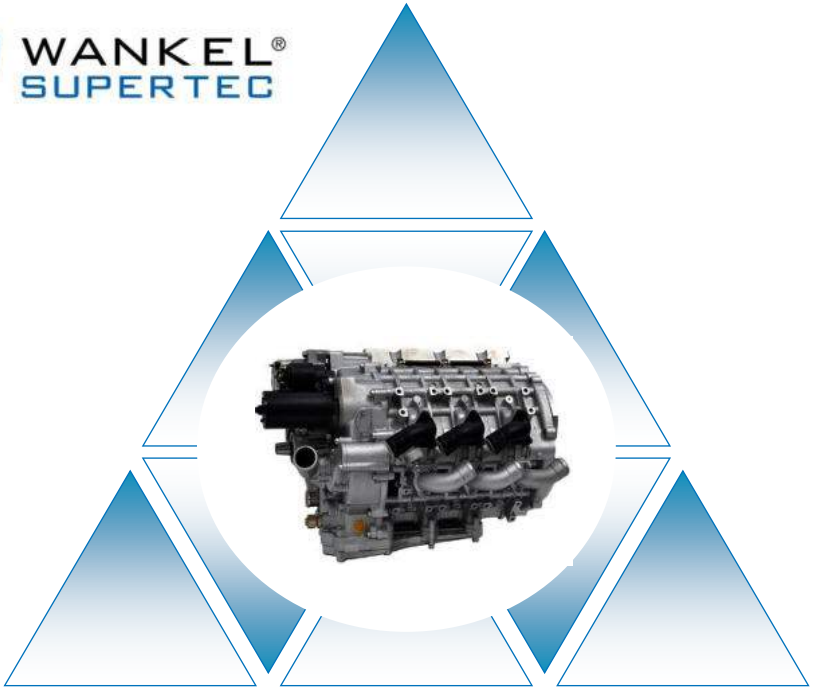
Wankel SuperTec GmbH Hydrogen Engines
2021-05-17

WST at a Glance



Existing fields of business:

- Light Aircraft & Drones
- Power Generation
- Marine

New field of business:

- Hydrogen engines & dual-fuel range extenders for electric vehicles

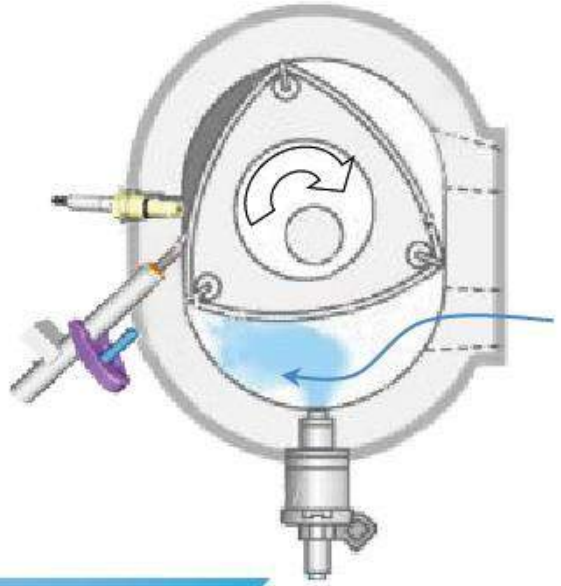
- Wankel SuperTec GmbH („WST“) is specialized in the development of advanced rotary engines
- Established some 20 years ago out of Cottbus Technical University, it is technology leader in its field
- WST is the only company producing rotary engines that can run on Diesel fuel

⇒ **From research institute towards industrial company**

Special Features of WST Rotary Engines - Multi-fuel Capabilities

WANKEL® SUPERTEC
Power of the new generation

	FOSSILE	ALTERNATIVE
LIQUID	diesel kerosine gasoline methanole	biodiesel plant oil ethanol
GASEOUS	natural gas LPG	hydrogen biogas



Development of Hydrogen Engines II

H2-Engine

- Development started late 2018
- Ca. 9 months for installation of H2-supply at engine test stand
- First successful test of KKM501H2 in Sept. 2019

Present stage:

⇒ Stable operation

⇒ Fuel consumption 100g - 110g H2/kWh

⇒ Efficiency 27% - 30%

Further development work:

⇒ Increase of efficiency – target is 35%

⇒ Optimization of gas injection & ignition

⇒ Optimization of lubrication

⇒ Longterm testing

⇒ Durability of surface materials

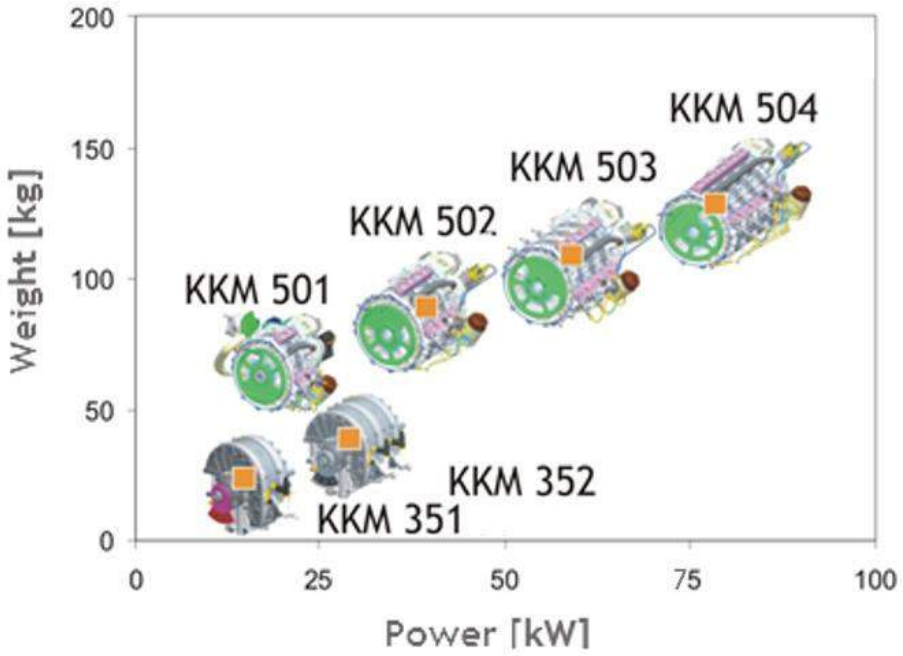
⇒ Exhaust levels and after treatment

⇒ Dual-fuel ability

Above: WST test stand with h2 engine

Existing Engine Series

Weight to power ratios of
WST‘s KKM 350 and KKM 500 series
fueled with hydrogen



All WST-engines feature

- high reliability
- excellent power to weight ratio
- low vibrations
- multi-fuel capability
- modular design
- WST‘s own ECU (hardware and software)
- patented sealing and lubrication designs
- increased efficiency and reduced exhaust through propriatory fuel injection and ignition technology

Specfications KKM502 & 503 with Diesel fuel

- KKM501d: maximum permanent power 45 kW for 1 hour at 5,500 RPM
- KKM502d: maximum permanent power 83 kW for 1 hour at 5,500 RPM
- KKM503d: maximum permanent power 117 kW for 1 hour bei 5,500 RPM

Consumption of Diesel fuel approximately 300g per kWh

Weights without cooling:

	Total weight	Base engine	Starter 12V/2,5 kW	Generator 12/45A	Turbo charger	Exhaust pipe	Air intake pipe	Fuel system	Blowby	Wiring harness /ECU
	Kg	kg	Kg	kg	kg	Kg	kg	kg	kg	kg
KKM 501D & GT 2252	73,2	51,5	5,2	2,2	8,5	0,65	0,5	1,3	0,7	2,6
KKM 502D & GT3071R	98,6	69,3	5,2	2,2	12,8	1,5	1	2	1	3,6
KKM 503D & GTX3576R	127,7	87,1	5,2	2,2	20	2,2	1,5	3	1,3	5,2
KKM 504D & 2x GT3071R	154,4	104,9	5,2	2,2	25,6	3	2	3,7	1,6	6,2

Existing Fields of Business:
Light, Small and Low-vibration, High-power Diesel Engines

Wherever excellent power-to-weight ratio, low vibrations and operation with Diesel fuel are important – examples:

Light aircraft & Drones

Equator Aircraft's hybrid amphibious airplane, powered by WST KKM 352 Diesel engine (picture courtesy of Equator Airplane Ltd.)

Power generation equipment II

Deutsche Bahn, Germany's railway company, has since 2015 equipped a total of 60 Diesel lokomotives with our auxiliary power systems, using WST KKM 351 Diesel engine

Power generation equipment I

compact and lightweight 30 kVA power generation unit, equipped with KKM 501 Diesel engine

Marine

small & light C-Fury RIB powered by WST KKM 352 Diesel engine (picture courtesy C-Fury Ltd.)

Applications for Hydrogen Engines: Dual-fuel Range Extenders for Electric Vehicles

WANKEL® SUPERTEC
Power of the new generation

Main Features

- With rotary engines at the core
- Driven by hydrogen
- But also able to run on conventional fuels

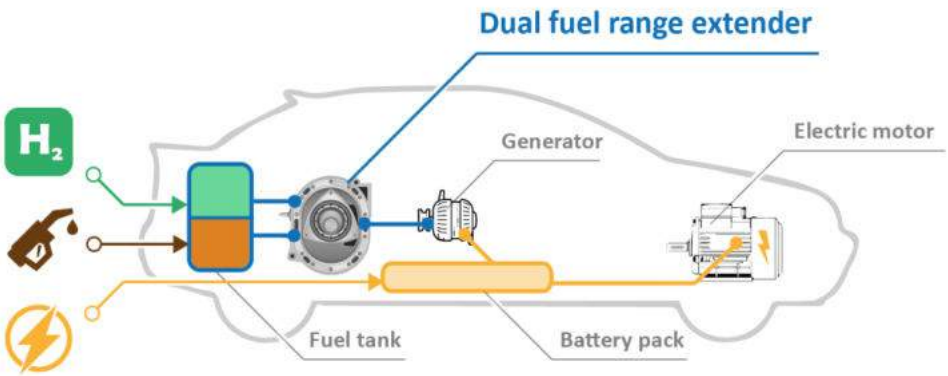
Main Advantages

- Allows reduction of battery size & costs
- No rare materials needed
- No dependency on charging stations, no long charging stops, no use of conventional electricity
- Can also run on low-purity hydrogen
- Does not depend on supply of hydrogen
- Easy & cheap to produce and repair
- long life-time
- CO2-free if run on hydrogen
- Small, light, low vibrations

disruptive technology for sustainable mobility

Above: WST range extender prototype

One car – 3 sources of power



Cooperation with Chinese EV-Manufacturers

Cooperation with leading producer of battery and fuel cell busses

⇒ Presently under negotiation

- For marketing of existing busses in Germany
- For equipment of battery busses with WST hydrogen range extenders

Cooperation with leading producer of light electric vans

⇒ Presently under negotiation

- For marketing of existing vans in Germany
- For equipment of battery vans with WST hydrogen range extenders

Applications for Hydrogen Engines: Wankel Aviation GmbH -

Subsidiary for EASA-Certified Aviation Engines

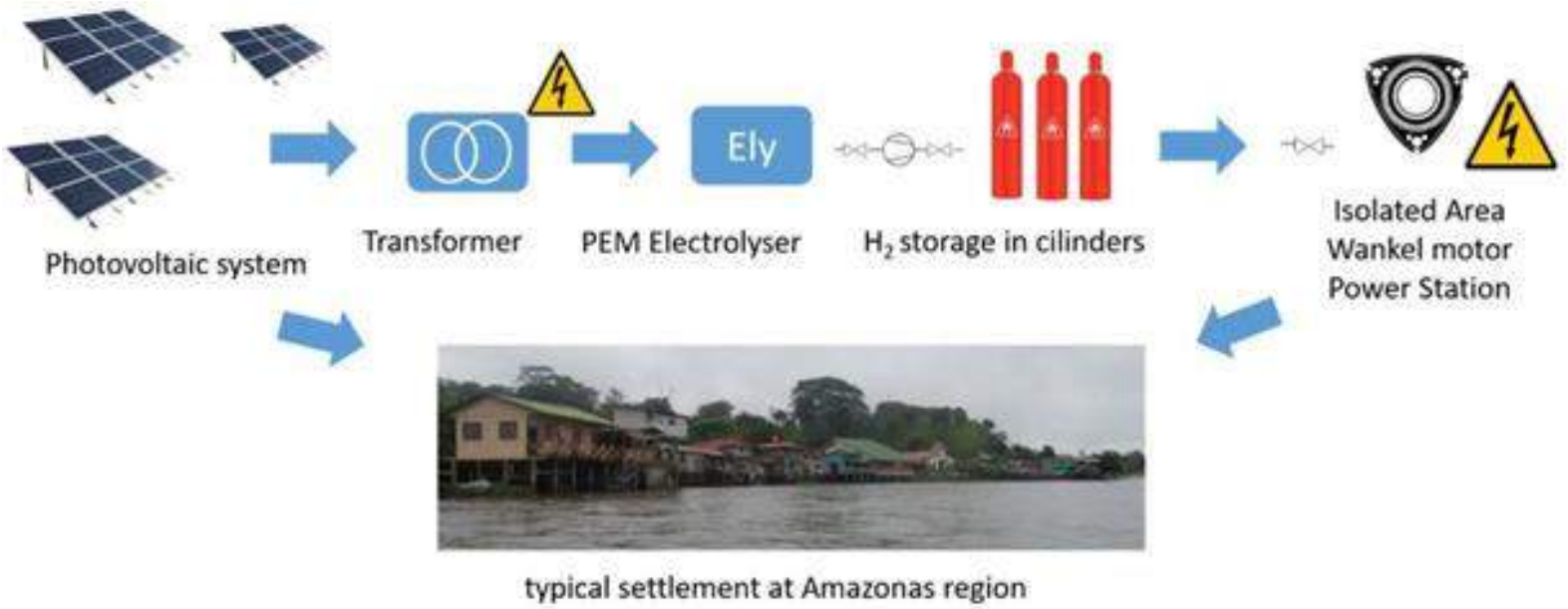
- Rotary engines particularly advantageous for aviation, due to light weight and low vibrations
- Multi-fuel ability of our engines allows CO2-neutral aviation if using hydrogen or biofuels such as Ethanol
- Use of diesel allows utilization in environments where for reasons of safety or logistics no other fuel is available

Use of hydrogen in aviation

- WST hydrogen engines likely to obtain EASA-certification earlier than on-board hydrogen storage systems

