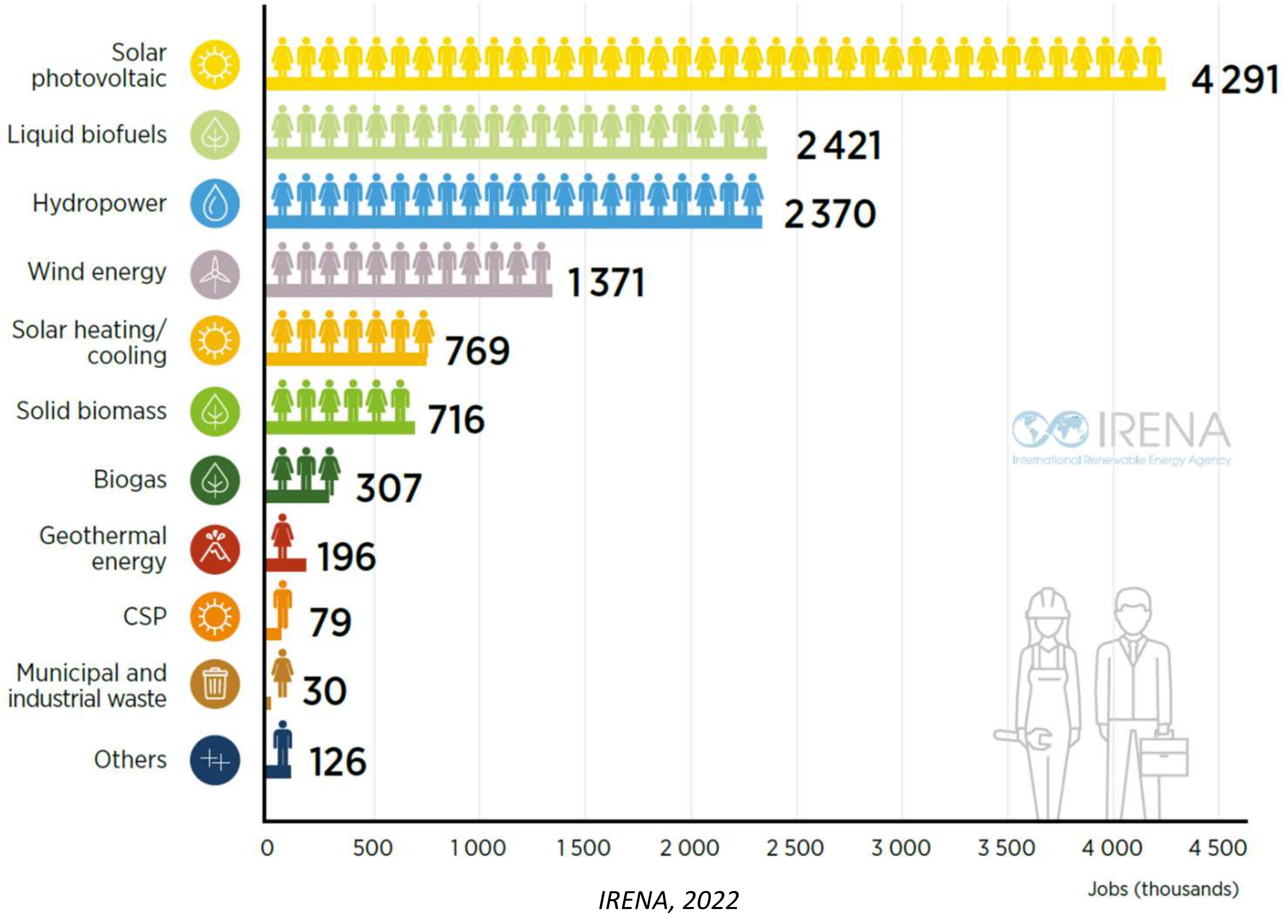
Million in 2021



IRENA, 2022

leXsolar H_2 Lab

Module 0

- History of Fuel Cell Technologies
- H_2 Production
- H_2 Transport
- H_2 Storage
- H_2 Applications

leXsolar Experimental Kits

3. H_2 Expert
- Comprehensive experimental kit of PEM fuel cell technology
- Process control and data acquisition
- Efficiency of the fuel cell system
- Influence of the temperature and air supply

2. H_2 Advanced
- Operation and characteristics of electrolyzer
- Generation of “Green” hydrogen
- Operation and characteristics of PEM fuel cell stack
- Efficiency of fuel cell

1. H_2 Beginner
- Fundamentals of fuel cells
- Proton Exchange Membrane Fuel Cell
- Direct Ethanol Fuel Cell
- Direct Flame Solid Oxide Fuel Cell

H_2 Lab

- Certification
- Blockchain credentials
- Issuer verification
- Certificate validation
- Skill pass

H_2 Lab

Target group	TVET (Technical and Vocational Education and Training)
ISCED Level	5 - Short-cycle tertiary education
Age group	16 – 50+
Number of students	20-30 students per classroom
Students per equipment	6-12 Students can work simultaneously with experimental kits
Focus of lab-equipment	Green Energy Education for TVET
Subjects:	Renewable Energies, Environmental and Electrical Engineering, STEM, Chemical
Quality standard:	leXsolar is an official member of the Worlddidac Association and Didacta e.V. Germany

