https://www.youtube.com/watch?v=NTffUpjoCdc

Energy Storage in Hydrogen and Re-electrification; Fuel Cells

InnoTeP 2016: De Makers van de Energie van Morgen, 30 September 2016, Nijmegen, The Netherlands

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(European Federation of Chemical Engineering)
Co-founder Nedstack

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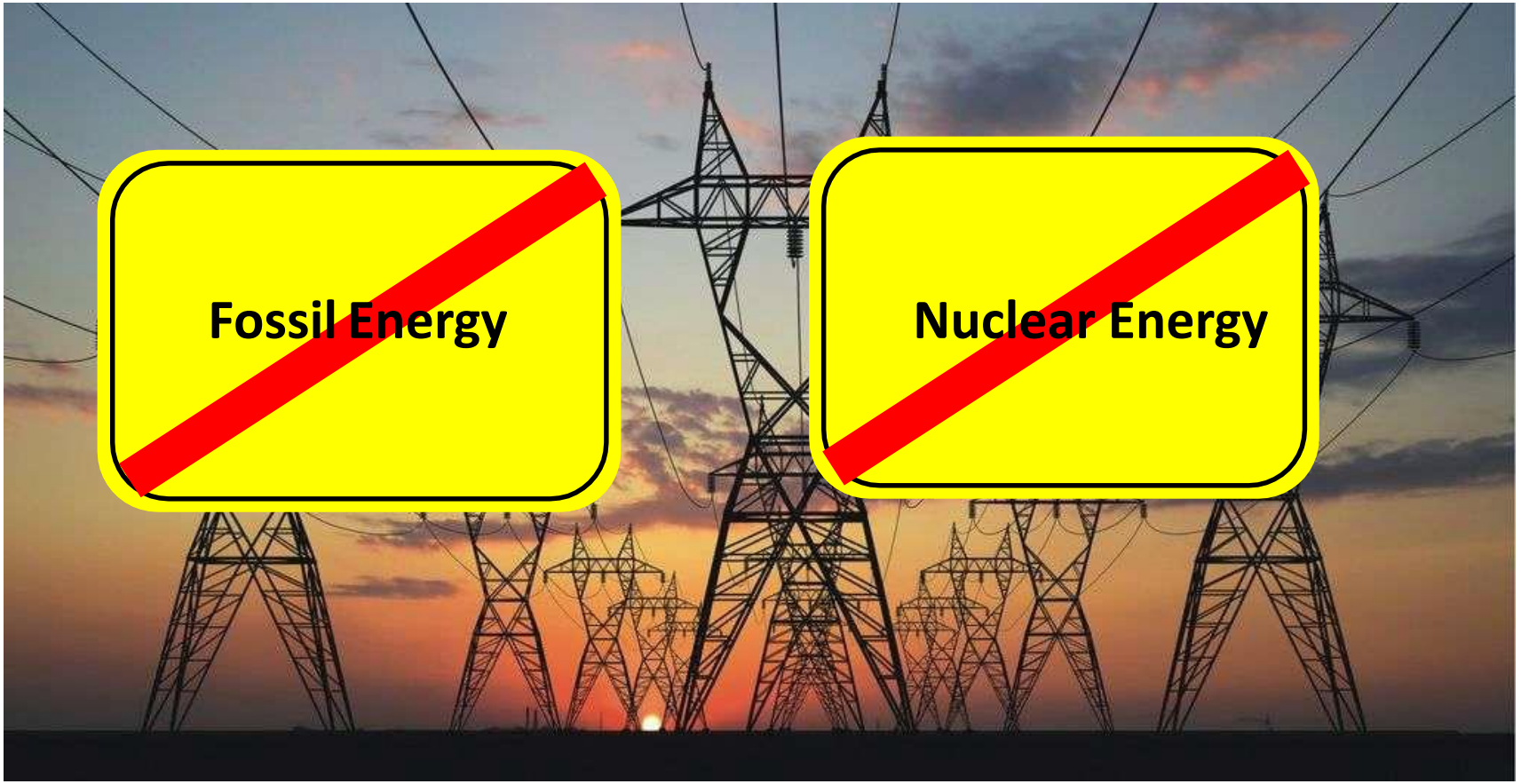
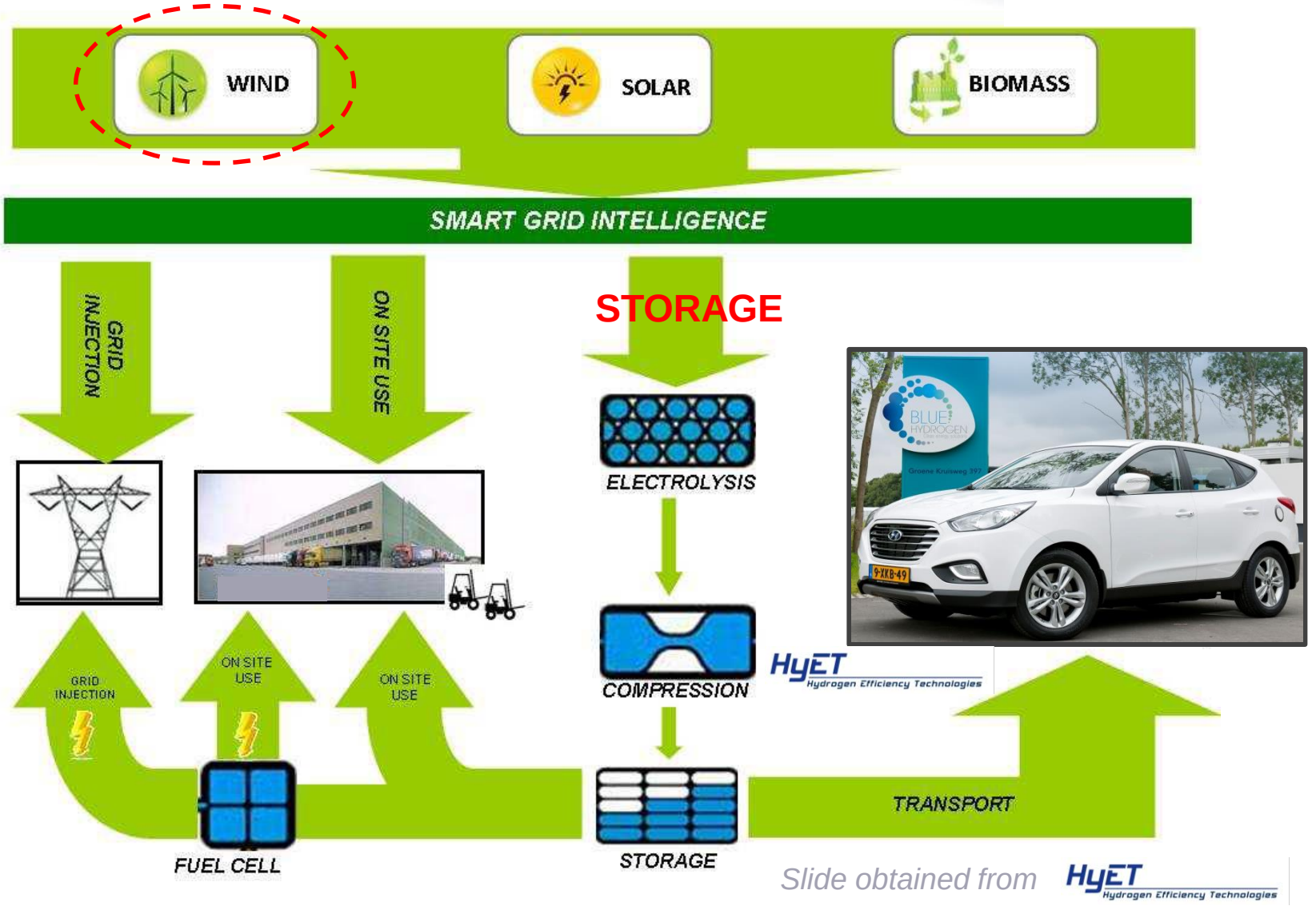
Climate agreement