⇒ Discussing cooperation with small aircraft manufacturers for complete system engineering

Applications for Hydrogen Engines: Stationary Power Generation / CHP



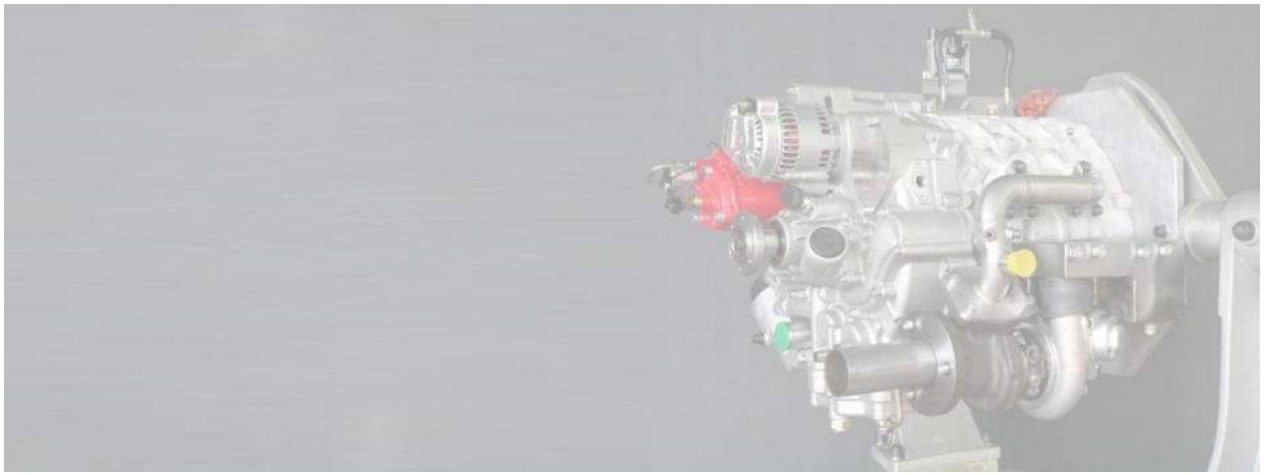
- For replacement of diesel-generators so far used in remote locations, like indigenous settlements in the Amazon rainforest
- Business rational:

  higher investment costs offset by savings in fuel and fuel logistics

  Energy storage as hydrogen cheaper than batteries for bigger energy quantities

- Advantages of WST H2-combustion for electricity generation from hydrogen:
  - Low requirements regarding hydrogen purity
  - Repairable
  - Insensitive to environmental impacts (temperature, humidity, etc.)
  - Cheap to produce at bigger numbers

Contact Information



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We Care for a Better Future.

Erfahrungen mit dem Wasserstoffeinsatz im BHKW.

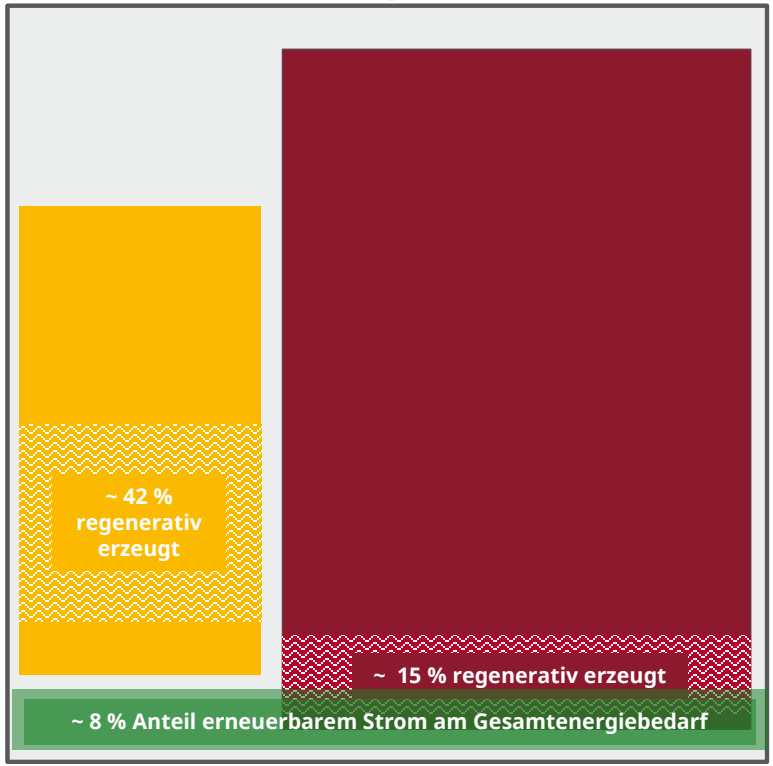
Frank Grewe, CTO, 2G Energy AG

19.05.2021

2G Eckdaten.

- Gründung 1995 - Hauptsitz in Heek / Münsterland
- Einer der führenden Hersteller von Blockheizkraftwerken in Europa
- Lösungsanbieter (Entwicklung, Produktion, Projektmanagement, Service, Finanzierung)
- Leistungsspektrum: 20 bis 2.000 kW elektrische Leistung
- Starker Technologiefokus -> höchste Wirkungsgrade
- 9 Tochtergesellschaften im In- und Ausland
- Seit 2007 börsennotiert
- Ca. 650 Mitarbeiter weltweit
- Über 6.000 Anlagen in 50 Ländern installiert

Gesamtenergiebedarf in Deutschland.



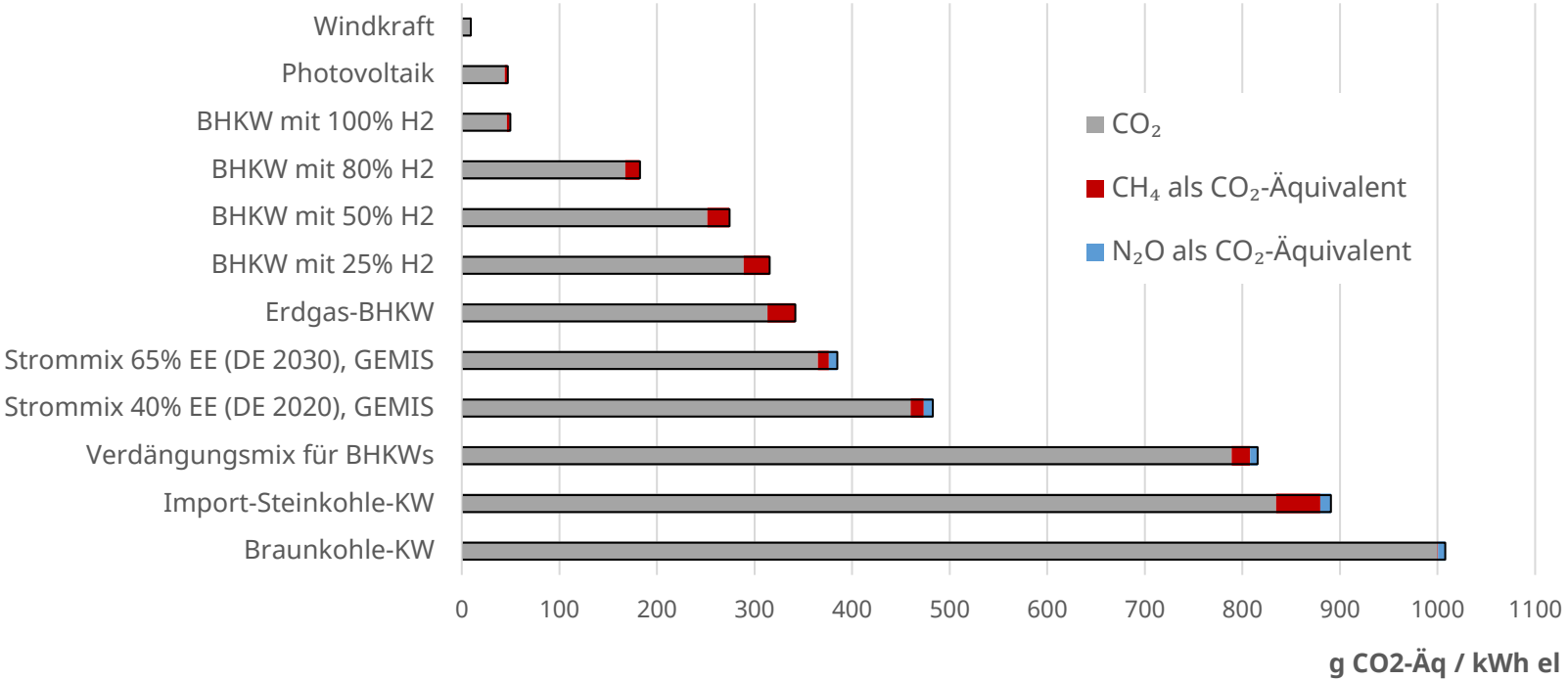
~ 2500 TWh Gesamtenergiebedarf

~ 500 TWh Strombedarf

~ 1400 TWh Wärmebedarf

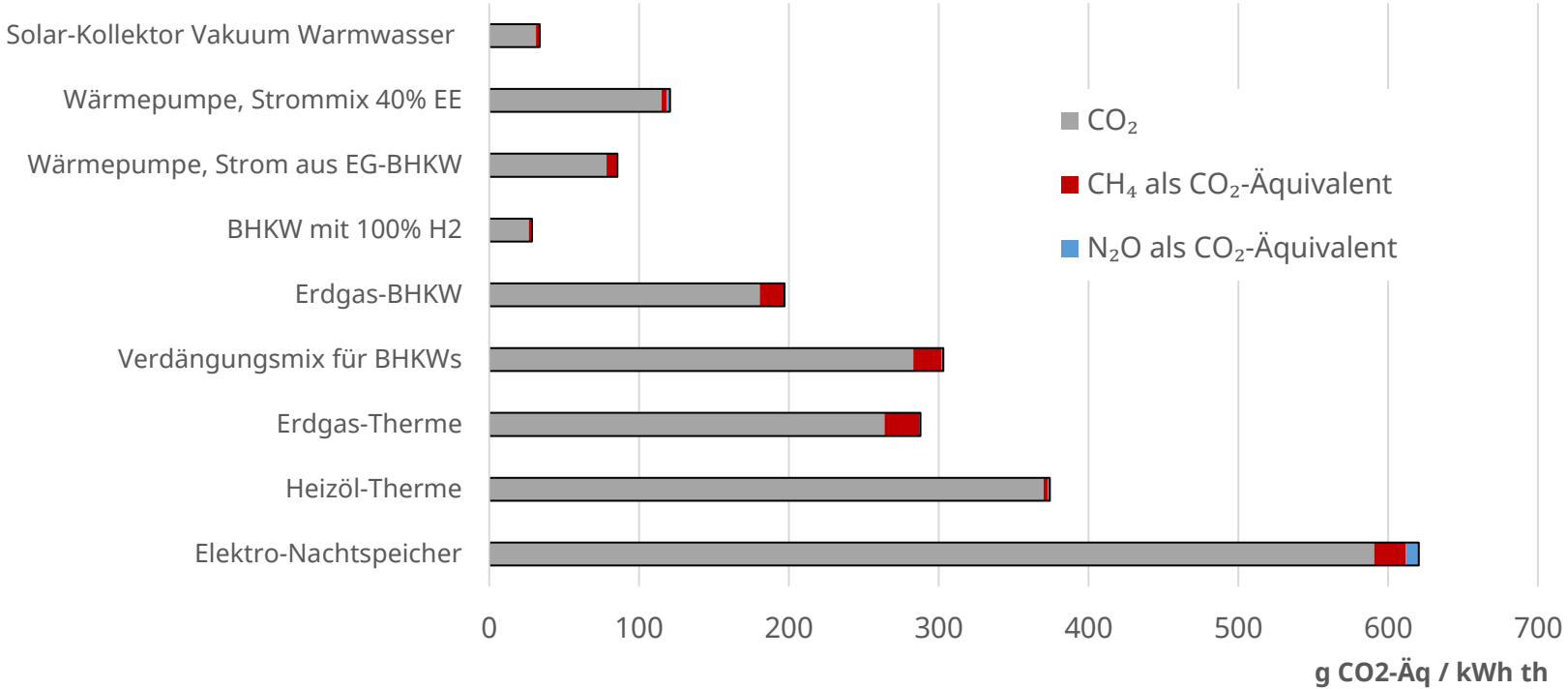
Quellen: www.umweltbundesamt.de, Angaben mit Stand 2019
www.handelsblatt.com „Wenn Russland den Gashahn zudreht“

Treibhausgasbilanz verschiedener Energiesysteme im Stromsektor.



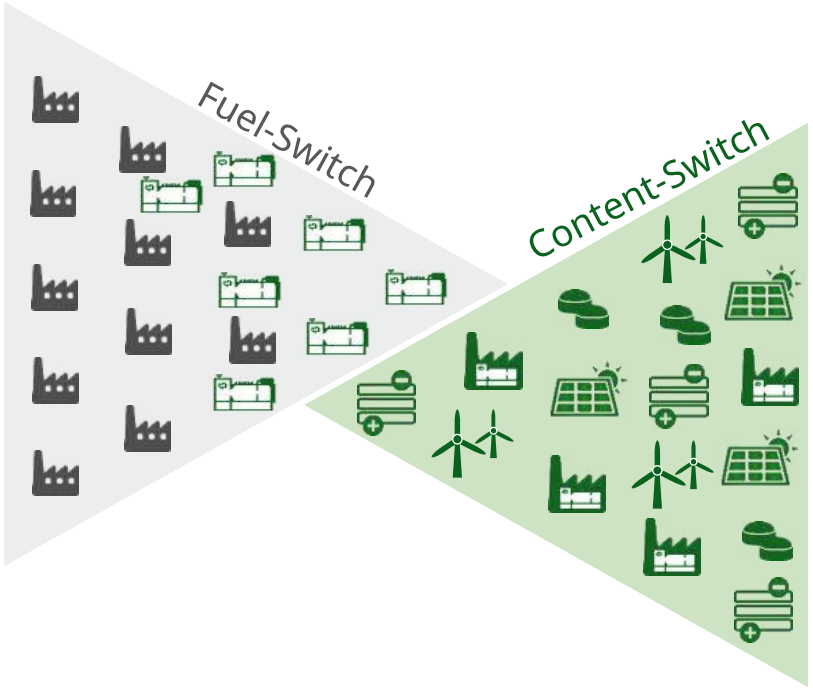
Quellen: GEMIS, 2017 und eigene Berechnungen

Treibhausgasbilanz verschiedener Energiesysteme im Wärmesektor.