Module 0: Fundamentals of hydrogen technologies

- **Previous knowledge:**
  - School level STEM
- **Learning objectives:**
  - Hydrogen safety
  - Basics of hydrogen economy
  - Current and emerging methods for producing hydrogen
  - Applications of hydrogen and fuel cells
  - Options for storing and transporting hydrogen
- **Duration:**
  - 3 units
  - 4 – 8 hours (self-paced),
  - up to 16 hours (as a part of the guided lessons)

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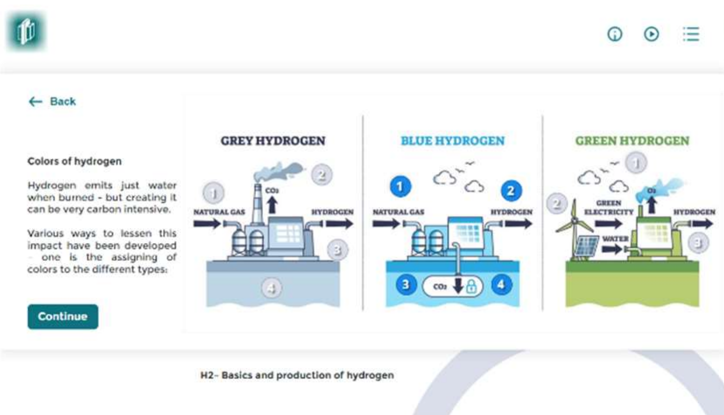
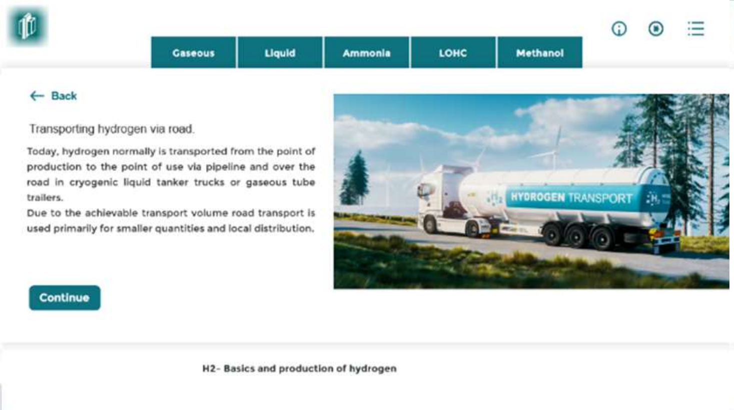
Module 0: Fundamentals of hydrogen technologies

Production of Hydrogen



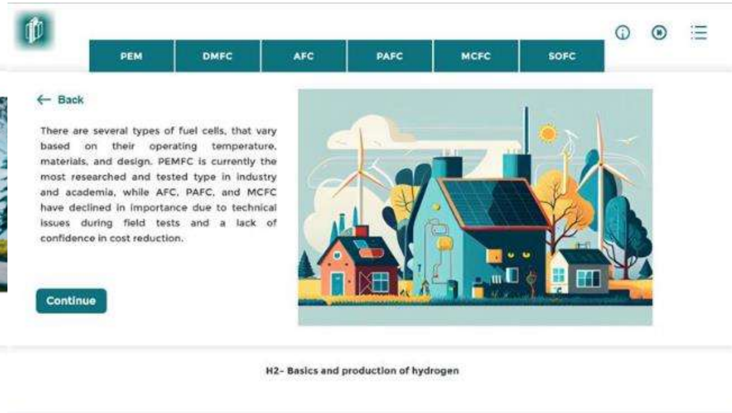
- Hydrocarbon Reforming
  - Steam Reforming
  - Partial Oxidation
- Hydrocarbon Pyrolysis
- Biological Processes
- Electrolysis
  - Alcaline
  - Solid Oxide Electrolyser Cell
  - Proton Exchange Membrane
- Other methods

Transport and Storage



- Chemical-based storage
  - Adsorbent
  - Liquid organic
  - Hydride
- Physical-based storage:
  - Liquid storage
  - Gas storage
- Hydrogen transport

Application



- Hydrogen as energy carrier
- Hydrogen as fuel
  - Portable
  - Stationary
  - Mobility
- Hydrogen in fuel cells
  - Proton Exchange Membrane
  - Alcaline
  - Phosphoric Acid
  - Molten Carbonate
  - Solid Oxide
  - Direct Alcohol

Module 1: H_2 Beginner

Previous knowledge:

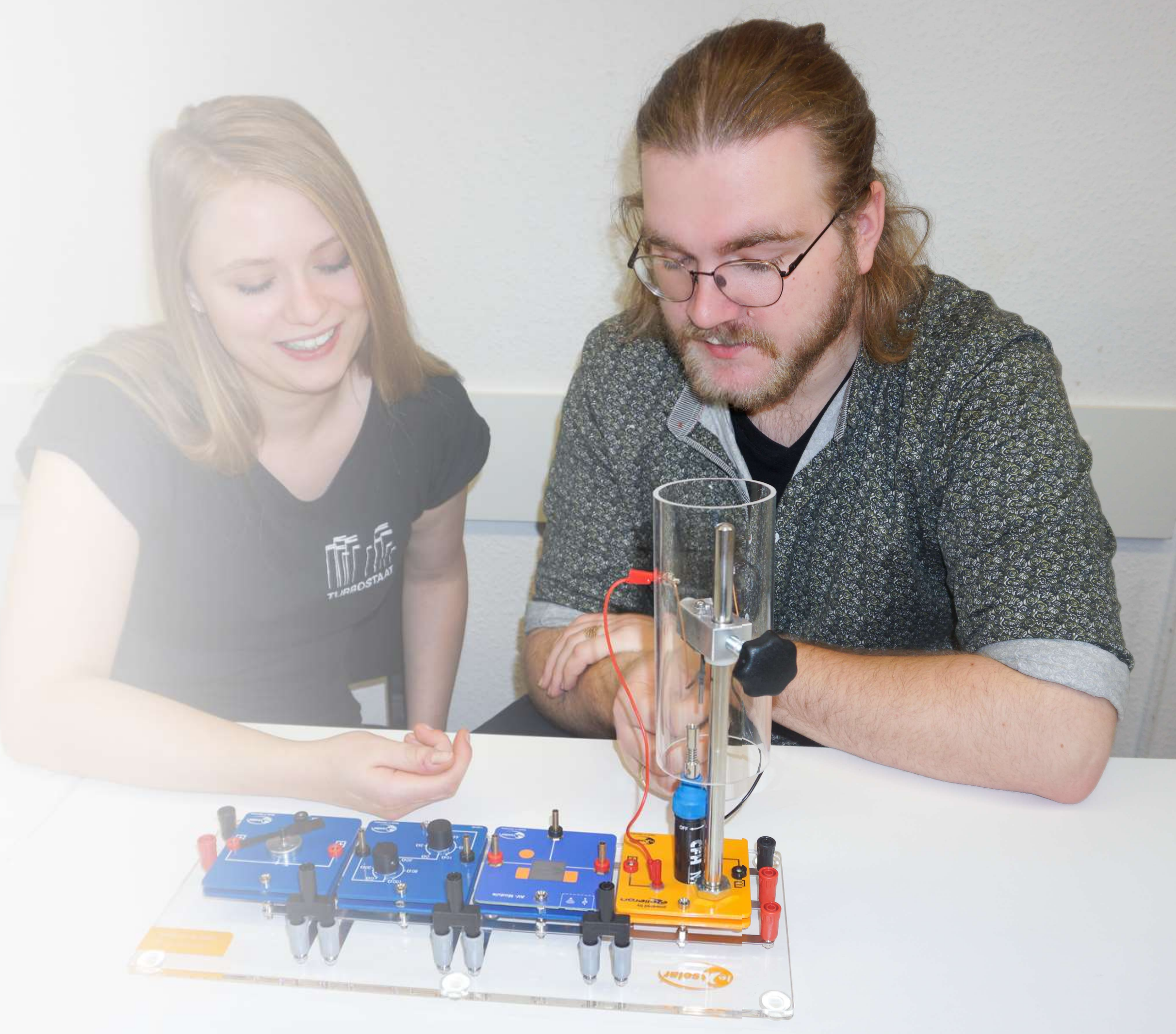
- Not required

Learning objectives:

- Basics of a solar-hydrogen energy cycle
- Conversion of electrical energy into chemical using electrolyser
- Conversion of chemical energy into electricity using fuel cells
- Types of fuel cell (PEM, EtOH, SOFC)
- Hydrogen storage in metal-hydride cartridges

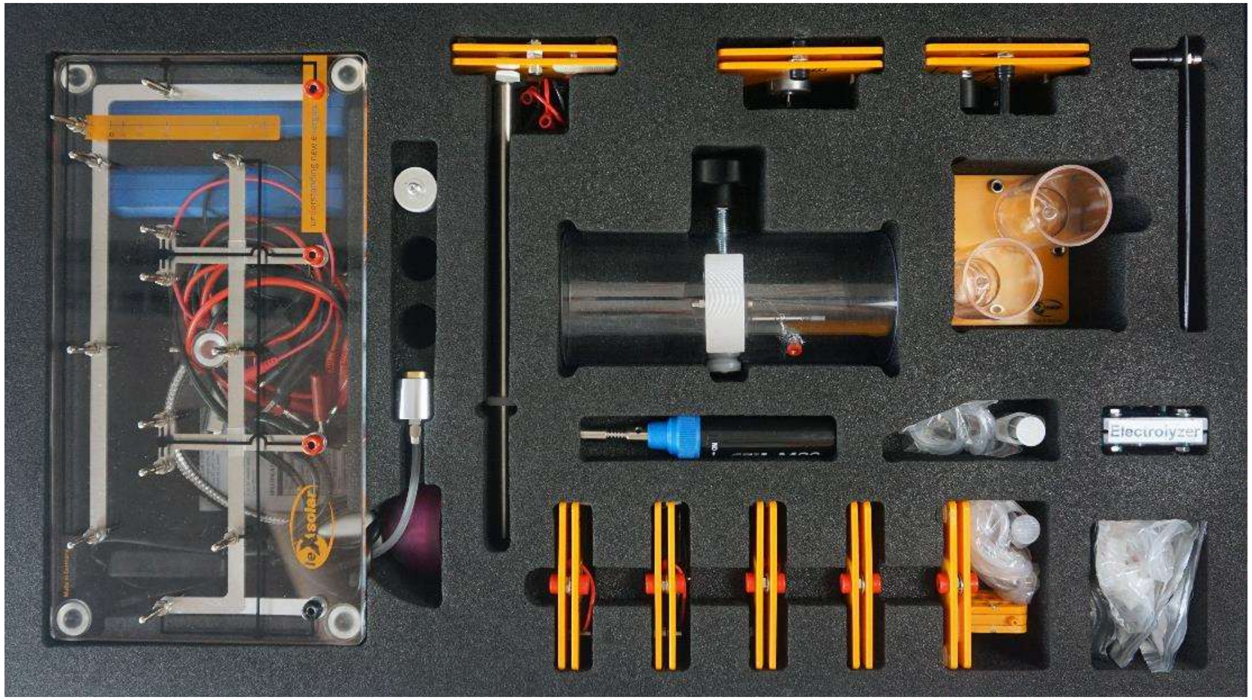
Duration:

- 4 main units; 8 - 12 hours

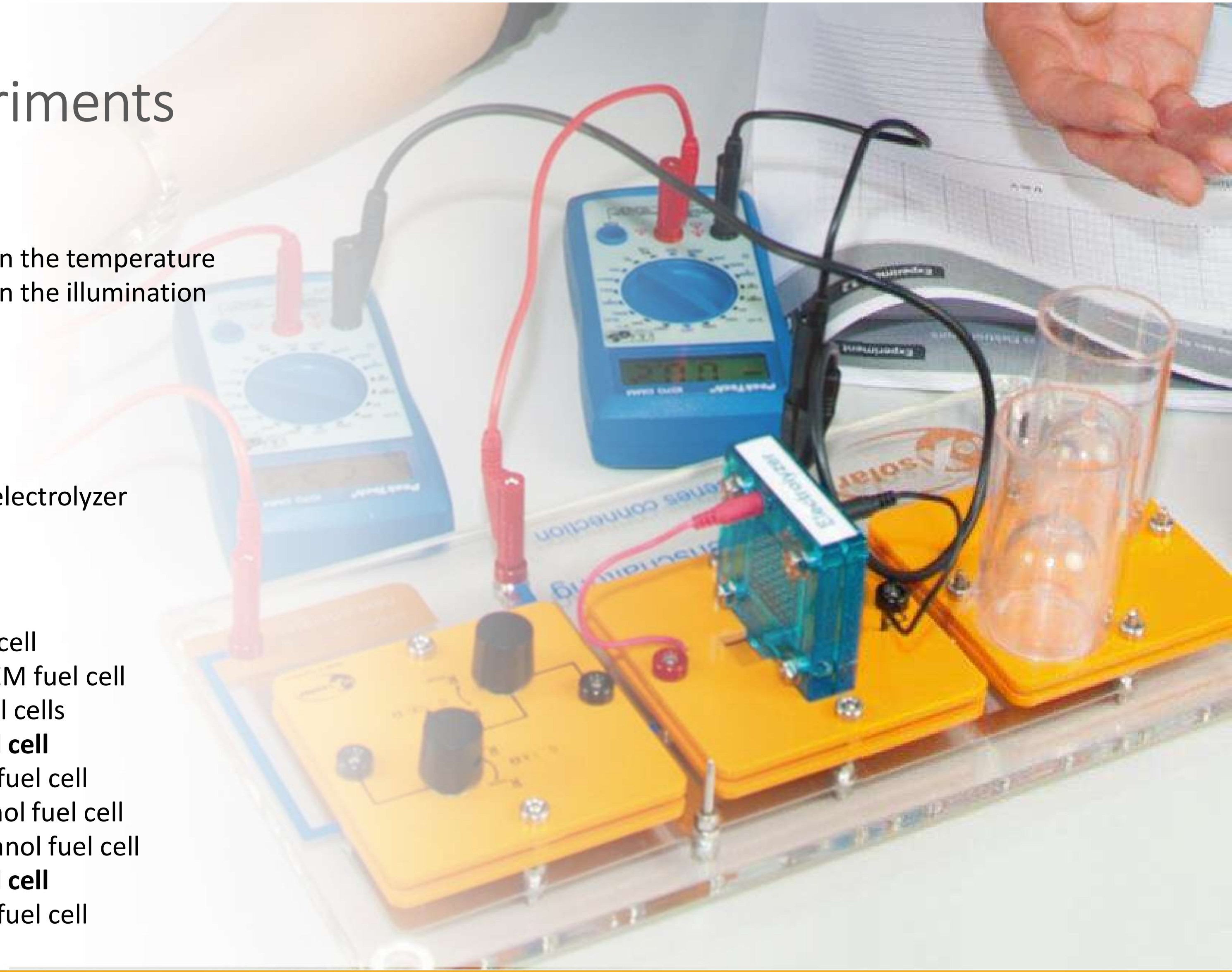


H_2 Beginner: Components

- Base unit
- Potentiometer module
- Motor module
- Solar module 2.5 V, 420 mA
- H_2 Storage
- Gas storage module
- 3x PEM-Fuel Cell Module
- Electrolyzer module 2.0
- Ethanol fuel cell
- SOFC fuel cell
- Fuel cell stand
- Gas burner
- Lamp with table clamp
- 2x Digital multimeter
- 2x Test lead black 25 cm
- 2x Test lead red 25 cm
- Test lead black 50 cm
- Test lead red 50 cm
- Valve for H_2 Storage
- Silicone hose 4 mm (o.d.)