Wind, solar, Bio require new energy infrastructure



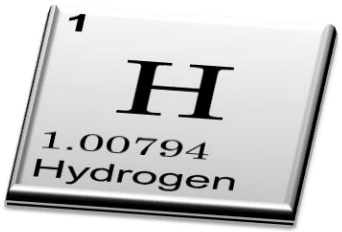
Integration of Renewables, Hydrogen and Fuel cells can play key role in future energy infrastructure

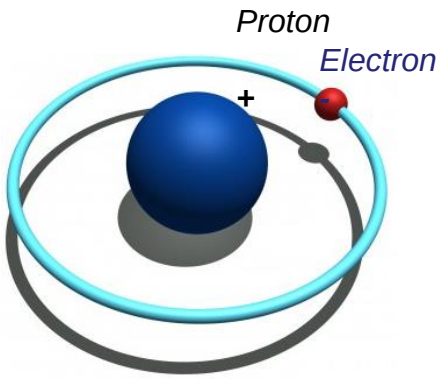


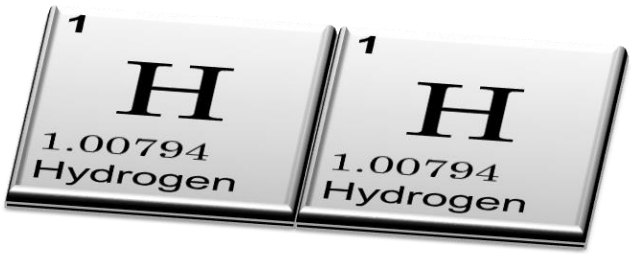
Enabling integration of renewable electrical energy and using H_2 for buffering/storage

Facts on Hydrogen

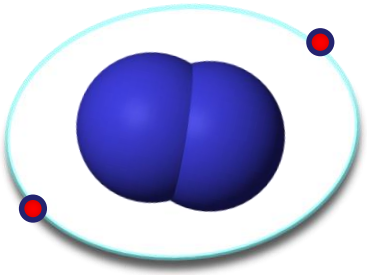
Ideal energy carrier for conversion between Electrical and chemical energy storage







stable molecule



Hydrogen element: **H**

- First element, lowest mass
- Ionisation possible *separate proton/electron*
- Most abundant element in Universe
- 0.14% present in earth crust, mostly bound as compound (*e.g.* water, methane)

Hydrogen molecule: **H_2 (gas)**

- Lightest gas: *14.4x lighter than air*
- Odourless, colourless
- non-toxic, non-carcinogenic, non-corrosive
- Rare in earth atmosphere *1 ppm*
- Flammable, forming pure water
- Highest combustion energy *141 MJ/kg*
- Boiling point -253°C *liquefiable @ -240°C 40bar*
- Energy density depends on pressure *4.5 MJ/L @ 690 bar*

Slide obtained from HyET Hydrogen Efficiency Technologies

Production of H2

Today mainly via CH4 reforming

Today

- Reforming of natural gas to H2
  - Hydrogenation of (heavy) oil fractions
  - Reactant in Chemical industry

  → Huge amounts H2 produced, H2 pipelines between producers and users and between main (petro) chemical industrial area's

- Side product in Chemicals production
  - E.g. Chlor Alkali Industry and Chlorate Industry. 10-100% vented

Production of H2 and H2 value

Future (also) via electrolysis, transport FC highest value

Future

- Electrolysis using surplus electricity from wind and solar
  - Large scale energy storage needed. H2 is particularly suited for large scale long-term re-electrification applications. E.g. via H2 storage in salt caverns or NH3 storage.

- Reforming of bio natural gas

Value Hydrogen dependent on application

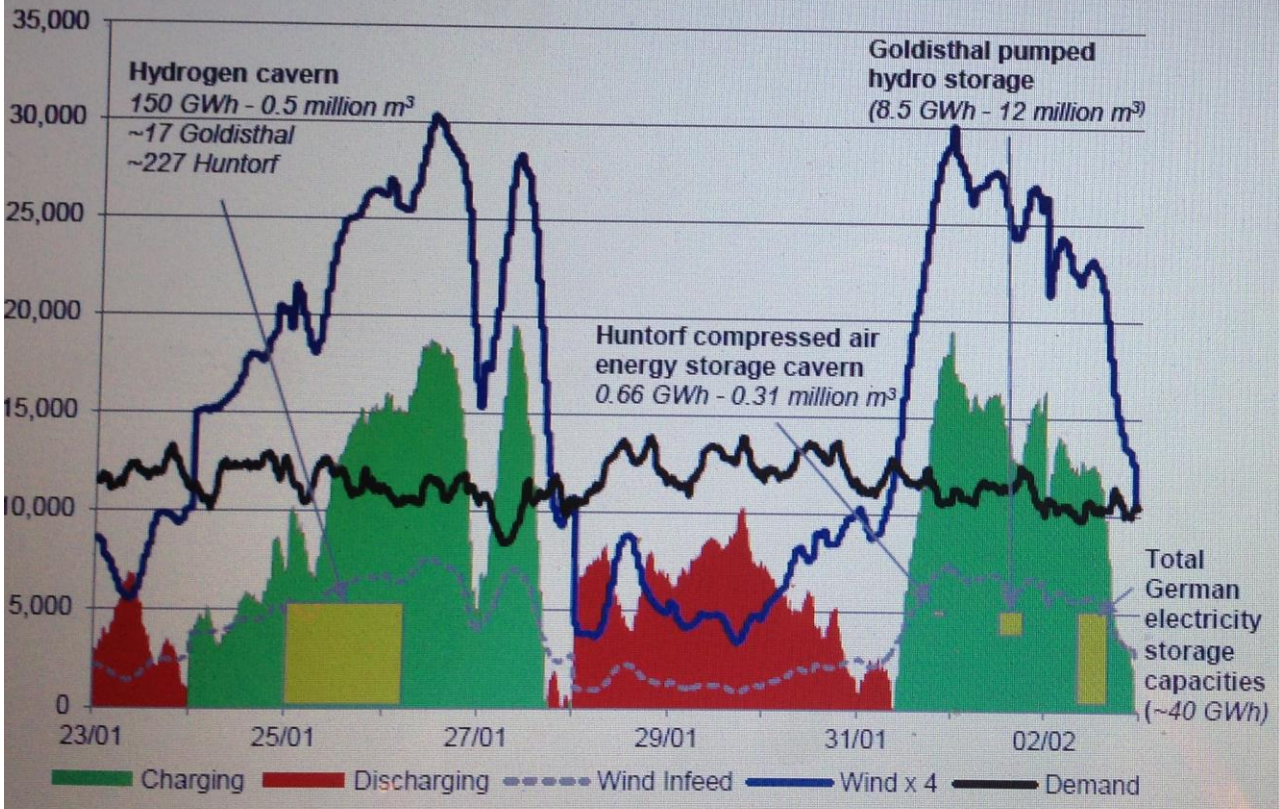
- Transport with Fuel Cells > Chemical Use > Electrical Power Generation > Combustion

