Renewable Hydrogen: Enabling a Clean Energy Economy

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The need for a sustainable energy system

- Greenhouse gases emitted through our current energy production and consumption patterns are leading to drastic shifts in the environment
- 2015 Paris Climate Conference had 195 countries universally agree to limit the global temperature increase to well below 2°C
- To achieve COP21 goals, we must make a transition – from a system fueled primarily by high carbon-based energy sources to one fueled by low-carbon and renewable sources
- Hydrogen provides a sustainable solution and enables the shift to a clean, low-carbon energy system

Climate Protection Goals 2020, 2030, 2050

	EU	Germany	USA	China
Baseline:	1990	1990	2005	2030
Reduction of CO_2 emissions	20% by 2020	40% by 2020	32% by 2030 (power plants)	0% increase after 2030
Increase of Energy Efficiency	20% by 2020	50% by 2050		
Increase of Renewable Energy	20% by 2020	80% by 2050		20% by 2030

GERMANY: NO PROGRESS IN TRANSPORT

- In 2014, for the first time since a number of years, the greenhouse gas emissions in Germany dropped significantly.
  - Total emissions in 2014 was 901.9 Mt CO_2 equivalent
  - 4.6 % below the level of the year before
- In the transport sector, however, the greenhouse gas emissions **climbed** by 1.2 % to 161 Mt CO_2, mainly due to the increasing road traffic.
- **Since 2005 there has been almost no progress in the climate balance in the transport field.**

Source: DWV Hydrogen Mirror 2/2016

The World is Addicted to Poison

Dieselkraftstoff

enthält: Brennstoffe, Diesel – nicht spezifiziert

Gefahr

Gefahrenhinweise

H226	Flüssigkeit und Dampf entzündbar.
H304	Kann bei Verschlucken und Eindringen in die Atemwege tödlich sein.
H315	Verursacht Hautreizungen.
H332	Gesundheitsschädlich beim Einatmen.
H351	Kann vermutlich Krebs erzeugen.
H373	Kann die Organe schädigen bei längerer oder wiederholter Exposition.
H411	Giftig für Wasserorganismen, mit langfristiger Wirkung.

Sicherheitshinweise

P210	Von Hitze/Funken/offener Flamme/ heißen Oberflächen fernhalten. Nicht rauchen.
P261	Einatmen von Staub/Rauch/Gas/Nebel/Dampf/ Aerosol vermeiden.
P273	Freisetzung in die Umwelt vermeiden.
P280	Schutzhandschuhe/Schutzkleidung/Augenschutz/ Gesichtsschutz tragen.
P301 +P310	BEI VERSCHLUCKEN: Sofort GIFTINFORMATIONSZENTRUM oder Arzt anrufen.
P331	KEIN Erbrechen herbeiführen.

Health hazard
(may cause or suspected of causing serious health effects)

Exclamation mark
(may cause less serious health effects or damage the ozone layer*)

Environment*
(may cause damage to the aquatic environment)

“Clean Diesel”: ***isn’t***

Factor	Diesel, Gasoline, CNG, LNG, Propane with IC-Engines	Renewable Hydrogen with FC Engines
Harmful Emissions $_{\text{Tank-to-Wheel}}$	NO_x, SO_x, methane-”slip”, CO, CO_2, HC’s, Particulates, Soot 75 to 85% heat	**None** Water, liquid and vapour 50 to 60% heat
Other Point of use Emissions	Adblue (Urea), Engine Additive, Engine Lubricant emissions, brake dust	**None** Reduced mechanical brake dust due to battery hybrid
Extraction, Refinery , Transport Emissions Well-to-Tank	Flares, other refinery emissions, Road spills and slicks, Ocean spills/slicks, Shipping/trucking emissions (see point of use emissions)	**None**, if transported by pipeline or locally generated
Health Effects$_{\text{Tank-to-Wheel}}$	Respiratory illness, Asthma, Cancer, Acid rain, Ozone damage, CO-death Fire and explosion risk	**None** Lower fire and explosion risk than with fossil-based fuels
Health Effects$_{\text{Well-to-Tank}}$	Spills and climate change affects all life, especially aquatic, which includes the human food chain, Military loss of life	**None**

