RERC 2014 – 16.06.2014 - Oslo

HYDROGEN FOR RENEWABLE ENERGY STORAGE:

DEVELOPMENT OF PEM WATER ELECTROLYSERS

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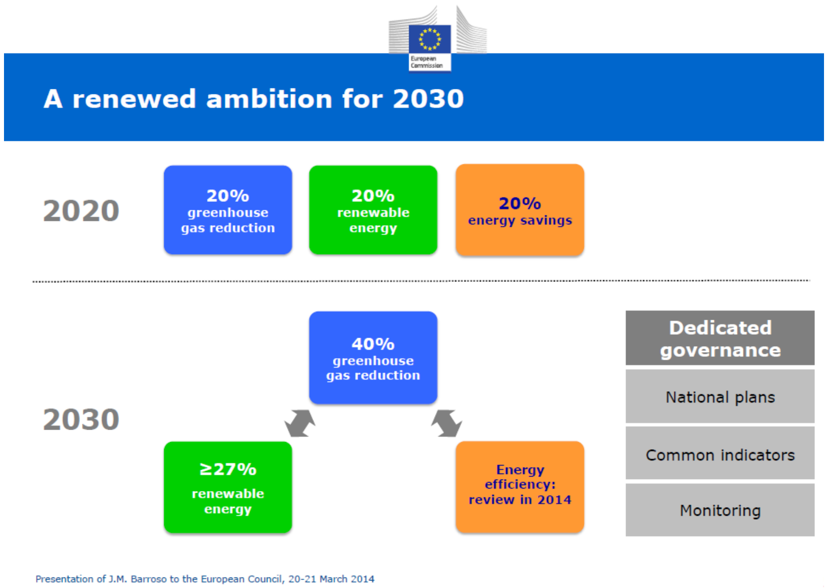
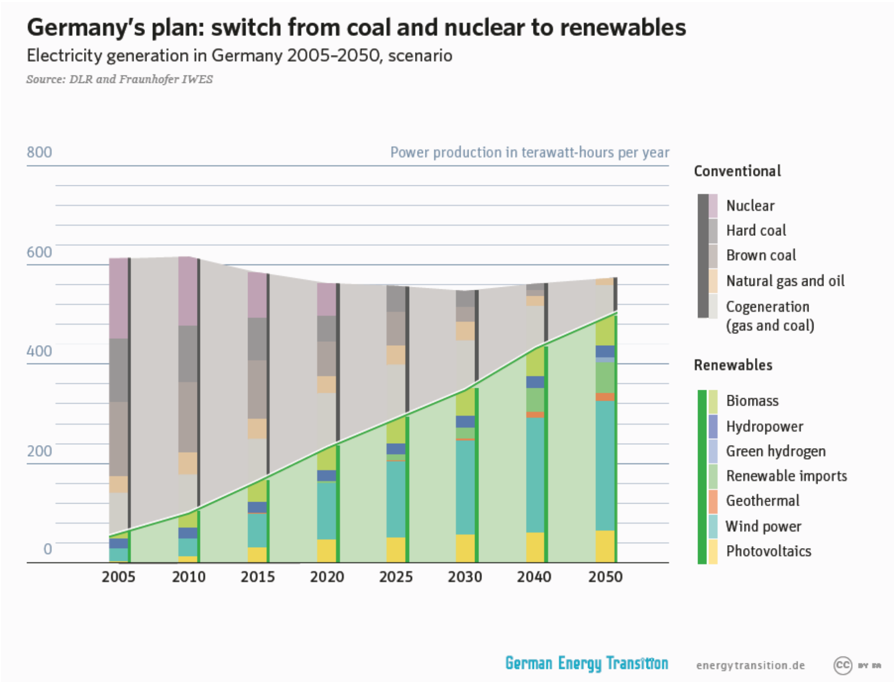
SINTEF Materials and Chemistry

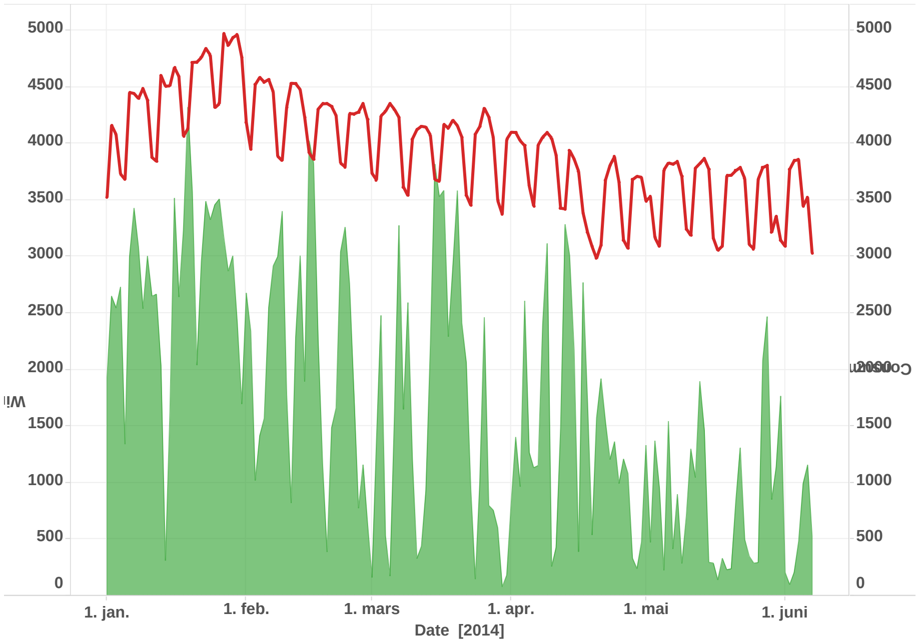
Background

- Political (and public) pull for increased use of renewable energy sources
- >27% renewables in EU by 2030
- 40% renewables in Germany by 2020, 80% by 2050.