Hydrogen (or NH3) storage will be key to create energy buffer needed

Time: the physical properties of hydrogen make it particularly suited to large-scale, long-term re-electrification applications

Source: SBC energy institute

COMPARISON BETWEEN HYDROGEN AND CONVENTIONAL STORAGE – ILLUSTRATIVE SIMULATION
MW, 50 Hertz Data from 23rd January to 2nd February 2008



How to read this graph?

To simulate the storage potential that would result from a fourfold increase in wind capacity in northern Germany, the wind power that was actually generated and fed into the 50Hertz grid during the week of the 23/01-02/02/2008 (the dashed grey line) has been multiplied by four: this is the Wind x 4 blue line.

The difference between this simulated wind power production and power demand[1] (black line) in that week is depicted by the green and read areas:

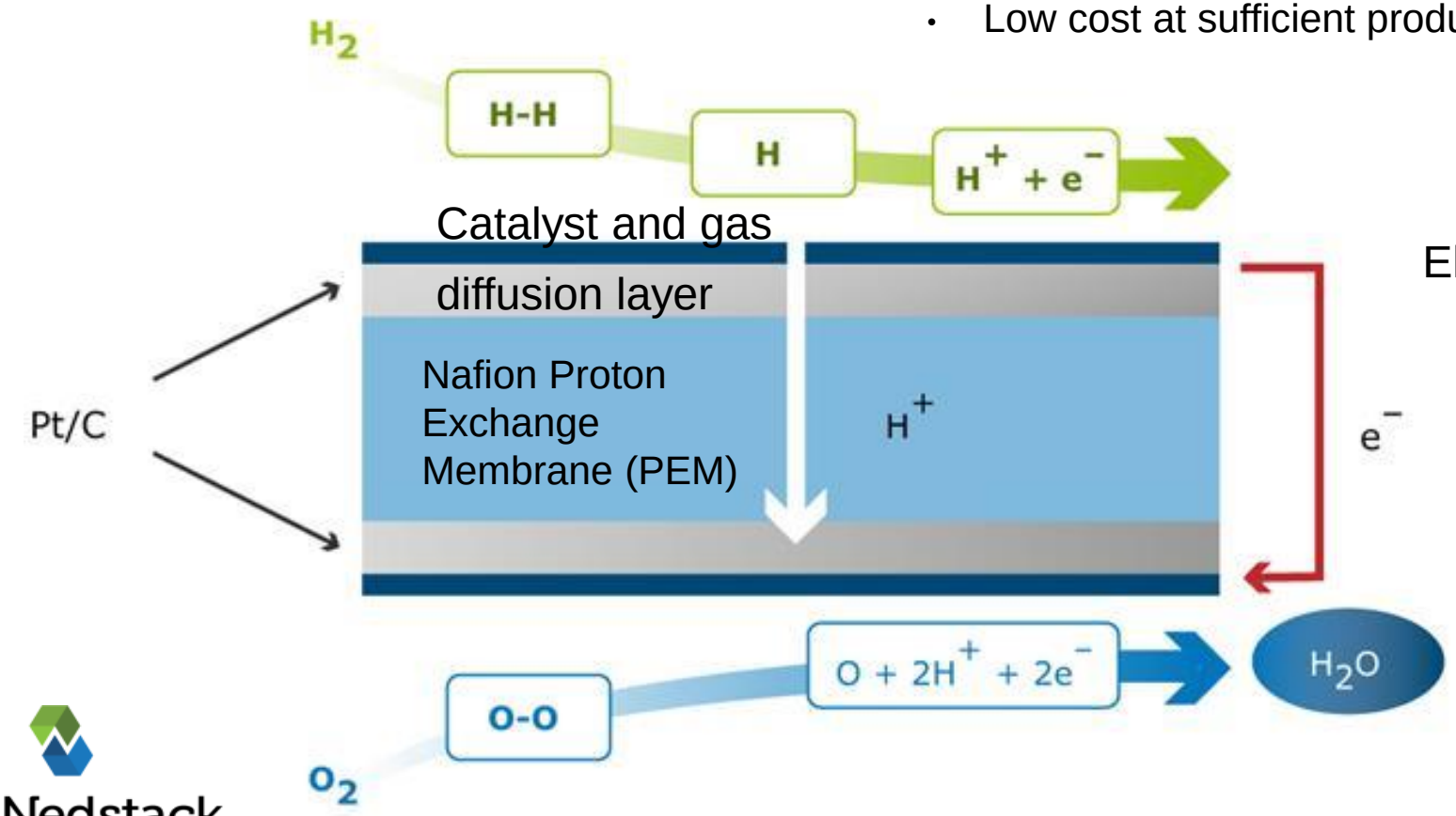
- Green when simulated wind generation > demand, enabling storage charging
- Red when simulated wind generation < demand, requiring storage discharge

Finally, the yellow rectangles depict, on the same scale the energy-storage capacity of a typical hydrogen cavern and of existing storage plants in Germany: a CAES cavern (Huntorf), a PHS[2] plant (Goldisthal), as well as the country's total electricity-storage capacity. The location of the yellow rectangles is unimportant.

PEM fuel cell (and electrolyzer) principle

Efficient, Clean, Silent, Low cost

- 45%-70% on LHV hydrogen
- No NOx, SOx, CO, CO2, Fine dust, VOC‘s
- No moving parts, only protons, electrons, and gasses move
- Low cost at sufficient production volume



Overall reaction:

$2H_2 + O_2 \rightarrow 2H_2O$ + electricity + heat

Nedstack PEM FUEL CELLS To be sure.

PEM Fuel Cell Stack

- number of cells per stack: 75
- nominal stack voltage: 52.5 Volt
- nominal cell voltage: 700 mV
- cell voltage monitoring unit on top

Nedstack
PEM FUEL CELLS
To be sure.

