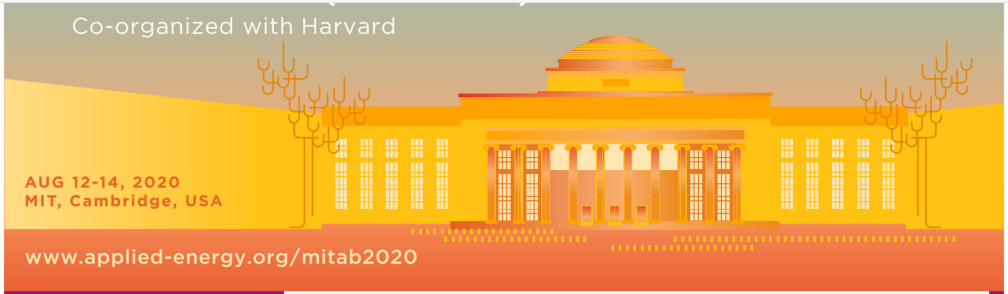

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2020 MIT A+B Applied Energy Symposium Going Virtual, August 13-14, 2020

Welcome to the Applied Energy Symposium： MIT A+B.

The IPCC report "Global Warming of 1.5°C" (Oct. 2018) issued a dire warning that unless CO2 emissions are halved by 2030, devastating changes, which will be sooner than expected and irreversible, will occur in ocean and on land. Time is running out for transitioning to new energy systems globally. Logic and numbers show that the world must take a two-step approach: (A) deploy existing, industrially proven technologies, namely solar, wind and nuclear base load at an unprecedented scale and pace, from now to 2050 -- when a house catches fire, firemen must run to the closest hydrants and stop disputing which water stream would be purer; and (B) develop new concepts and technologies that may replace the dirtier parts of (A) post-2050, at terawatt scale.

The Applied Energy Symposium: MIT "A+B" (MITAB) is dedicated to the accelerated deployment of (A), and new concepts and emerging technologies for (B). For (A), reducing capital and operating costs, managing social dynamics, and minimizing environmental impact while maintaining extreme productivity are key; automation, artificial intelligence, social mobilization, governmental actions and international coordination will provide essential boosts. For (B), we seek new concepts and emerging technologies (e.g. fusion power engineering, superconducting transmission, etc.) that stand a chance to scale to terawatts after 30 years, i.e. "baby technologies" can grow to adulthood in 20-30 years.

MITAB 2020 consists of a three-day symposium on Aug 12-14, 2020, at the Massachusetts Institute of Technology, Cambridge, USA. All presentations (with the author's permission) will be video recorded and posted on YouTube or other open sources for public dissemination. Outstanding presentations will be recommended by the session chair and scientific committee to be further considered for publication in a special issue of Applied Energy (journal Impact Factor 8.4, please find more information at. https://www.journals.elsevier.com/applied-energy).

To be invited to present at this symposium, please upload one of the following: a .zip file (<20MB) containing a video or voice file (≤10 min), or a Powerpoint presentation (≤30 slides), or an abstract (≤2 pages) or a conference paper (≤6 pages), which explain how and why your work matters to A or B. The manuscript will be reviewed by symposium organizers for acceptance to the conference. Examples of topics include, but are not limited to, the following:

- Renewable energy: Solar energy (A or B), wind energy (A), bioenergy (A or B), ocean energy (A or B), and others.
- Clean energy conversion technologies: Fuel cells and electrolyzers (A or B), conversion of petroleum/gas/coal to high-valued materials and chemicals (A), hybrid energy systems, such as the combination of intermittent renewable energies and nuclear heat storage for load following, chemicals/materials/fuel production (A or B), multi-energy carrier energy systems (A or B).
- Energy storage: Grid-scale batteries (A), battery management systems (A), fuel cell/electrolyzer management systems (A), pumped hydro/compressed air (A), thermal energy storage (A or B), distributed energy storage (A).
- Nuclear energy: Innovative concrete solutions and civil constructions (A), application of robotics and AI (A), shipyard constructed floating reactors (A), small modular reactors and micro-reactors (A or B), fast neutron reactors (B), fusion reactors (B).
- Mitigation technologies: Carbon capture and sequestration (B), nuclear waste (A), solar waste (A), battery waste (A), reduced-CO2 production of cement, bulk metals and chemicals (A or B).
- Intelligent energy systems: Smart grids (A), ultra-efficient/superconducting power transmission (B), wireless power transmission (B); electrification of transportation and industrial production, such as electric cars/trucks (A or B), electrified air flight (A or B), microwave-plasma-electrochemical processing (A or B).

Prof. Ludger Josef Fischer

Lucerne University of Applied Sciences and Arts

Sensible & Seasonal Thermal Energy

Dr. Said Al-Hallaj

CEO, All Cell Technologies LLC

Recent Developments in Li-ion Battery Pack Thermal Safety

Prof. Simona Onori

Stanford University

Grid-level Battery Energy Storage: Characterization of Grid Applications for Physics-Based Modelling, Design Optimization, and Technology Evaluation

Moderator

Prof. Xin Li

Harvard University

Hydrogen

15:35-17:35, August 14

Prof. Reinhard Haas

Vienna University of Technology

Prospects and Impediments for a sustainable hydrogen-based energy system

Prof. Jeffrey Reed

University of California Irvine

Prospects for Achieving a Self-Sustaining, Large-Scale Renewable Hydrogen Sector in California

Dr. Chukwunwike Iloeje

Argonne National Laboratory

Implications of power-to-gas energy storage for CO2 mitigation and enhanced energy grid flexibility

Moderator

Prof. Buz Barstow

Cornell University

Promoting Innovation and Entrepreneurship for Economic Nuclear Energy

(Pre-recorded)

*Please click title to view video

Dr. Ashley Finan

The Director of the National Reactor Innovation Center

Ashley Finan is the Director of the National Reactor Innovation Center. In this role, she is responsible for overseeing initiatives to provide resources to reactor innovators to test, demonstrate, and conduct performance assessments to accelerate the deployment of advanced

PROSPECTS AND IMPEDIMENTS FOR A SUSTAINABLE HYDROGEN-BASED ENERGY SYSTEM

Reinhard HAAS,
Amela AJANOVIC

Energy Economics Group, TU Wien

MIT, August 2020

CONTENT:

1. Motivation: Energy Problems
2. History: vision of a hydrogen economy
3. A survey of hydrogen technologies
4. Costs & economics of hydrogen
5. The colour of H2: Environm. benignness
6. Scenarios & technol. learning
7. Policy strategies
8. What if it is not feasible?
9. Conclusions

1. INTRODUCTION

Motivation:

* Paris agreements – reducing GHG emissions

* Urgent needs for clean energy carriers

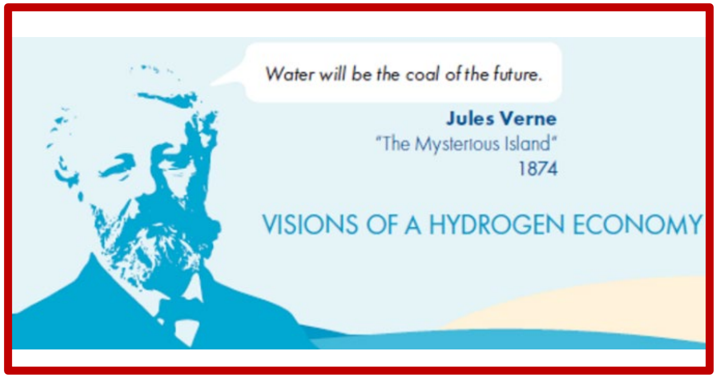
* It is not possible to force variable renewables into the system → storage needed

* Hydrogen is seen as such a clean energy carrier since decades, yet so far it has not delivered

Core objectives

- To analyze the prospects and impediments of a H2-based energy system
- to identify the role of hydrogen to integrate even larger amounts of renewables into the electricity system
- To analyze how efficient technical solutions based on hydrogen can be
- To investigate the economic prospects
- To identify environm benignity of various „colours“

2. HISTORY: VISIONS OF HYDROGEN



The vision of the hydrogen economy is very old. Still, in 1874 Jules Verne in his work “The Mysterious Island” said:

“*I believe that water will one day be employed as fuel, that hydrogen and oxygen which constitute it, used singly or together, will furnish an inexhaustible source of heat and light, of an intensity of which coal is not capable.*”

1766: Hydrogen was first identified as a distinct element

1838: Discovered fuel cell effect

1874: Vision of hydrogen economy

1958: The first PEM fuel cell

1959: The first fuel cell vehicle – farm tractor powered by an alkaline fuel cell

1966: General Motors used fuel cell technology in production of the Electrovan

1993: The first PEMFC car

2008: Commercialization begins (FCX Clarity – first FCV commercially available)

2011: > 100 fuel cell buses worldwide

2013: > 4000 fuel cell forklifts worldwide

2015: First hydrogen fuel cell powered tramcar

2019: The global FCV stock ~13000

The vision of a hydrogen „society“

H2 from Nuclear (Germany, 1984)

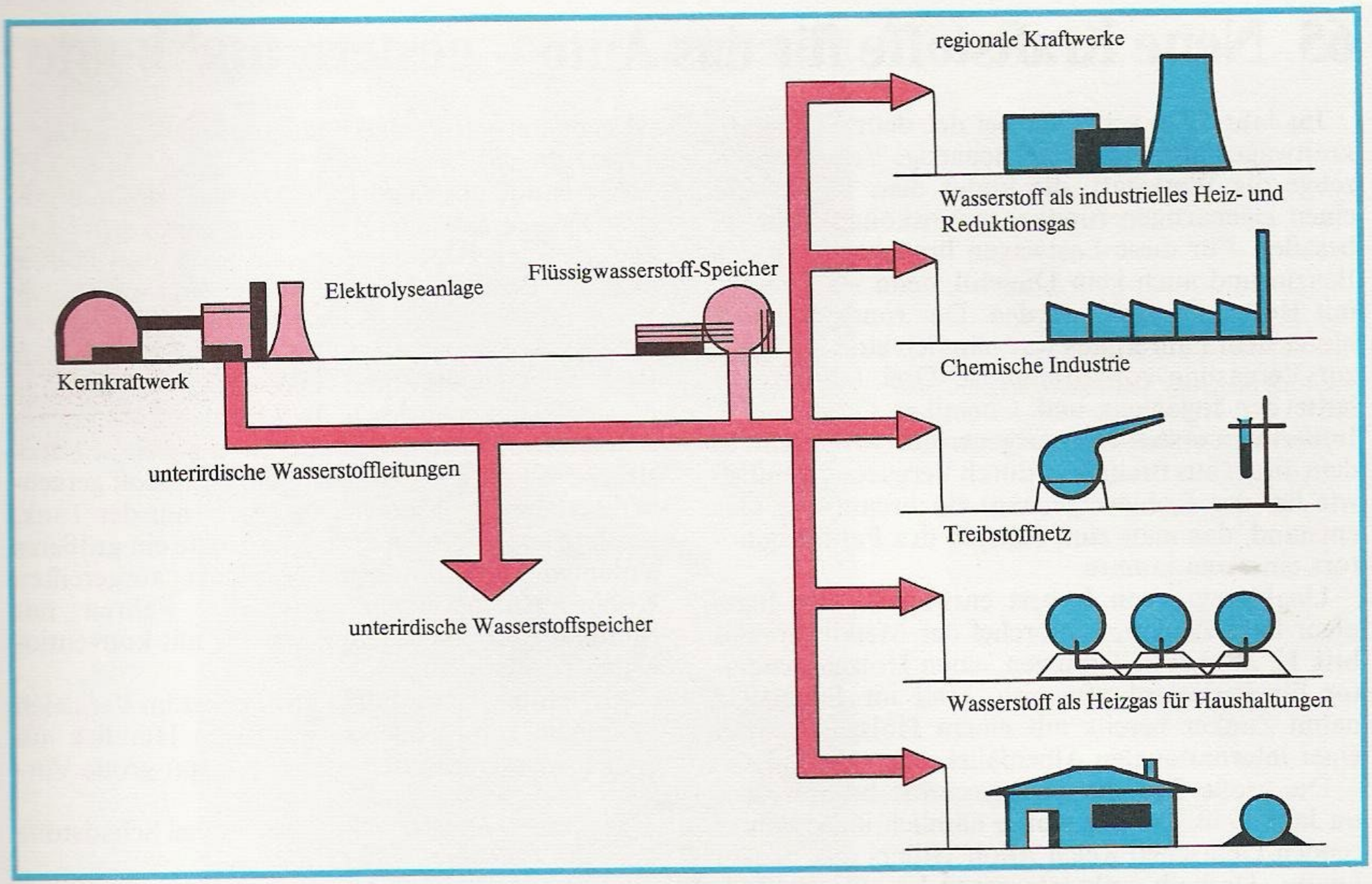
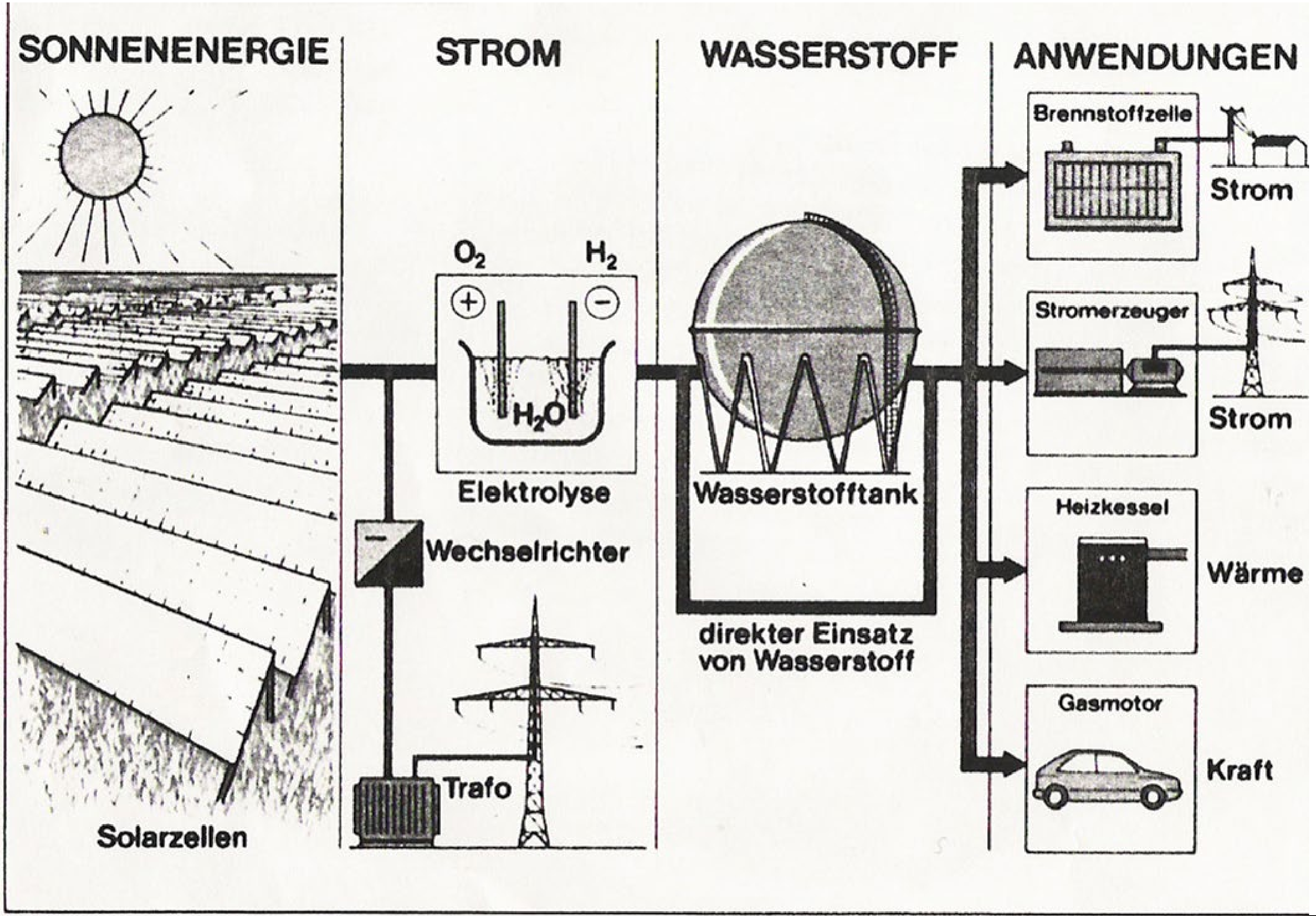