Quellen: GEMIS, 2017 und eigene Berechnungen

Fuel-Switch und Content-Switch.



Öl- oder Kohlekraftwerke

Gaskraftwerke

Photovoltaik

Biogasanlagen

BHKW

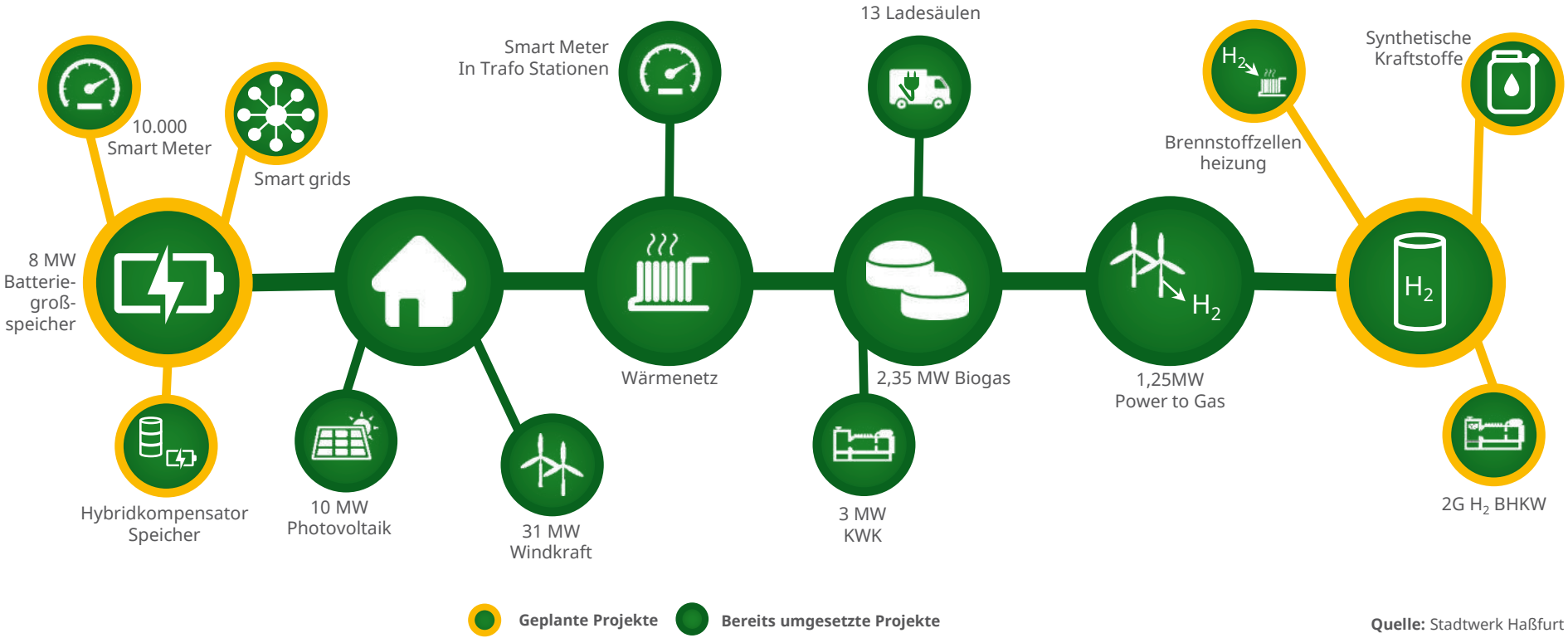
Wind

Power to Gas

Stadtwerk Haßfurt.

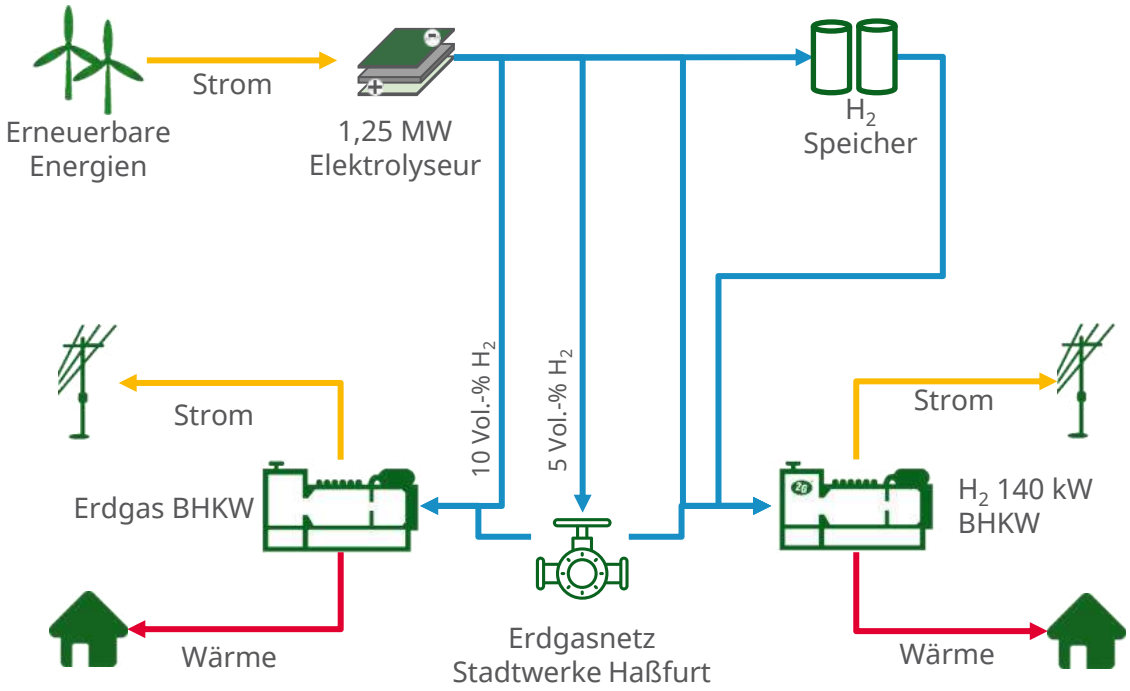
Quelle: Stadtwerk Haßfurt

Versorgungskonzept Stadtwerk Haßfurt.



Quelle: Stadtwerk Haßfurt

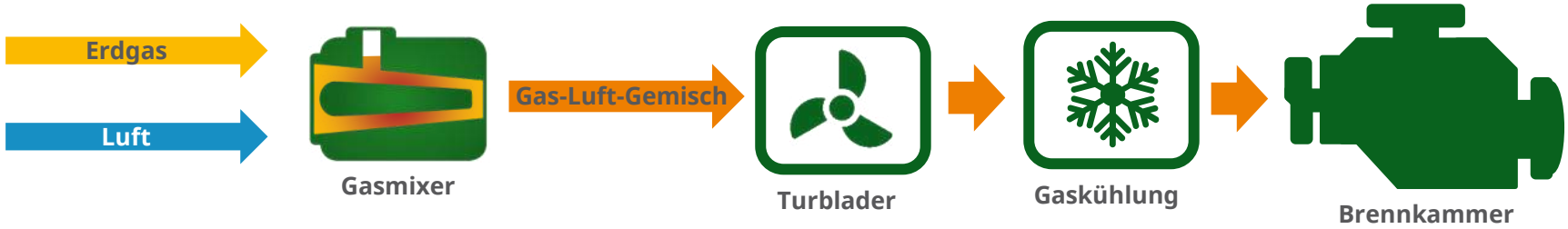
Versorgungskonzept Stadtwerk Haßfurt.



Quelle: Stadtwerk Haßfurt

agenitor 406 SG im Container – H_2 Projekt Haßfurt.

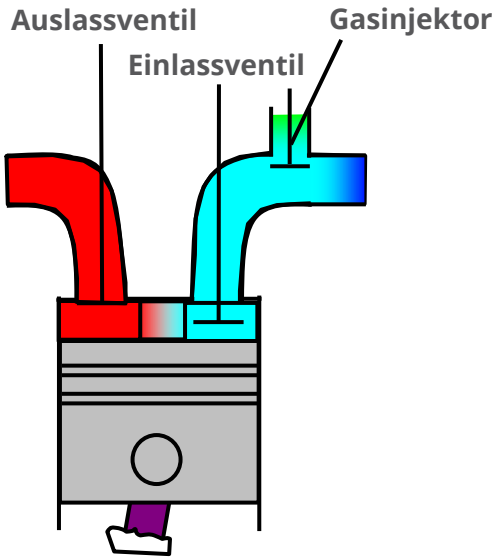
Verlgeich: Erdgas BHKW vs. Wasserstoff BHKW



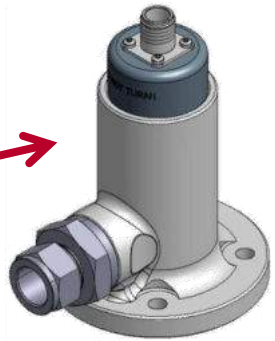
Erdgas BHKW

Wasserstoff BHKW

2G Wasserstoff- Motorentechnologie.

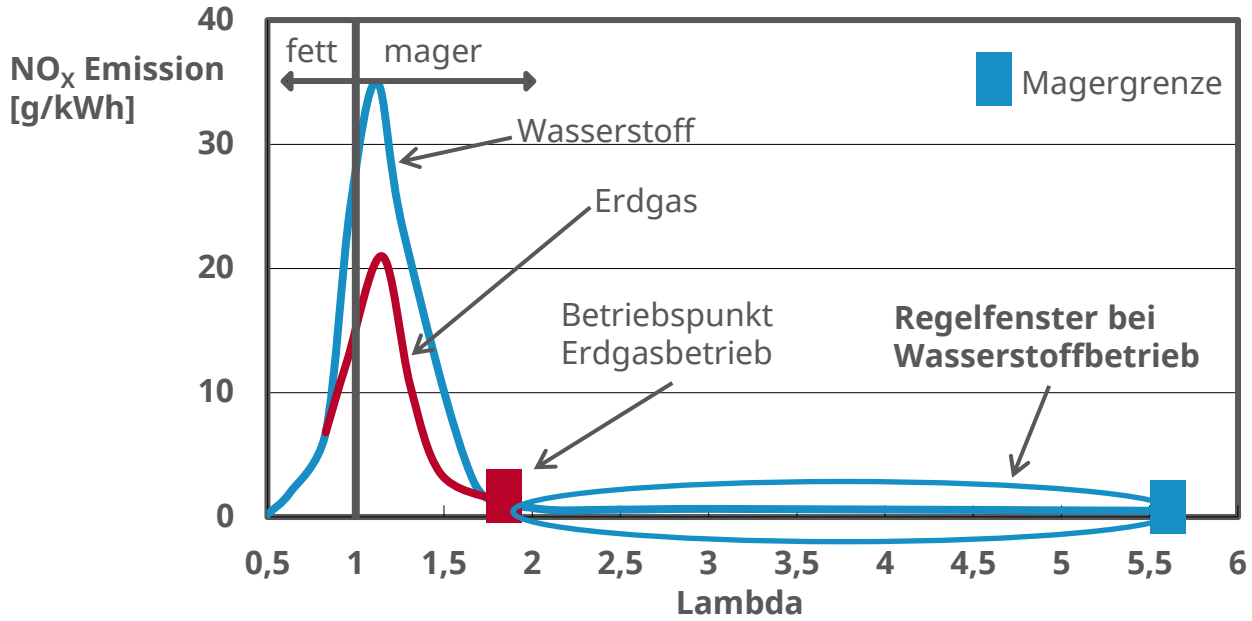


Gasinjektor:
Äußere Gemischbildung kurz vor dem Brennraum



Gasinjektor

Regelfenster und Emissionen bei Wasserstoffbetrieb.

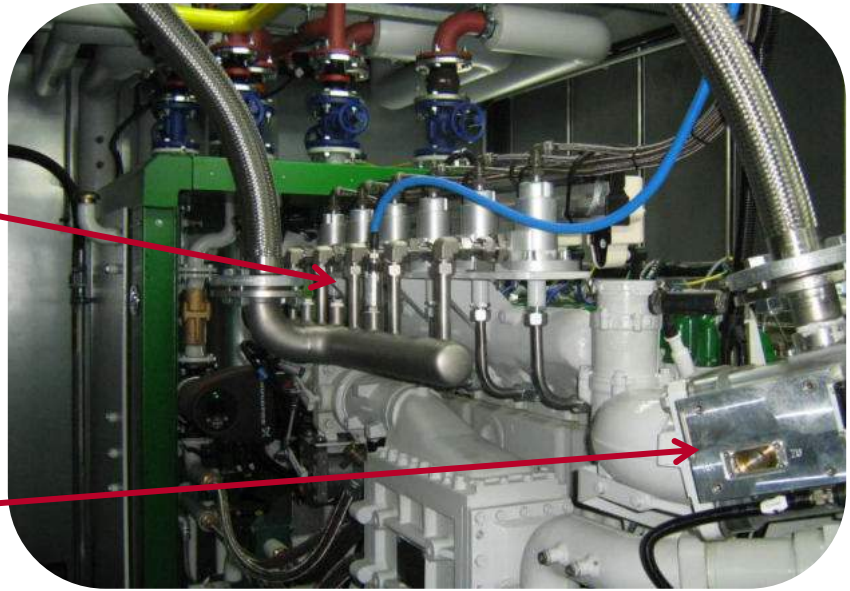


Die **Stickoxidemissionen (NOx)** bewegen sich im Wasserstoffbetrieb an der **Nachweisgrenze**.
Es entstehen zudem **keinerlei CO_2-Emissionen.**

Variabler Betrieb mit Wasserstoff und herkömmlichen Gasen.

Gasinjektor
für Wasserstoff-
betrieb

herkömmlicher
Gasmischer



Die 2G Wasserstoffmotoren können sowohl mit reinem Wasserstoff als auch mit herkömmlichem Erd- oder Biogas betrieben werden. Das erhöht ihre Einsatzfähigkeit zur Stromspitzendeckung signifikant.