Case 1: PEM Fuel Cell range extenders for e-buses, a proven technology (www.hymove.nl)

HyMove
Hydrogen moves your world

Nedstack
PEM FUEL CELLS
To be sure.

NTSA
TECHNOPOWER

Electrical buses
Zero Emission Mobility

HyMove
Hydrogen moves your world

Gives a more healthy environment

- ✓ no air polution
- ✓ no noice nuisance
- ✓ only emission: H_2O

Using sustainable energy sources

- ✓ wind, solar, bio
- ✓ no CO_2
- ✓ long term available
- ✓ 30% more energy efficient

Possible solutions

HyMove
Hydrogen moves your world

- Battery with overnight charging

  → *Transportation in City only due to limited range of ~200 km/day*

- Battery with opportunity charging

  → *high infra costs, inflexible routes*

- Trolley bus

  → *high infra costs, inflexible routes*

- Hydrogen PEM Fuel Cell

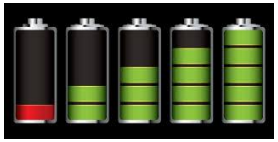
  → *need of H2 source*

System architecture

Hybrid configuration, battery and fuel cell

HyMove
Hydrogen moves your world

Charging



Braking energy

e-Drive line

H2 Fuel Cell
Range Extender

H2 Storage

Possible solutions, Hydrogen Fuel Cell
Hydrogen-Fuel Cell + small battery

HyMove
Hydrogen moves your world

FCEV with H2FC range extender

- ✓ using H2 infrastrucure
- ✓ overnight fuelling
- ✓ fuelling time ~ 10 minutes
- ✓ max range without fuelling upto ~ 500 km

→ *Regional and City due to extended range*

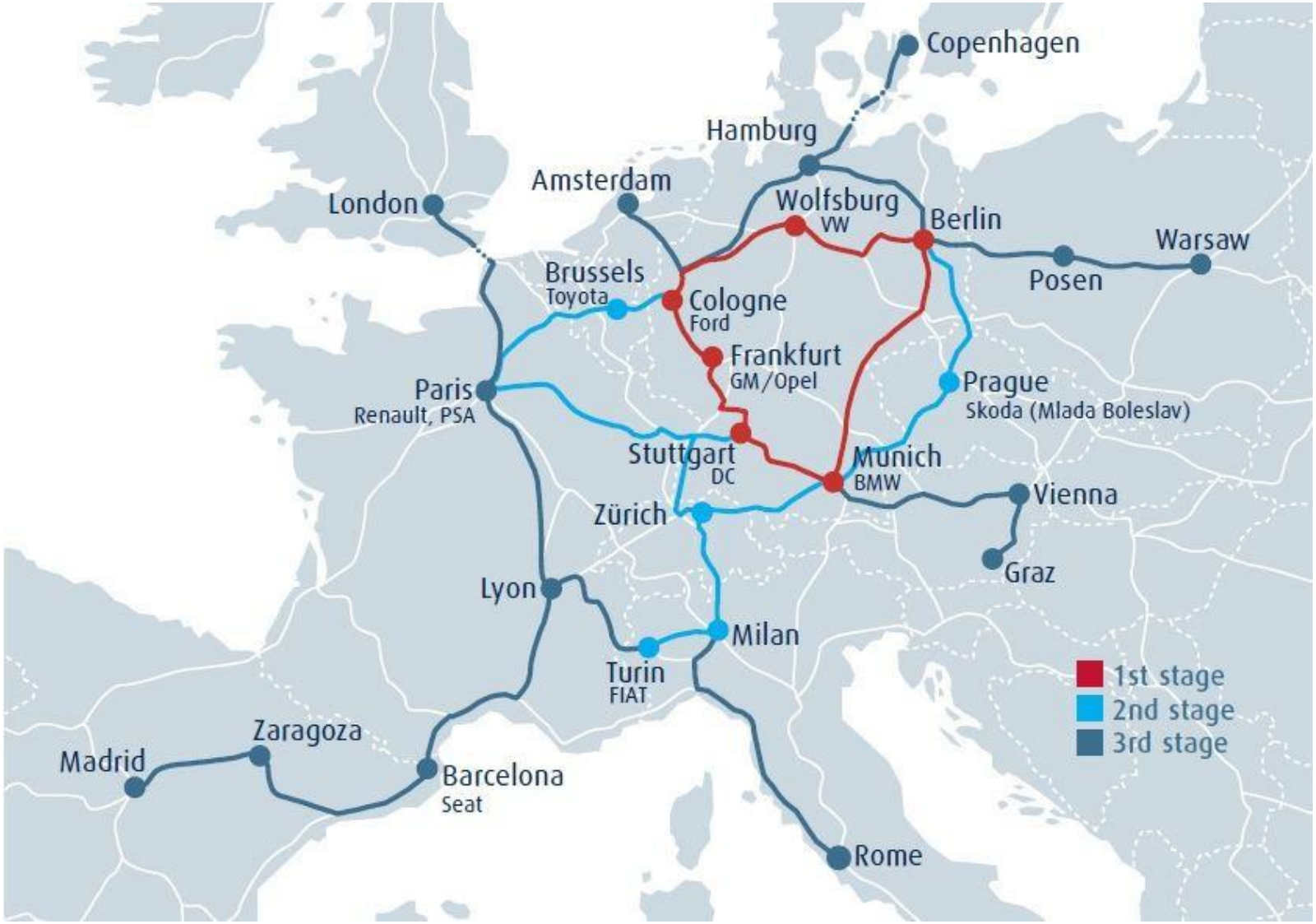
Pro's

- ✓ up to ~500 km range
- ✓ flexible routes
- ✓ quick refuelling
- ✓ infrastucture easy to organize

Con's

- ✓ medium infra cost
- ✓ high cost of bus
- ✓ need constant source of H2

European Hydrogen Highway for transportation purposes



Hydogen more safe than gasolinie,CNG,etc
H2 fire (left) versus Gasoline fire (right)

0 sec

3 sec

Photo 3 - Time: 1 min, 0 sec - Hydrogen flow is subsiding, view of gasoline vehicle begins to enlarge

60 sec

References, proven reliability since 2011

HyMove Proof of Concept bus
1st generation range extender successful in operation from 2011 until 2013

Powered by HyMove
Solbus, bus OEM in **Poland**, applies the HyMove H2FC range extender in their electric city bus
“Powered by HyMove”

Powered by HyMove
Ursus Bus, bus OEM in **Poland**, applies the HyMove H2FC range extender in their electric city bus
“Powered by HyMove”

First bus operational in Q3 2016
First bus in service from Q3 2016 with Syntus/Keolis in the Netherlands between Arnhem and Apeldoorn

Case 2: Fuel Cell PEM power plants in the Chor-Alkali industry to convert waste H2

- 20% of a chlorine factory's electricity consumption can be recovered through fuel cells
- Heat from the fuel cell can be used to preheat the brine.
- Additional CA production in times of electricity shortage