Bild 1 Schema einer Wasserstoff-Energiewirtschaft. Sie bietet neben der Nutzung der Sonnenenergie zum Beispiel die Möglichkeit, Großkernkraftwerke mit allen Anlagen zur Brennstoff- und Abfallbehandlung an einem Ort zu konzentrieren,

H2 from Solar energy in the desert (Germany, 1986)

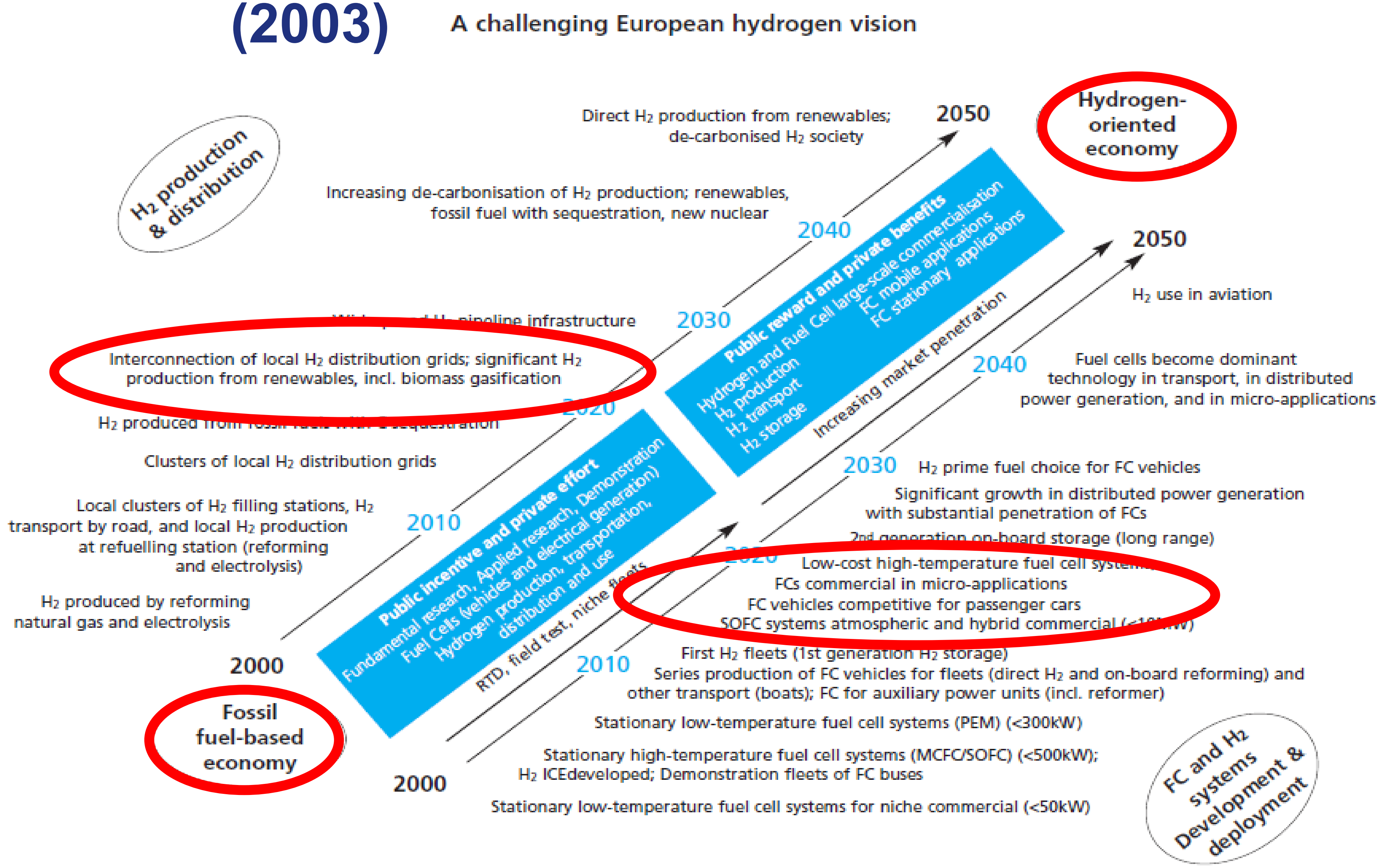


Rifkin: The vision of a hydrogen-based energy system and „society“

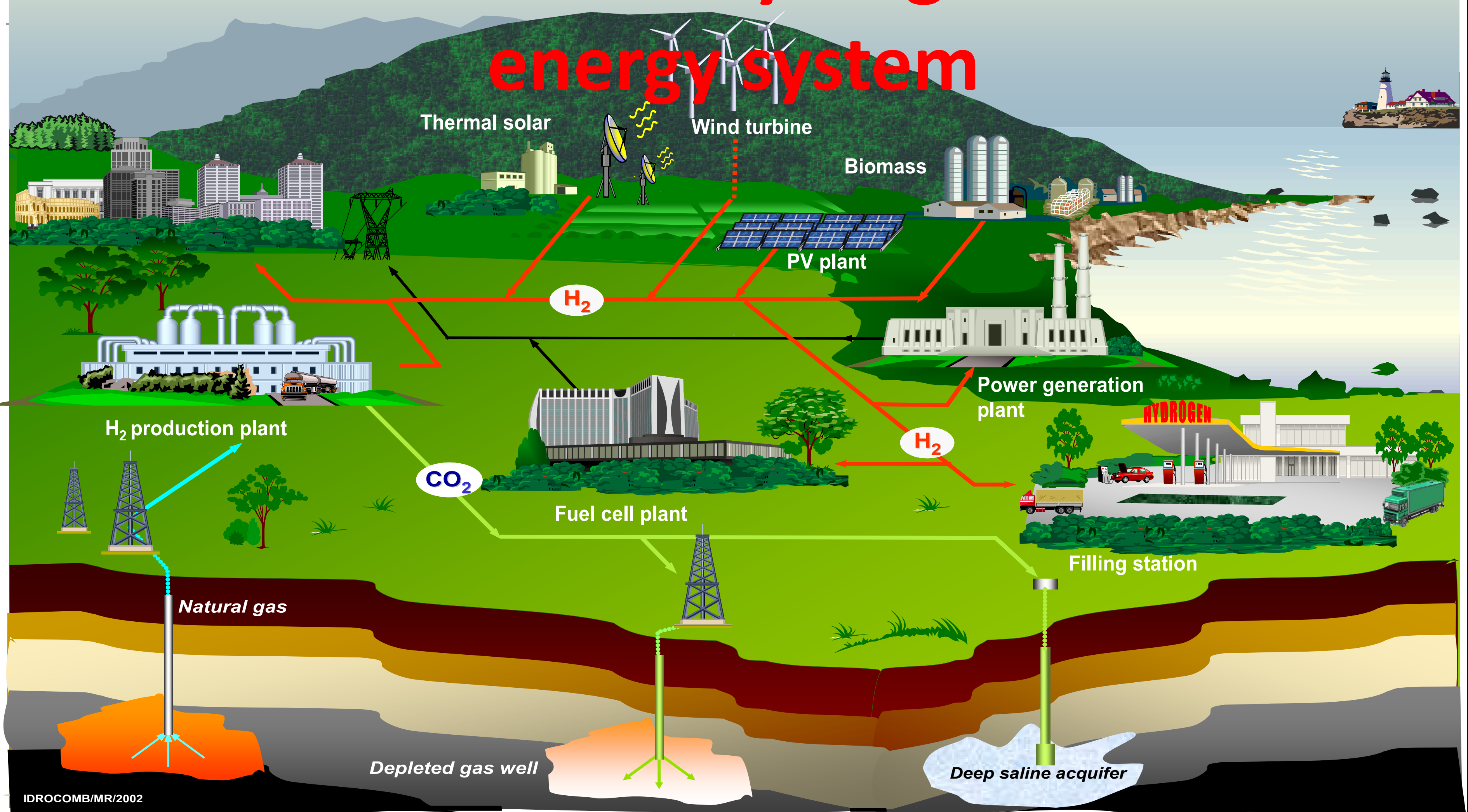
Jeremy Rifkin: „The Hydrogen economy“ (2002):

The road to global security," writes Jeremy Rifkin, "lies in lessening our dependence on Middle East oil and making sure that all people on Earth have access to the energy they need to sustain life. Weaning the world off oil and turning it toward hydrogen is a promissory note for a safer world." Rifkin's international bestseller **The Hydrogen Economy** presents the clearest, most comprehensive case for moving ourselves away from the destructive and waning years of the oil era toward a new kind of energy regime. Hydrogen-one of the most abundant substances in the universe-holds the key, Rifkin argues, to a cleaner, safer, and more sustainable world

EU-Roadmap H2 (2003)



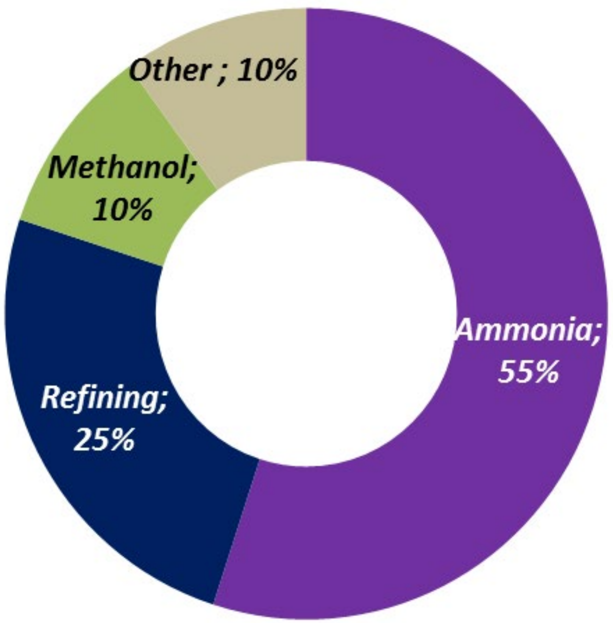
The vision of a hydrogen–based energy system

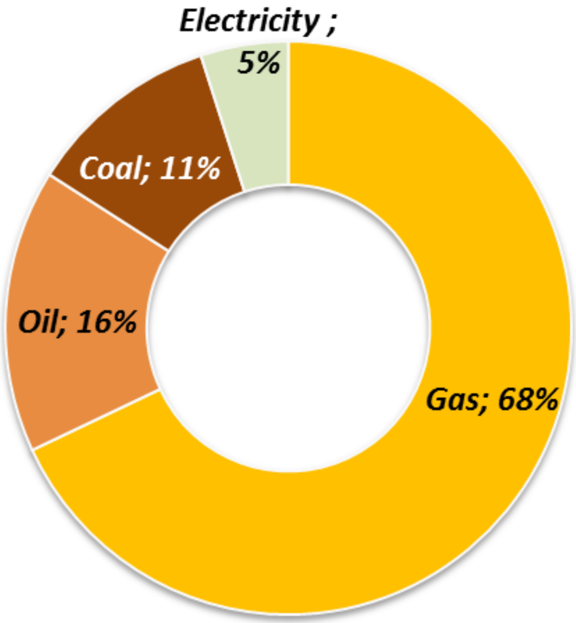


This is how an integrated energy system of the future might look – combining large and small fuel cells for domestic and decentralised heat and electrical power generation. Local hydrogen networks could also be used to fuel conventional or fuel cell vehicles.