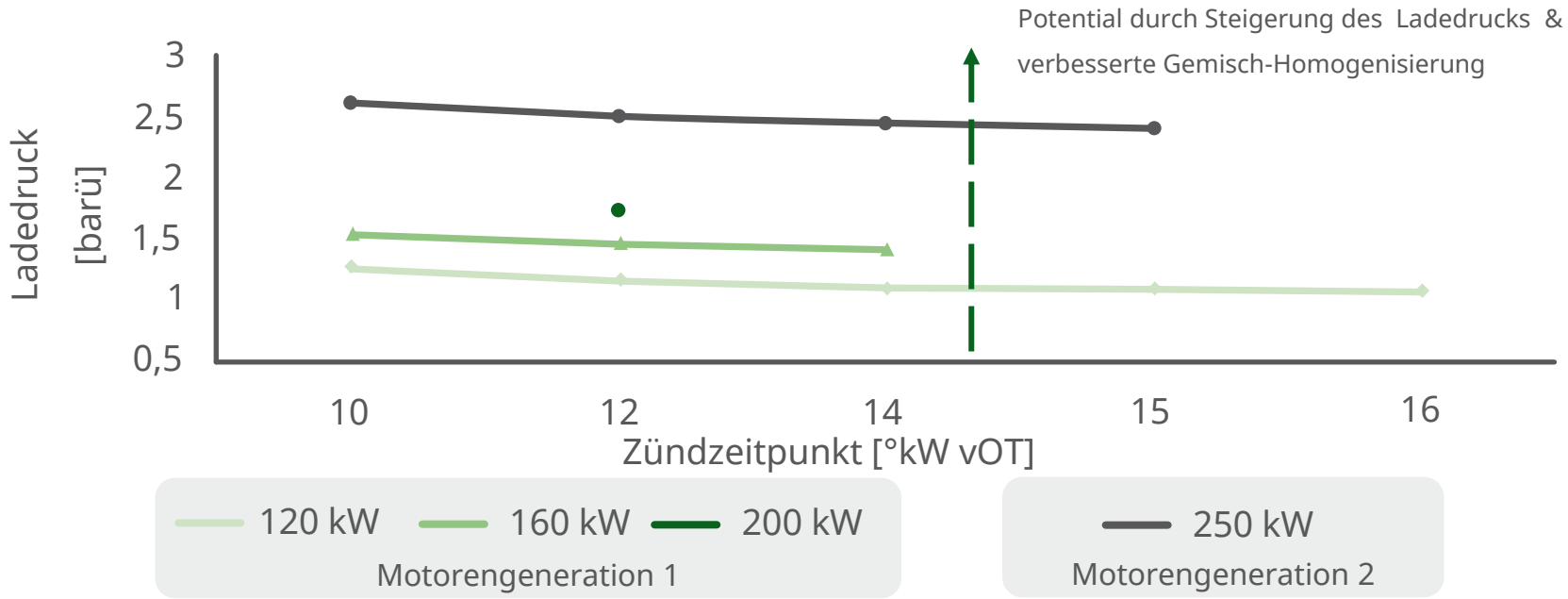
Heute Erdgas und morgen Wasserstoff.

Erdgas

Wasserstoff

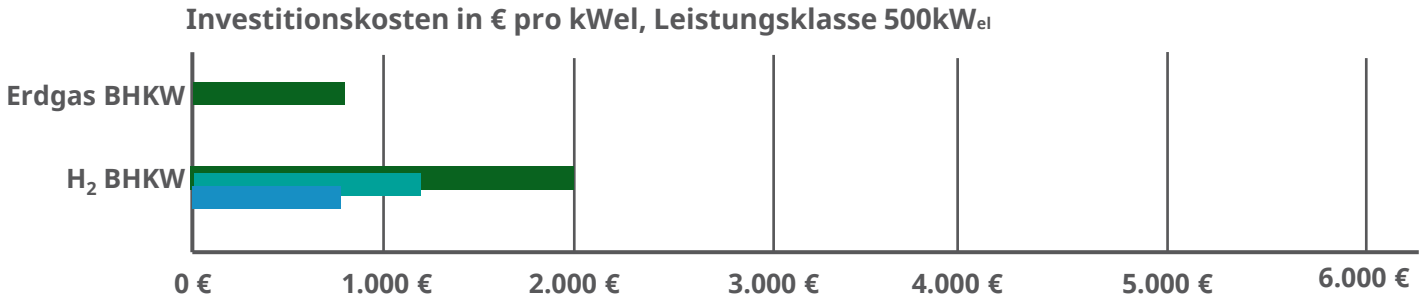
Weiterentwicklung H2 Motoren.

2G Modul agenitor406H2. Betrieb mit bis zu 250 kW_{el} (17,5 bar BMEP)



Kostenvergleich Verstromungseinheit.

Gestern **Heute** **Morgen**



Wartungskosten / TCO: Standard Motorenbauteile in großen Stückzahlen am freien Markt verfügbar
- Lebensdauer < 60.000 Bh -

Weitere Anwendungsbeispiele.

TOTAL Wasserstoff Service Station am BER Flughafen
agenitor 306 H2 mit 2G Wasserstofftechnologie

Stadtwerk Haßfurt
agenitor 406 H2 mit 2G Wasserstofftechnologie

Siemens Projekt in Dubai
agenitor 412 H2 mit 2G Wasserstofftechnologie

APEX in Rostock
agenitor 404c H2 mit 2G Wasserstofftechnologie

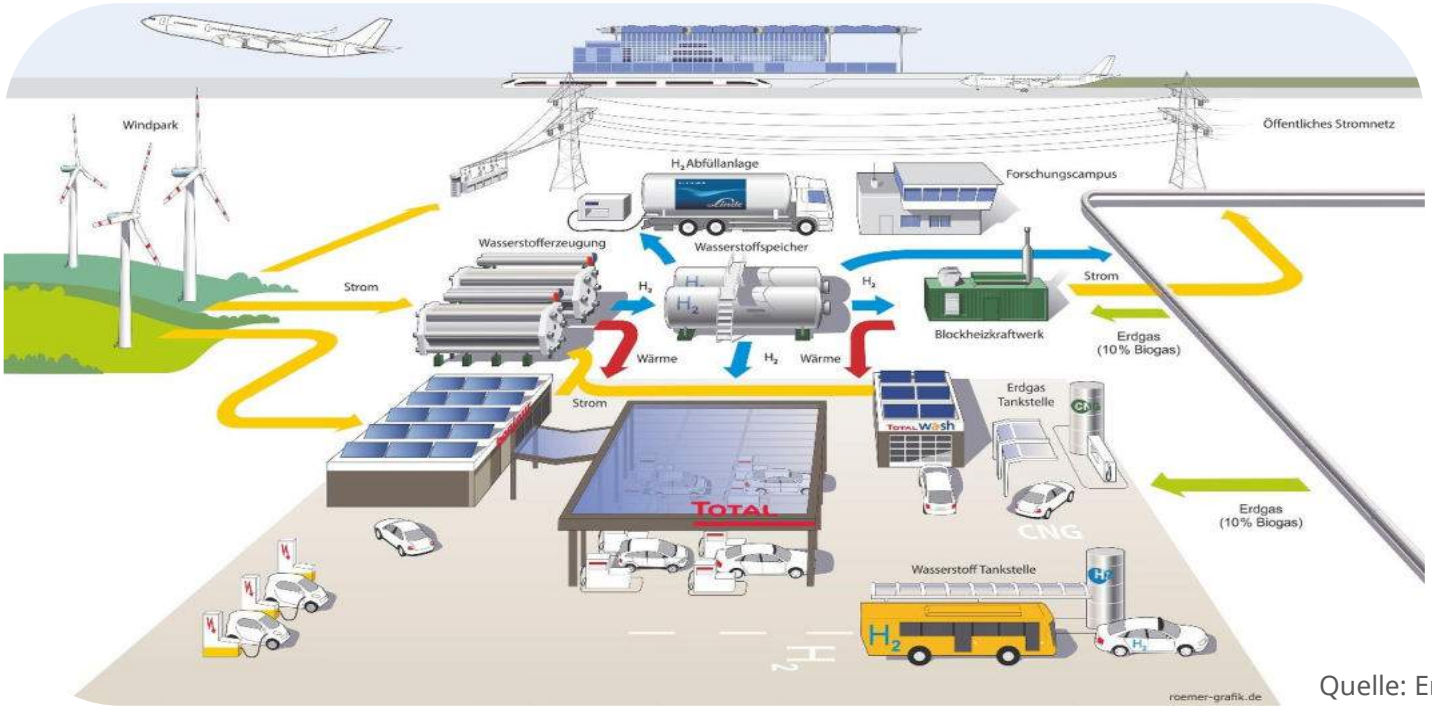
Klimaneutrales Quartier Esslingen
agenitor 406 H2 mit 2G Wasserstofftechnologie

Kirkwall Airport in Groß Britannien
agenitor 406 H2 mit 2G Wasserstofftechnologie

Japanischer Energieversorger, westlich von Tokio
agenitor 412 H2 mit 2G Wasserstofftechnologie

...

Fallstudie Flughafen Berlin (BER).



Quelle: Enertag / Total

Referenz.

Project: TOTAL Hydrogen Service Station am Flughafen in Berlin (BER)

Wasserstoff in Dubai – EXPO 2020.

Einer der weltweiten größten Solar- Parks
(1.000MW in 2020 / 5.000MW in 2030)
der Mohammed bin Rashid Al Maktoum (MBR)
in Dubai.
Siemens und die DEWA entwickeln dort die
hydrogen economy 2020.

Klimaneutrales Quartier Esslingen.

500 Wohnungen, Geschäfte, 12-geschossiges Bürogebäude und Campus für 1800 Studenten. Konzeptentwurf als Blaupause für die ökologische und ökonomische Stadtteilversorgung.

Hydrogen Airport.

Das European Marine Energy Centre (EMEC) arbeitet mit der Highlands and Islands Airports Limited (HIAL) zusammen, um die Wärme- und Stromversorgung am Flughafen Kirkwall durch grüne Wasserstofftechnologie zu dekarbonisieren. Der Wasserstoff wird in Containertanks an den Standort geliefert.

Vielen Dank für die Aufmerksamkeit!

2G Energy – We care for a better Future.

- Komplettlösungsanbieter
- BHKW 20 – 4.000 kW
- Finanzierungsangebote
- Großes Servicenetzwerk
- 7.000 Anlagen weltweit
- 700 Mitarbeiter*innen

2G Energy AG | Benzstraße 3| 48619 | Heek
Tel: +49 (0) 2568 9347-0 | info@2-g.de | www.2-g.de

Erfahrungen mit Wasserstoff-BHKW

2. Workshop, Erzeugung von grünem Wasserstoff, Cottbus 2021

INNIO Jenbacher GmbH & Co OG
Jenbach, Austria
www.innio.com

Dr. Klaus Payrhuber

Mai. 17th, 2021

Pushing beyond the impossible and looking boldly toward tomorrow

INNIO* is...

- A leading technology provider of gas engines, power equipment, a digital platform, Headquartered in Jenbach, Austria, with additional primary and related services for power generation and gas compression at or near the point of use.
- Renowned for our proven Jenbacher* and Waukesha* product brands.

  Gas engines from 200 to 10,400 kW
- Operations in Welland, Ontario, Canada, and Waukesha, Wisconsin, USA.

JENBACHER
INNIO

Transitioning to 100% Renewable fuels

Today

45% ⬅ EU ➡ 55%

Natural Gas CHP

Biogas

Today's mix of fossil natural gas and renewable gases

Tomorrow

Biomethane or Synthetic Methane CHP

Biomethane & CO_2 usage

Hydrogen CHP

Biogas

Carbon neutral fuels & green hydrogen

Jenbacher gas engines with hydrogen operation

MW scale

Jenbacher's experience with Hydrogen & Hydrogen mixtures

Coke gas (Profusa)
COD 1994

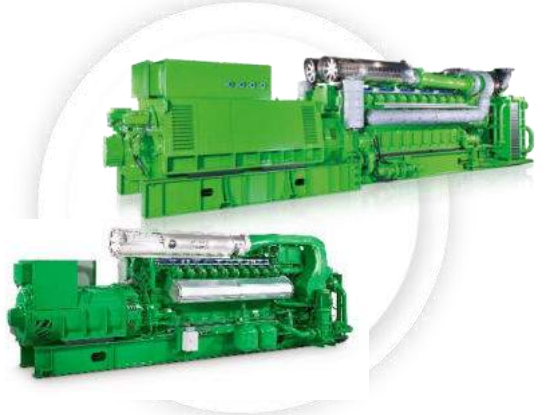
H_2: ~50-70Vol%
CH_4: ~20-25Vol%
LHV: ~5 kWh/m^3

Process gas (Krems)
COD 1996

H_2: ~15-17 Vol%
CH_4: ~1.5 Vol%
LHV: ~0.5 kWh/m^3

Syngas (Mutsu)
COD 2003

H_2: ~30-40 Vol%
CO: ~25-30 Vol%
LHV: ~2.5 kWh/m^3



Pure Hydrogen
2021+

H_2: … 100 Vol%
Nat. Gas or Inerts
LHV: ~3 kWh/m^3

Commercial operation

Future

More than 250MW installed with syngas / process gases

90 projects in 28 countries and experience with all engine types

Jenbacher gas engine solutions for H_2

A

H_2 in natural gas pipeline

A-1: Low H_2 blending
Optimized for NG
<5%v H_2

A-2: Medium H_2 blending
broadband product
5-20 (30)%v H_2

B

H_2 local admixing

B-1: Special gas engine
operational optimized
up to ~60%v H_2

B-2: NG / H_2 engine
dual gas engine 100%v
NG / H_2

C

Pure H_2

C: H_2 engine
hydrogen engine (H_2)
100%v H_2

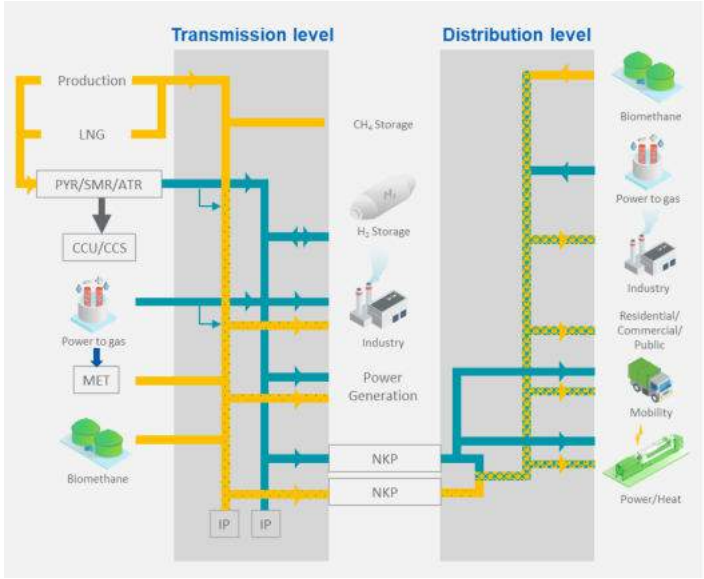
Conventional NG+H2 fuel mixture boosted system