2MWe + 1.5 MWth

1400 m^3/h Hydrogen

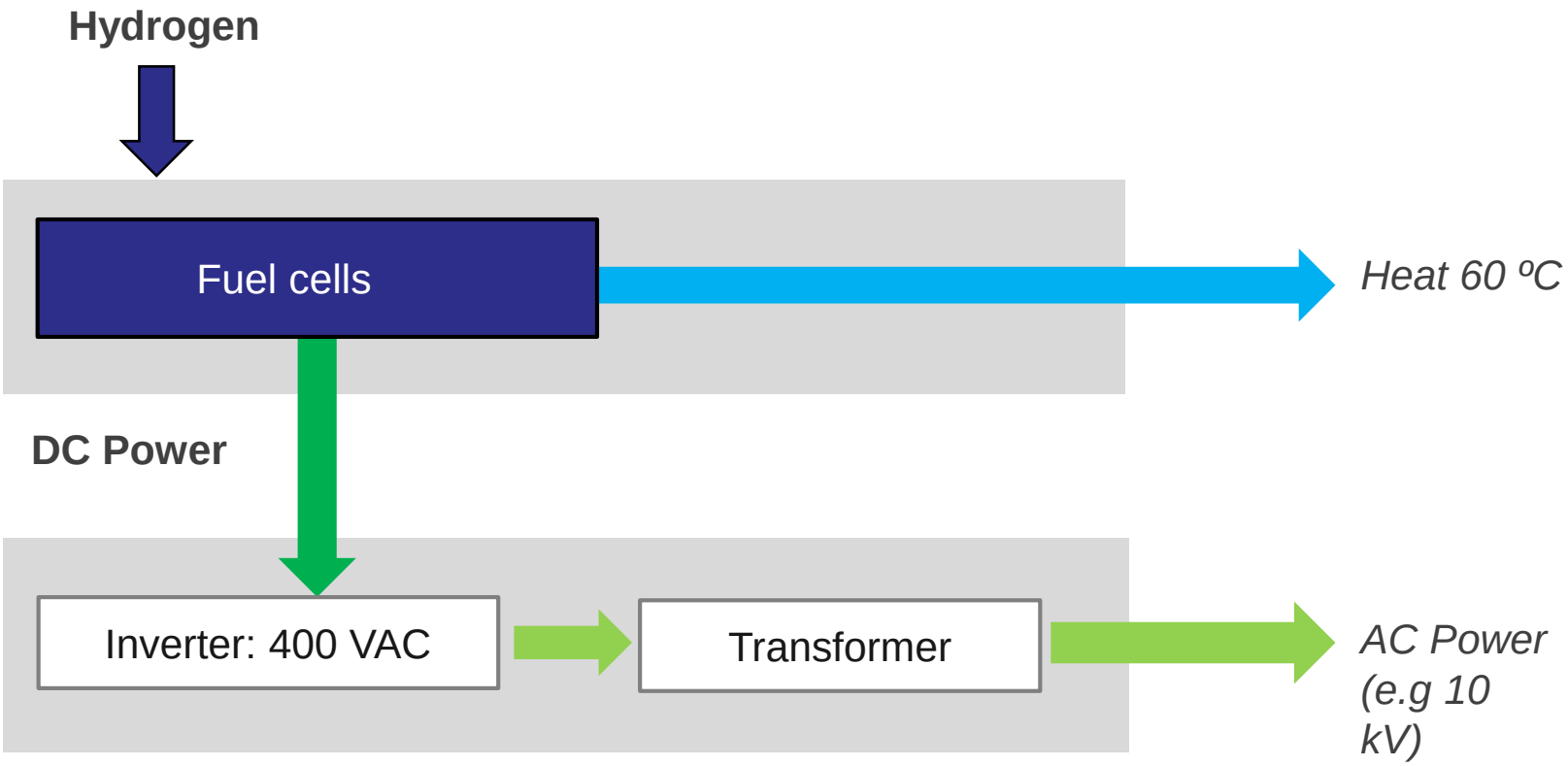
34 kton/year Cl_2 Production Consumes 10 MWe

Nedstack PEM FUEL CELLS To be sure.

INTSA TECHNOPOWER

Cogeneration of AC-power and heat

System efficiency > 85% (55% electrical)



Nedstack PEM FUEL CELLS To be sure.

INTSA TECHNOPOWER

AkzoNobel PEM Power Plant has proven reliability in practice since 2007

AkzoNobel's Delfzijl PEM Power Plant

- So far >45,000 hours on grid
- Uptime >90%
- Stack lifetime in real life conditions has proven to be >20,000 hours
- Reliable operation, low maintenance costs
- Fully automated, remote monitoring and control
- Mobile set-up

Nedstack
PEM FUEL CELLS
To be sure.

MTSA
TECHNOPOWER

1MWe PPP at Solvay has proven reliability and performance since start up in 2011

5 minute film:
https://www.youtube.com/watch?v=EvFV9wXyzbU&feature=em-upload_owner

Nedstack
PEM FUEL CELLS
To be sure.