Source: EU, 2003

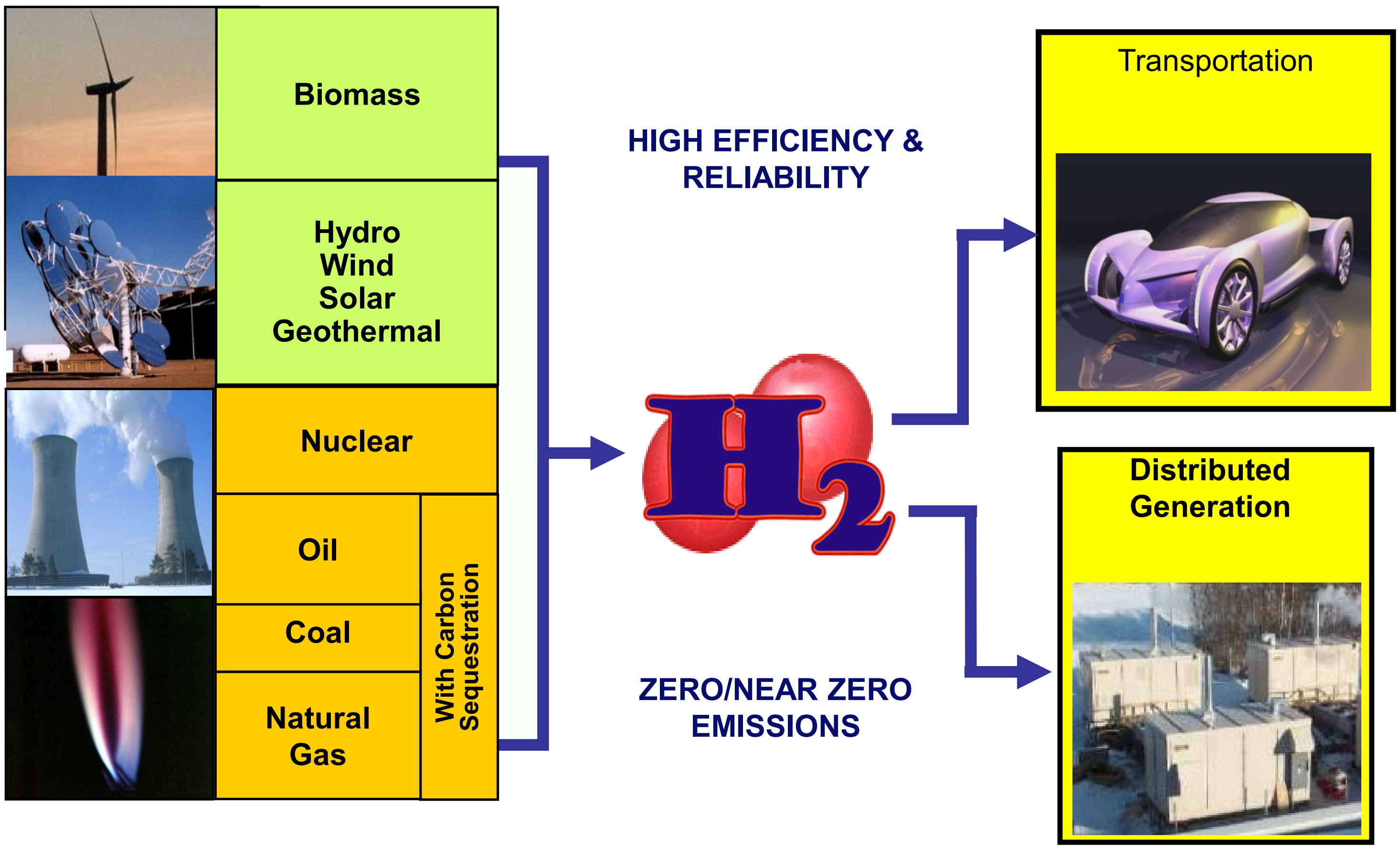
Global hydrogen use and production



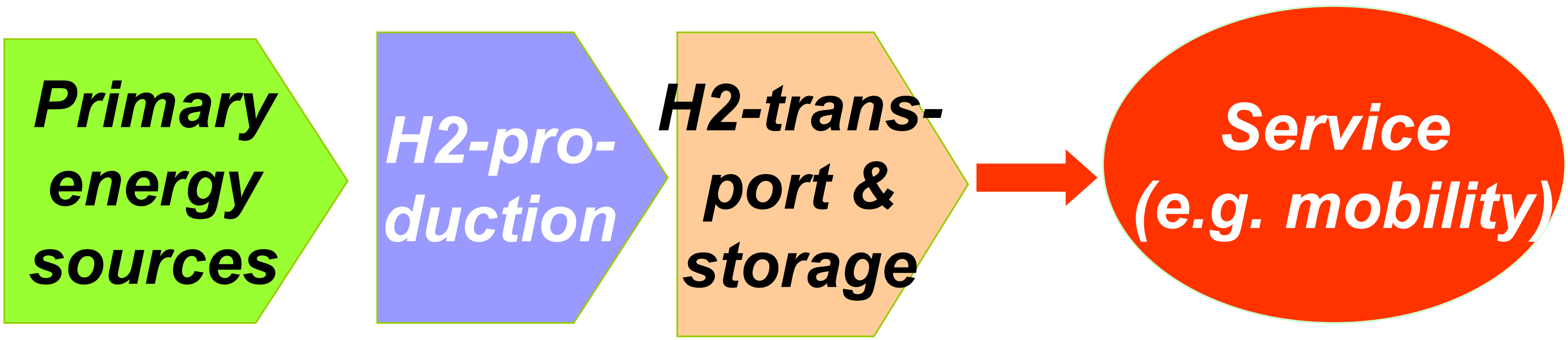


3. A survey of hydrogen technologies

Hydrogen supply chains



Hydrogen supply chains



Major hydrogen production processes

Primary Method	**Process**	**Feedstock**	**Energy**	**Emissions**	**Stage of Development**
	Steam Reforming	*Natural Gas*	*High temperature steam*	*Some emissions. Carbos sequestration can mitigate their effect.*	*Developed commercial technology*
	Thermochemical Water Splitting	*Water*	*High temperature heat from advanced gas-cooled nuclear reactors*	*No emissions*	*Fundamental research*
Thermal	*Gasification*	*Coal*, Biomass***	*Steam and oxygen at high temperature and pressure*	*Some emissions. Carbos sequestration can mitigate their effect.*	**Developed commercial technology **Proven technology*
	Pyrolysis	*Biomass*	*Moderately high temperature steam*	*Some emissions. Carbos sequestration can mitigate their effect.*	*Proven technology*

Major hydrogen production processes

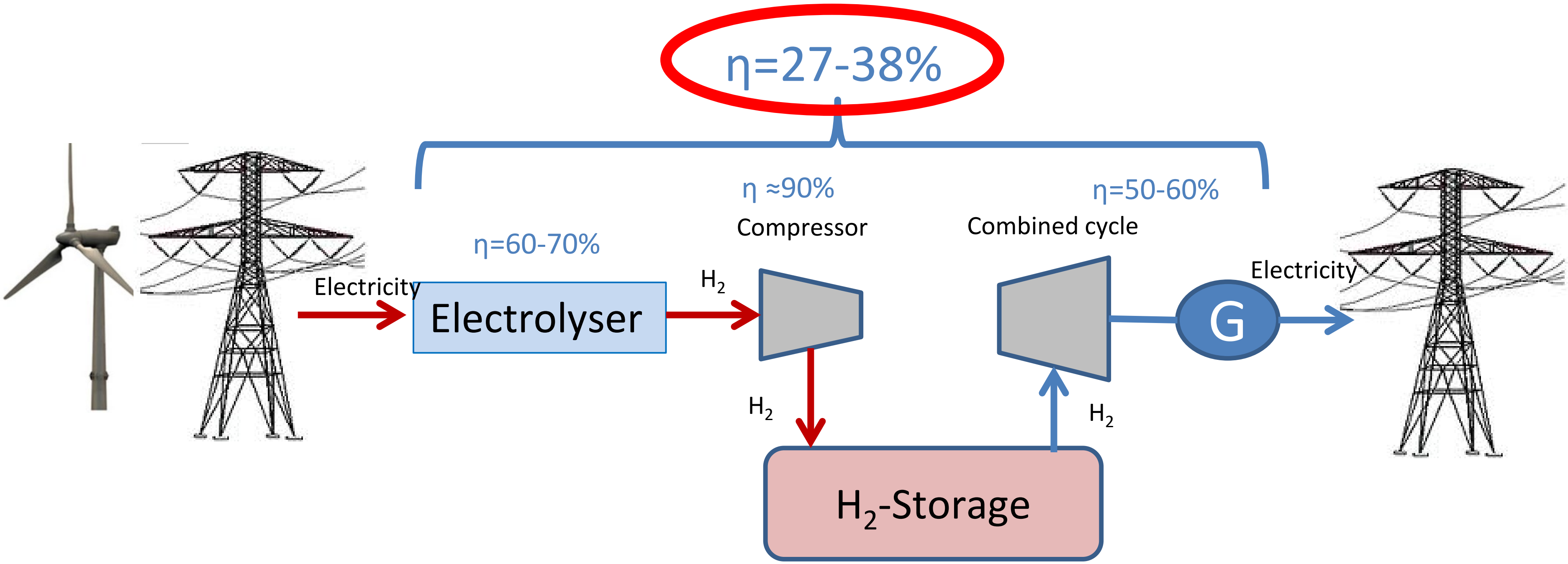
Primary Method	***Process***	***Feedstock***	***Energy***	***Emissions***	***Stage of Development***
	Electrolysis	*Water*	*Electricity from wind, solar,hydro and nuclear*	*No emissions.*	*Developed commercial technology*
Electrochemical	*Electrolysis*	*Water*	*Electricity from coal or natural gas*	*Some emissions from electricity production.*	*Developed commercial technology*
	Photo-Electro-chemical	*Water*	*Direct sunlight*	*No emissions.*	*Fundamental research*

Major hydrogen production processes

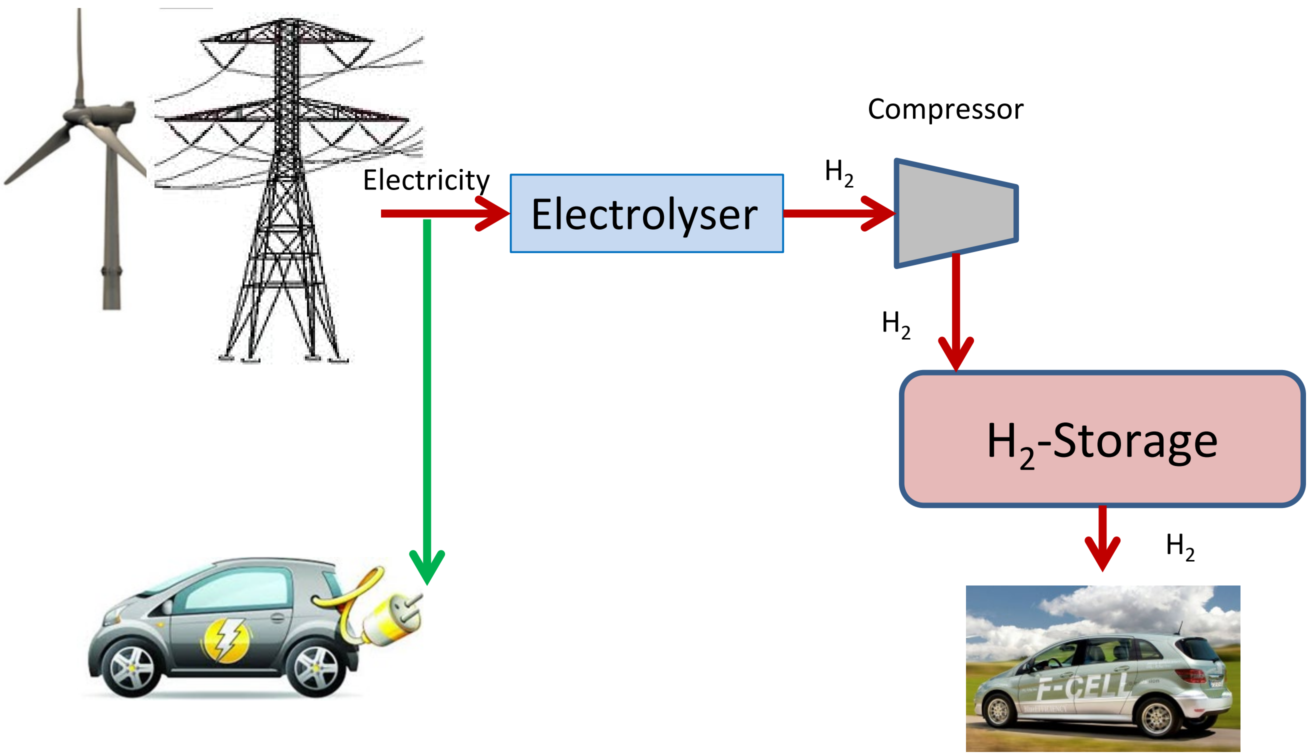
Primary Method	***Process***	***Feedstock***	***Energy***	***Emissions***	***Stage of Development***
	Photobiological	*Water and algae strains*	*Direct sunlight*	*No emissions.*	*Fundamental research*
Biological	*Anaerobic Digestion*	*Biomass*	*High temperature heat*	*Some emissions.*	*Fundamental research*
	Fermentative Microorganisms	*Biomass*	*High temperature heat*	*Some emissions.*	*Fundamental research*

Hydrogen as storage

Very low roundtrip efficiency for electricity!