H_2 Beginner: Experiments



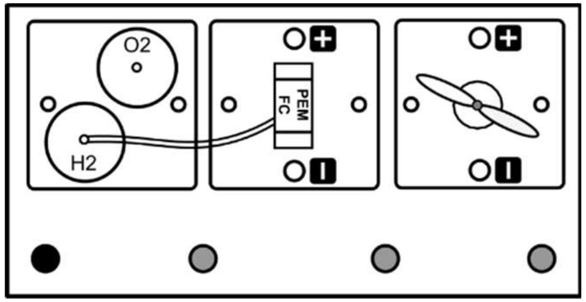
- **Basic experiments:**
  - I-V characteristics of the solar cell
  - Dependence of the solar cell power on the temperature
  - Dependence of the solar cell power on the illumination intensity

- **Experiments with electrolyzer:**
  - Generation of “green” hydrogen
  - I-V characteristics of the electrolyzer
  - Faraday and energy efficiency of the electrolyzer

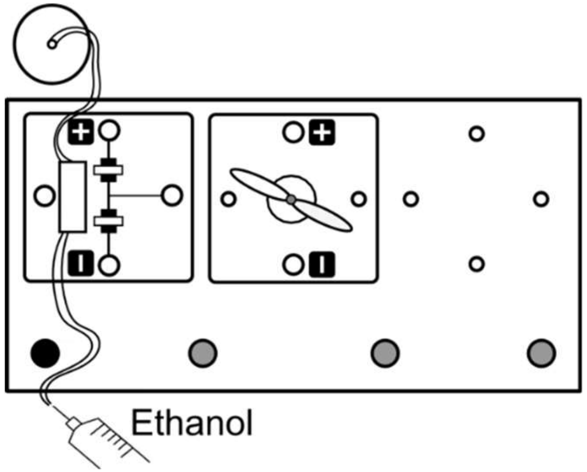
- **Experiments with fuel cell:**
  - **Properties of a PEM fuel cell**
  - I-V characteristic curve of a PEM fuel cell
  - Faraday- and energy efficiency of a PEM fuel cell
  - Series and parallel circuits of PEM fuel cells
  - **Working principles of an ethanol fuel cell**
  - I-V characteristic curve of an ethanol fuel cell
  - Temperature dependence of an ethanol fuel cell
  - Concentration dependence of an ethanol fuel cell
  - **Working principles of solid oxide fuel cell**
  - I-V characteristic curve of an ethanol fuel cell

H_2 Beginner: Working principle of the fuel cells

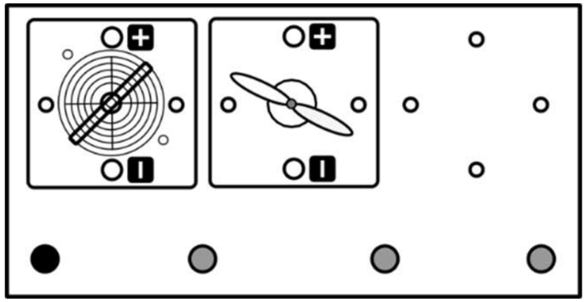
Investigate and compare the working principle of PEM, EtOH, and SOFC fuel cells