H2 fuel injection system

no modifications required	existing versions available	existing versions available	pilots available (pre-serial engines)	pilots available (pre-serial engines)

JENBACHER
INNIO

H_2 mixed in pipeline natural gas



Important fuel properties to consider

- Heating Value
- Methane Number
- Laminar Flame Speed

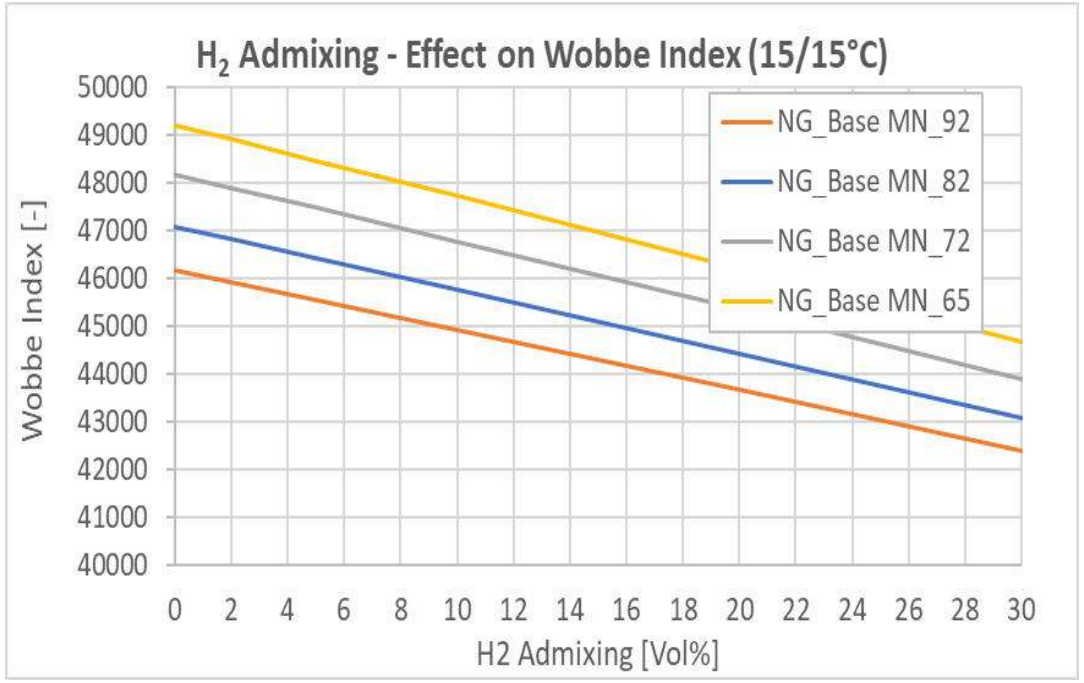
	Characteristic	Limits	Unit
LHV	Fluctuation	≤ 4	%/min
MN	RoC	≤ 10	MN/min
H_2 content in NG	RoC	≤ 4	Vol%/min
100% H_2	H_2 purity	not relevant	% H_2

Mixture

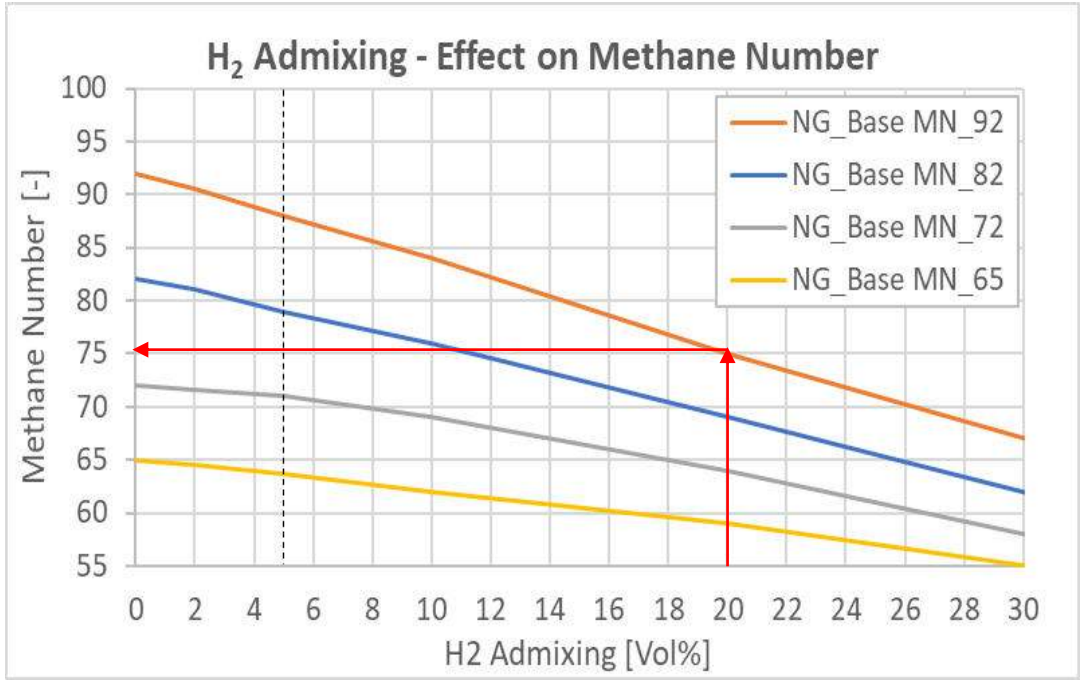
		NG example	Hydrogen
CH4	Vol-%	97.6	0
C2H6	Vol-%	2	0
C3H8	Vol-%	0.4	0
H2	Vol-%	0	100
LHV	kJ/Nm³	36 730	10 800
WI	kJ/Nm³	48 704	41 000
MN	-	92	0
Laminar flame speed	cm/s	38	>300

Hydrogen added to pipeline Natural Gas

H2 Admixing-Effect on Wobbe Index



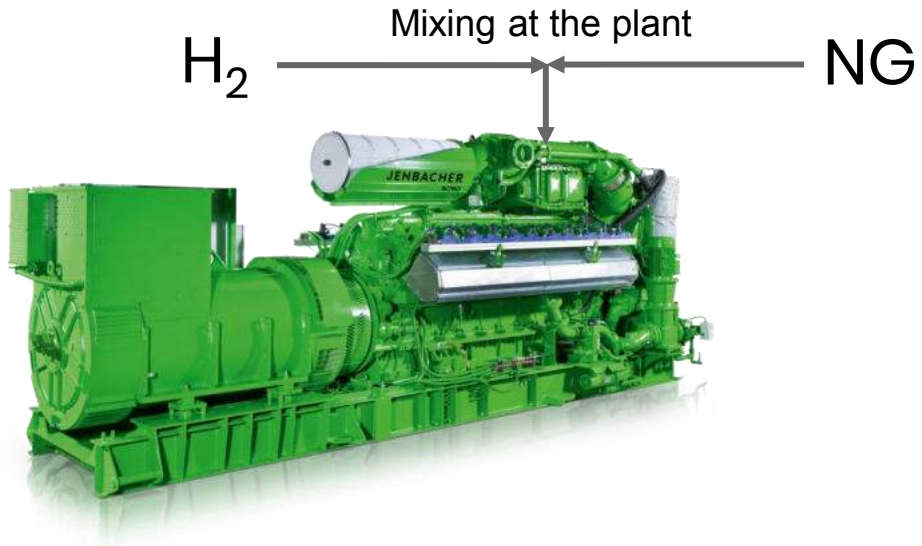
H2 Admixing-Effect on Methane Number



>5%(v) H_2 in pipeline gas … we recommend a signal to gas engines about H_2 content

>5%(v) H_2 in pipeline gas … typically requires a broadband product

H_2 local admixing to natural gas



		Hydrogen
CH4	Vol-%	0
C2H6	Vol-%	0
C3H8	Vol-%	0
H2	Vol-%	100
LHV	kJ/Nm³	10 800
WI	kJ/Nm³	41 000
MN	-	0
Laminar flame speed	cm/s	>300

Important fuel properties to consider

- Heating Value
- Methane Number
- Laminar Flame Speed

✓ H2 content to control system available

		NG example
CH4	Vol-%	97.6
C2H6	Vol-%	2
C3H8	Vol-%	0.4
H2	Vol-%	0
LHV	kJ/Nm³	36 730
WI	kJ/Nm³	48 704
MN	-	92
Laminar flame speed	cm/s	38

H_2 local admixing demo projects

30%v H_2

Bozen - Italy
2017, Horizon 2020 Demo

J612, main fuel NG

Sinfonia

30%v H_2

Biogas Stream- Austria
2008 Demo

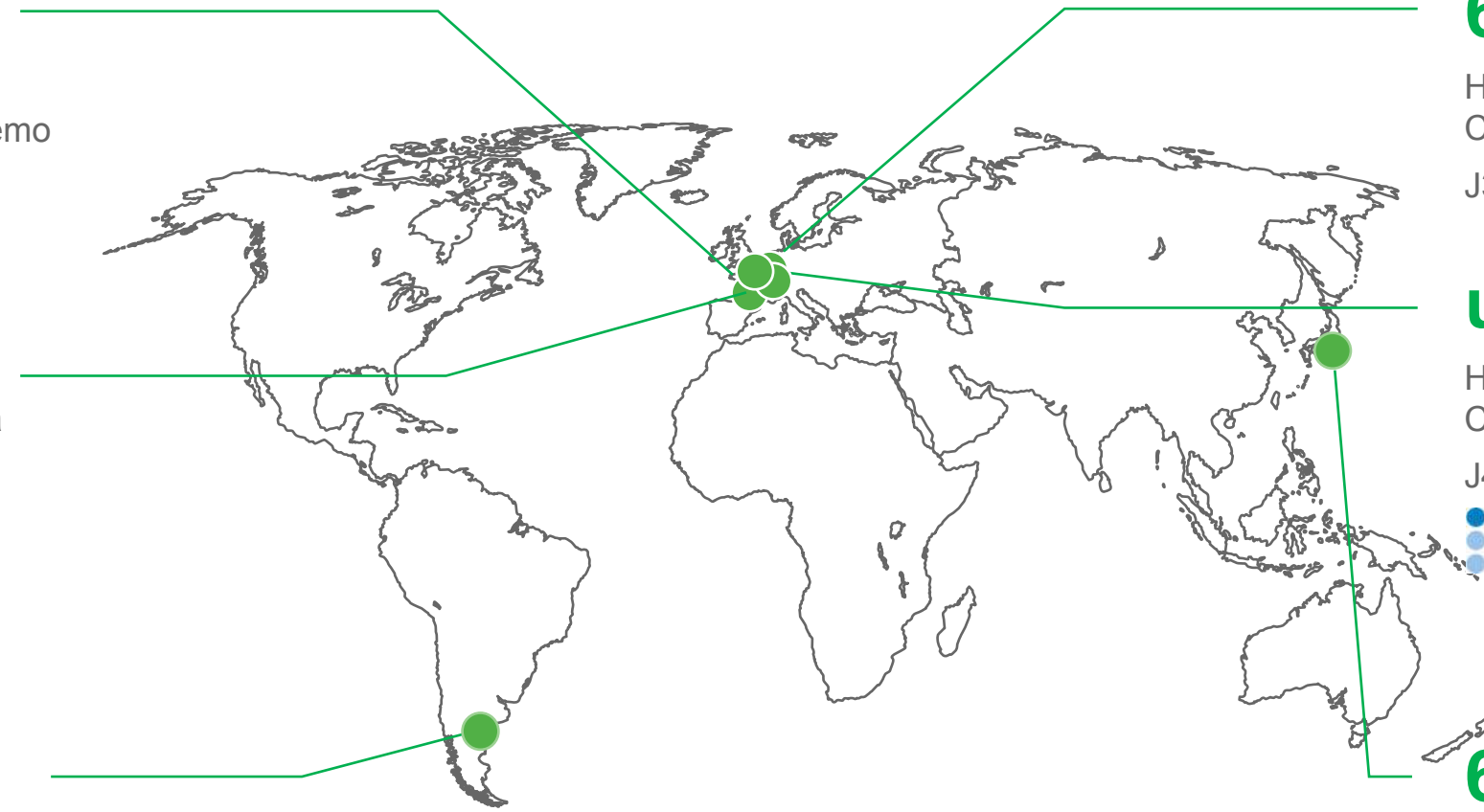
J312, main fuel NG

42%v H_2

Hychico – Argentina
Operating since 2008

J420, main fuel NG

HYCHICO



60%v H_2

DLR

H2ORIZON - Stuttgart
Commissioning 2020

J312, main fuel NG

up to 100% H_2

HanseWerk Natur - Hamburg
Commissioning 11/2020

J416, main fuel NG

HanseWerk

60%v H_2

Ando Hasama - Japan
Commissioning 01/2020

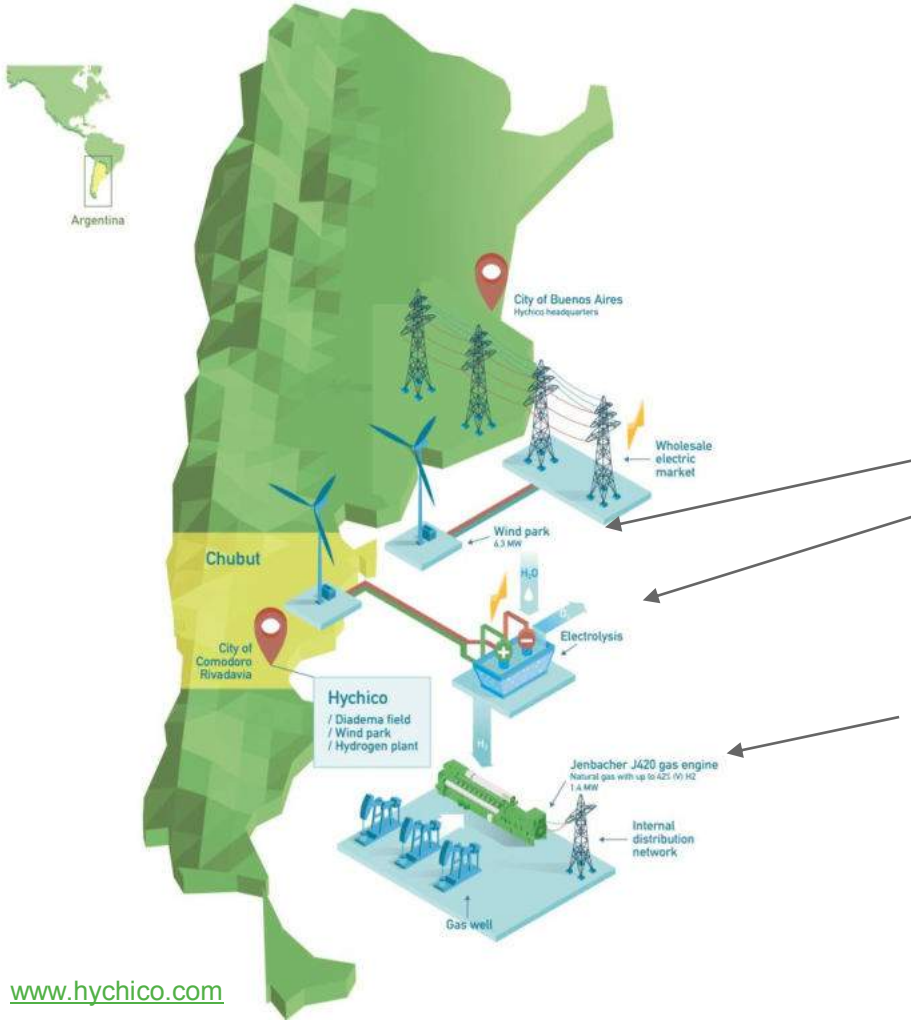
J312, main fuel NG

HAZAMA ANDO CORPORATION

JENBACHER

INNIO

Hychico, Argentina site



www.hychico.com

Hychico, Diadema Wind Park and Hydrogen Plant, Chubut Province, Argentina

About the region:

Currently large oil & gas fields
2,000 GW wind power potential, compared to 600 GW global installations today
Ideal place for exporting green H_2 and e-fuels in the future

Green H_2 demo :

6.3 MW wind park with **54.9% CF (2017), avg. >50%**
0.8 MW of electrolyser (2 units), 120 Nm^3/hr H_2
H_2 with high purity (99.998%), O_2 for local market
Underground H_2 storage research

J420 converts H_2 back to power

Output 1,415 kW_{el}
Main Fuel: NG MN >90
Operation with **controlled H_2 blending**
0-27 v% H_2 1,415 kW
28-42 v% H_2 1,415 to 1,180 kW

~70,000 oh
since 2008

JENBACHER
INNIO

First 100% Hydrogen pilot engine with ~1MW HanseWerk Natur (E.on), GER

Engine type and version	J416 C202	J416 C202
Fuel	Natural gas	**Hydrogen**
Nom. output Pel*	999 kWel	>600 kWel
Elec./total eff. @ nom. output	~42%/~93.5%	40+%/~93%
Expected H_2 content w/o derating*	-	~20 Vol%
Max H_2 content (w/ derating)*	-	100 Vol%

* Controlled H_2 blending, base gas quality MN~80

CHP Othmarschen, Hamburg/GER

Engine designed and optimized for operation with natural gas fuel,
Engine capable to run on 100% hydrogen and any mixture of natural gas and hydrogen (Dual-Fuel engine)

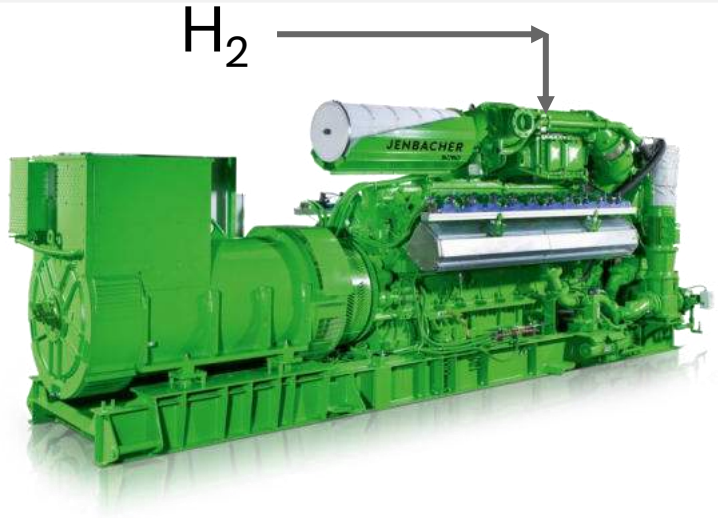
- 100% NG as commercial fuel achieving max. total efficiency
- Up to 100% H_2 operation possible (H_2 as demonstration fuel)

Milestones

- ✓ Factory test successful in Aug., 2020
- ✓ Site demonstration in Nov. 2020
- ✓ PR about site demonstration by INNIO and E.ON in Q4, 2020

With hydrogen becoming a commercial fuel, INNIO Jenbacher will invest in optimizing gas engine performance

100% H_2



		Hydrogen
CH4	Vol-%	0
C2H6	Vol-%	0
C3H8	Vol-%	0
H2	Vol-%	100
LHV	kJ/Nm³	10 800
WI	kJ/Nm³	41 000
MN	-	0
Laminar flame speed	cm/s	>300

Important fuel properties to consider

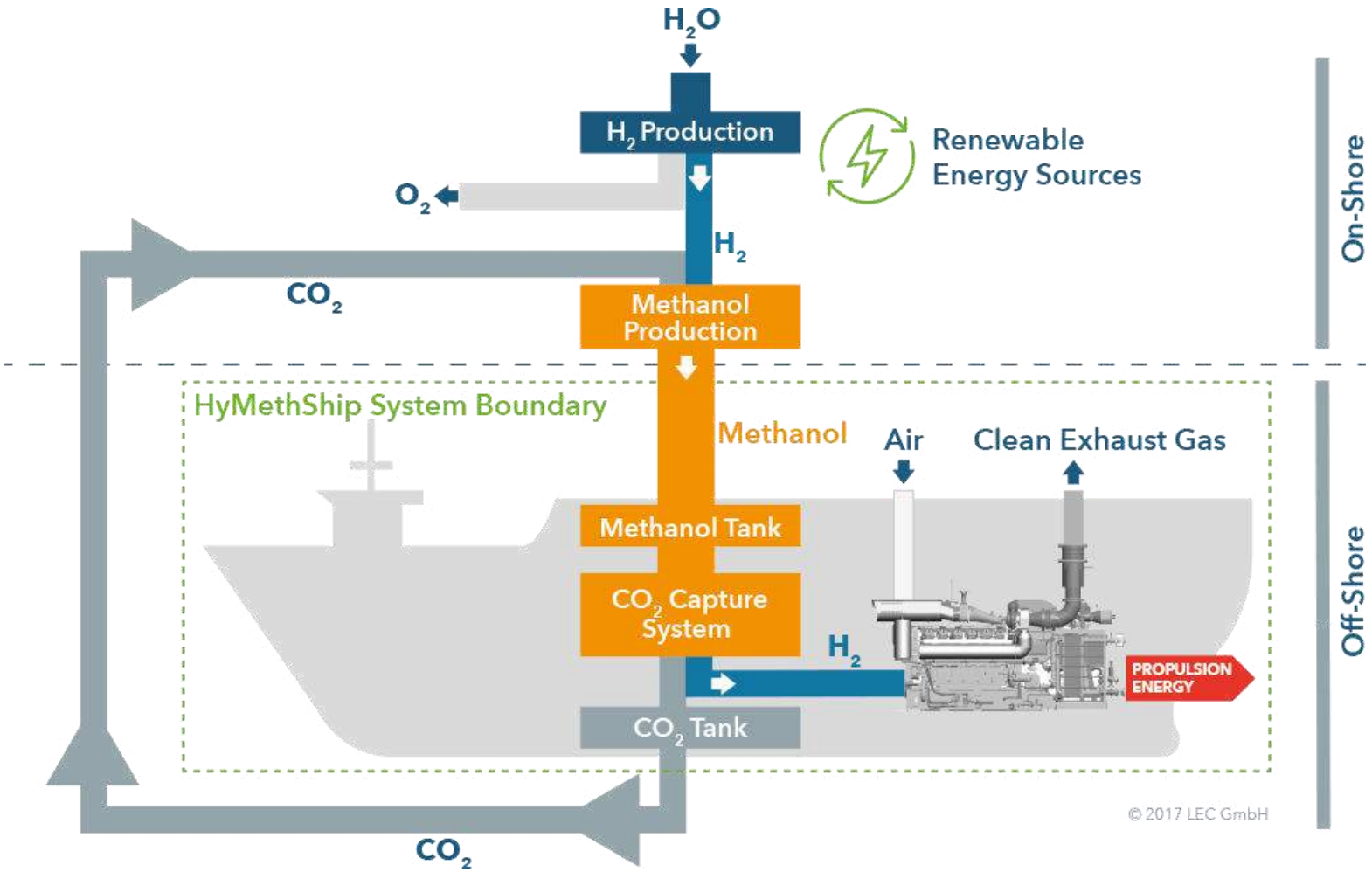
- Heating Value
- Methane Number
- Laminar Flame Speed
- ✓ First 100% H2 demo in 2001

Illustration 19: Hydrogen test engine JGS 156 GS.L

JENBACHER
INNIO

“Emission-free” Ship Propulsion (Methanol fuel & H2 Engine)

www.hymethship.com



- 97% reduction in GHG emissions
- Elimination of SOx and PM emissions
- Minimization of NOx emissions
- ~45% increase in system efficiency compared to the technology with conventional CO_2 capture / separation
- Full-size (1 MW) system demonstration in 2021
  - H_2 operation (multi cylinder engine)
  - Methanol reforming and CO_2 capture
  - Interaction of the 2 subsystems

This project has received funding from the European Union’s Horizon 2020 research and innovation programe under grant agreement No 768945

Offerings & Outlook

100% H2 – Type 4 – 50Hz (pre-serial engine)

NG: 250mgNOx@5%O2	J420 C202	J420 C202
	Natural gas	**Hydrogen**
Epsilon & min. MN @ Power	CR11.8, MN 70	CR11.8
ICWT	40°C	< 40°C
Nominale Leistung Pel	1500 kWe	900 - 1000 kWe
BMEP (spec. output)	20.2bar	12 - 14bar
Eta-el @ nom. Power	42%	~40+%
H2 blending (w/o derating)*	-	~25 Vol%
Max H2 content (w/ derating)*	-	100 Vol%

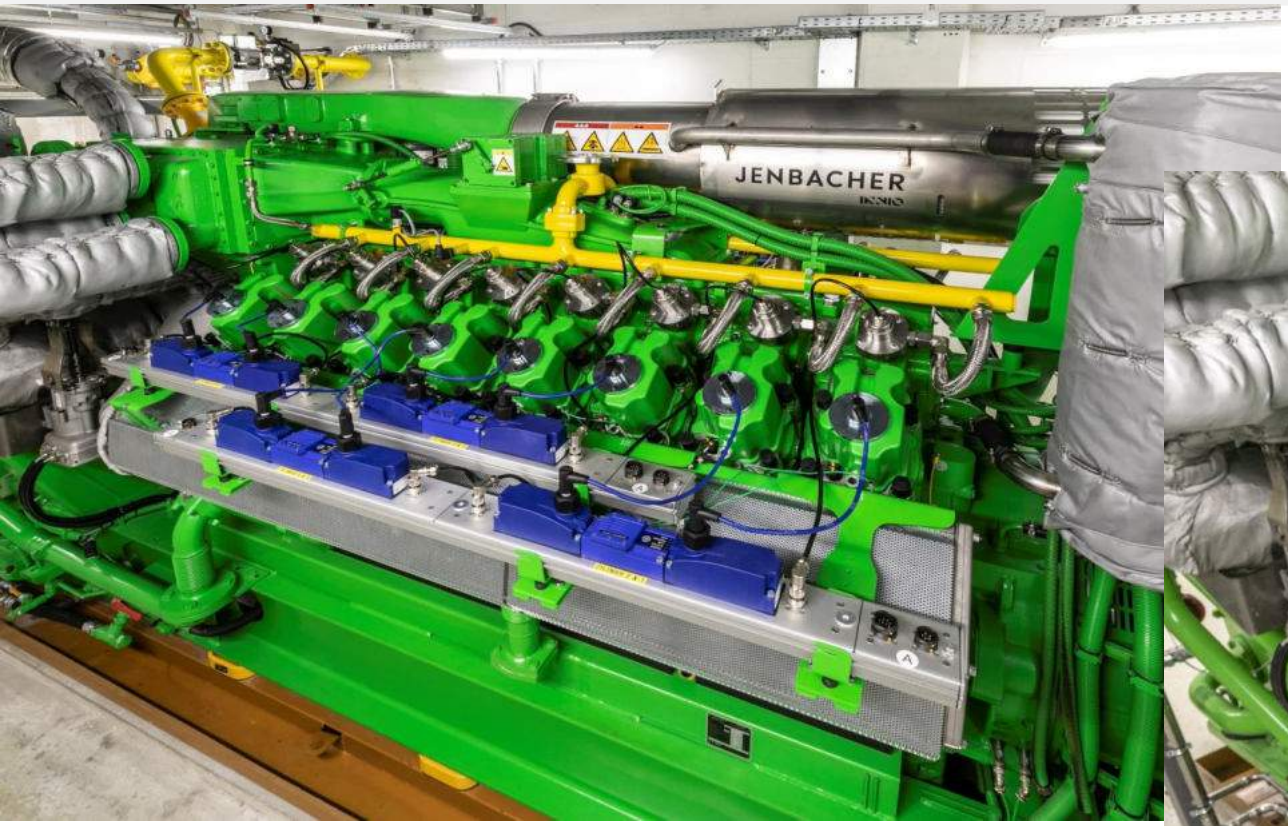
Technology

- Port injection (gas pressure 8+bar)
- Cylinder selective combustion control
- Wastegate for turbo charger

* Controlled blending (subject to base MN)