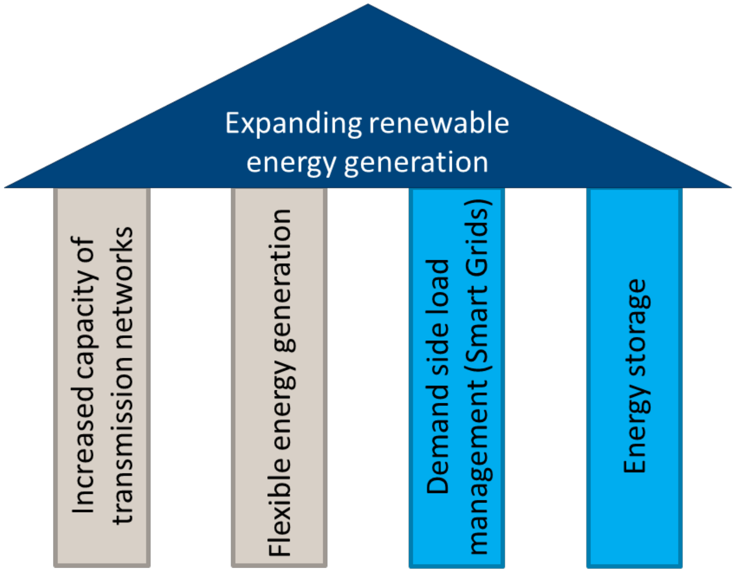




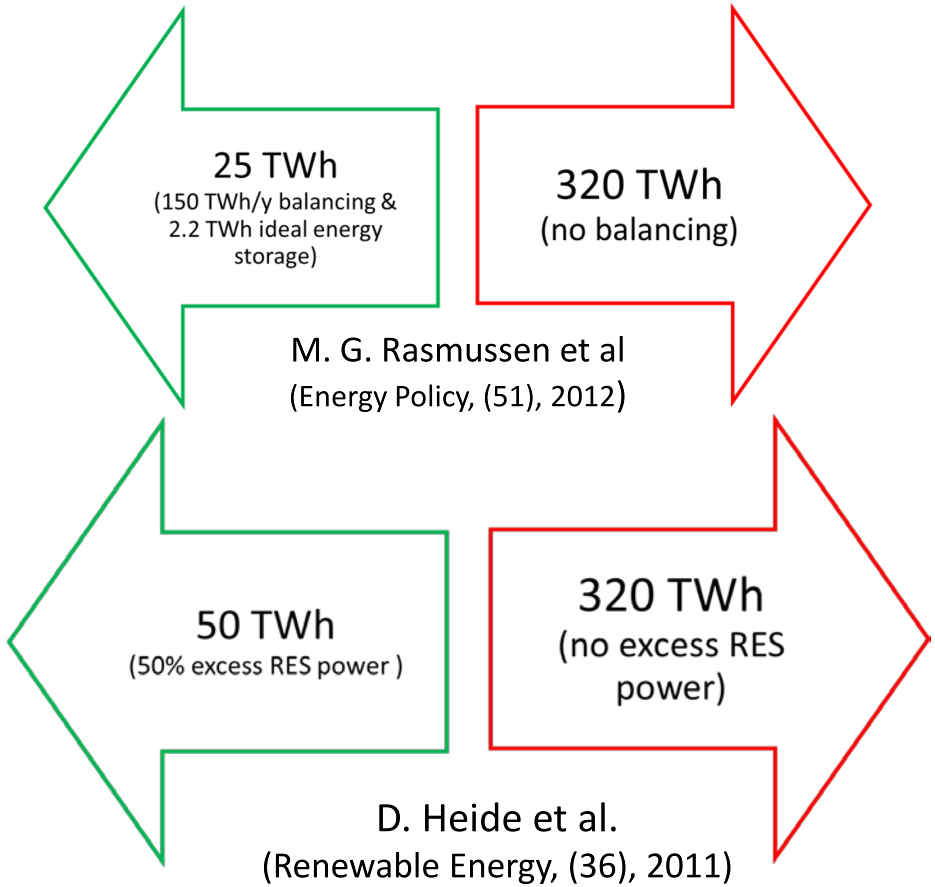
RES intermittency needs countermeasures



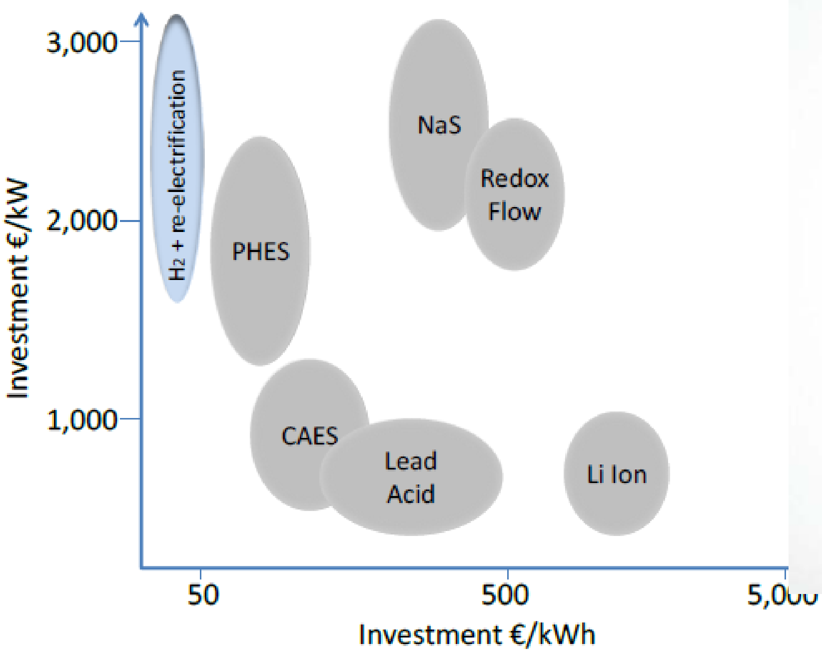
Energy consumption and wind power production in Denmark 2014



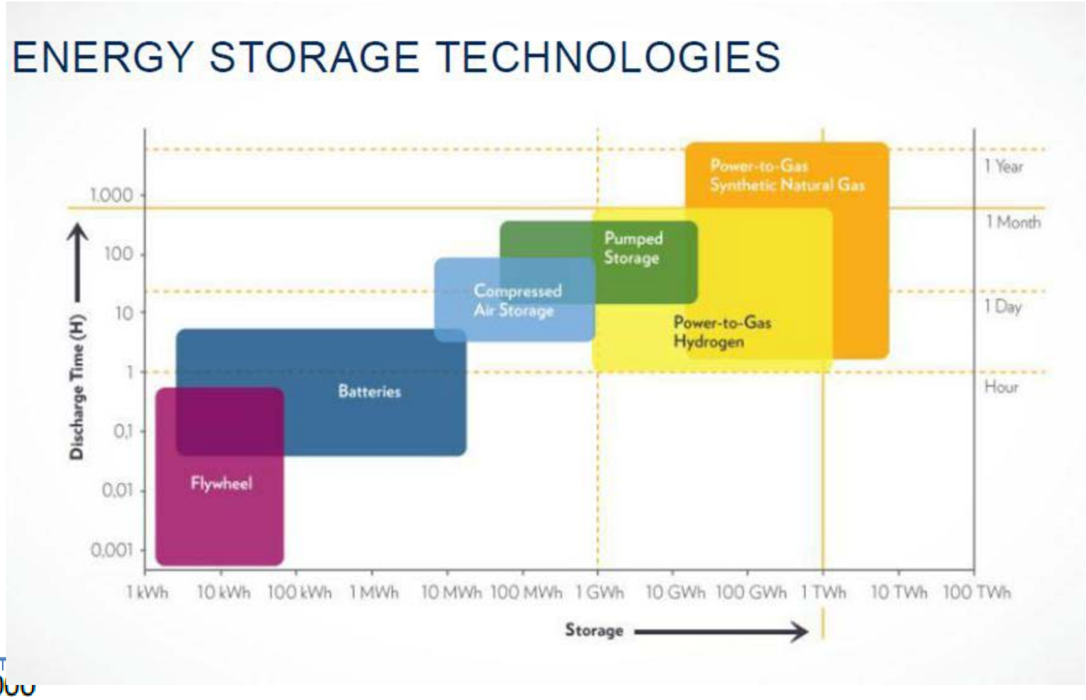
What is the need for energy storage?
– 100% Renewables in Europe



Hydrogen as energy storage - large scale!