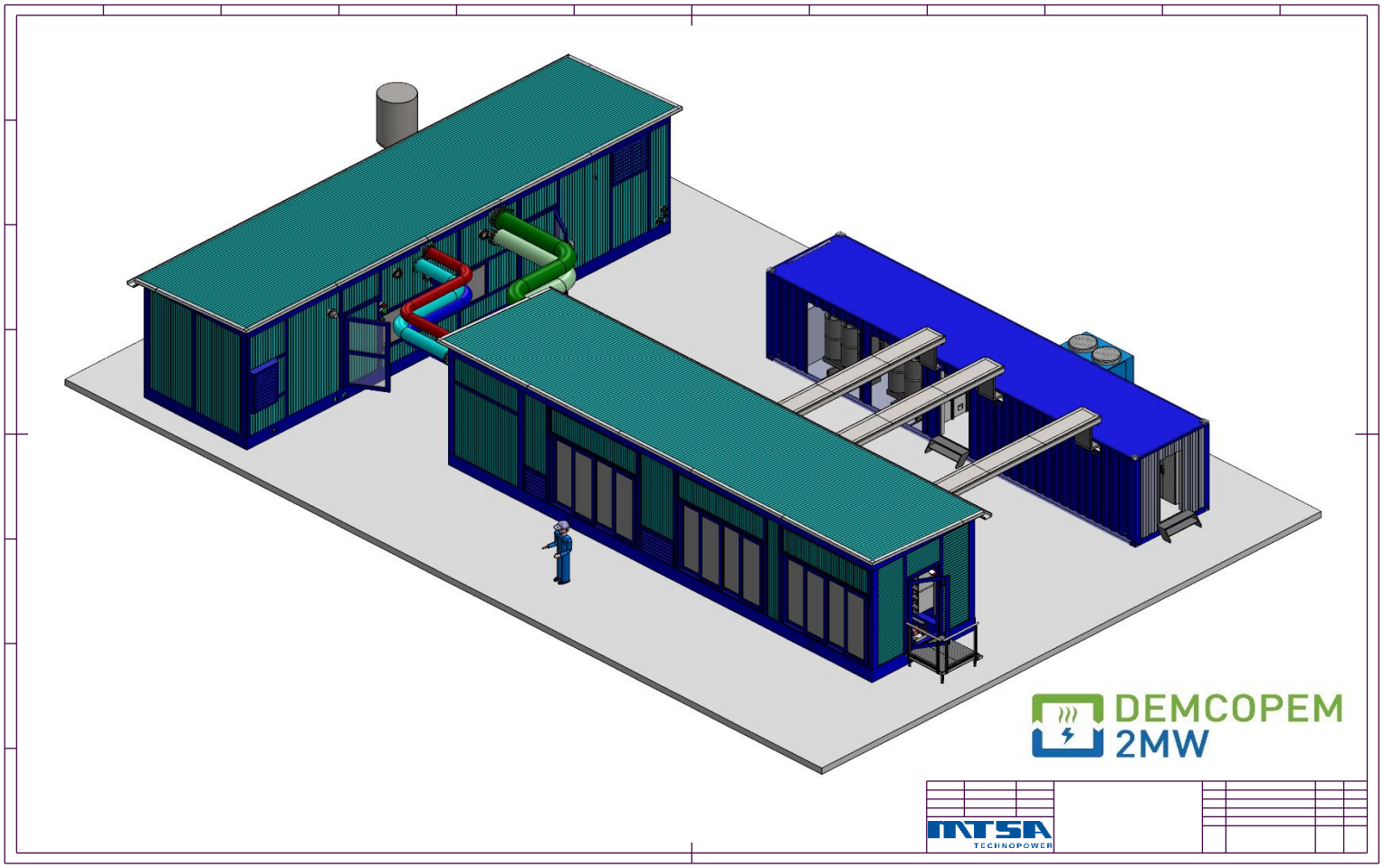
INTSA
TECHNOPOWER

New 2 MWe PEM Fuel Cell project* at Ynnovate in China Operational Q3 2016

Partners:

* This project receives funding from the European Union's Seventh Framework Programme Fuel Cell and Hydrogen Joint Undertaking (FCH JU) under proposal nr. 621256 and project acronym DEMCOPEM-2MW.

Lay-out 2 MWe PEM power plant



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Construction

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Transport to site

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PEM FUEL CELLS
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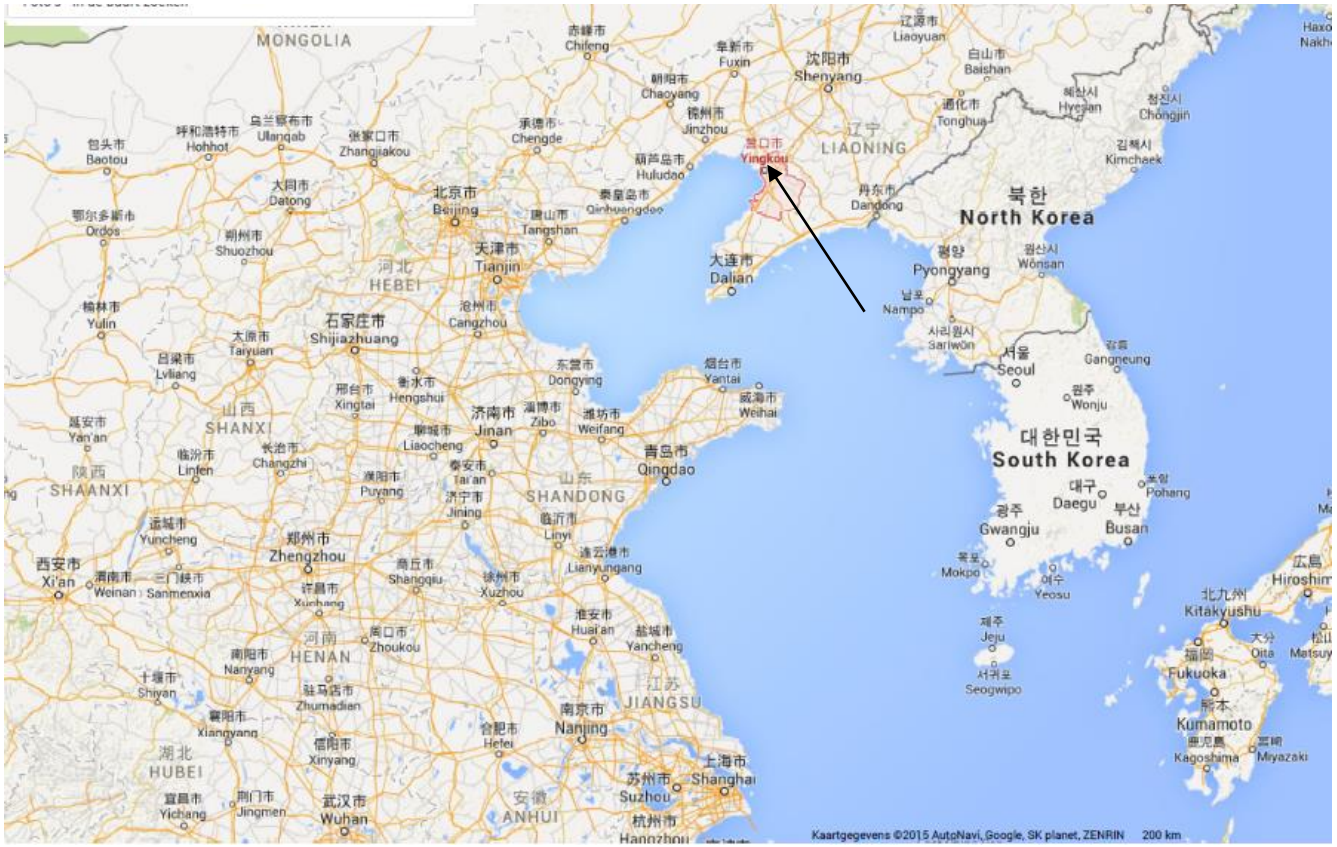
Ynnovate, Yingkou, Liaoning, China



Ynnovate site

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Fuel cell and hydrogen joint undertaking

7 years EU supported program of ~ 1,5 billion Euro

Objective

Implement a programme at EU level to develop a portfolio of clean and efficient solutions that exploit the properties of *hydrogen as an energy carrier* and *fuel cells* as energy converters to the point of market readiness by 2020