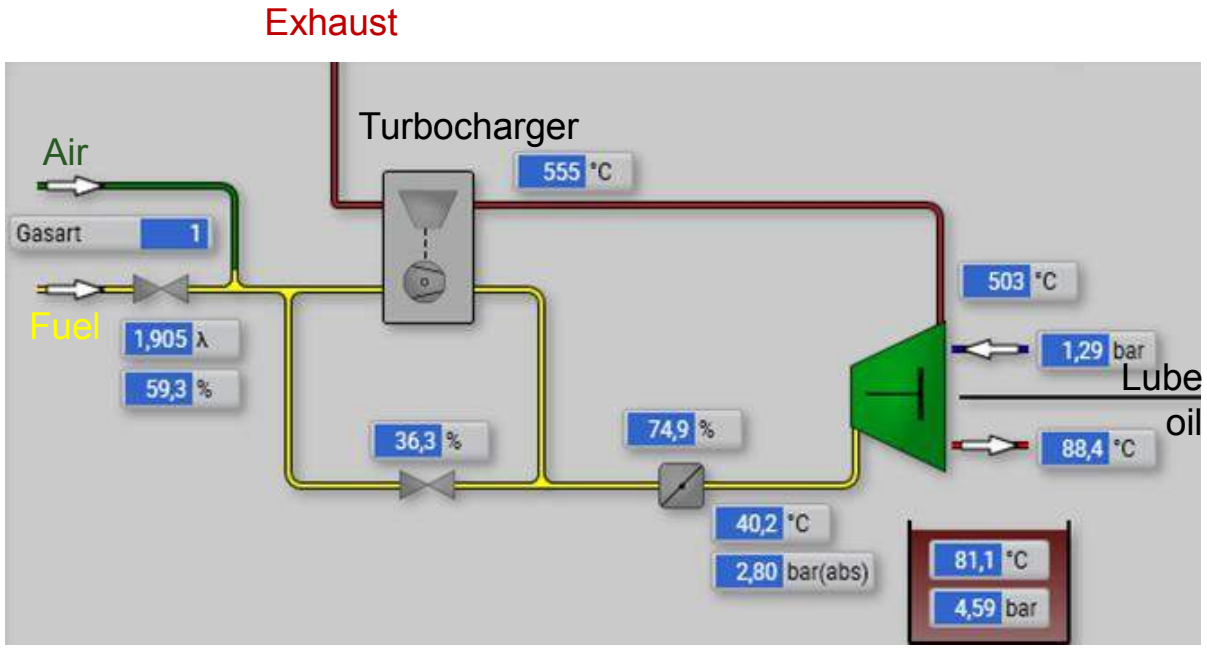
"Dual Fuel Product" – 100% NG / 100% H2 –
& controlled blending of H2 from ~5 – 95 Vol%

First 100% Hydrogen pilot engine with ~1MW HanseWerk Natur (E.on), GER

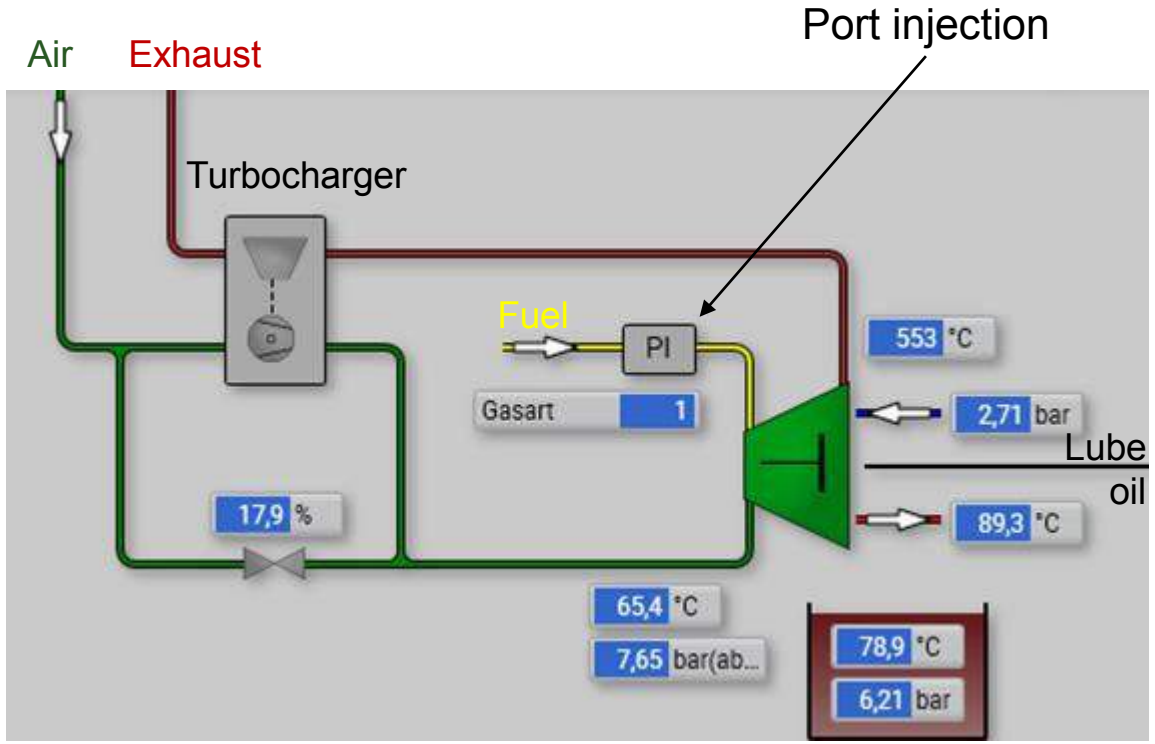


Main difference between a NG engine and a H2 engine

NG engine



H2 engine

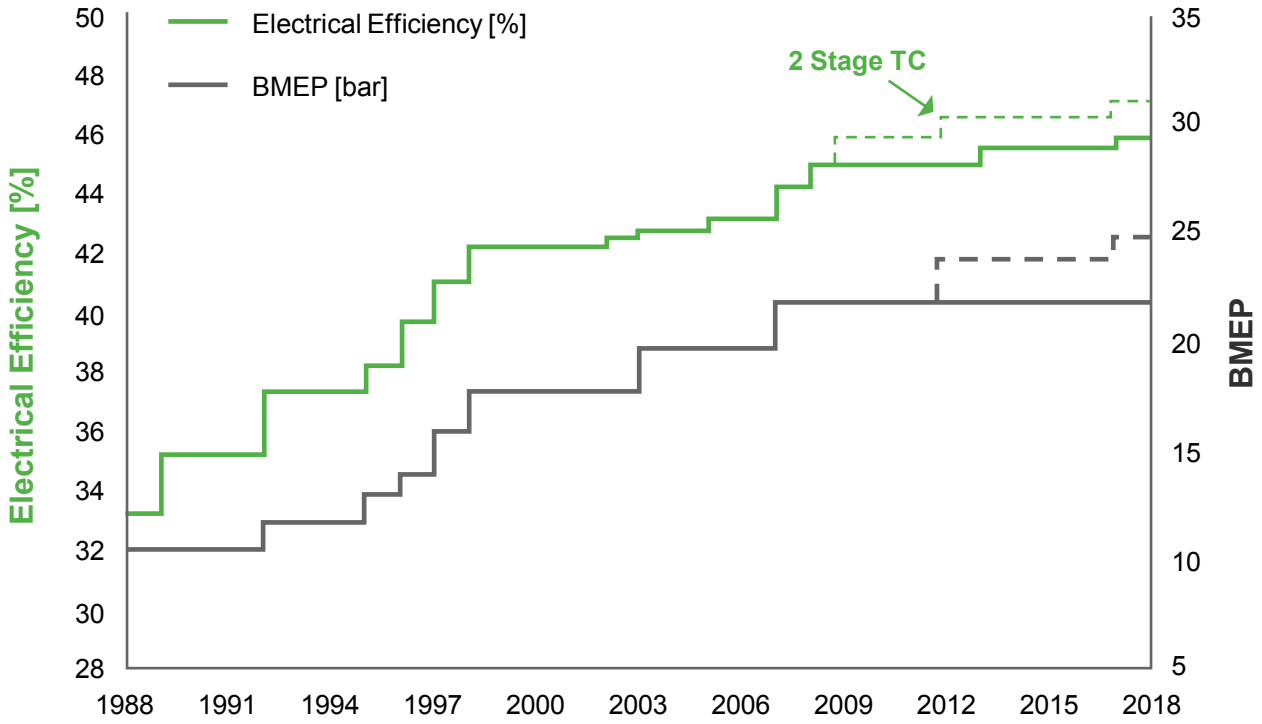


Intercooler on both pictures is not shown

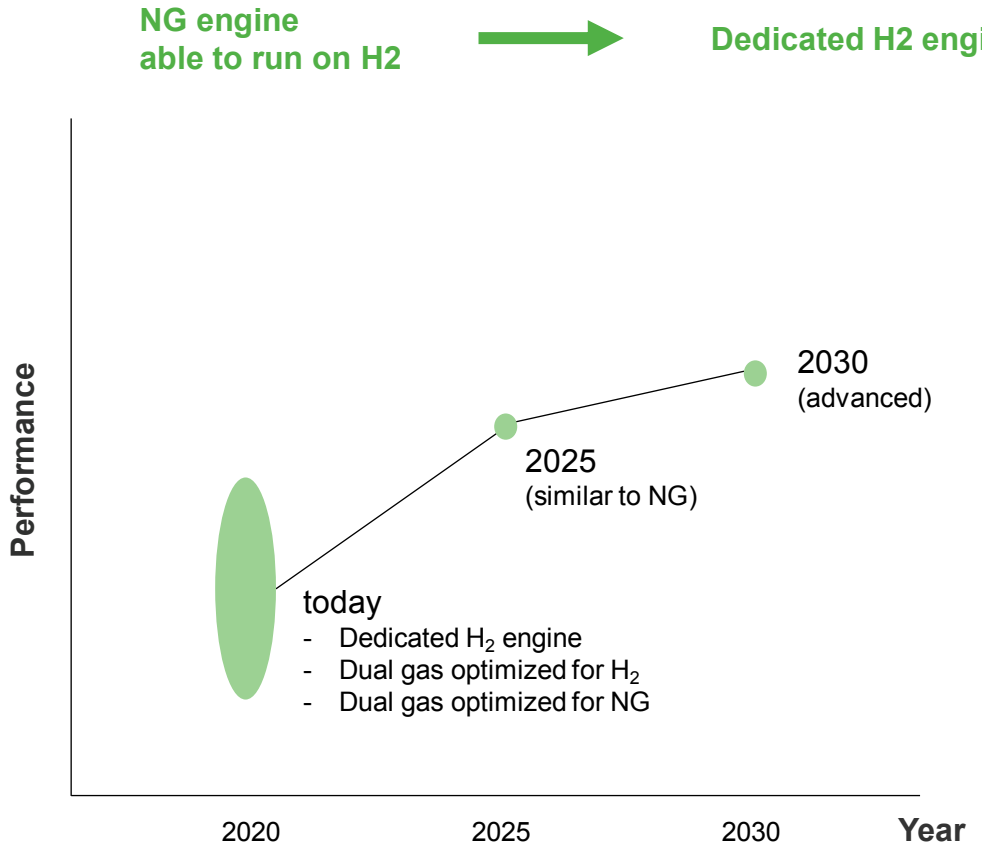
Continuous innovation driving technology improvements

Type 6 Nat. Gas … 30 years old and still evolving

Output/Cylinder 2.5 x
Efficiency 33 -> 47%

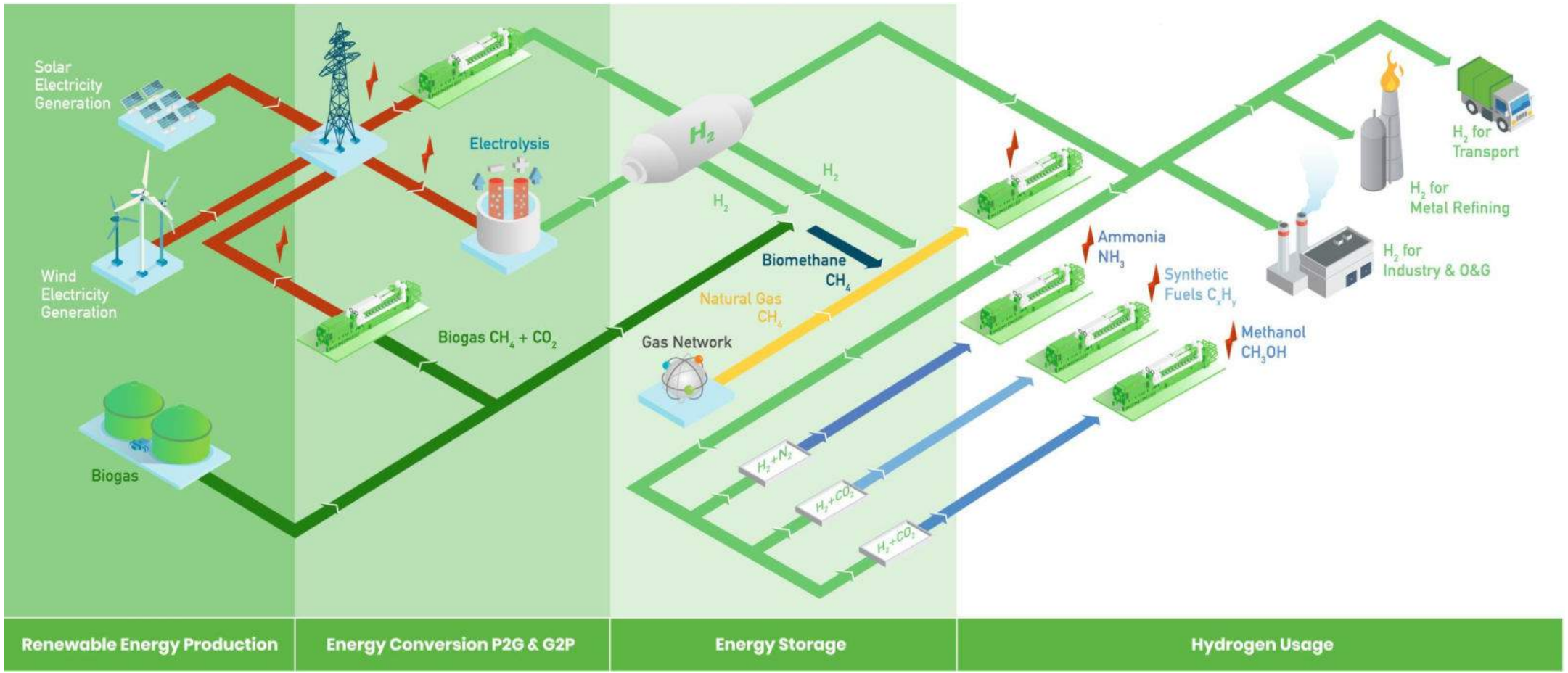


H2 performance will increase in the next years



BMEP … a measure for the specific cylinder output

Future role of Jenbacher gas engines in a renewable world



THE HYDROGEN ECONOMY CAN BECOME A REALITY ACROSS ALL SECTORS – IF WE USE THE EXISTING INFRASTRUCTURE!