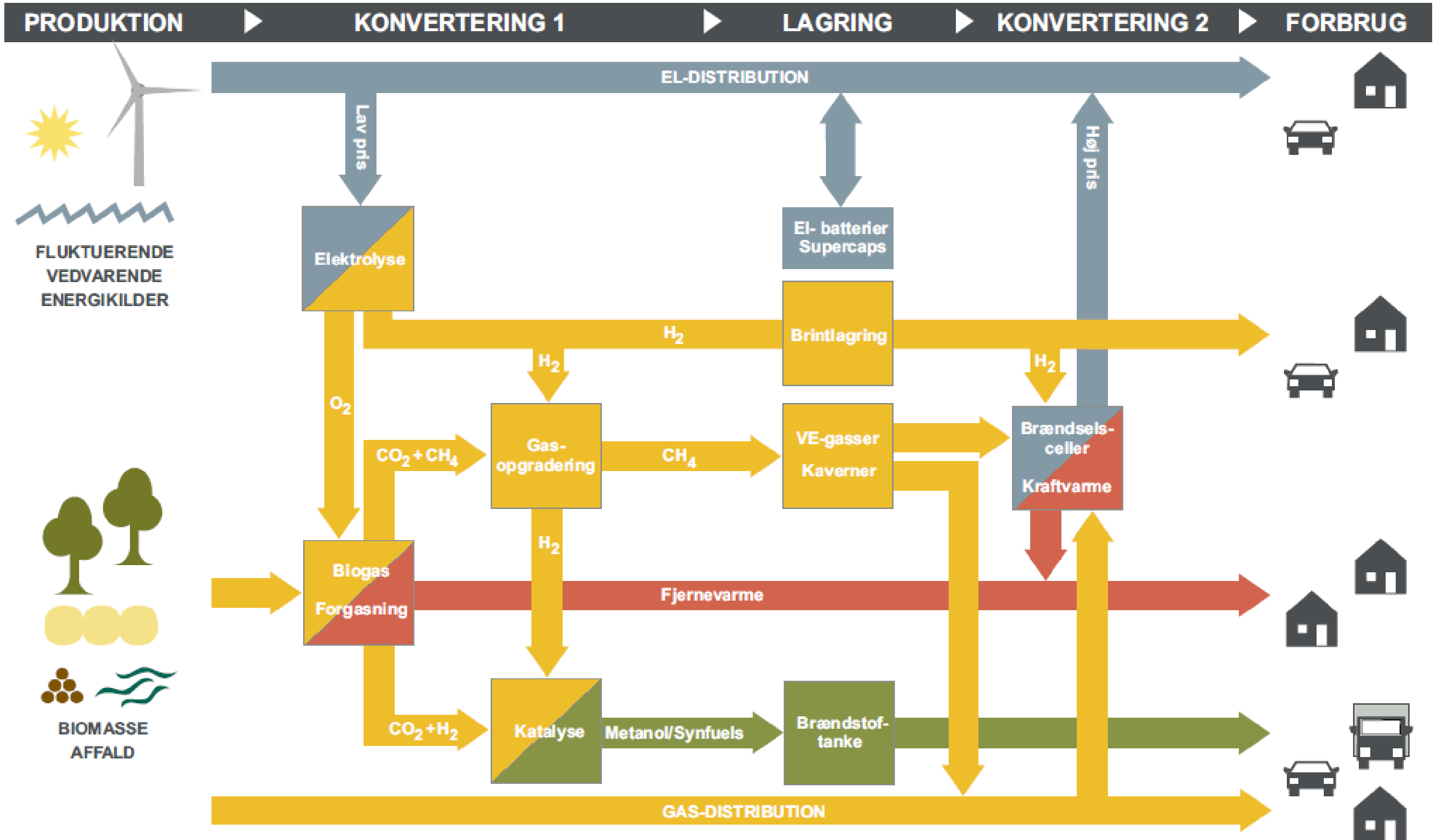


Hyunder deliverable 2.1 www.hyunder.eu



ITM Power

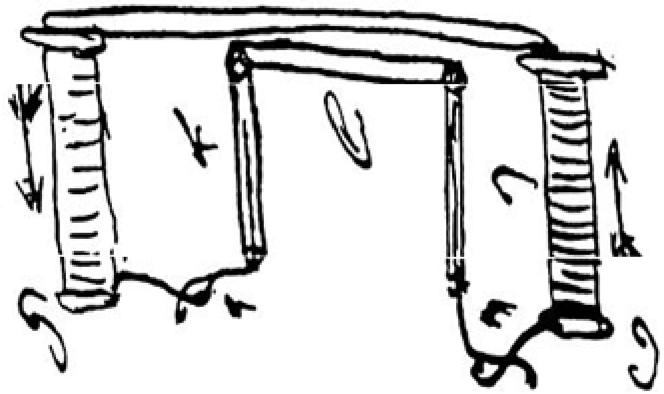
Hydrogen as energy storage – linking energy sectors

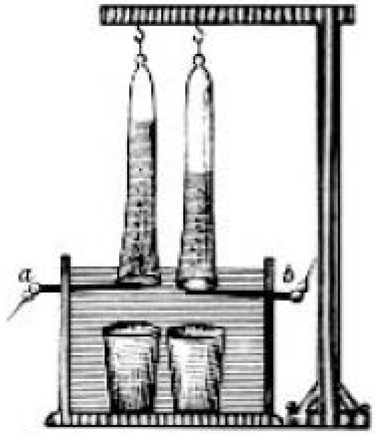


Source: Hydrogennet.dk

Water electrolysis – technological status

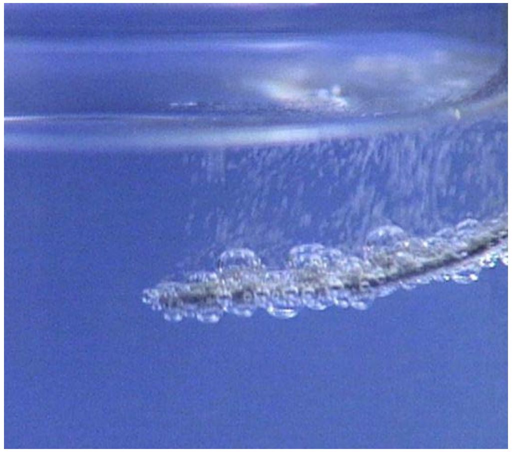
- The Dutch merchant van Trostwijk and medical doctor Deinman observed the decomposition of water into ”combustible air” and ”life giving air” in 1789.
- In 1800 Alessandro Volta published the invention of the voltaic pile (see original sketch)
- J. W. Ritter, W. Nicholson and A. Carlise demonstrated "water electrolysis" only months after





Test set-up of Ritter

Water electrolysis – technological status



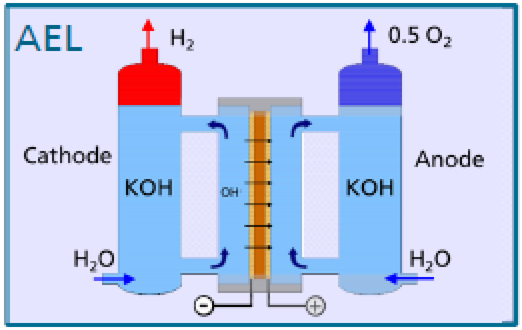
- Production of hydrogen by water electrolysis
  - 1-2 % of total hydrogen production in the world
  - Onsite production, from very small to large scale
  - Very pure hydrogen

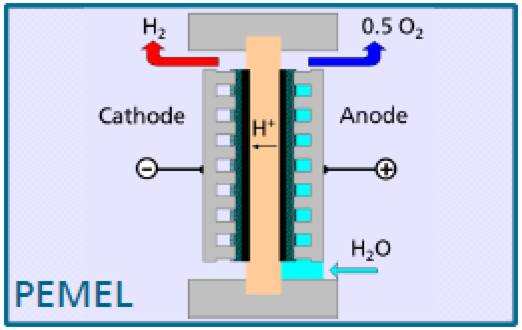
- Applications
  - Food industry
  - Metallurgical industry and metal works
  - Semiconductor production
  - Chemical and petrochemical industry
  - Meteorological balloons
  - Research labs

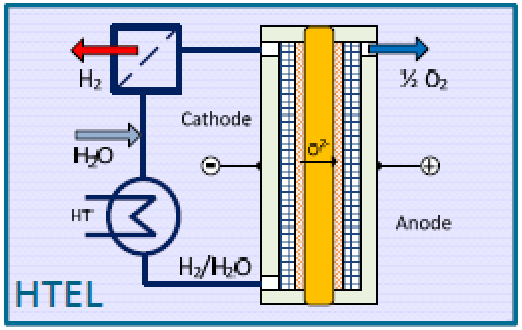
Industrial application	Typical size electrolyser
Jewellery, laboratory and medical engineering	5 - 500 Nl/h
Generator cooling in power plants	5 - 20 Nm^3/h
Feed Water Inertisation (BWR water chemistry)	10 - 50 Nm^3/h
Float glas production (protective atmosphere)	50 - 150 Nm^3/h
Electronics industry	100 - 400 Nm^3/h
Metallurgy	200 - 750 Nm^3/h
Food industry (fat hardening)	100 - 900 Nm^3/h