The cost verses benefit **must** be seriously considered

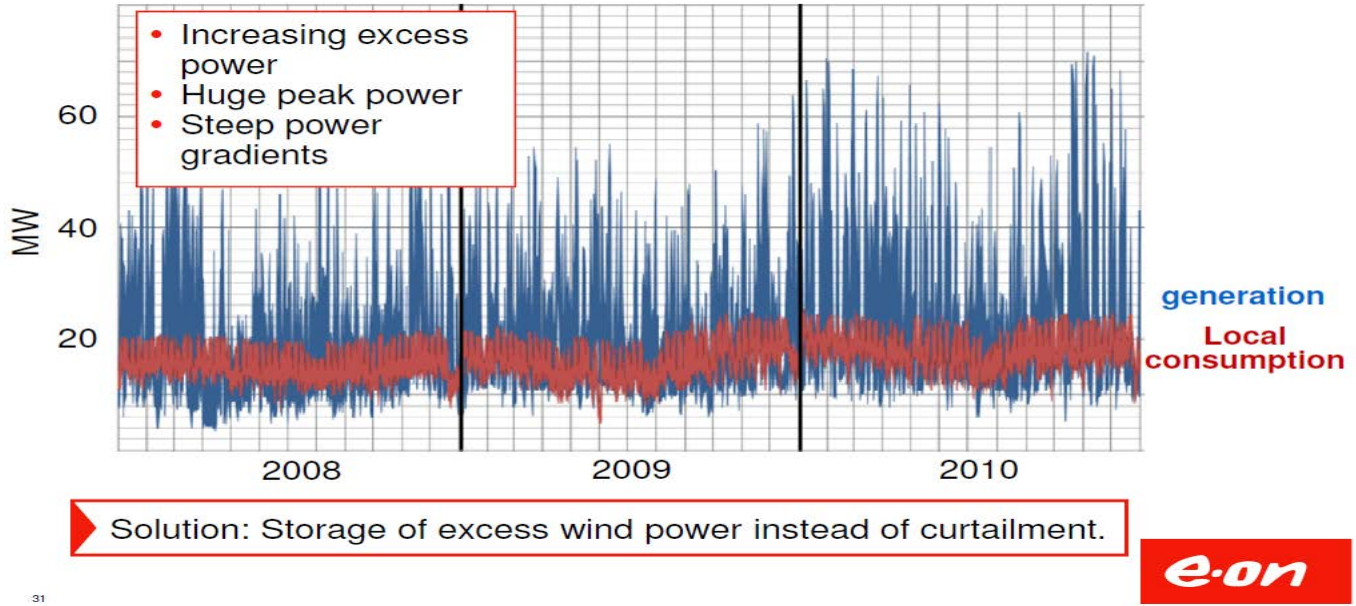
Factor	Diesel, Gasoline, CNG, LNG, Propane with IC-Engines	Hydrogen with FC Engines
Harmful Emissions $_{\text{Tank-to-Wheel}}$	Carbon trading complexities Carbon capture challenges Blackened buildings Filtration costs Greenhouse climate change	**Clean Air** **Clean Buildings** **Protected Climate** **Maintain sea levels** **Reduced extreme weather events**
Other Point of use Emissions	Engine Additive costs	**No chemical additives or their emissions**
Extraction, Refinery , Transport Emissions Well-to-Tank	Environmental disasters Shale gas chemical pollution Oil spill cleanup costs Water purification costs Military Costs	**Locally-produced, no imports** **Sustainable** **Self-sufficient**
Health$_{\text{Tank-to-Wheel}}$	Healthcare costs to the state Illness suffering, death - civilian and soldier	**Clean Breathing** **Better Health, less loss of life**
Health$_{\text{Well-to-Tank}}$	Poisonous if ingested, can cause cancer Animal suffering, Plant and animal extinction	**Protected se** **Clean Water** **Pure Food**

The cost-benefit must be fully and seriously considered

Factor	Diesel, Gasoline, CNG, LNG, Propane with IC-Engines	Hydrogen with FC Engines
Harmful Emissions Tank-to-Wheel	Carbon trading complexities Carbon capture challenges	**Clean Air** **Clean Buildings** **Protected Climate** **Maintain sea levels** **Reduced extreme weather events**
Other Point of use Emissions		**No chemical additives or their emissions**
Extraction, Refinery , Transport Emissions Well-to-Tank		**Locally-produced, no imports** **Sustainable** **Self-sufficient**
Health Tank-to-Wheel		**Clean Breathing** **Better Health**
Health Well-to-Tank	Animal suffering, Plant and animal extinction	**Protected se** **Clean Water** **Pure Food**

A significant increase in the capture and utilization of renewable energy is **only possible with matching capacity of Energy Storage**