- Base unit
- Electrolyser or H_2 storage
- PEM fuel cell
- Motor module

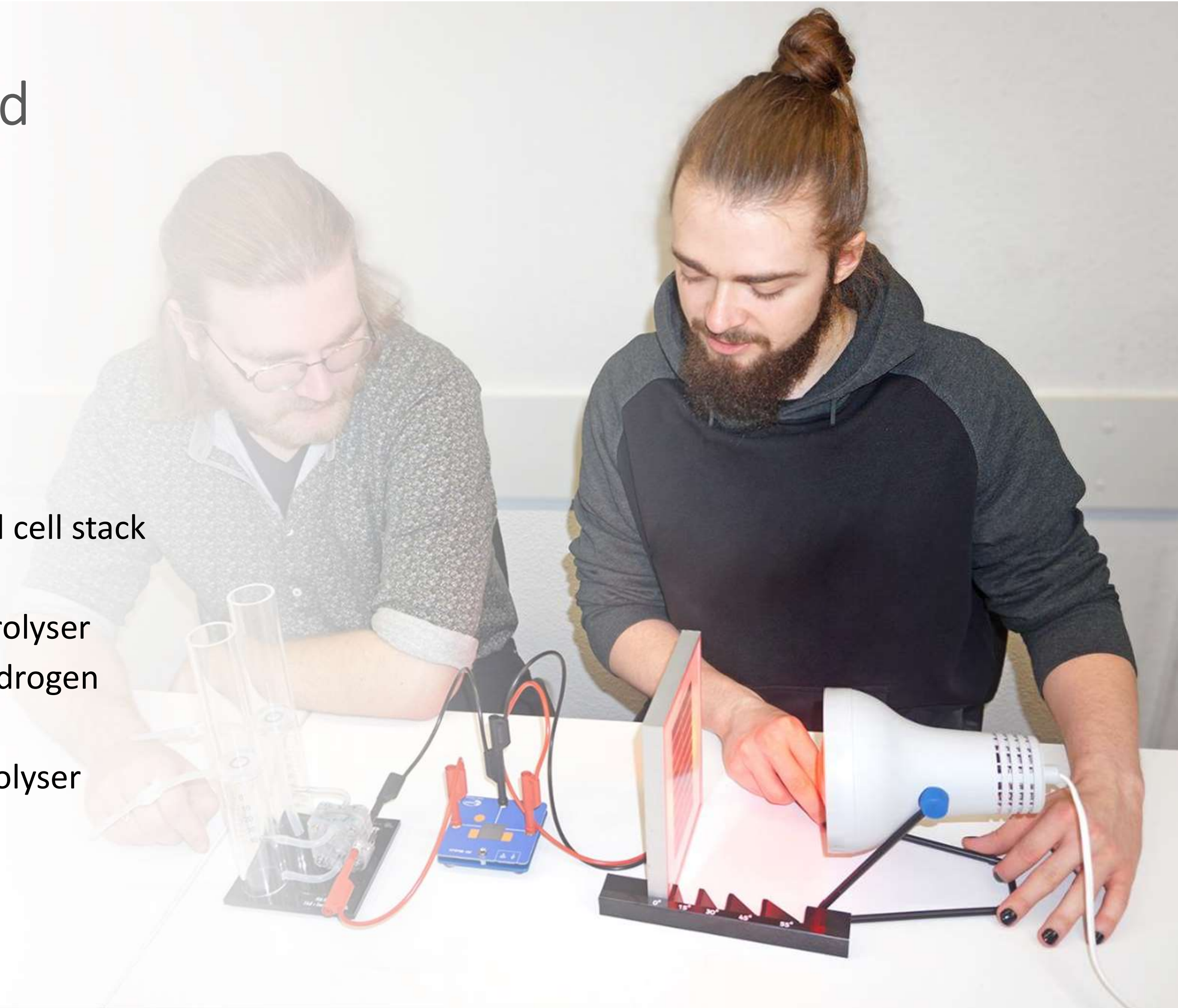


- Base unit
- Ethanol fuel cell
- Ethanol
- Syringe
- Motor module



- Base unit
- SOFC fuel cell
- Gas burner
- Motor module

Module 2: H_2 Advanced



Previous knowledge:
- Fundamentals of electrolysis
- Working principle of PEM fuel cells

Learning objectives:
- Basic properties of the solar cell
- Operation and properties of the PEM fuel cell stack (1-5 cells)
- Operation and characteristics of an electrolyser
- Solar-hydrogen energy cycle for green hydrogen generation
- Efficiency of the fuel cell stack and electrolyser

Duration:
- 3 main units; 8 - 12 hours

Module 2: H_2 Advanced

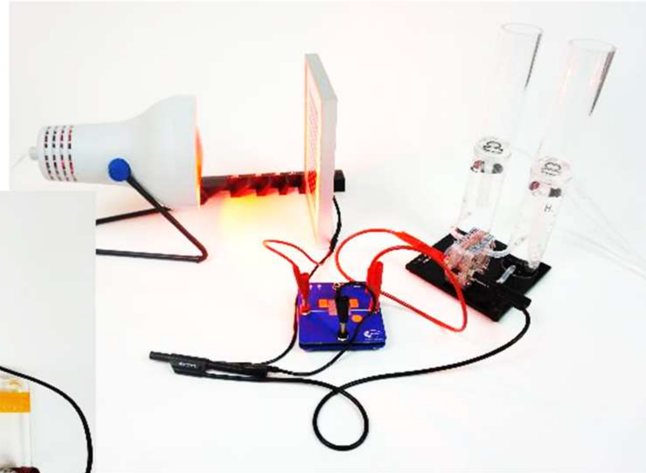
- Double cell electrolyser
- Fuel cell stack (1-5 cells)
- Model car
- Base unit
- Solar cell module 5,2 V with stand
- Infrared lamp
- Potentiometer
- AV module
- Power module
- Blower fan
- H_2 storage (metal hydride, 30 bar, 10 l)
- One-step pressure regulator
- Adapter 2 mm/4 mm
- Short circuit plugs
- Safety cables (4 mm), adapters
- Aluminum case

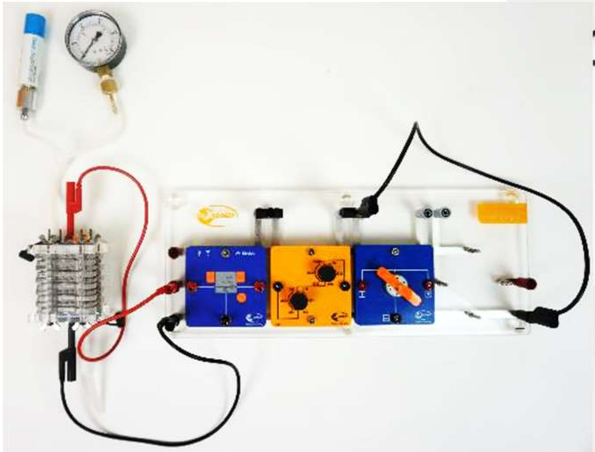
H_2 Advanced: Experiments

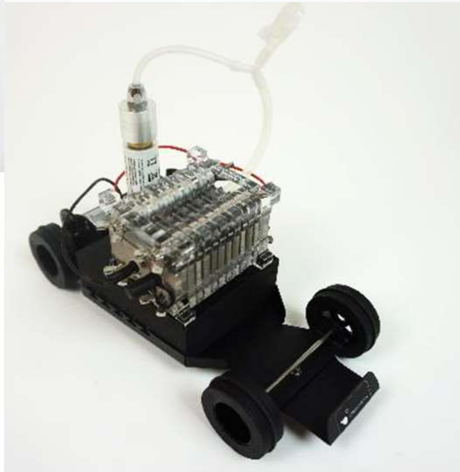
- **Basic experiments:**
  - I-V characteristics of the solar cell
  - Dependence of the solar cell power on the temperature
  - Dependence of the solar cell power on the illumination intensity