Approaches for water electrolysis

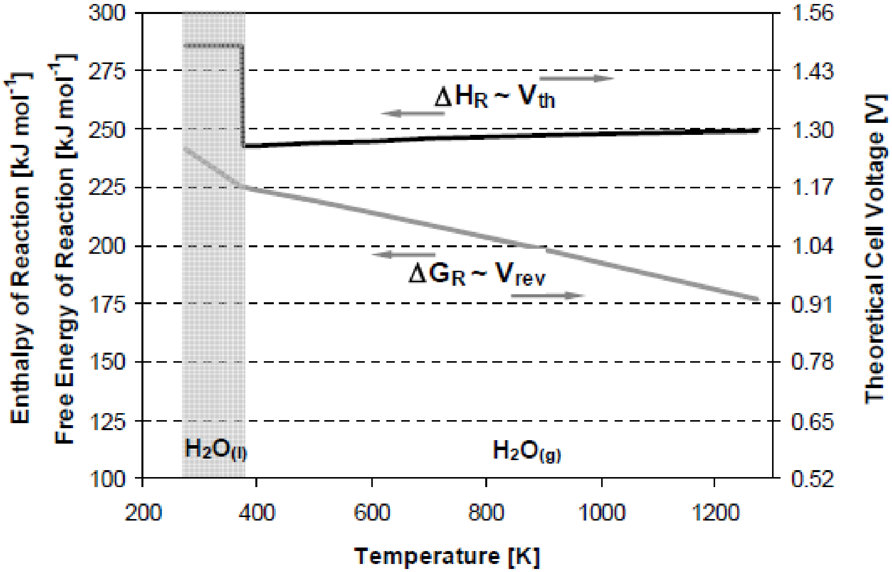
Technology	Temp. Range	Cathodic Reaction (HER)	Charge Carrier	Anodic Reaction (OER)
Alkaline electrolysis	40 - 90 °C	$2H_2O + 2e^- \Rightarrow H_2 + 2OH^-$	OH^-	$2OH^- \Rightarrow \frac{1}{2}O_2 + H_2O + 2e^-$
Membrane electrolysis	20 - 100 °C	$2H^+ + 2e^- \Rightarrow H_2$	H^+	$H_2O \Rightarrow \frac{1}{2}O_2 + 2H^+ + 2e^-$
High temp. electrolysis	700 - 1000 °C	$H_2O + 2e^- \Rightarrow H_2 + O^{2-}$	O^{2-}	$O^{2-} \Rightarrow \frac{1}{2}O_2 + 2e^-$

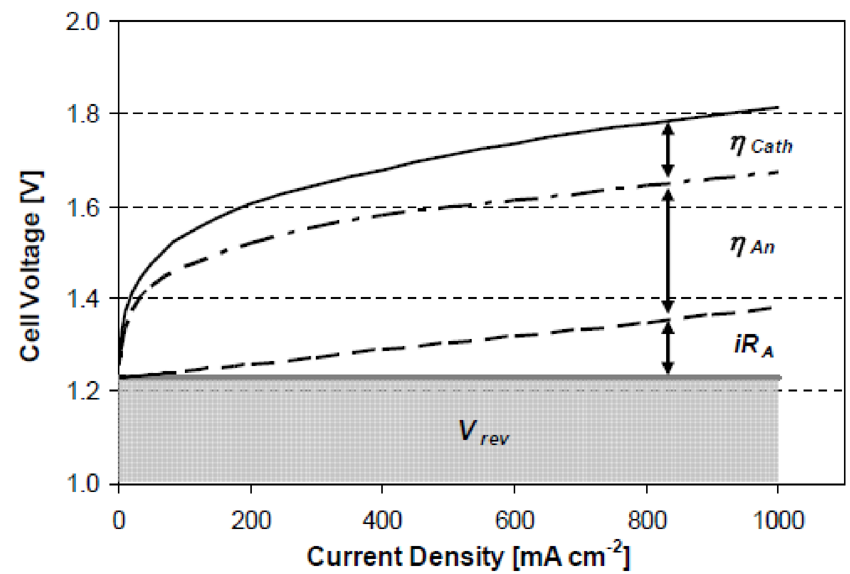






Efficiency of water electrolysis

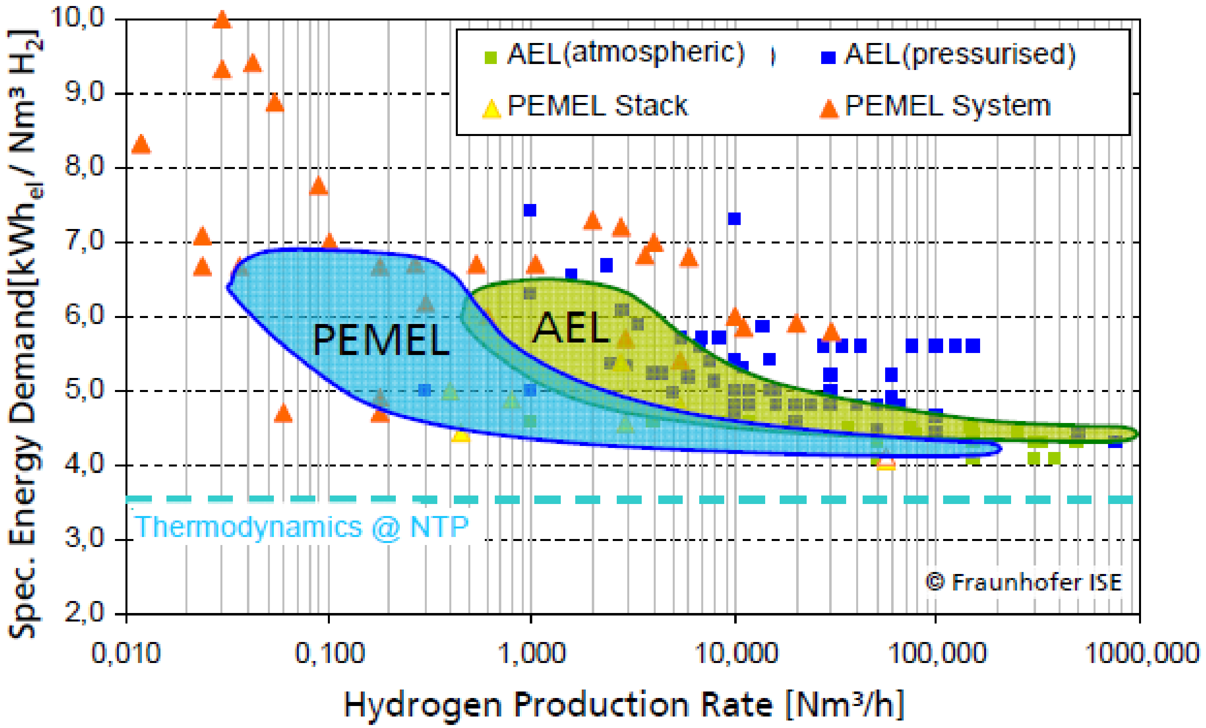




- Thermodynamics
  - Reversible losses
  - HHV: 3.54 kWh/Nm^3 H_2
  - Endothermal reaction
- Reaction kinetics
  - Irreversible losses
  - Overpotentials and internal resistance