Falkenhagen Region in Northern Germany



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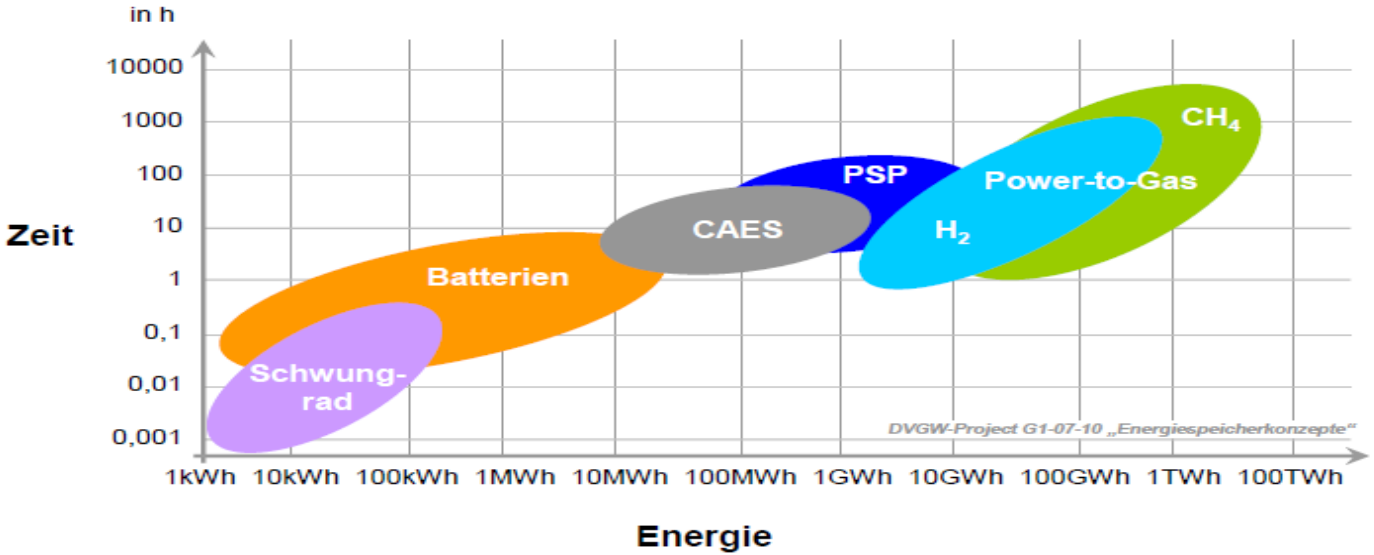
The required Energy Storage Capacity while meeting the Emissions targets is only achievable with Hydrogen



Harnessing and Utilizing Renewable Energy has Severe Limitations

The Electrical Grid

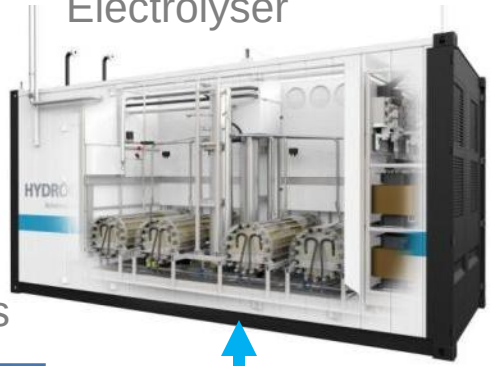
Pumped Hydro Electricity Storage

Battery Capability

But Hydrogen can be stored, transported and fueled like any gas

Energy Storage

Water Electrolyser



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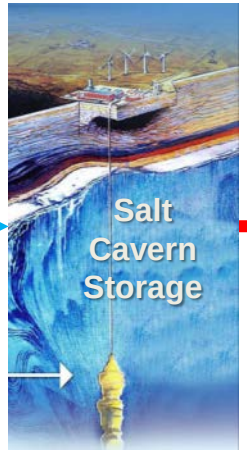