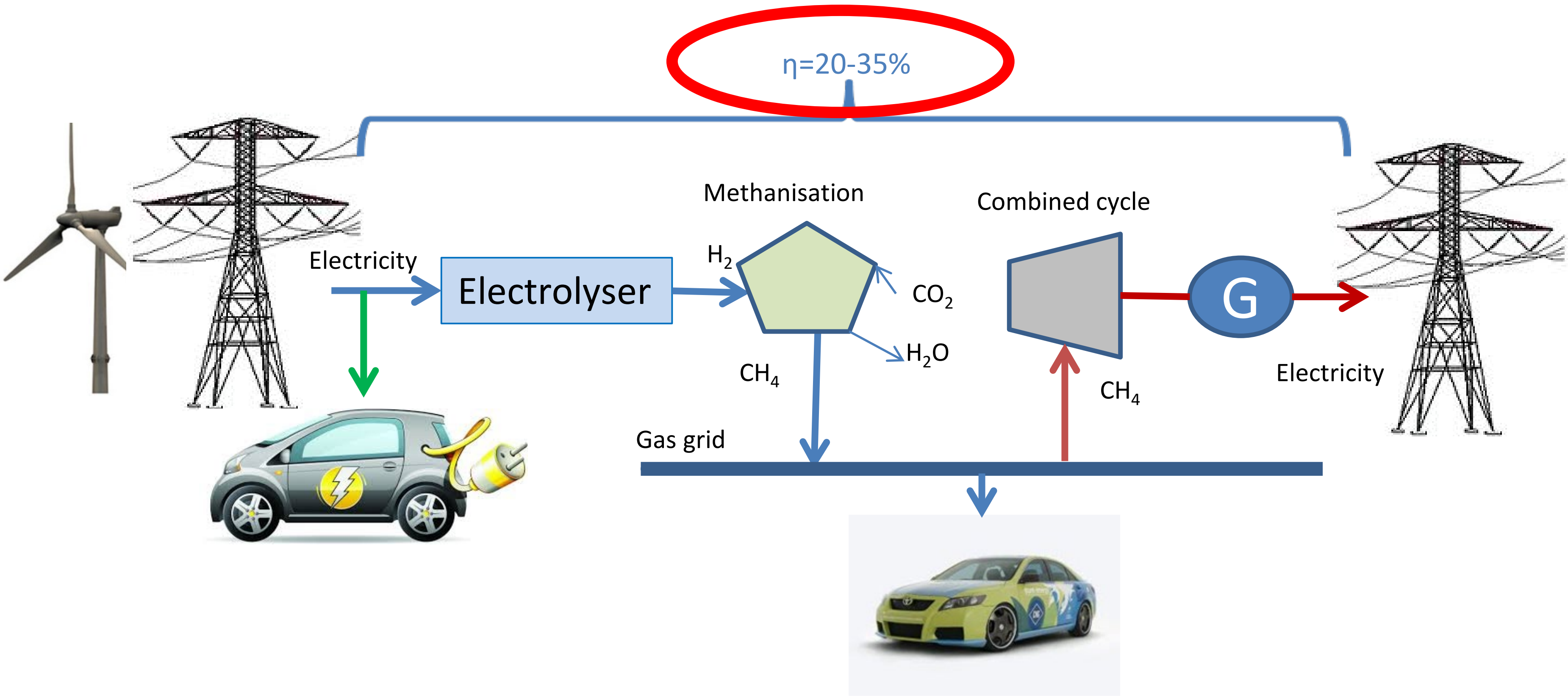


Hydrogen: storage and fuel



Energy supply chains: Storage and/or use of RES for mobility

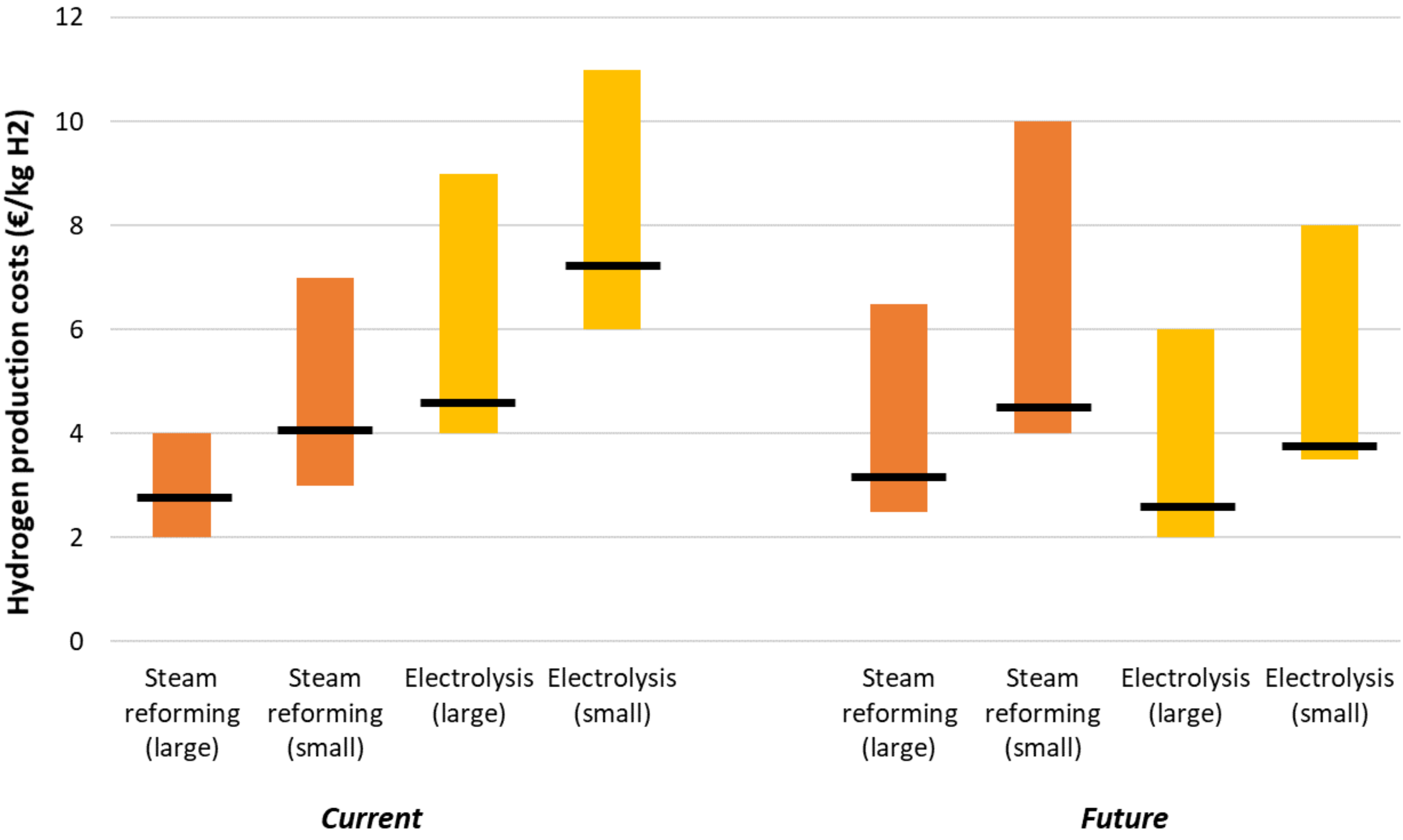
Methanisation of hydrogen



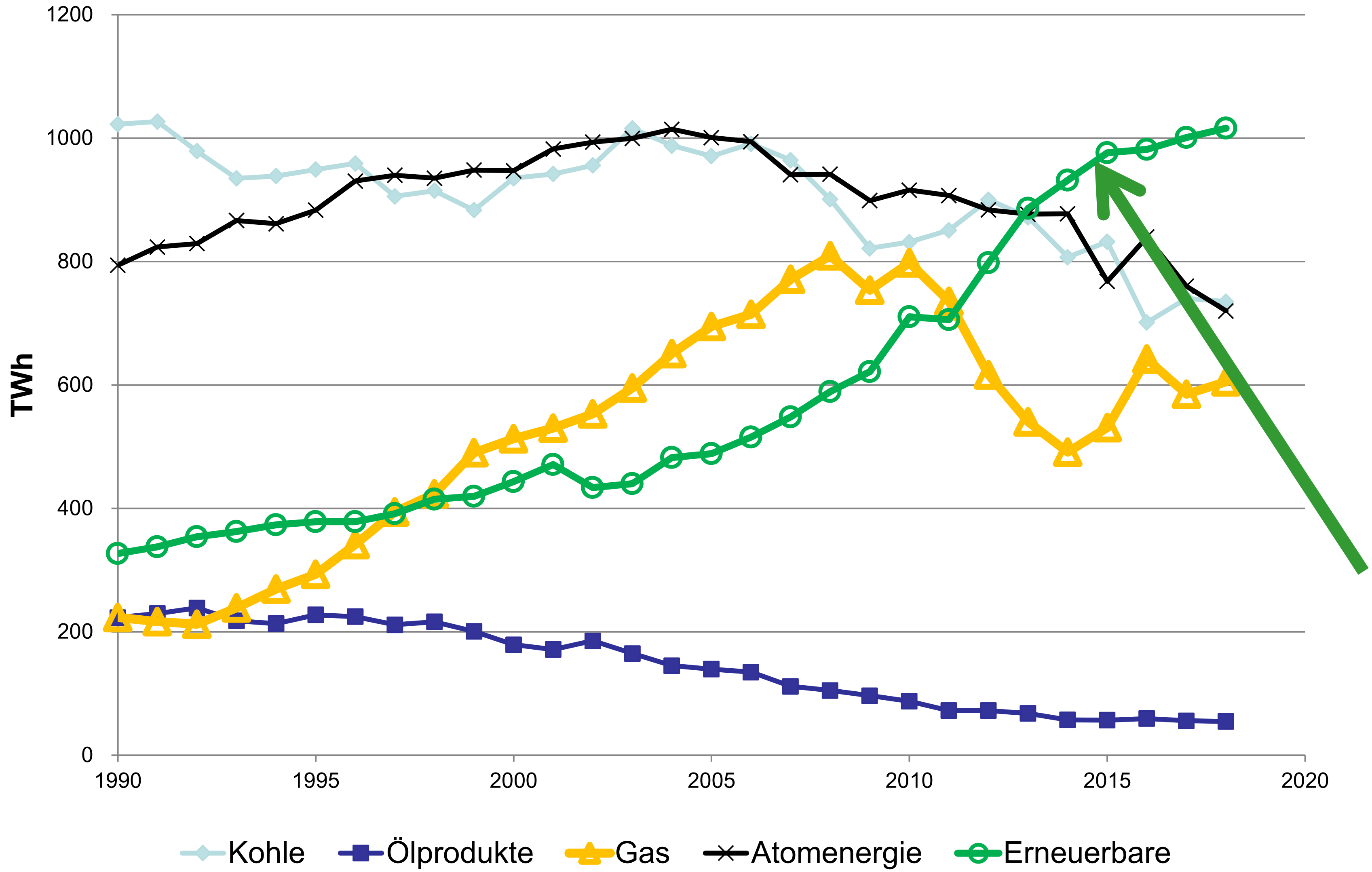
Energy supply chains: Methane for mobility