Performance and efficiencies of water electrolysis

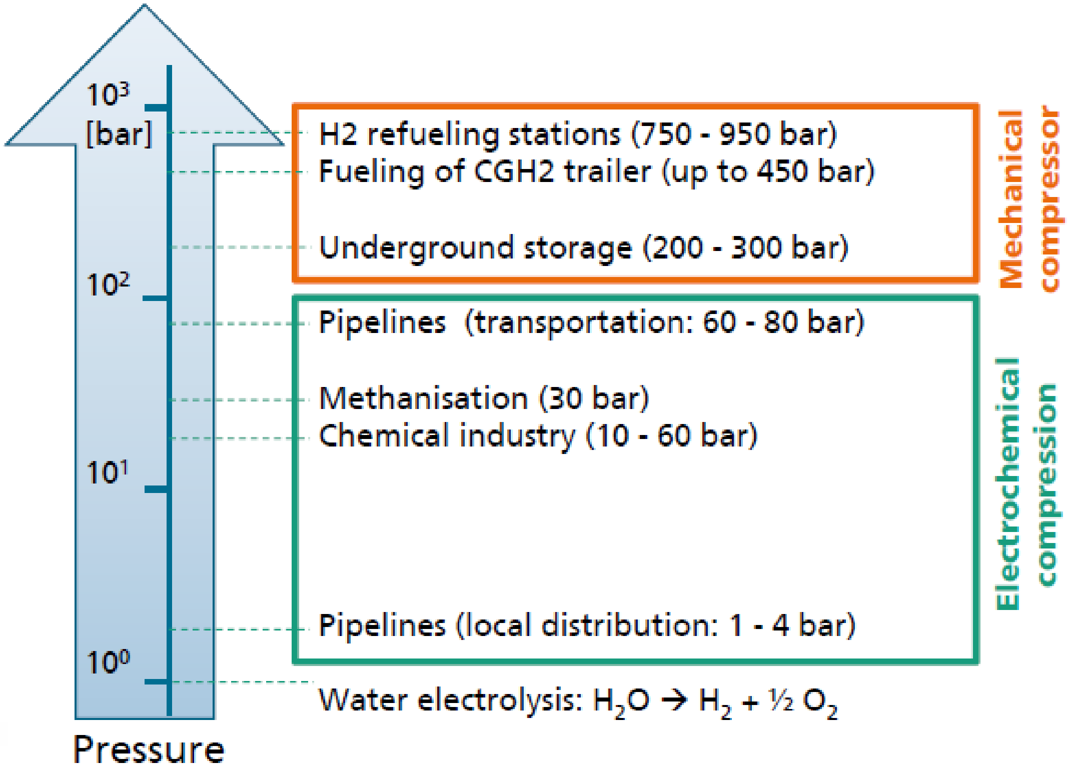
- No significant reduction of energy consumption can be expected
- Higher operating pressure
- Higher power density
- Dynamic operation



Pressurized electrolysers

- Pressurized hydrogen is needed for almost all applications
- Electrochemical compression more efficient than mechanical
- Mechanical compressors needed for high pressure applications

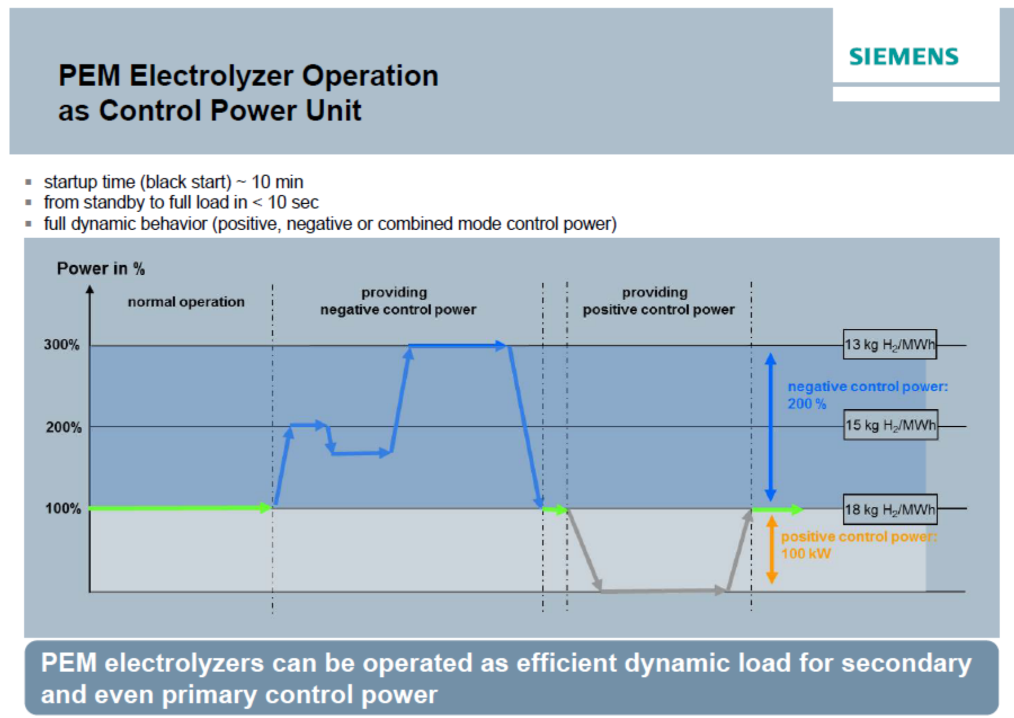
Pressure [bar]	AEL	PEMEL	HTEL
Typically	4 - 15	30	Atm.
Available	60	207	(Atm.)
Demonstrated	~ 345	~ 400	(10)



Dynamic operation

- PEM electrolysers capable of sub second regulation
- Alkaline electrolysers somewhat more sluggish
- High Temperature electrolysers need more stable operation