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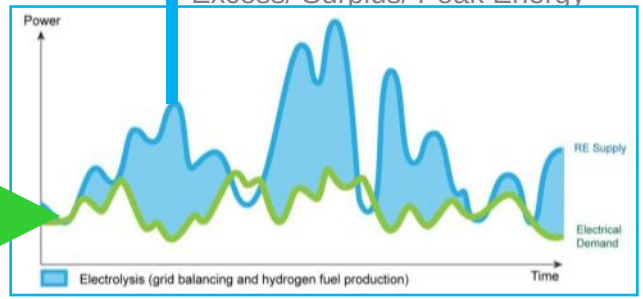
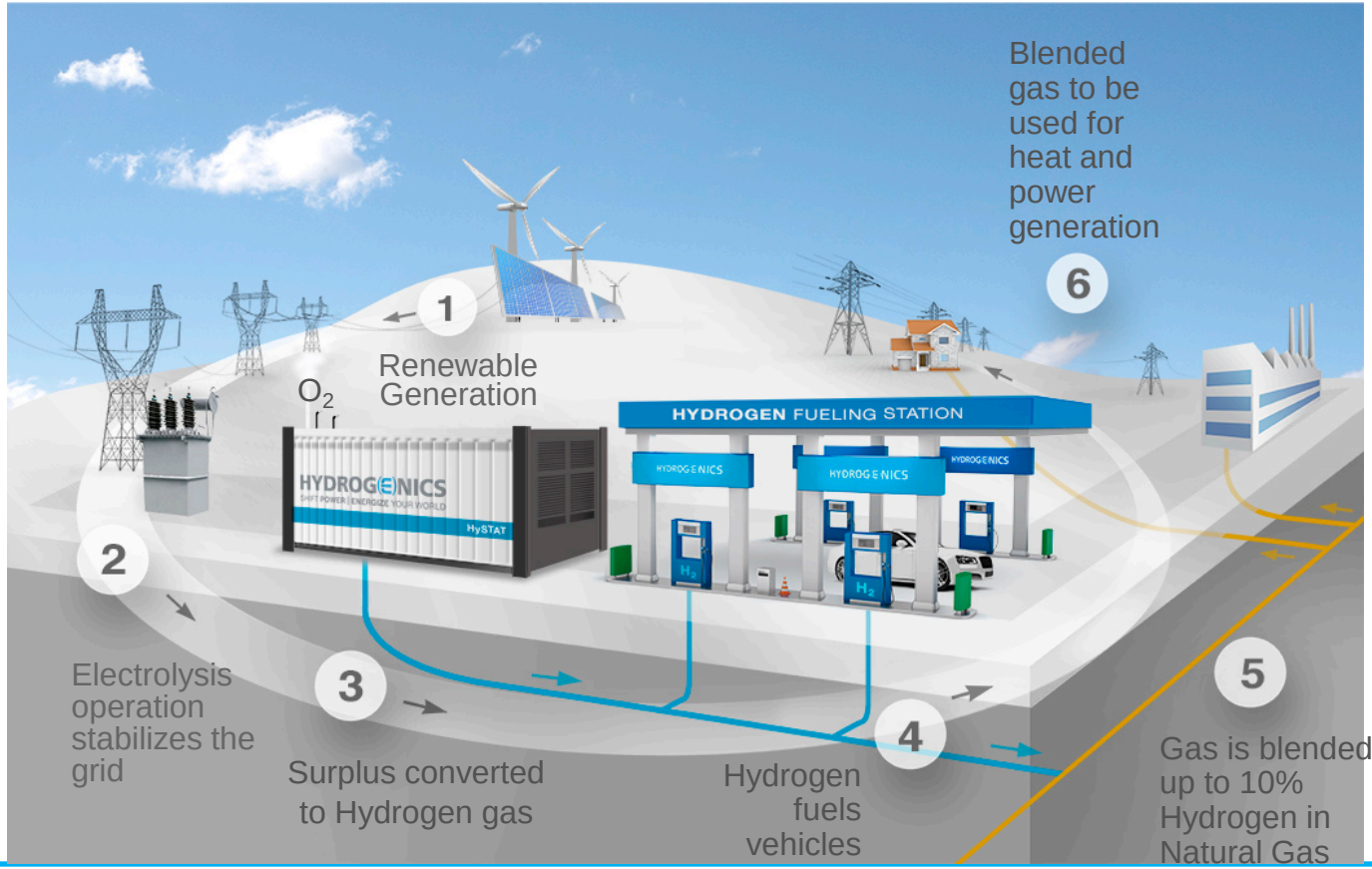
Renewable Energy sources