4. The economics of hydrogen

4. The costs of hydrogen (production)

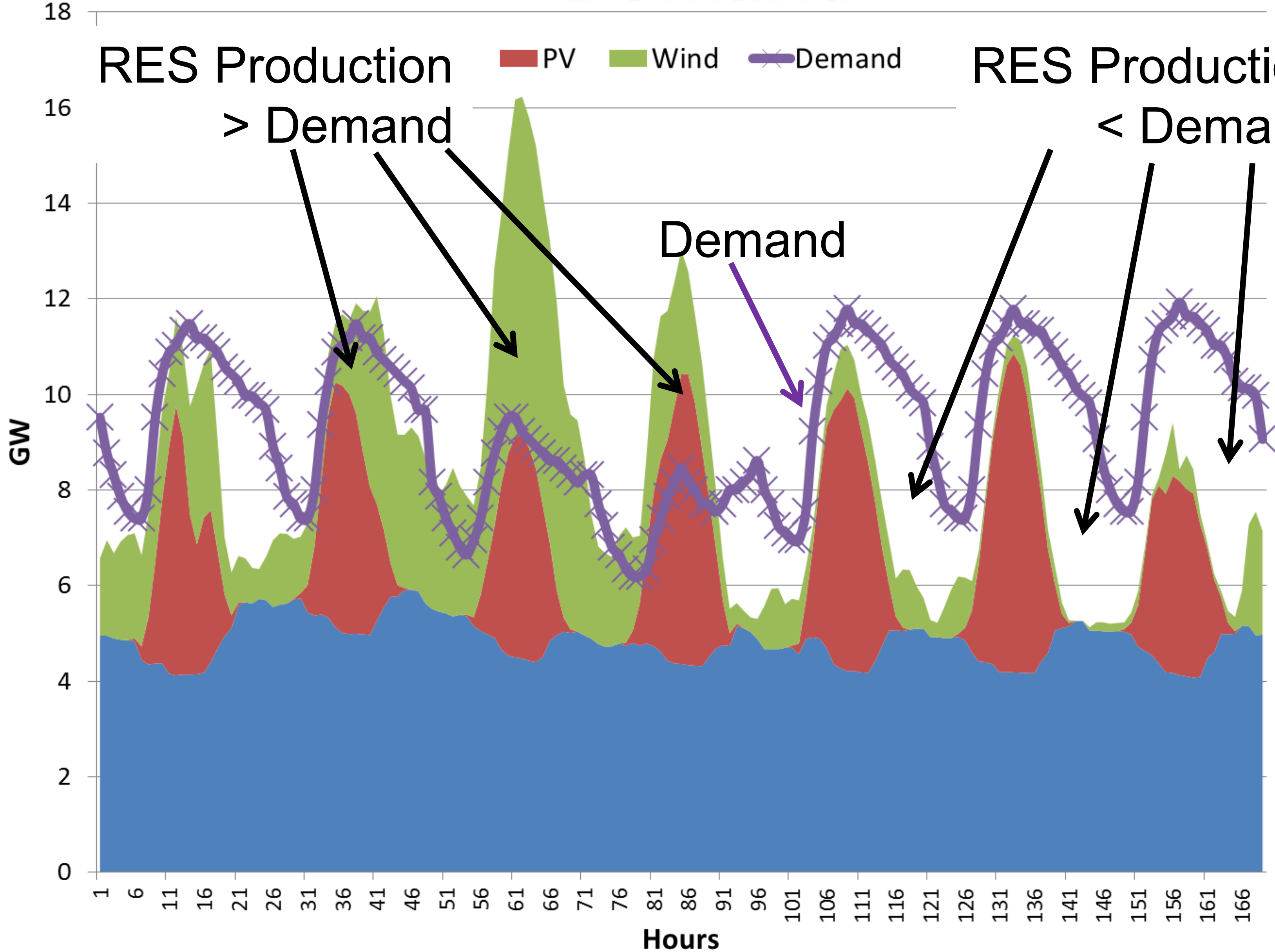


Electricity generation EU-28

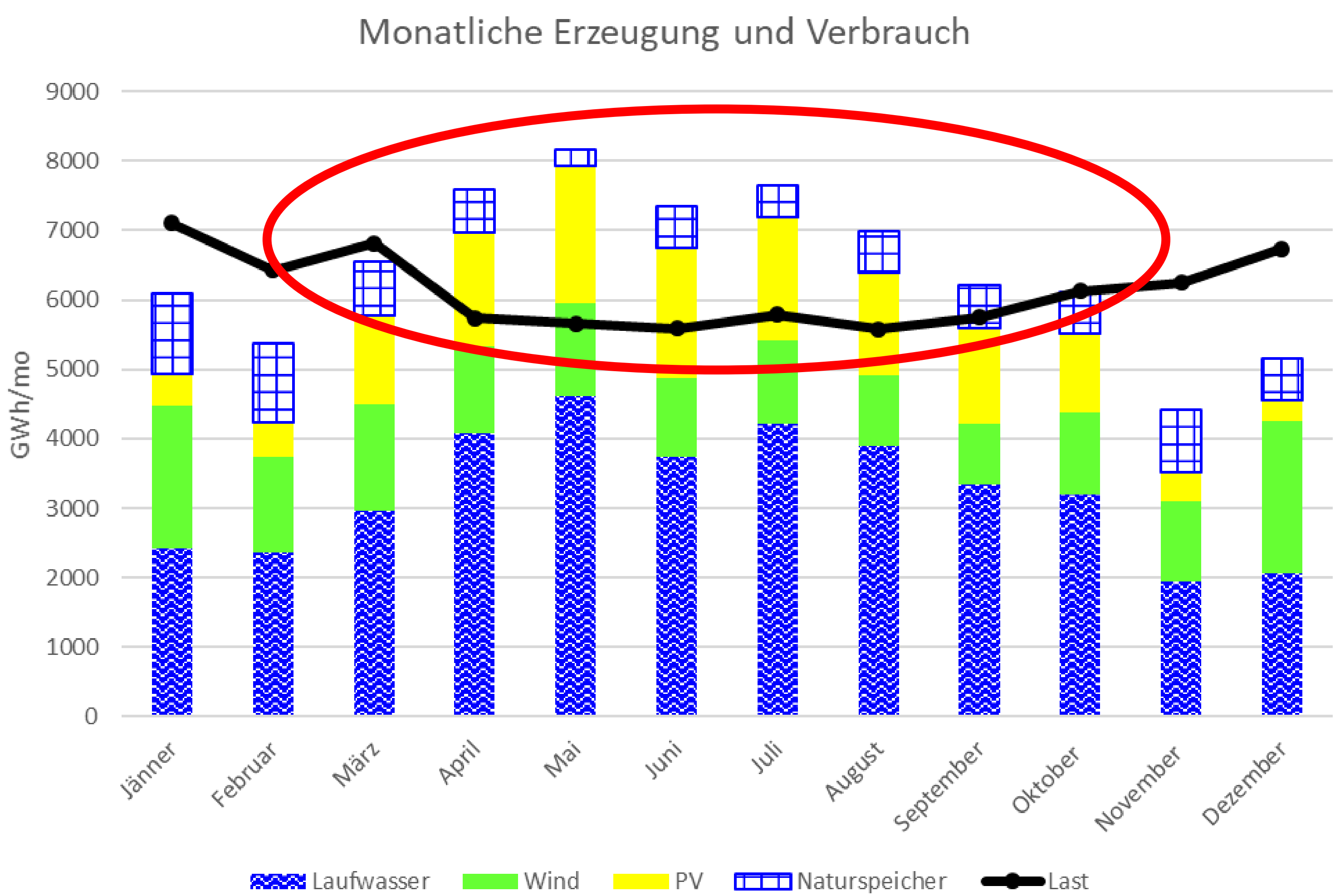


2017 und 2018 preliminary

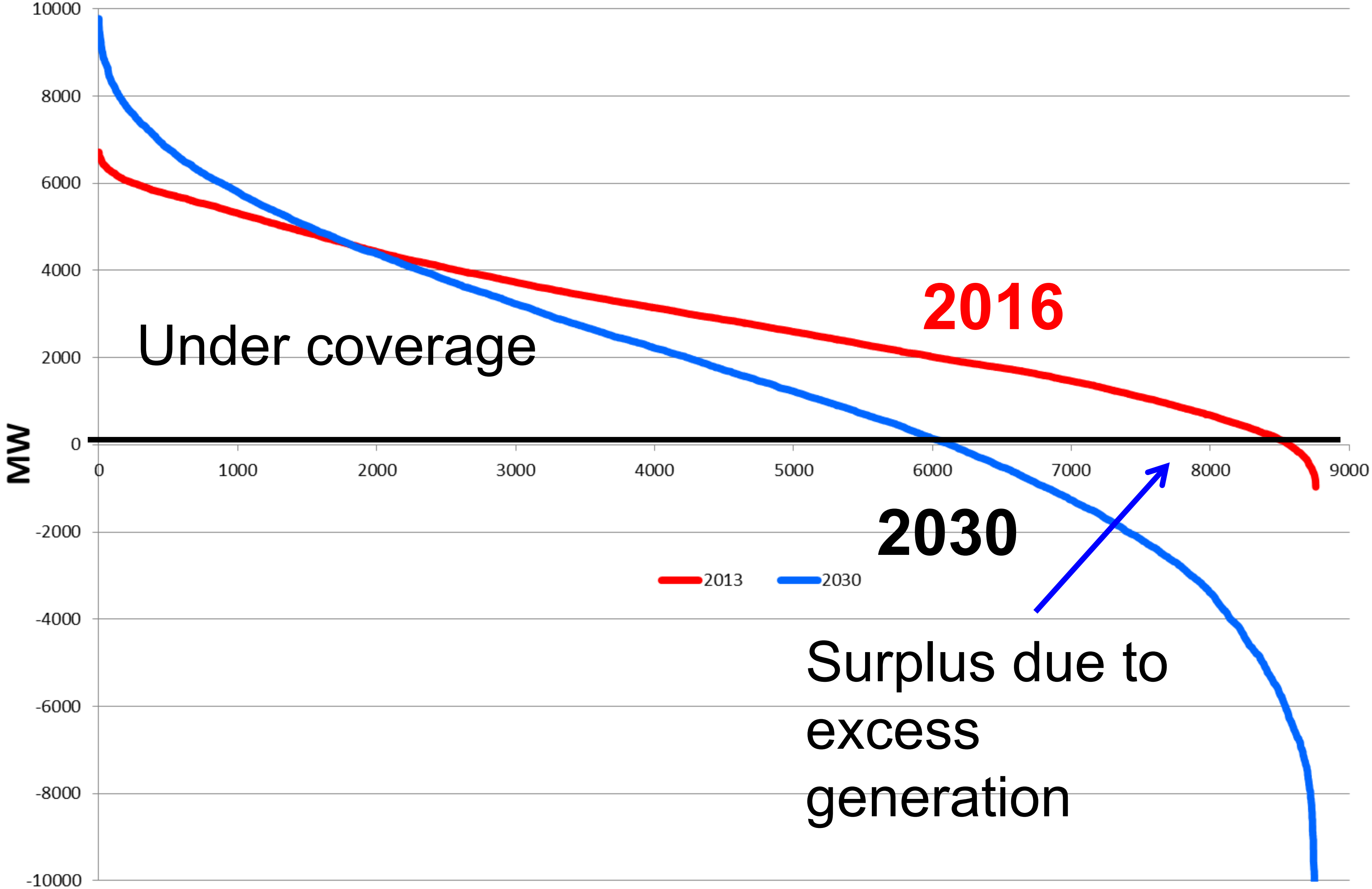
Example: Supply and Demand



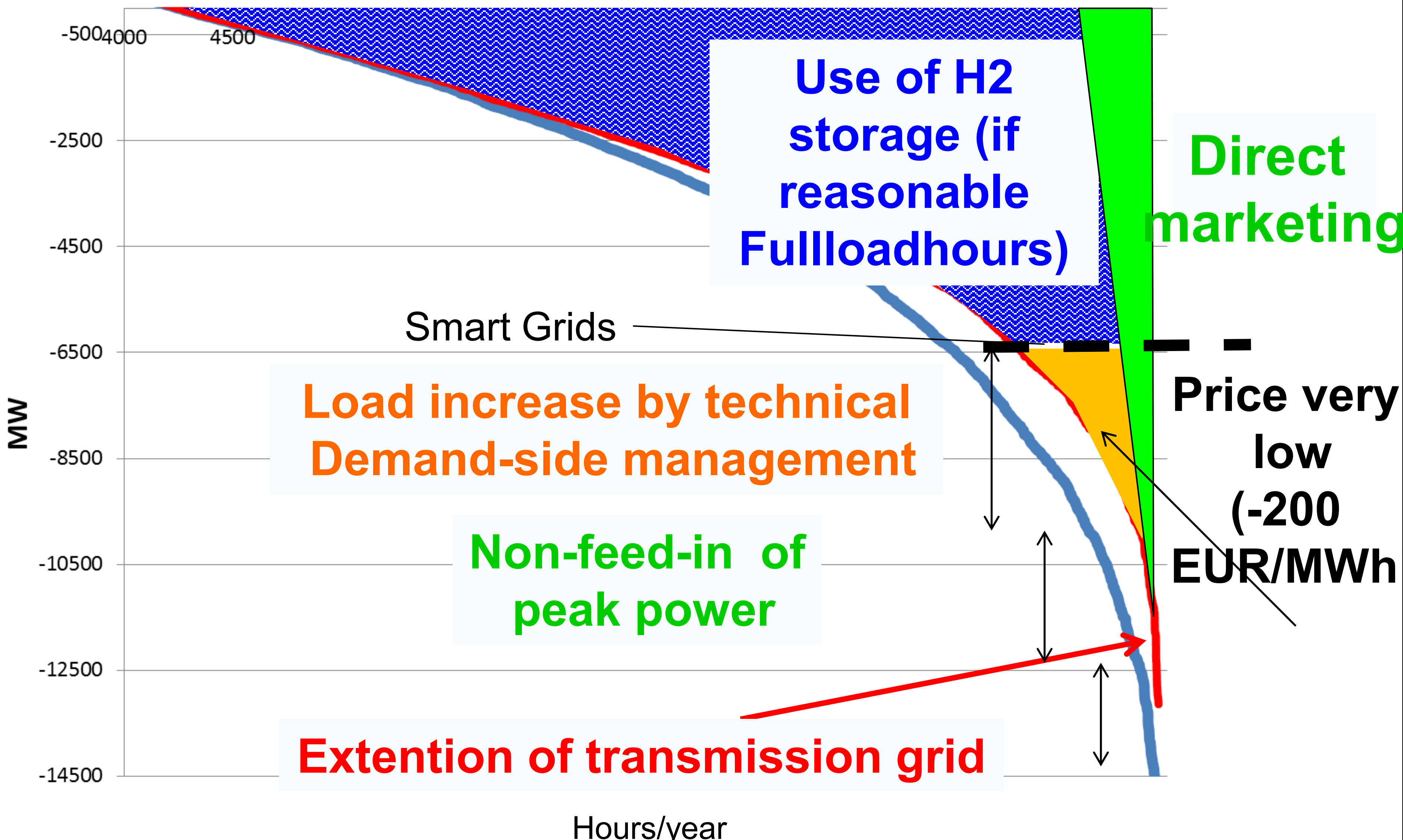
Monthly 2030



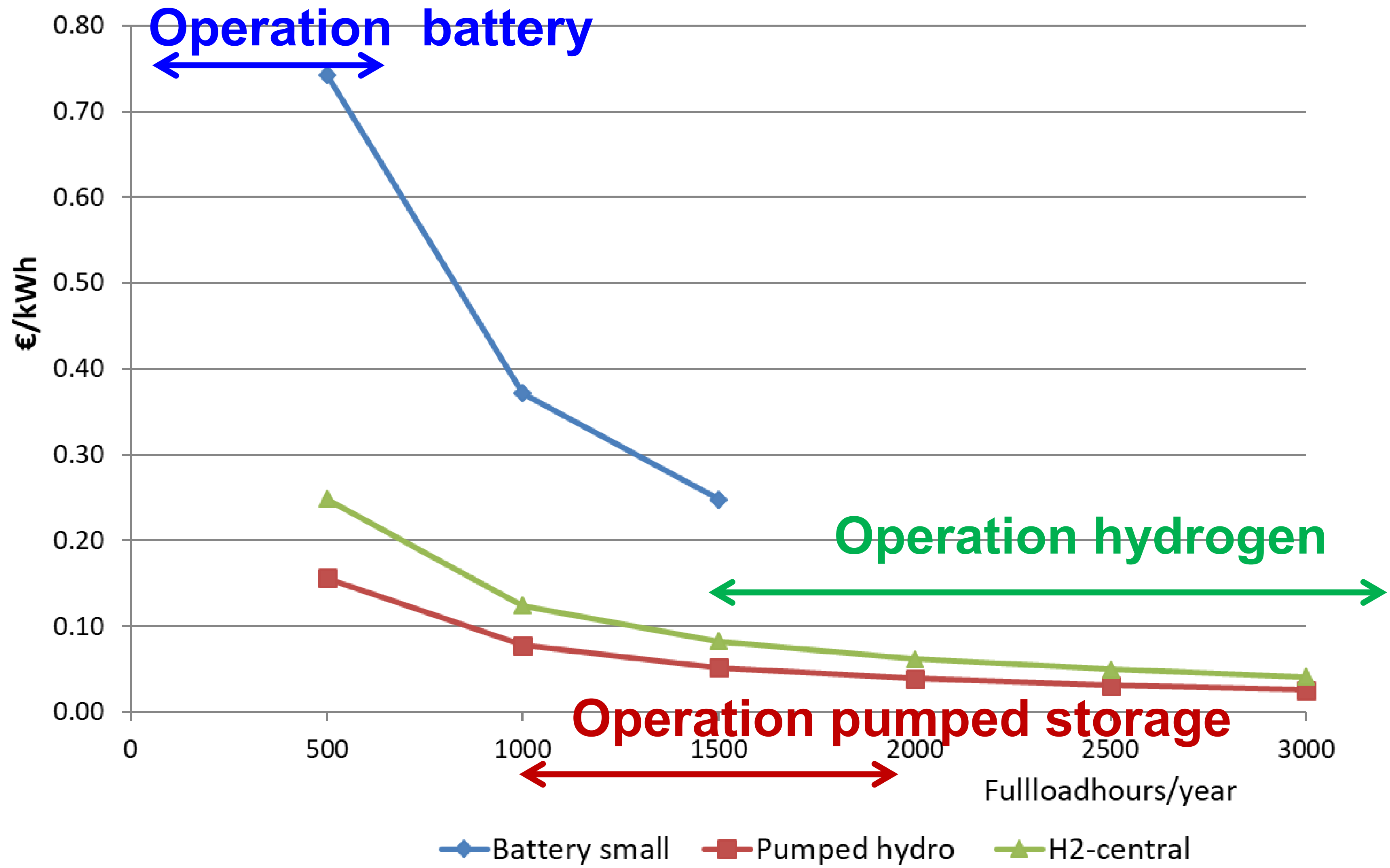