Strategy and focus

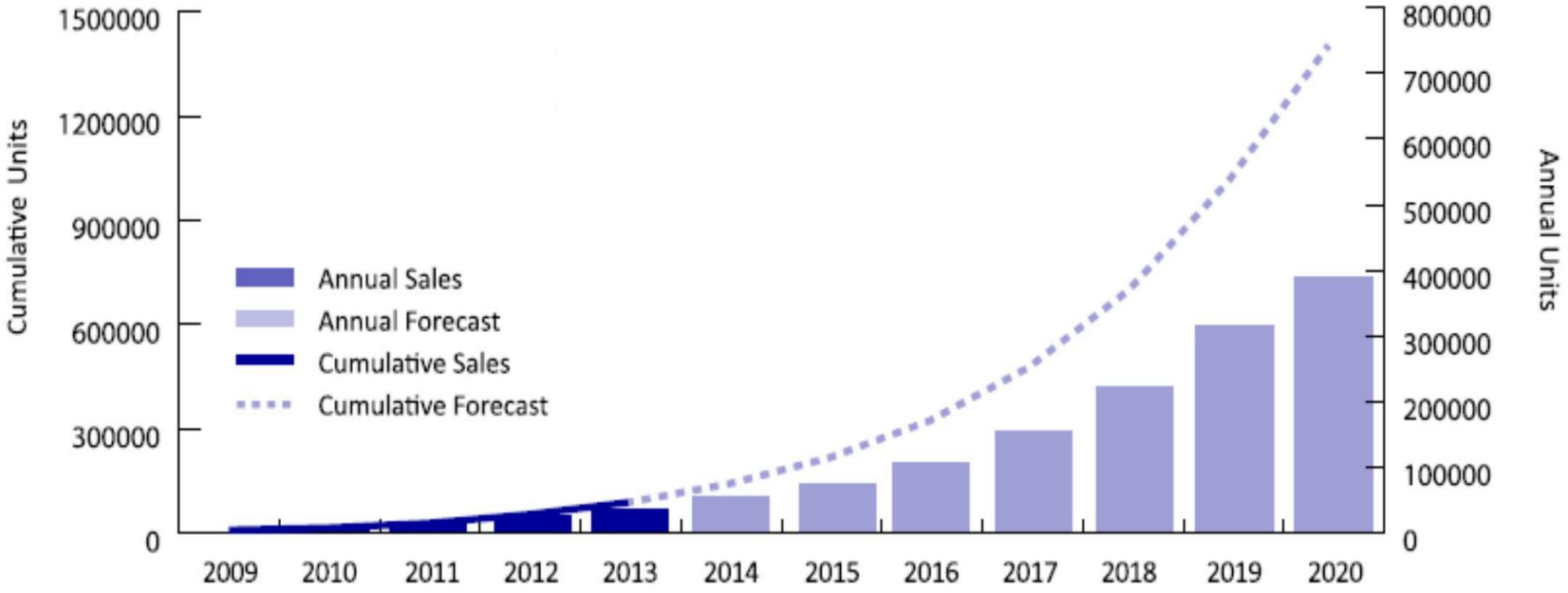
Industry led integrated FCH program with of applied research, development and demonstration activities

Focus on low-carbon *energy and transport systems*, creating leading position of Europe's FCH industry and safeguarding and creating jobs.

[1)] *Internet:* http://www.fch-ju.eu

Where does the journey go to?
Volumes will bring price PEM fuel cells down

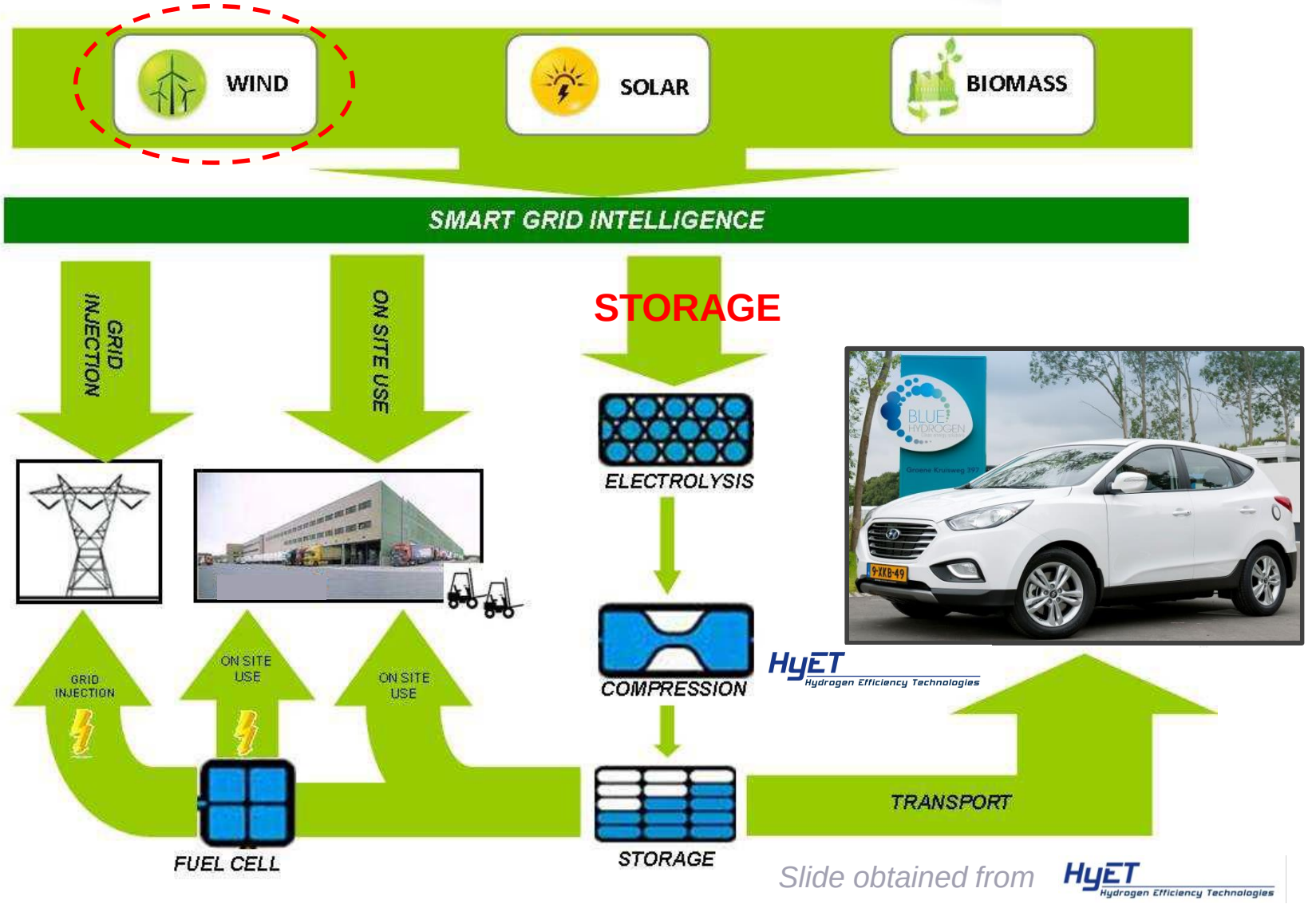
- Transportation sector has chosen for PEM Fuel Cells!!
  - Hyunday, Toyota, Honda, Mercedes and ?
- H2 refilling station network steadily growing
- Large stationary PEM PP gets mature



Forecast Ene-Farm deployment 2015–2020 based on announced government targets

Source: E4tech, The Fuel Cell Industry Review 2014

Integration of Renewables, Hydrogen and Fuel cells can play key role in future energy infrastructure