Excess/ Surplus/ Peak Energy

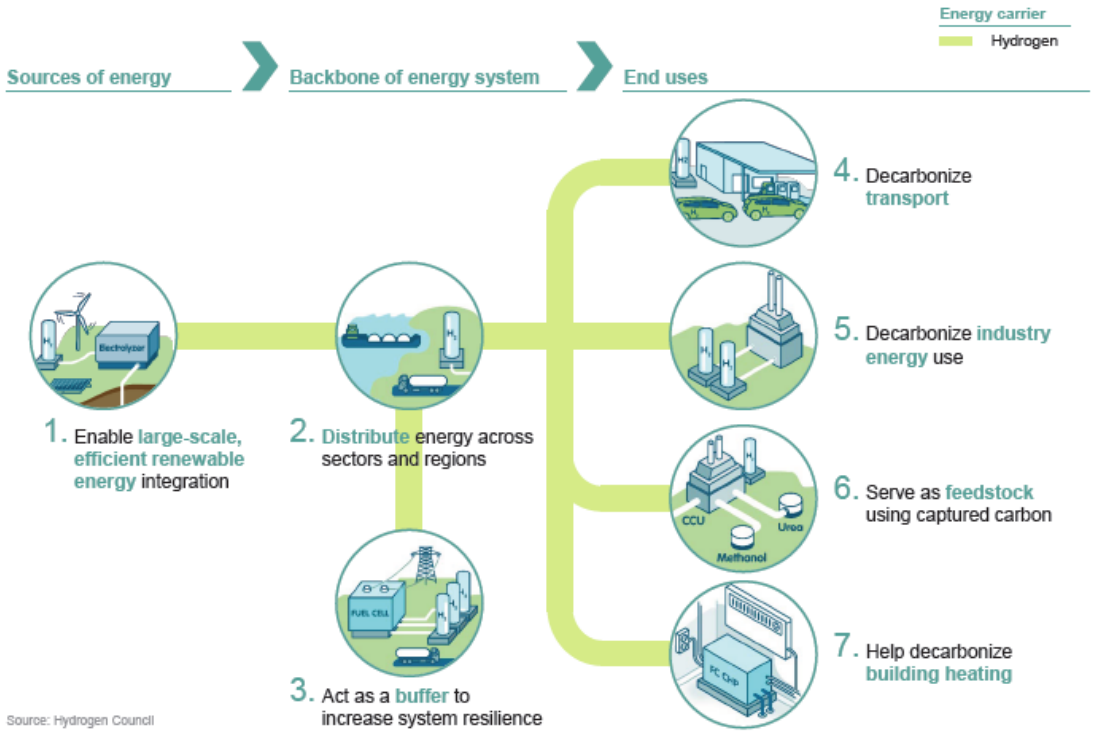


Surplus hydrogen can overflow to the natural gas grid = **Unlimited Storage**

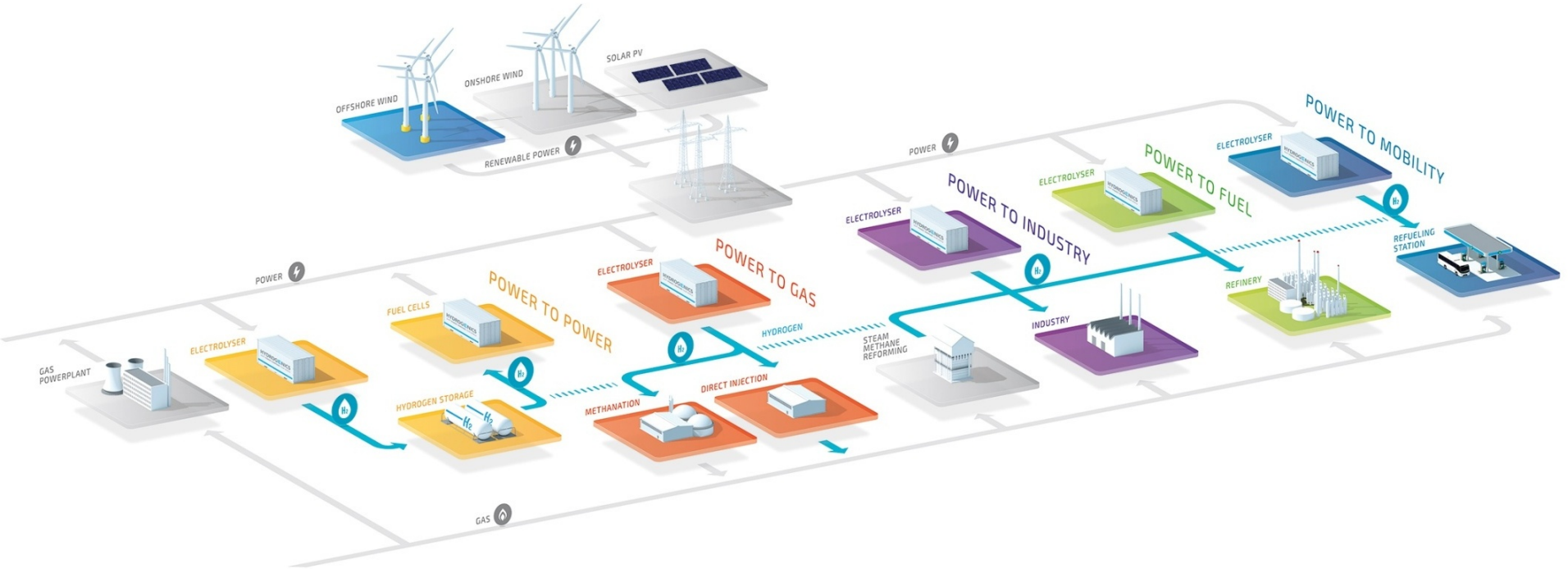


But there will be no need to store Hydrogen in the natural gas grid

Hydrogen has seven roles in decarbonizing major sectors of the economy



Renewable hydrogen enables the shift to clean energy



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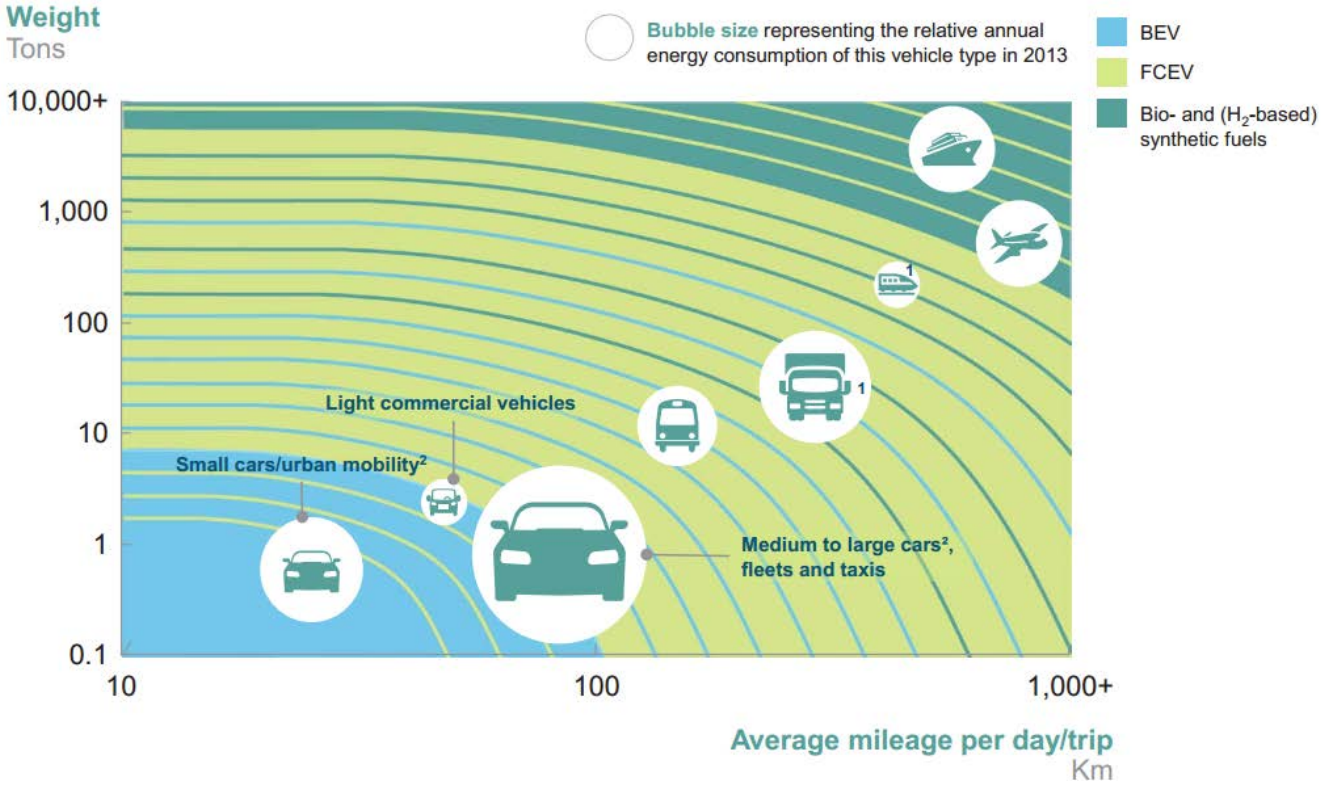
The Role of FCEVs to Decarbonize Transport



Source: Hydrogen Council, 2017

Hydrogen Enables Zero-Emission Transportation

- With approximately 14% of global carbon emissions coming from transportation*, hydrogen can enable zero-emission transport
- Fuel cell electric vehicles are zero-emission vehicles that only emit water vapour
- Similar to internal combustion vehicles, FCEVs can refuel quickly and drive long distances
- Refueling infrastructure can be built on existing gasoline distribution and retail infrastructure

Photo Credit: Eric Novak

Photo Credit: UPS

*Source: United States Environmental Protection Agency

Fuel Cell Vehicles are the most flexible zero emission option – Unlike battery-only solutions, they can be operated like diesel vehicles

High daily ranges

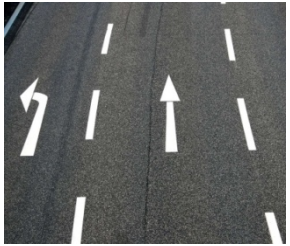
… bus range 300 km on average without refuelling … **further extension possible, if needed**

Performance

… **without compromise**, full payload, gradeability, no performance loss from battery discharge or cold weather

High passenger comfort

… **uncompromised climate control**, full speed to the destination



Full route flexibility

… not bound to any required infrastructure on the route – **any route, with any bus, at any time**