Classified residual load



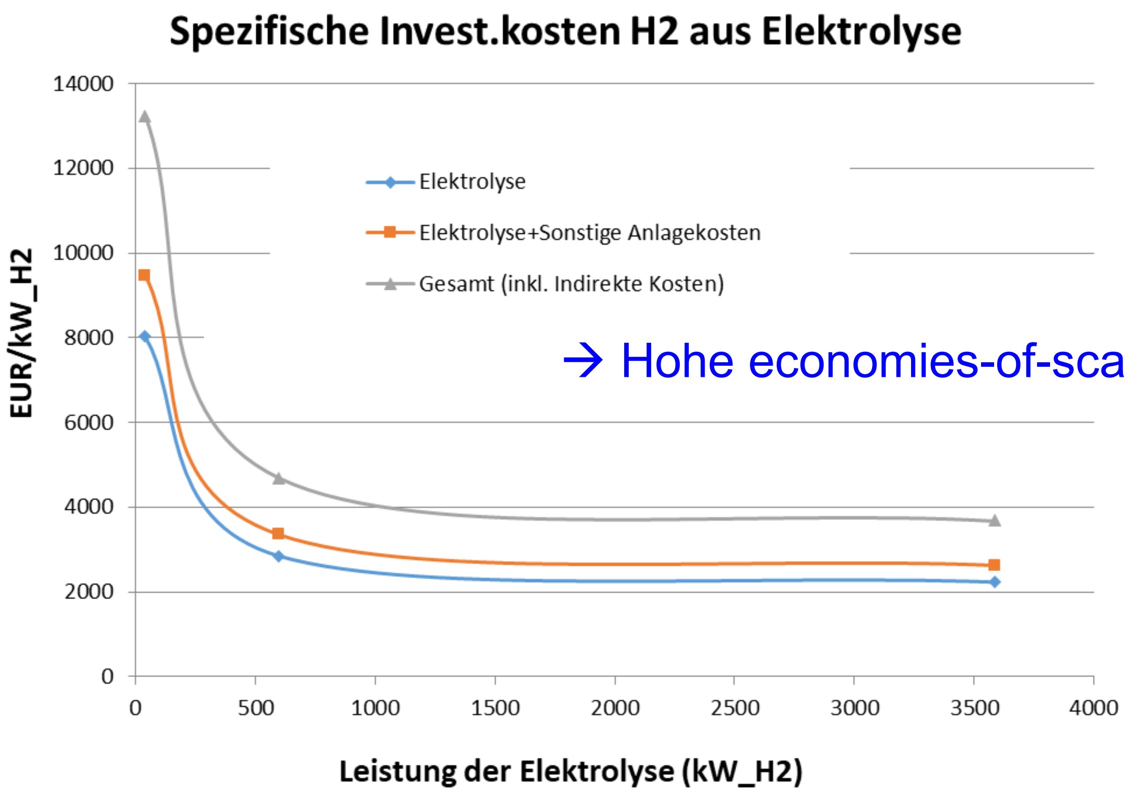
FLEXIBLE USE OF EXCESS ELECTRICITY



Fullloadhours and costs

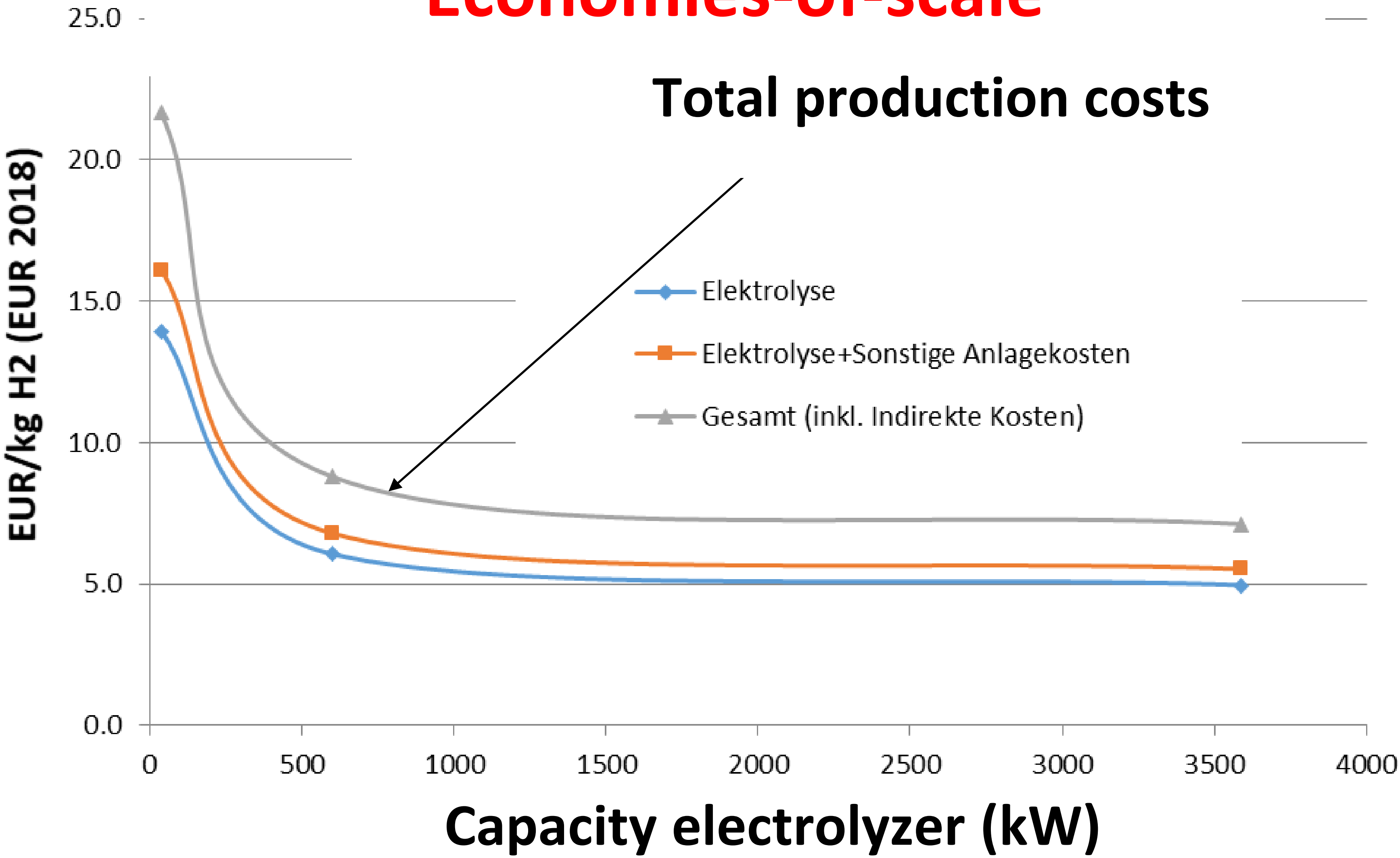


der
Wasserstofferzeugung

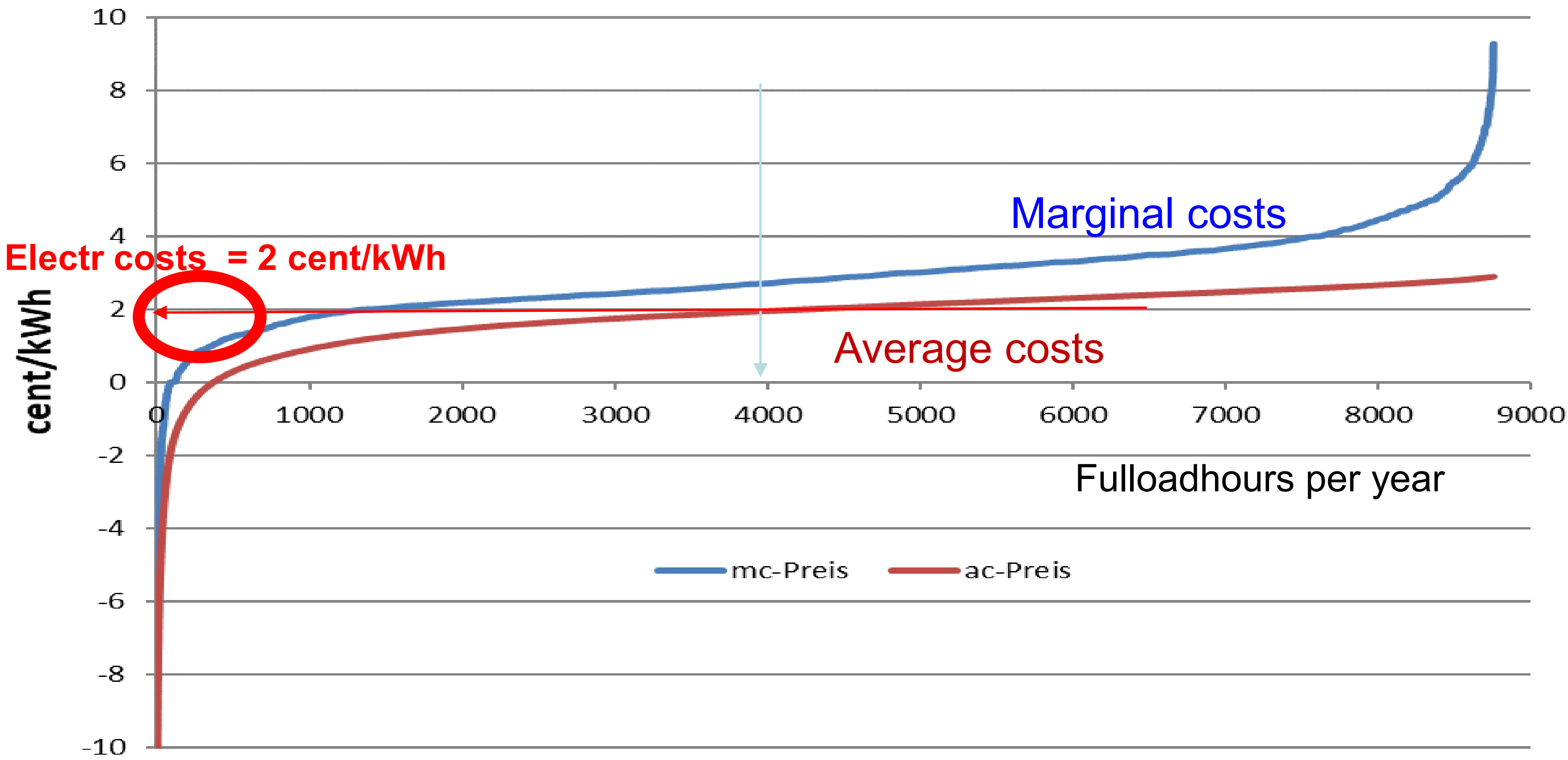


→ Hohe economies-of-scale

Costs of hydrogen production – Economies-of-scale

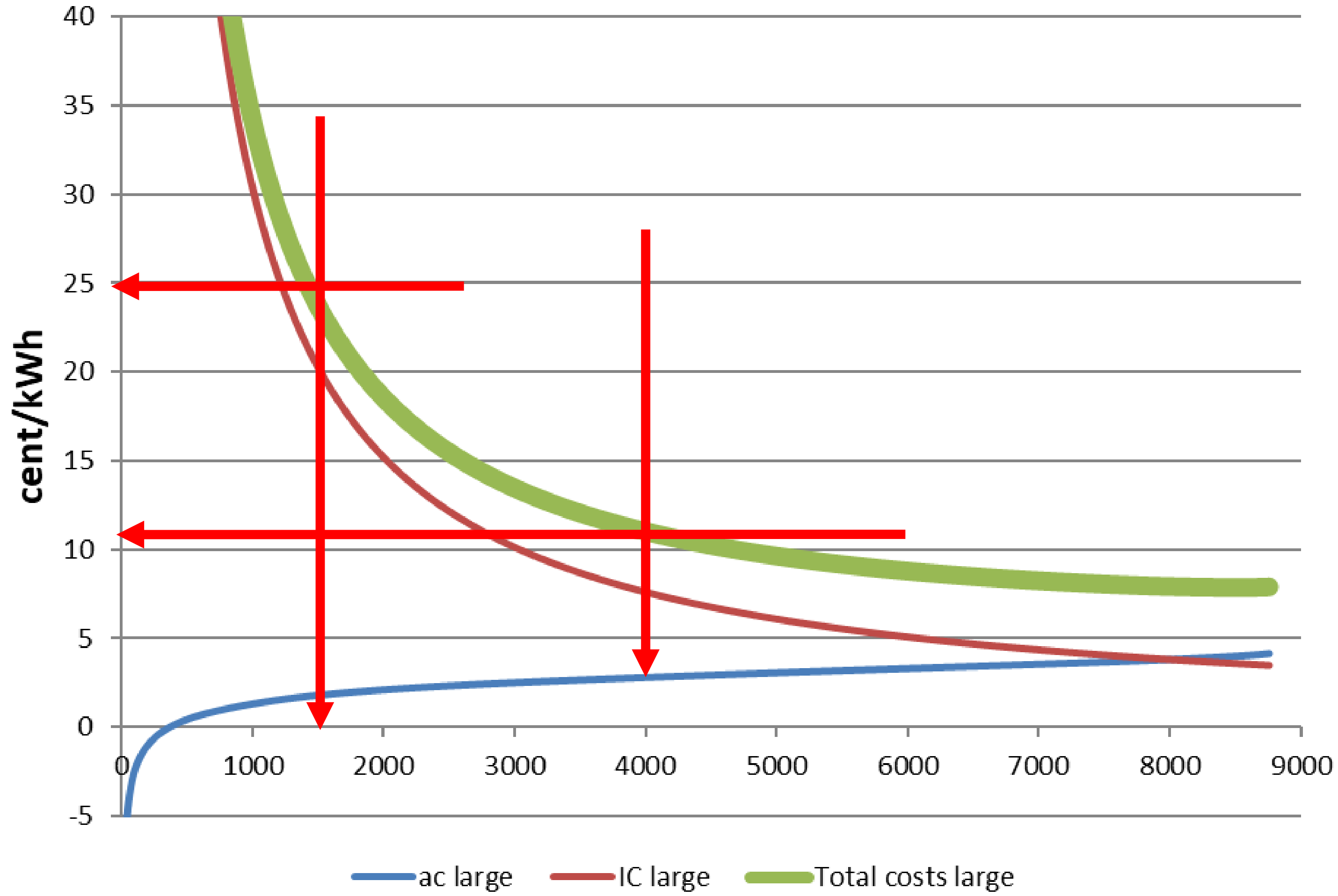