- Significant capacity for dynamic load management



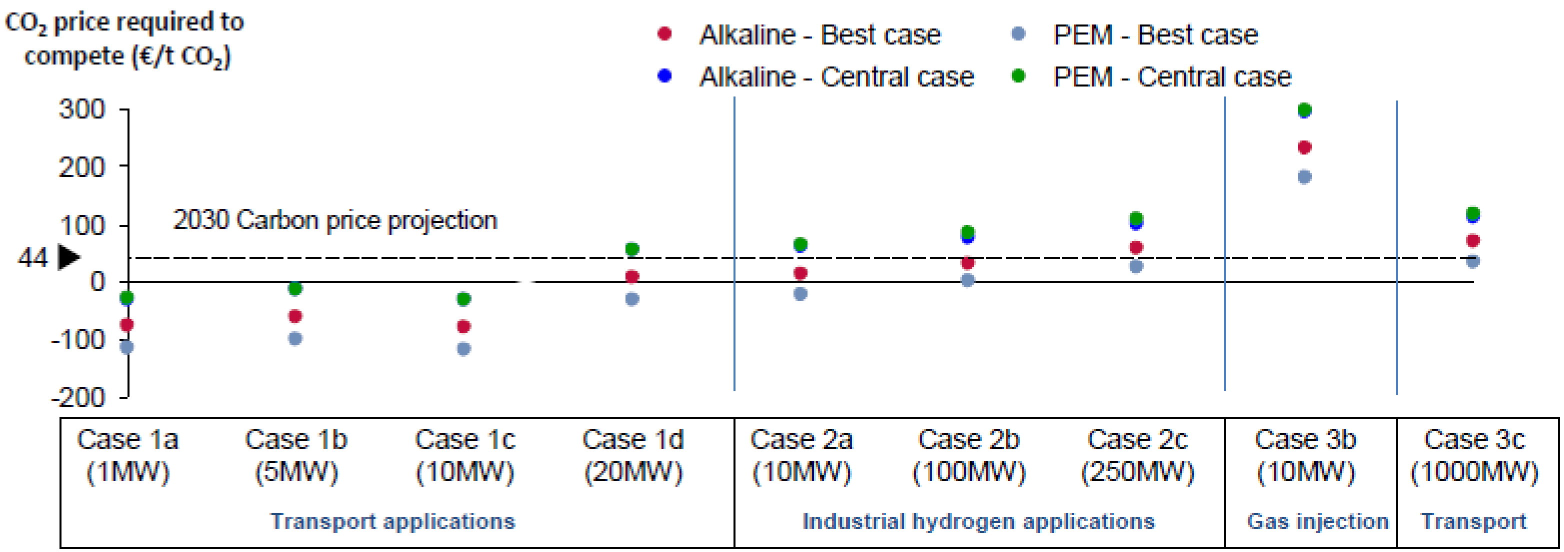
Hydrogen from renewables - economy

Fuel cells and hydrogen

Target setting – Carbon price to achieve parity with counterfactuals

Germany, 2030

Alkaline and PEM Water Electrolysers – Grid Connected

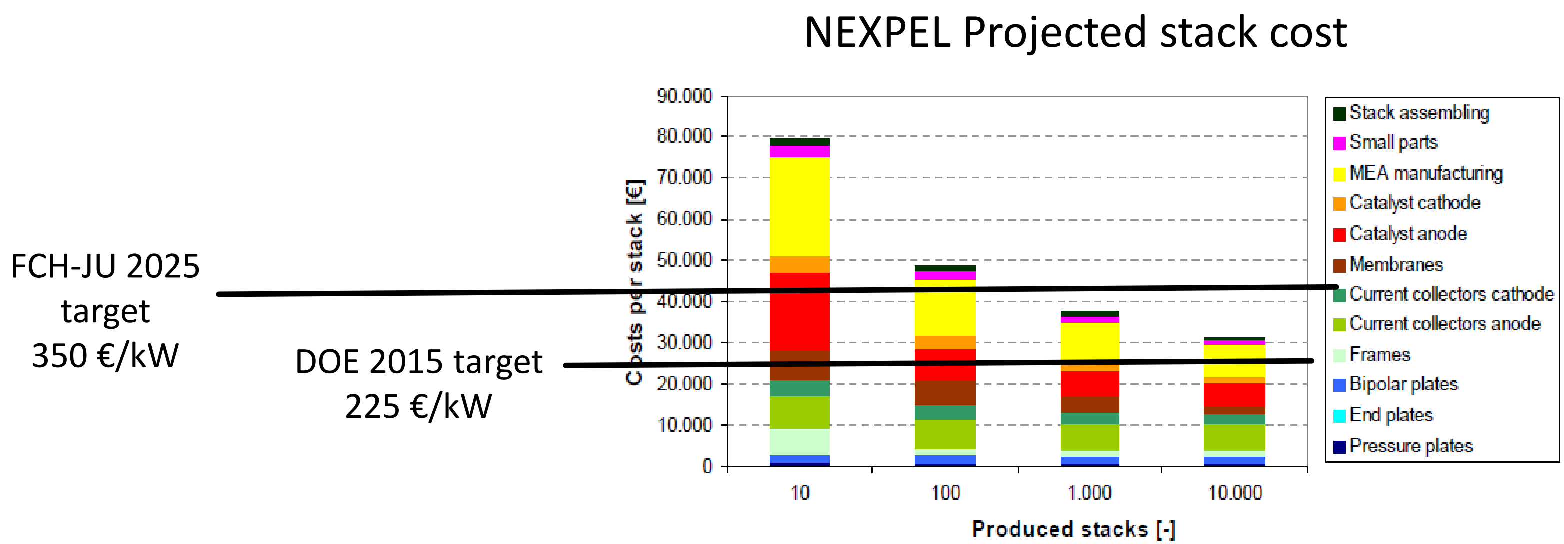


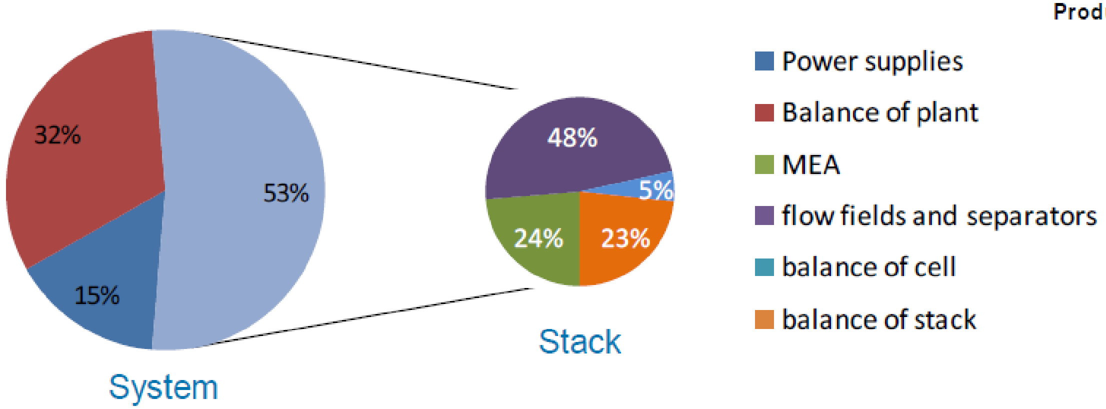
E4tech Sàrl with Element Energy Ltd
for the Fuel Cells and Hydrogen Joint Undertaking
February 2014