Fast refuelling

… refuel as fast as 7 minutes … several **full** refuelling cycles per day possible , **no charging queue**

Technology maturity

… onboard hybrid battery can be managed by the fuel cell for maximum battery performance and lifetime

Image credit: Roland Berger EC FCH JU Bus Study

Fuel cells can decarbonize urban Transport

Cardiff, Wales

Winnipeg, Canada & Scottsdale, AZ


Aachen, Germany


Barth, Germany


Honolulu, Hawaii


Volcano National Park, Hawaii


San Francisco, USA


SinoHytec, China

Perugia IT

Los Angeles, CA

Coming soon to Palm Springs, USA


London, UK

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September 2017: Alstom unveils the Coradia iLint at InnoTrans

Zero-emission hydrogen fuel cell regional trains

- ~ 40% of rail network in Germany is not electrified (operated with diesel)
- Too expensive to electrify all routes
- Increasingly stringent regulations (exhaust emission, noise)
- Expected price increase for diesel
- LOI from 4 German States zero emission passenger trains signed in 2014
- Unveiled at the Innotrans 2016 in Berlin

Growth in fueling infrastructure to support FCEVs

- Safe and meet SAE and local standards
- Can be located in densely populated urban areas
- Provides clean fuel – 99.999% purity
- Scalable – incremental fueling capacity added as required

130 kg/day (Stuttgart, Germany)

65 kg/day (Santa Monica, CA)

Hydrogen Fueling for European FC Bus Fleets

11 of 13 electrolyzer FC Bus fueling stations with HySTAT by Hydrogenics

CUTE	HYFLEET	CHIC	HiVLOCity	HyTransit
Reykjavik	Reykjavik	Bolzano	Aberdeen	Aberdeen 2
Amsterdam	Amsterdam	Aargau	San Remo*	
Porto		Hamburg	* delivered	
Barcelona	Barcelona	Oslo		
Hamburg	Hamburg			
Stockholm				