Electricity prices and costs

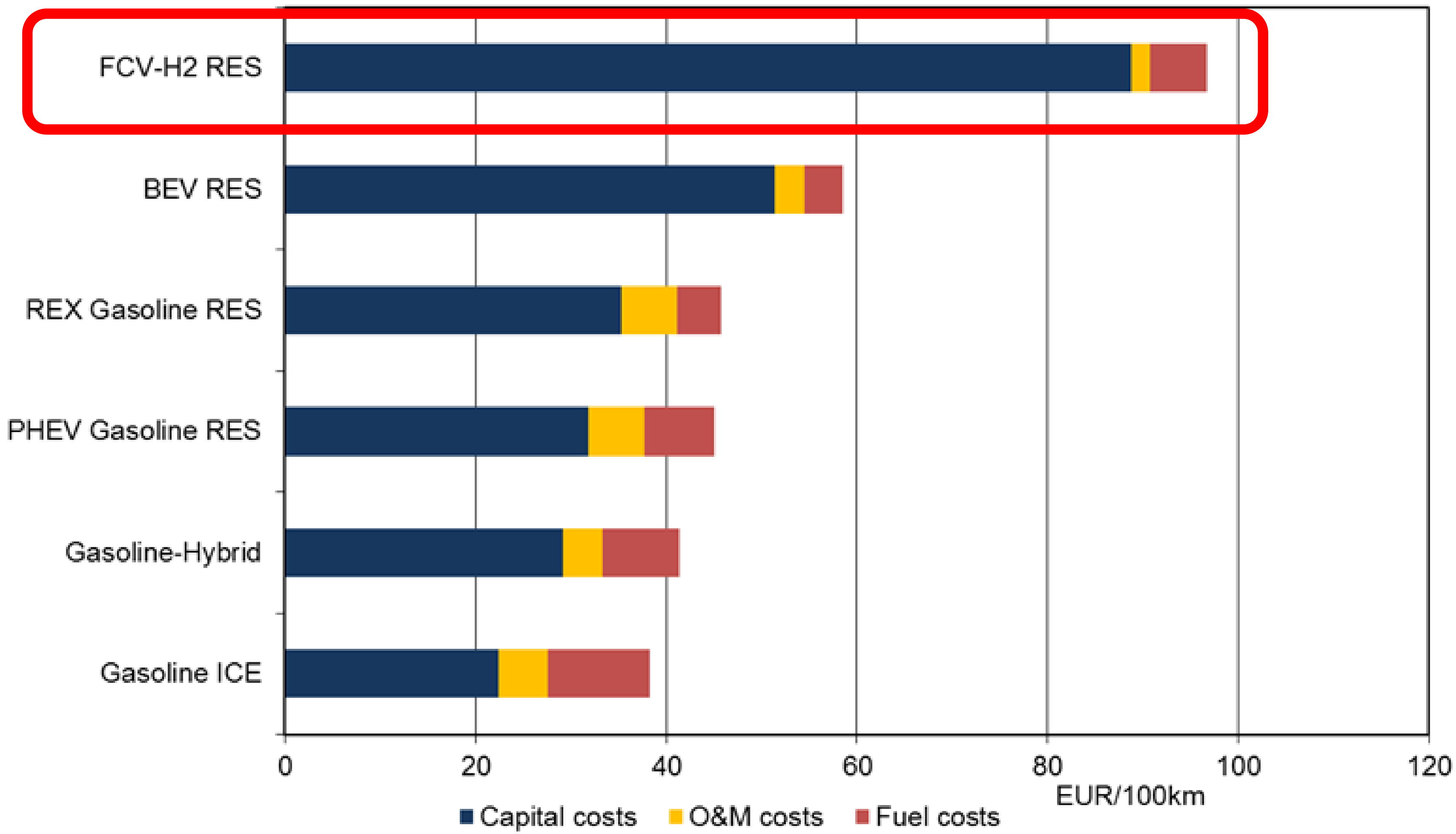


Source: Ajanovic/Haas (2018): The economic prospects of hydrogen in the energy system as a storage for electricity and a fuel in transport, Energy Policy

Optimal Fulloadhours 2 MW plant



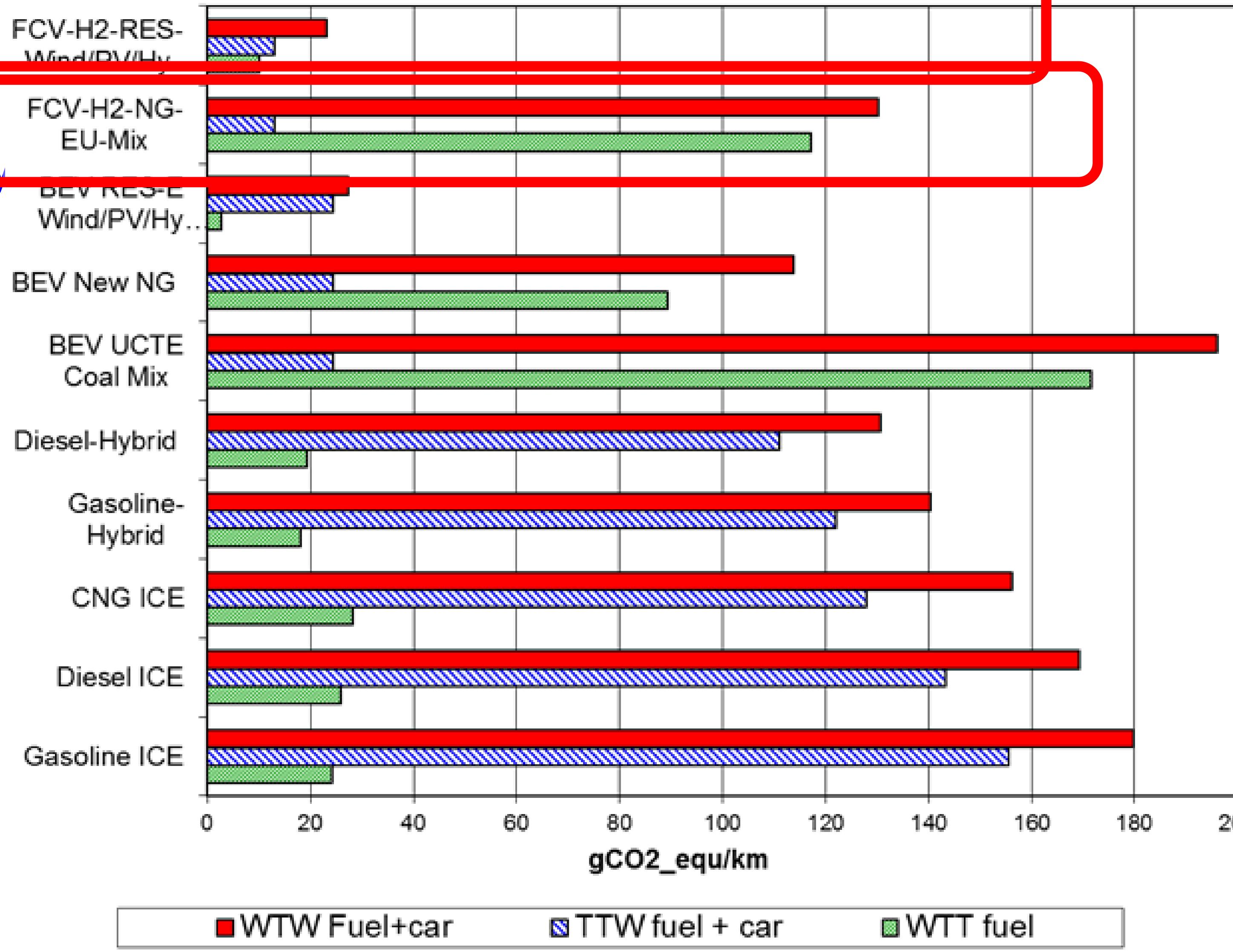
CURRENT ECONOMICS IN PASSENGER CAR TRANSPORT