http://www.fch-ju.eu/sites/default/files/study%20electrolyser_0.pdf

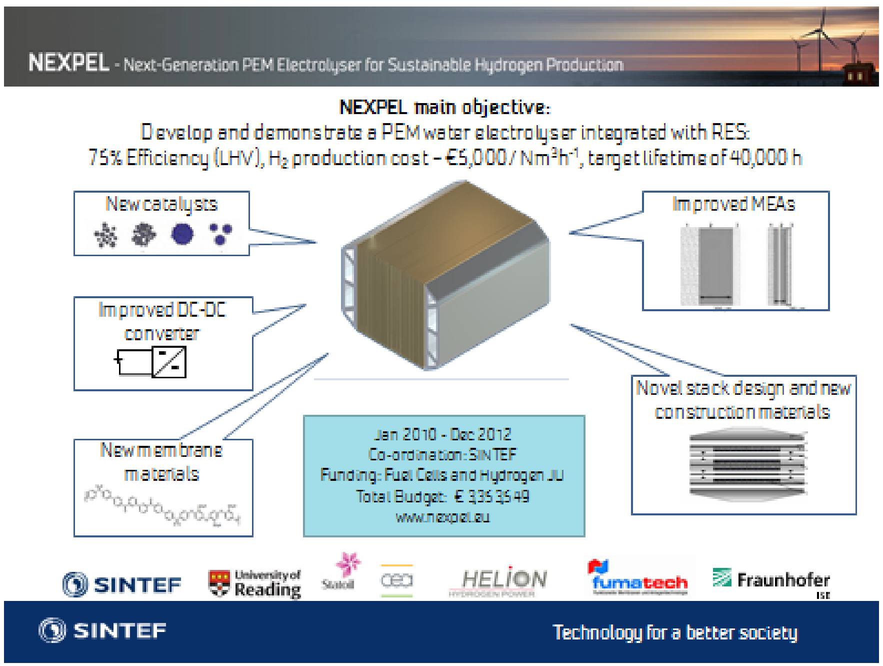
SINTEF activities on PEM electrolysers

Cost reduction and efficiency improvement





SINTEF activities on PEM electrolysers

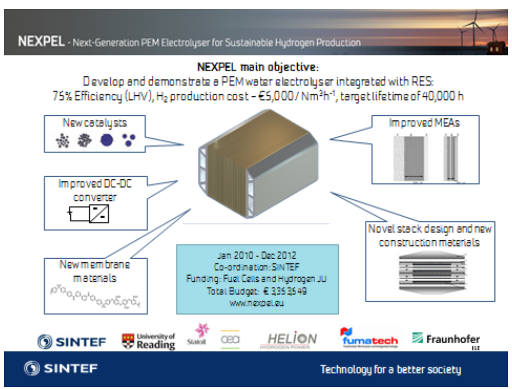


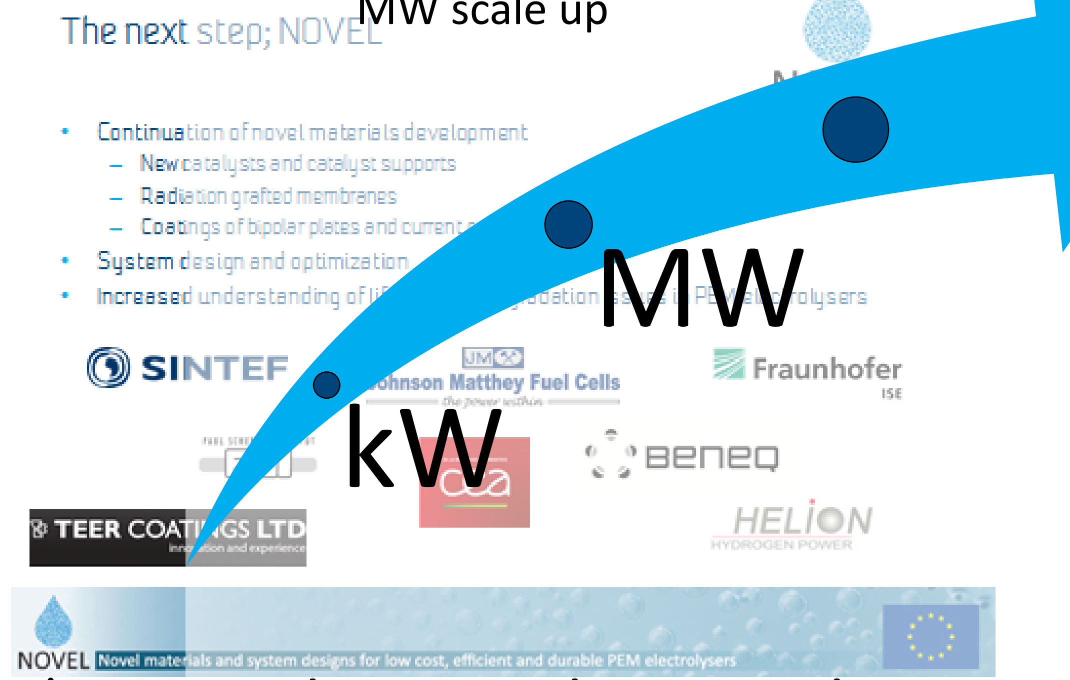
2010 2011 2012 2013 2014 2015 2016

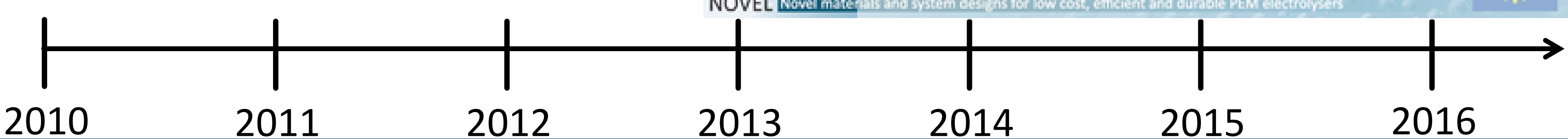
SINTEF activities on PEM electrolysers

- Coordinator of two FP7 (FCH-JU)projects on materials development for PEM electrolysers

FCH-JU project under negotiations
MW scale up



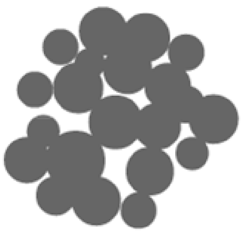




SINTEF activities on PEM electrolysers

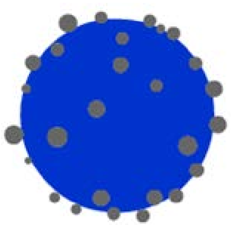
Advanced oxygen evolution catalysts

- Increase catalytic activity and stability of O_2 evolution catalysts by utilization of a support
  - Increase active surface area
  - Increase catalyst utilization
  - Reduce catalyst particle sintering by support stabilization
  - Increase specific catalytic activity by catalyst support interaction?

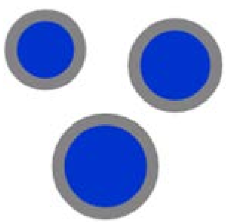


<u>Challenges</u>

- High surface area support
- Stable at elevated voltages and acidic environment for several 1000s hours.



Supported catalyst

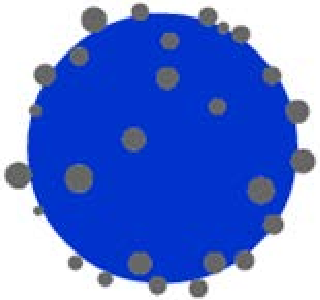


Core-shell structure

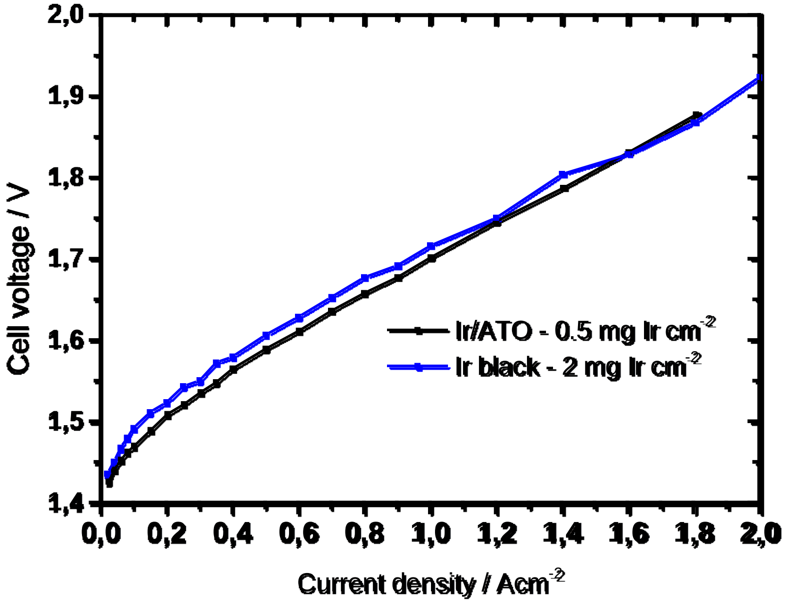
SINTEF activities on PEM electrolysers

Advanced oxygen evolution catalysts

- Iridium nanoparticles (d ~ 2-4 nm)
- Antimony doped Tin Oxide as support
- Noble metal loading of 20 wt%