2001 — 2017

Electrolyzer
Hydrogen Refueling Station

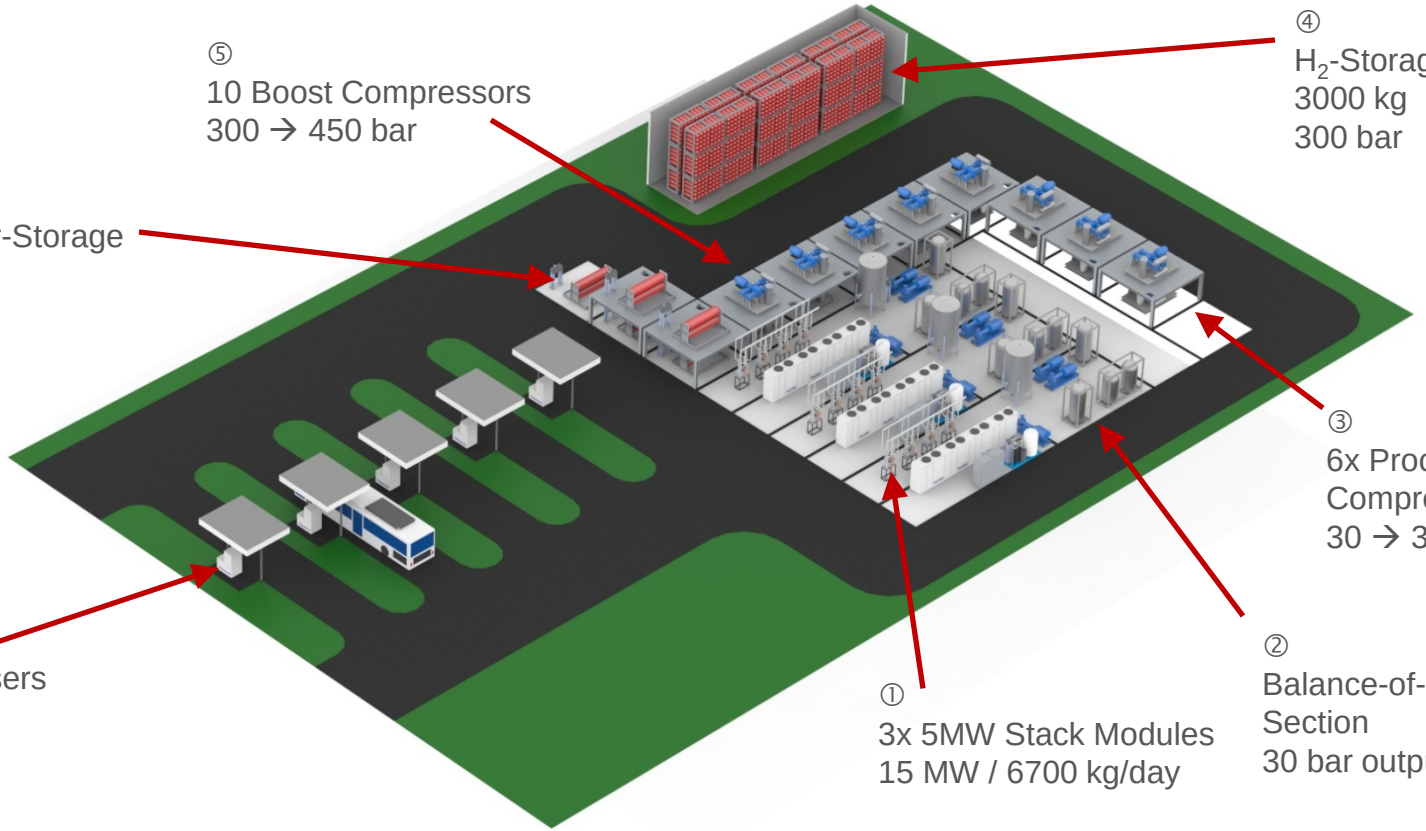
15 MW = 3 100 Nm3/h = **280 kg/h**

= 6 700 kg/24h

= 300 FC Buses/day

= 30…45 FC Trains/day

PEM Electrolysis HRS – Capacity for 300 Buses or > 30 Trains



NewBusFuel

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Hydrogen Fueling Comparison

	Unit	Personal Automobiles	Transit Buses
Average Distance	km/ day	~ 50	~ 250 … 300
Average Driving time	h/day	~ 1	~ 12 … 16
Station quantity and size		Many, small	Few, large
Station distribution		Wide, dispersed	1 per fleet hub
Vehicle fuel consumption	kg H_2/100km	0.8 … 1	7 … 8
Amount fueled per fill	kg H_2/fueling	4 … 6	20 … 30
Frequency of fueling	# days	every 7 … 10 days	every day
Days of operation	days/year	250	360
Fuel consumption annual	kg H_2/year/vehicle	150 … 200	7000 … 10000