Enabling integration of renewable electrical energy and using H_2 for buffering/storage

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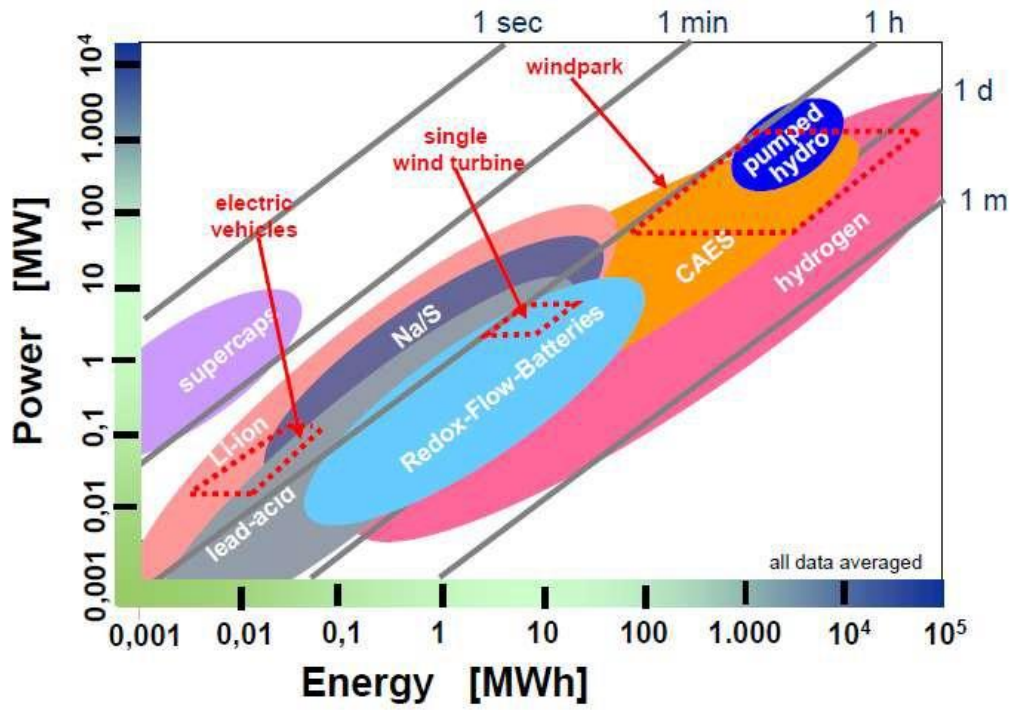
Backup

The key problem: storage

segmentation of large-scale (electrical) energy storage



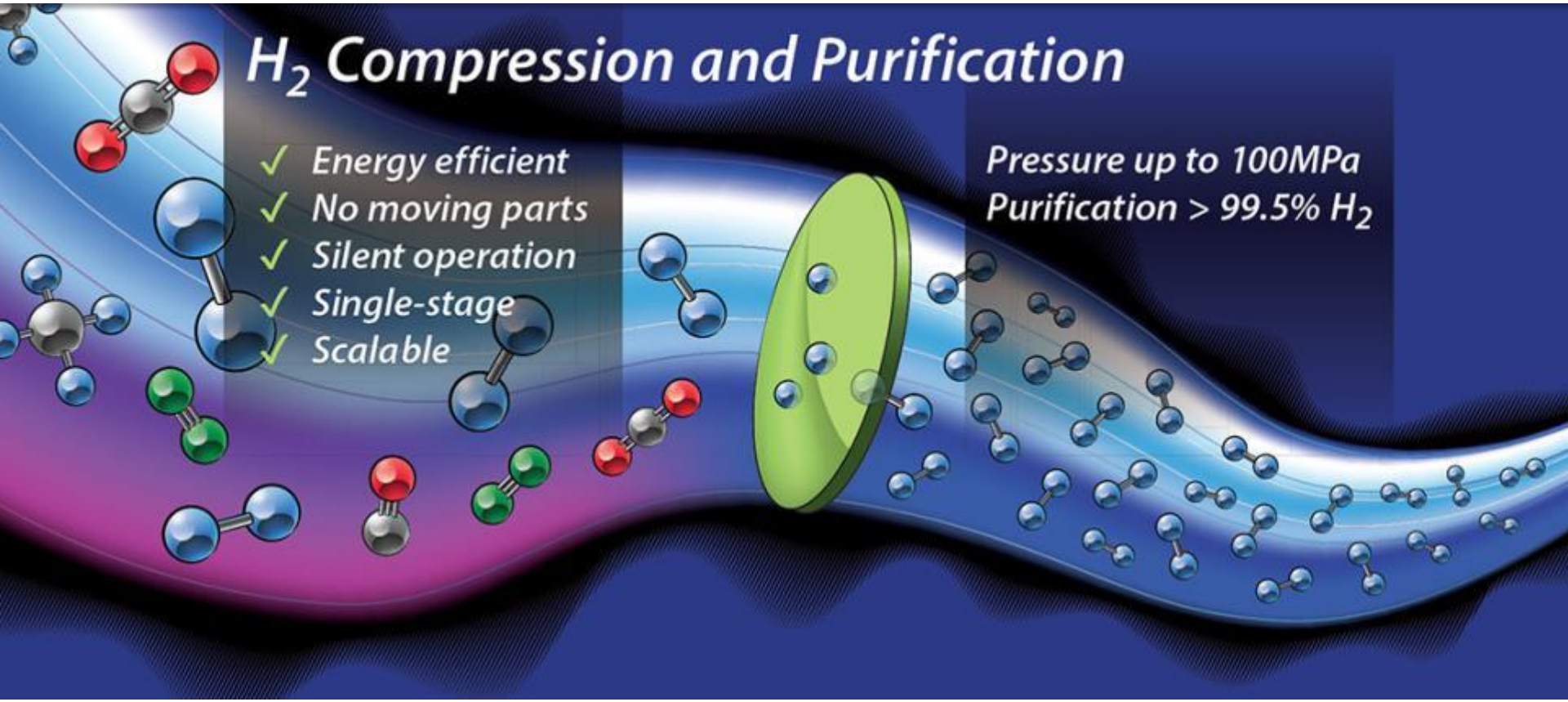
key statements:

- Battery storage applications are limited in the hour range
- Energy storage >100 MW can only be addressed by Pumped Hydro, Compressed Air (CAES) and Hydrogen
- The potential to extend pumped hydro capacities is very limited
- CAES has limitations in operational flexibility and capacity

Hydrogen is the only option to cover energy capacities > 10 GWh

HyET

Hydrogen Efficiency Technologies



Pure

Pressure

info@hyet.nl
www.hyet.nl

Mission & Core Competence

- **Mission:** Develop innovative, efficient, *silent* technologies enabling **Purification** and **Compression** of hydrogen gas for energy storage.

- **Core competence:** Our "pumping heart" achieved 100MPa pressure thanks to our bespoke membrane and supporting stack and system.