5. WHICH COLOUR OF H2?

The env benignity

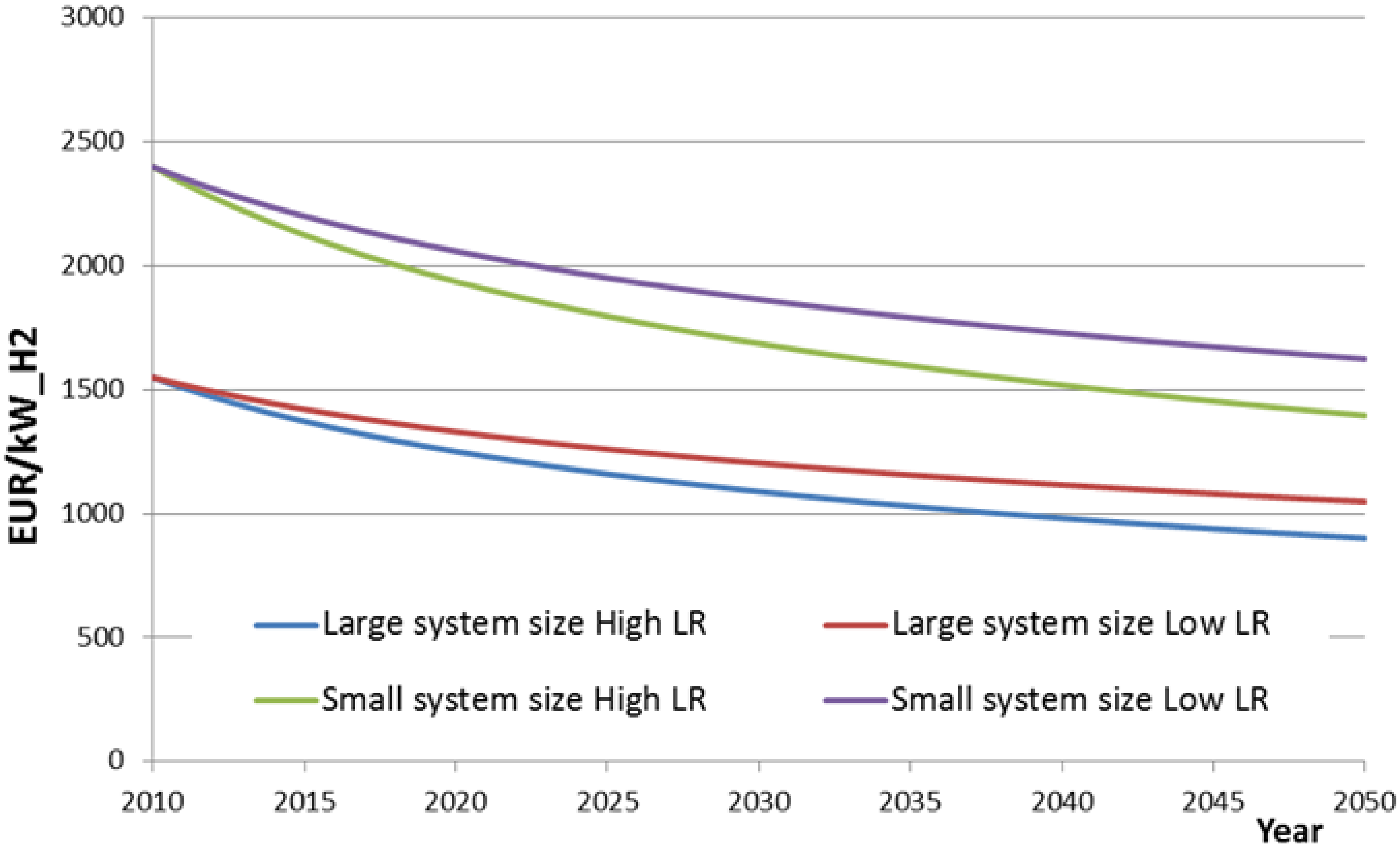
- Green
- Blue
- Turkis
- Grey H2



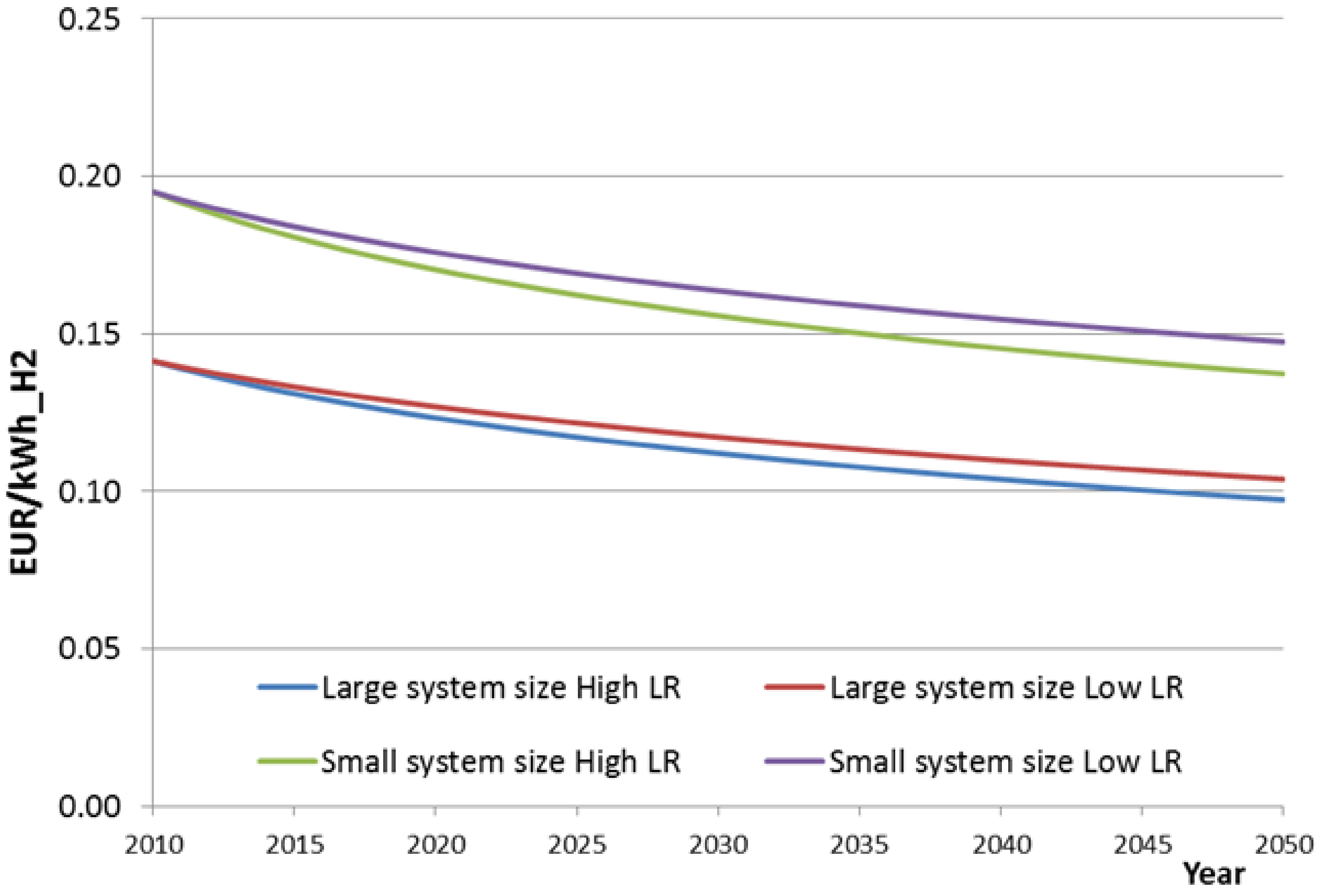
EXAMPLES

- Largest electrolysis plant is currently built in Hamburg → 100 MW, 2 tons H2/hour
- H2- Busses
- H2 – locomotives
- H2 – ships?

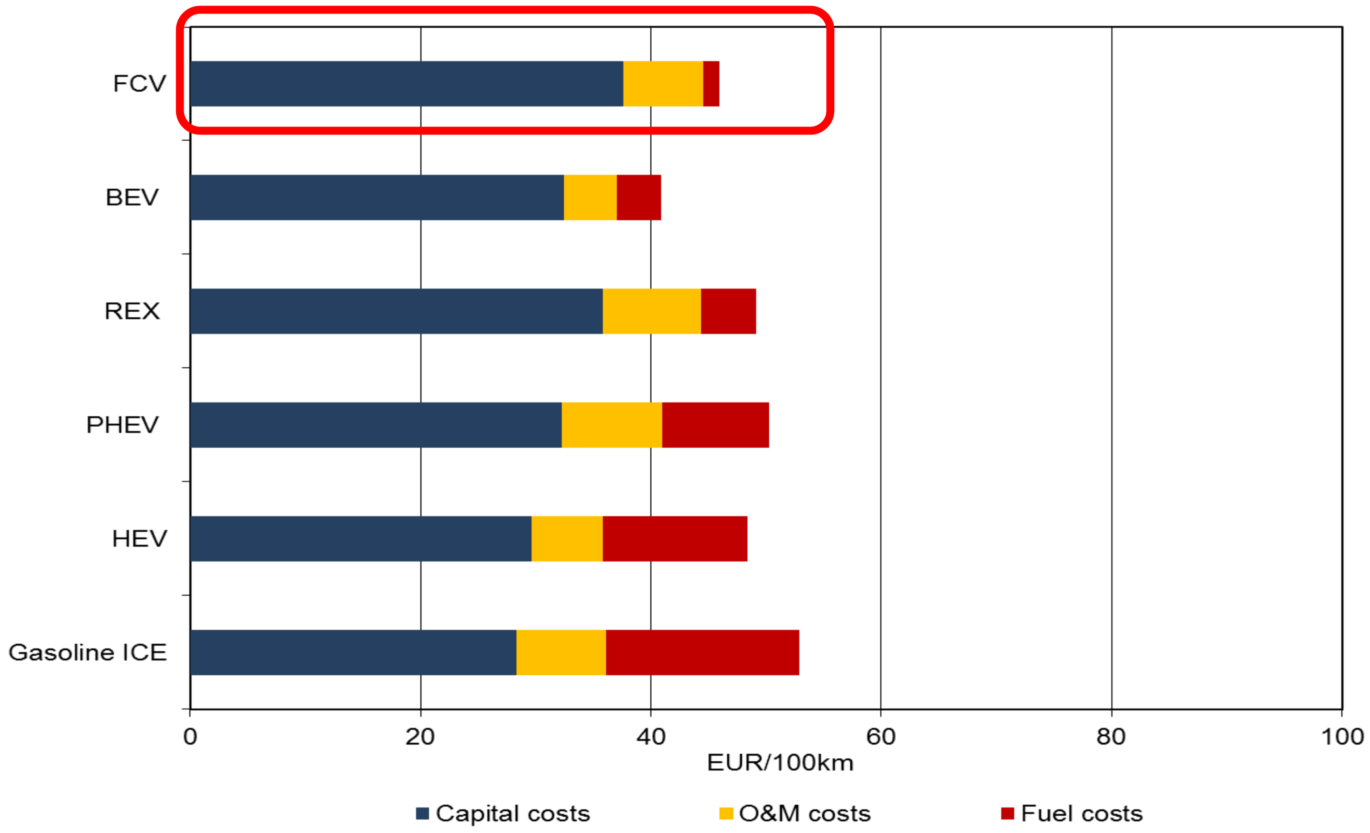
6. SCENARIOS : TL EXPECTED



SCENARIOS : TL EXPECTED



SCENARIO: ECONOMICS IN PASSENGER CAR TRANSPORT in 2050



7. POLICIES
WHAT ARE PROPER POLCIES? WHICH POLICIES ARE SUITABLE?

CURRENT POLICY STRATEGIES, TARGETS IN VARIOUS COUNTRIES

Which strategies and targets exist in different countries?

- EU: H2-strategy launched 10 June 2020.

In the first phase (2020-24) the objective is to decarbonise existing hydrogen production for current uses

- China: In 2019 a H2 strategy was launched with a focus on hydrogen busses and trucks.....

The country intends that hydrogen will account for 10% of the Chinese energy system by 2040

- USA: Since the 1970(!)s H2-strategies and targets exist

- Germany: in June 2020 a budget of € 9 billion was launched for the promotion of H2 … coop with Morocco

8. WHAT IF NOT ?

- What are finally the ultimatively, the lasting advantages of H2 over electricity expected?
- So far H2 has not delivered. What if electricity or technology surprise turns out to win?
- technologies are not really mature or not even available
- conversion efficiencies are over-all moderate
- environmental benignity only under specific conditions
- over-all costs are high
- economics still to be proven

9. CONCLUSIONS

- Are the technologies ready? On the production as well as application side? How far?

- How to produce the huge quantities of renewable electricity? Or will Western countries rely on H2 imports? From which countries?

- Can H2 survive in a competitive energy market ? Or is it necessary that the regulators interfer ?
- How will the Infrastructure be provided ? Will the existing one for natural gas be used?
- „Energy transition“: a broad portfolio of supply- and demand-side technologies → is "Picking Winners" justified ?

- What are finally the ultimative lasting advantages of H2 over electricity?