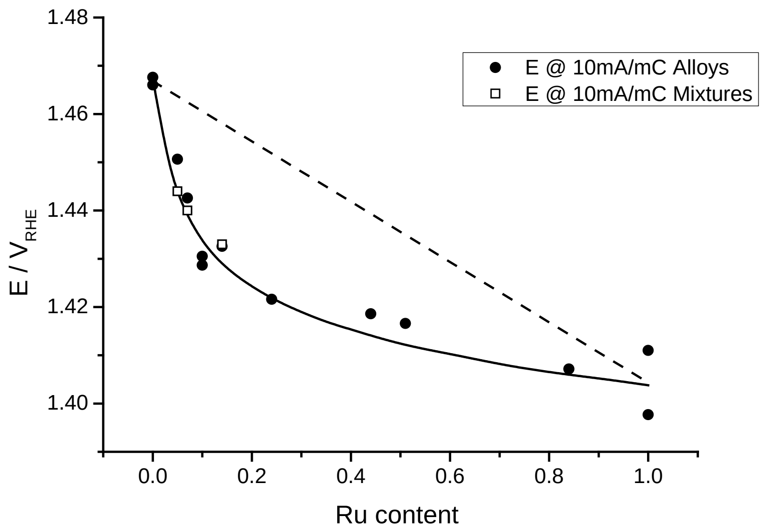
- 300% higher catalytic activity than state of the art OER catalysts

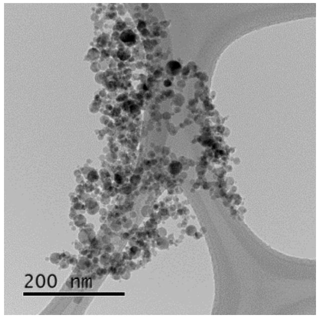


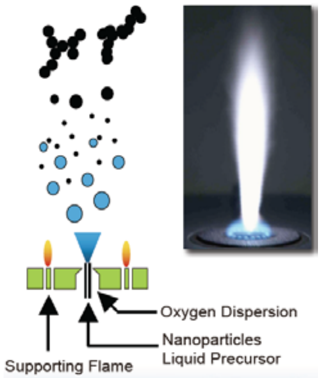
SINTEF activities on PEM electrolysers

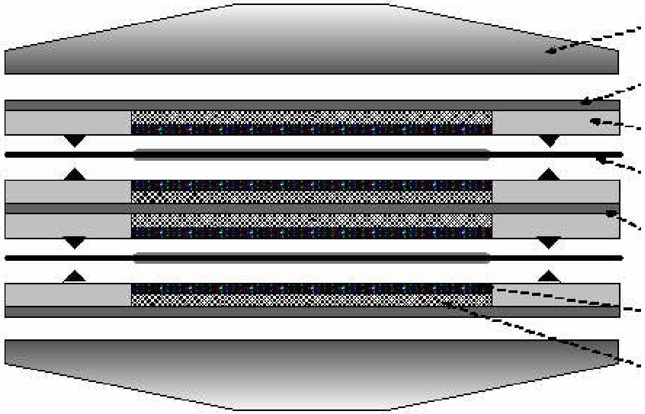
Other ongoing activities

- Development of new conductive oxides
  - Catalyst supports and coatings
- Advanced catalysts
  - Trimetallic alloys for supported catalysts
- Coatings for replacement of Ti as bipolar plates
- Studies of lifetime and degradation









SINTEF activities on High Temperature electrolysers

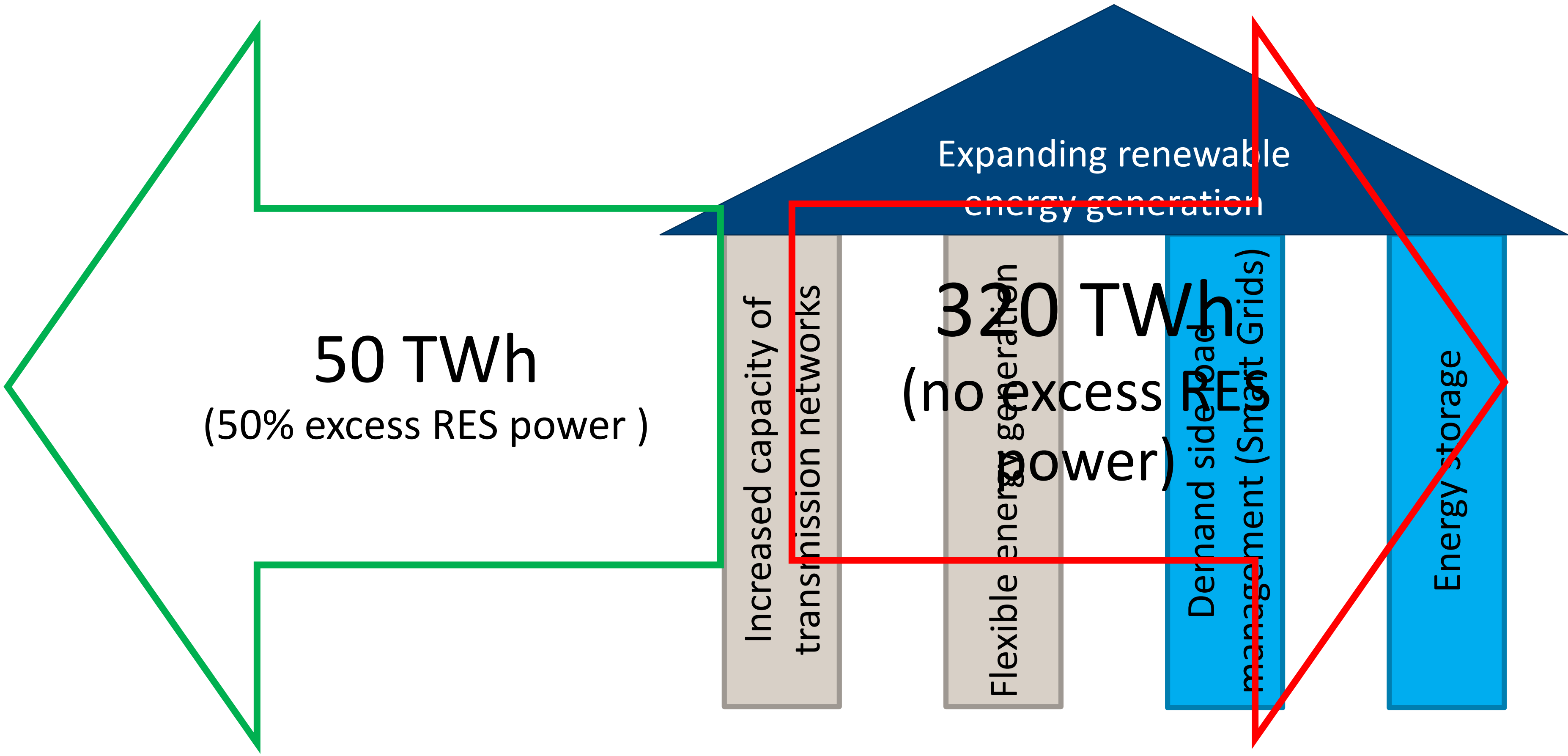
- NFR ENERGIX METALLICA project (coordinator: SINTEF, Partner: UiO) (2013-2017)

The primary objective is to develop a robust steam electrolysis technology for H_2 production based on novel **planar** alloy supported proton conducting electrolysers (PCEC) operating at 600°C for efficient use of heat and steam supplied by geothermal and solar plants. Proof-of-concept of CO_2 and steam co-electrolysis will also be demonstrated for potential integration of PCEC in industrial processes.

- FCH ELECTRA project (coordinator: UiO, Partners: PROTIA, CSIC; SINTEF, Carbon Recycling International, Abengoa Hidrogeno , Marion Technolgies) (2014-2018)

The main goal of ELECTRA is to design, build, and test a kW size **multi-tubular** proton ceramic high temperature electrolyser for production of hydrogen from steam and renewable energy.


Thank you for your attention
Technology for a better society
SINTEF


Expanding renewable energy generation
Increased capacity of transmission networks
Flexible energy generation
Demand side load management (Smart Grids)
Energy storage
50 TWh
(50% excess RES power)
320 TWh
(no excess RES power)