- **Experiments with electrolyzer:**
  - Properties of the electrolyzer:
  - I-V characteristics of the electrolyzer
  - **Solar-powered generation of hydrogen**
  - Faraday and energy efficiency of the electrolyzer

- **Experiments with fuel cell:**
  - **Operation of the consumer with the 5-cell stack**
  - Examination of the single cell compared to the fuel cell stack
  - Operation of the fuel cell stack with and without fan
  - Faraday and energy efficiency of the fuel cell stack
  - Operation of the model car with a fuel cell stack
  - Hydrogen consumption of the fuel cell

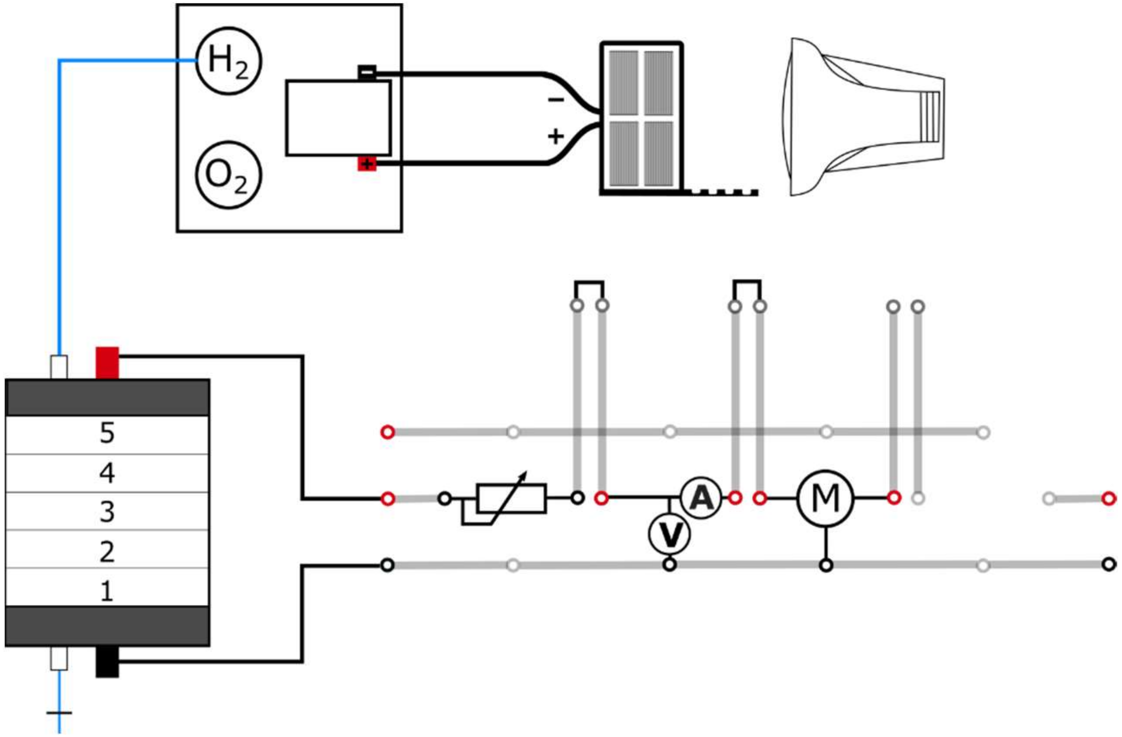






H_2 Advanced: Green Hydrogen Production

Direct utilization of produced "green" hydrogen in PEM fuel cell stack



Equipment:

- Base unit
- Solar module + base for solar panel
- Lamp
- AV-Module
- Potentiometer module Electrolyser
- Fuel cell stack
- Cables and adapters

Optional:

- Power module, 4V (for "brown" hydrogen generation)

Module 3: H_2 Expert

Previous knowledge:

- Working principle of the PEM fuel cell
- Efficiency of the PEM fuel cell

Learning objectives:

- PEM fuel cell stack
- Process control and efficiency of the fuel cell system
- Operating modes of the fuel cell system
- Recognizing and eliminating errors
- Hydrogen consumption

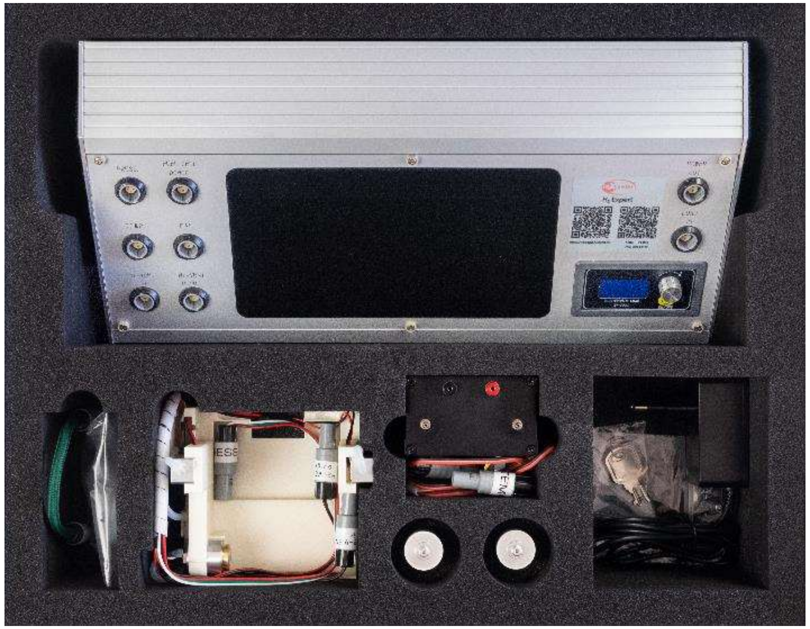
Duration:

- 1 main unit; 6-10 hours

H_2 Expert: Components

Fuel cell stack:

- Type: Proton Exchange Membrane (PEM)
- Nominal power: 20 W (7.6 V @ 2.6 A)
- Open circuit voltage: 12 V
- Start-up time: ≤ 30 s (25 °C)
- Maximal stack temperature: 55 °C
- H_2 pressure: 0.4 - 0.6 bar



Controller:

- Contol unit for the fuel cell
- Data acquisition (cell temperature, H_2 pressure, voltage, current, power)
- Integrated webserver with control dashboard and data logger
- Error management
- Export of measured data as .csv

Electronic load:

- Input voltage: 1 – 30 V
- Discharge current: 0 - 5 A, adjustable in 0.01 A
- Power supply: 12 V
- Maximum power: 35 W

H_2 Expert: Experiments

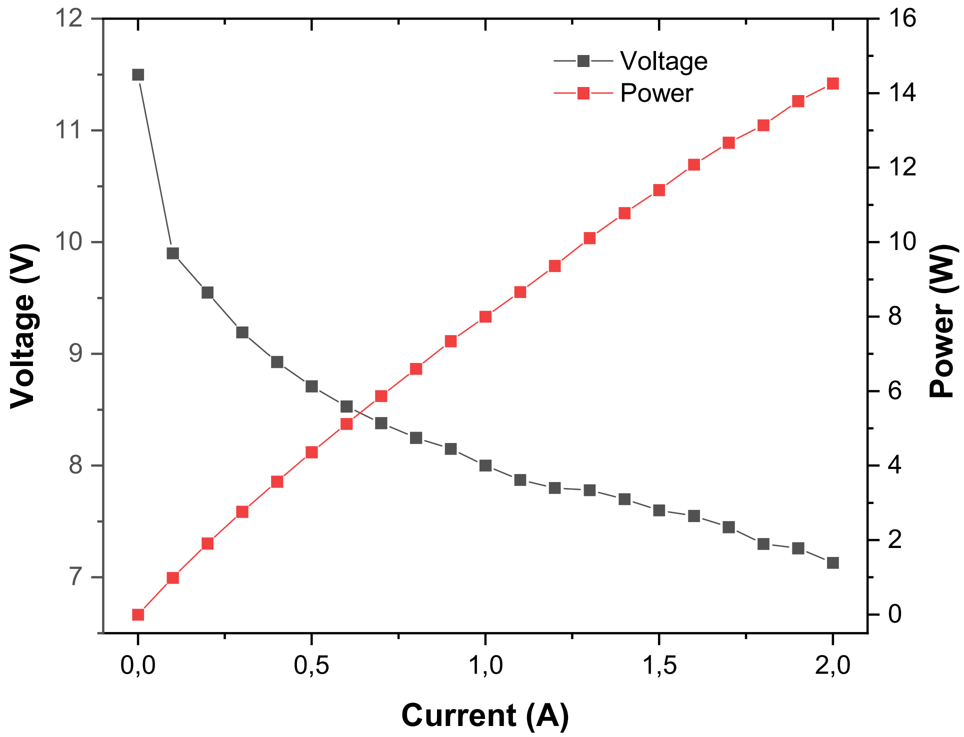
1. Set up and operation of the fuel cell system
2. I-V characteristic curve of the fuel cell stack
3. Efficiency of the fuel cell stack
4. Parameters influencing the characteristic curve
5. Hydrogen consumption of the fuel cell stack
6. Efficiency of a fuel cell system

H_2 Expert: I-V Characteristics of the Fuel Cell Stack

Determine the voltage-current characteristics of a fuel cell stack

Equipment:

- Fuel cell stack
- Fuel cell controller (http://webapp.fuelcell.de)
- Fuel cell stand
- H_2 storage
- Load connection cable



H_2 Lab: Safety

- Small volume of produced hydrogen and oxygen (max. 80 ml)
- Relatively low-pressure metal hydride hydrogen storage (30 Bar, max. 10 L)
- Hydrogen generator for recharging metal-hydride cartridges
- Direct alcohol fuel cell with non-toxic ethanol as a fuel
- Solid oxide fuel cell does not require an external heater
- Can be used in almost every laboratory and classroom with adequate ventilation

Contact

leXsolar GmbH
Strehlener Straße 12-14
01069 Dresden
Germany

Tel: + 49 351 - 47 96 56 101
Fax: + 49 351 - 47 96 56 111
e-mail: info@leXsolar.com

www.leXsolar.com

Summary

Advantages:

- Sustainable development
- Non-toxic energy transfer operation
- Energy security
- Universality
- Global environment issue
- Technological innovation

Barriers:

- Safety
- Liquid hydrogen storage
- Increased production cost
- Increased conversion cost
- Viability/cost – low ratio
- Logistics require expensive investments