For a station economics, fueling buses is more attractive than cars

Onsite Generated Hydrogen Fueling Station Comparison

3…30 cars/day

= 130 kg H_2/24h = 60 Nm3/h = 5.4 kg H_2/h

= 300 kW

Utilization highly variable

→ **Low Economy of Scale**

300 buses/day

= 6 700 kg H_2/24h = 3 100 Nm3/h = 280 kg H_2/h

= 15 MW

Exactly known & plannable

→ **High Economy of Scale**

Over 35 Power-to-X demonstrations running in Europe

- Power-to-X Applications
  - Direct Injection
  - H2 Fueling
  - Biogas Methanation
  - Industrial H2 Feed

- Only 5 of these projects are 1MW or larger

- Commercial Scale projects will be 20MW, 40MW, 50MW and up to 100MW

Source: DNV KEMA . “Systems analyses Power to Gas: A technology review”. June 20, 2013

Renewable hydrogen is the key enabler of the clean energy economy

Fixed fuel cost for the operating life of the equipment!

100% Fossil Fuel:
Imported energy
Polluting emissions
Fuel expense dictates cost

Uncontrollable

100% Renewable:
Fully self-sufficient
Zero-emissions
CapEx defines cost

Bankable

Renewable hydrogen is the key enabler of the clean energy economy

- Only renewable hydrogen can handle the scale needed
- It becomes economically viable at scale
- It offers multiple value propositions
- It solves the cost impact of the intermittency of renewable energy sources

- And a final point: nothing to develop... just deploy


We're Ready.

Shifting Power Across Industries Around the World

> $90M USD multi-year fuel cell contract with hi-tech mobility OEM

> $50 M USD multi-year fuel cell contract with leading rail OEM

Our raw materials, water & renewable power are infinite!

2,000+ fuel cell sites

1 single focus: hydrogen solutions

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> $100 M USD order backlog (YE 2016)

Publicly traded

NASDAQ (HYGS) and TSX (HYG) since 1995

500+ electrolysis plants in operation

Global leader in 2 main hydrogen technologies: electrolysis and fuel cells

65+ years of experience

1,500+ electrolysis plants sold since 1948

> 55 H2 Fueling Stations with Hydrogenics electrolysers worldwide

Leading PEM Stack & System Technology Innovator

Our Principal Product Lines

HyPM™ and CELERITY™ PEM Fuel Cell Power Modules and Systems for Mobility

- World leading feature list, innovation and product line maturity
- Variants customized to any requirements

HyPM™ Fuel Cell Power Modules and HyPM™-R FC Racks Systems for Critical Power

- World leading feature list, innovation and product line maturity
- Unlimited scalability

HySTAT™ Alkaline Electrolyzer Plants for Industrial, Hydrogen, Energy Storage and Fueling

- World leading market share
- The industrial standard

HyLYZER™ PEM Electrolyzer Plants for Energy Storage and Fueling

- 3 MW in a single stack
- World leading power density
- Scalable to 50 MW, 100 MW

Established Leader, Established Technology

Alstom, Germany

- World's first commercial contract for hydrogen fuel cell trains
- 10-year agreement, contract value > €50M

ASKO, Trondheim, Norway

- Norway's largest grocery wholesaler
- Trucks of 27 tons
- Supplying four (4) complete HyPM™ HD90-based fuel cell power **systems** including H2 storage, power electronics and controls

Uniper (e-on), Germany

- MW-scale Power to Gas facilities in Germany
- Wind power and Hydrogenics' electrolysis equipment to transform water into hydrogen

Fuel Cell Buses, China

- Certified Integration Partner Program
- Agreements with multiple strategic partners for thousands of fuel cell buses throughout China

[Renewable] hydrogen
Selection of recent demonstration projects

Country	Project	Size	Year	Electrolyser technology	Power	Gas	Industry	Mobility	Fuel
Thailand	EGAT	1.2 MW + 500 kW FC	2017	PEM	•				
Canada	Embridge P2G	2 MW	2017	PEM		•			
Germany	MefCO2	1 MW	2017	PEM					•
Denmark	HyBalance	1.2 MW	2017	PEM			•	•	
UK	Levenmouth	370 kW + 100 kW FC	2016	Alkaline + PEM	•			•	
Denmark	BioCat	1 MW	2016	Alkaline		•			
Italy	Ingrid	1 MW	2016	Alkaline	•	•	•		
UK	Aberdeen	1 MW	2016	Alkaline				•	
Germany	WindGas Reitbrook	1.5 MW	2015	PEM		•			
Canada	Raglan Copper mine	350 kW + 200 kW FC	2015	Alkaline	•				
Belgium	DonQuichote	150 kW	2015	Alkaline + PEM	•			•	
Germany	WindGas Falkenhagen	2 MW	2014	Alkaline		•			

Main conclusions from these projects:

1. Hydrogen **technologies work fine** and deliver according to expectations.
2. There is still room for further technical improvement but **no technology breakthrough is expected**.
3. There is a important potential for further **cost reduction**: going from project manufacturing to product manufacturing
4. Energy **regulatory framework is not suited** for these applications and **business operation** of these projects **remains very challenging**