INNIO JENBACHER Waukesha

MOVE THE WORLD FORWARD MITSUBISHI HEAVY INDUSTRIES GROUP

Mitsubishi Heavy Industries
Hydrogen Roadmap

2. Workshop: Erzeugung von grünem Wasser stoff 17.05.2021

Wasserstoff - Rückverstromungstechniken

CEBra e.V.
Dr. Ing. Christian Bergins
c_bergins@eumhi.com

Mitsubishi Heavy Industries EMEA, Ltd.

MITSUBISHI HEAVY INDUSTRIES

Company Overview

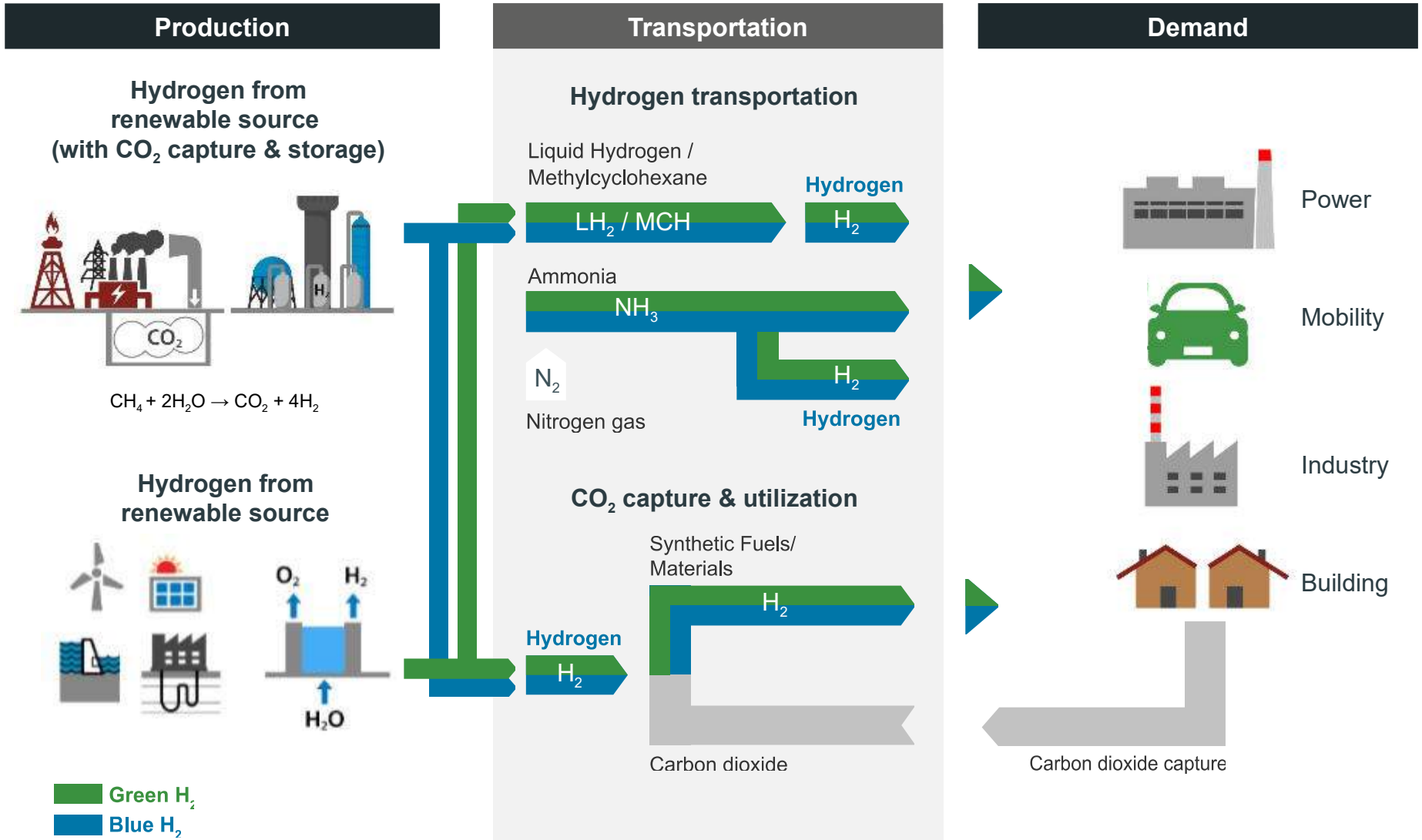
** This table is not exhaustive. It lists only companies and products related to hydrogen business*

MITSUBISHI HEAVY INDUSTRIES GROUP

Research & Innovation Centre

Energy Systems	Plants and Infrastructure	Integrated Defense and Space Systems
		
Jet Engines (Mitsubishi Heavy Industries Aero Engines, Ltd.)	Iron Making (Primetals Technologies, Ltd.)	Aircraft (Mitsubishi Aircraft Corporation)
Compressor (Mitsubishi Heavy Industries Compressor Corp.)	Ammonia & Methanol Co-Production Plants CO2 Capture Plants (Mitsubishi Heavy Industries Engineering, Ltd.)	H-IIA Rocket
Power Generation (Mitsubishi Power)	Gas Carriers (Mitsubishi Shipbuilding Co., Ltd.)	

Overview of Global Hydrogen Supply Chain



Green Hydrogen

Mitsubishi Heavy Industries EMEA, Ltd.

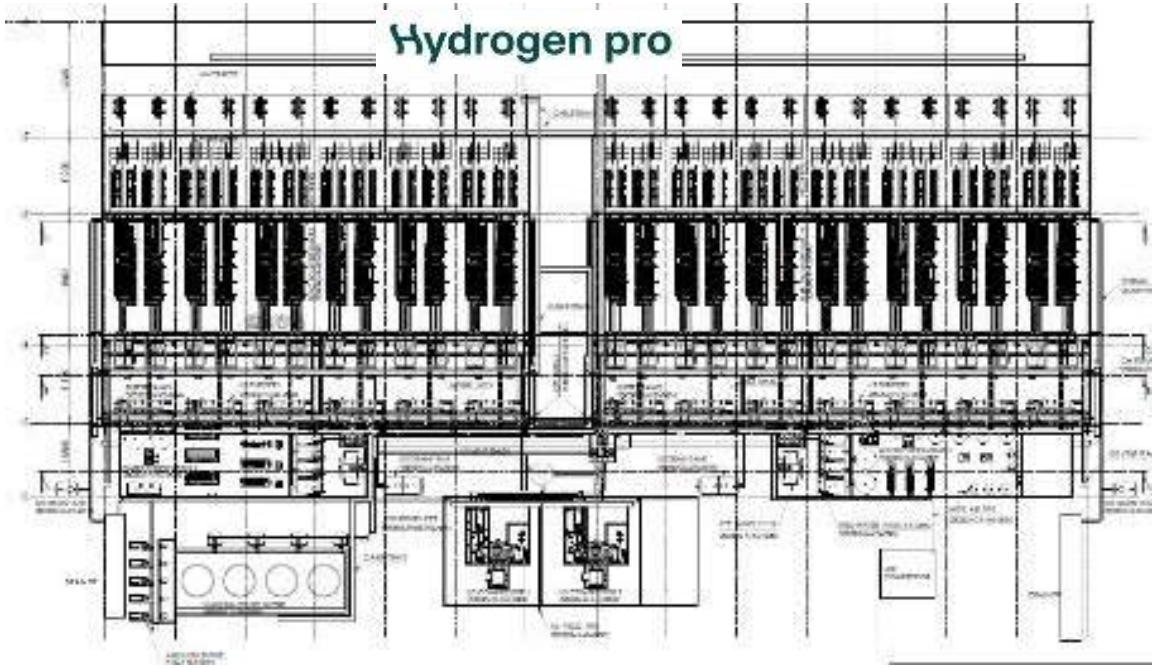
Green hydrogen production by electrolysis

PRESS INFORMATION

MHI Group Undertakes Investment in HydrogenPro of Norway,
Leading Producer of Advanced Electrolyzers
-- Move Will Contribute to Creation of a Sustainable Society through Hydrogen Energy --

2020-10-14

Type	Op.- Pressure (bar)	Spec. Power (kWh/Nm³)
Pressurized Alkaline Electrolyzer	15-30	4,5-4,7 (AC)



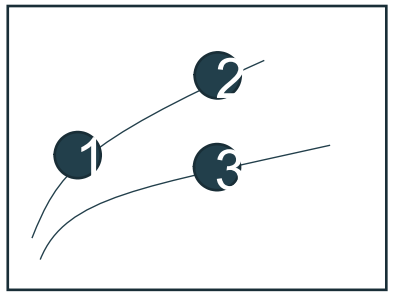
- Collaboration towards 100MW scale green hydrogen plants
- Scaling up technology and ramp–up of manufacturing

Future plant design large scale production process

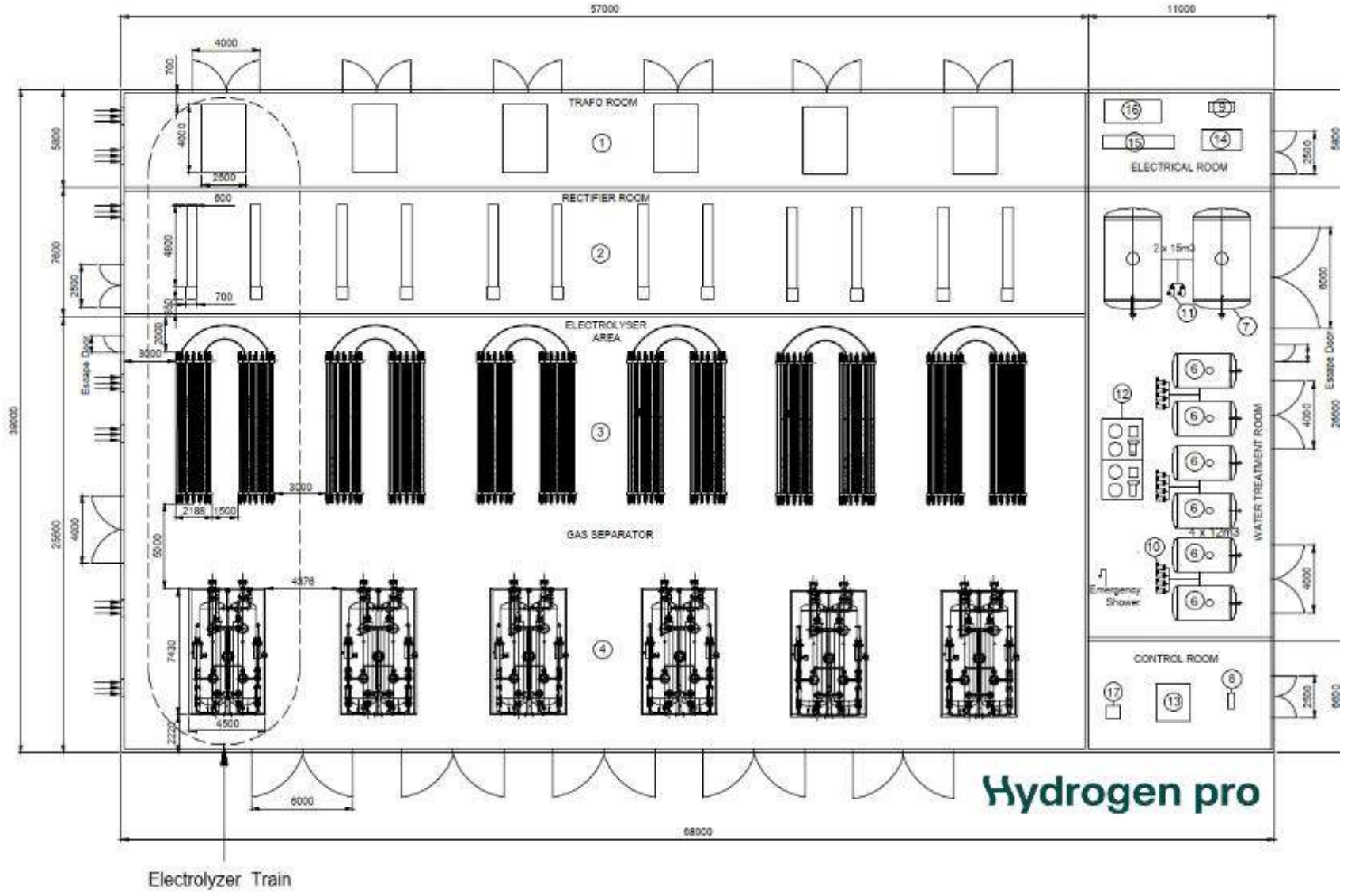
Safety, efficiency and flexibility

1 today‘s stacks
2 today‘s stacks, higher A/m²
3 today‘s stacks, higher A/m², & new electrodes

kWh/Nm³(AC)



A/m²



> 40 reduction in equipment cost and space demand by new technology

Hydrogen ready gas turbines

Mitsubishi Heavy Industries EMEA, Ltd.

Range of H_2 Combustion Technology

Mitsubishi Power has 3 types of combustors catering to individual project requirements and hydrogen densities.

Large Frame Gas Turbines

	Type	Low NOx tech	Turbine inlet temperature (˚C)	H_2 density (volume %)	Schedule
Ready	**Type 1: Diffusion** 	N_2 dilution, Water/ Steam injection	1200~1400	**100%**	1970 Cogen/IGCC → **2025 Magnum H_2 conversion**
Ready	**Type 2: Pre-Mix (DLN)** 	Dry	1600	**30%**	1982 DLN → **2018 30% co-firing test completed** (NEDO)
Under development	**Type 3: Multi-Cluster (DLN)** 	Dry	1650	**100% (target)**	**Mar, 2025 Rig test completion target** (NEDO)

PRESS RELEASE

Mitsubishi Power Commences Development of World's First Ammonia-fired 40MW Class Gas Turbine System
-- Targets to Expand Lineup of Carbon-free Power Generation Options, with Commercialization around 2025 --

2021-03-01

H-25 Series gas turbine

- Today delivered gas turbines are “hydrogen ready” for 30 vol.-% co-firing. Small GT can use up to 100%
- Development towards 100% for all GTs finished ~2025
- Ammonia combustion and ammonia splitting developed in parallel

*This presentation is based on results obtained from a project commissioned by NEDO that is a government organization in Japan.
(NEDO: New Energy and Industrial Technology Development Organization)
**DLN : Dry Low NOx

SOFC for multifuel application

Mitsubishi Heavy Industries EMEA, Ltd.

Solid oxide fuel cell, SOFC

Cell Stack Durability

Long Life time of Cell Stack

Electrical High Efficiency

55%(LHV)

***73**%(CHP)

Operation Flexibility

Capable of Partial Load Operation:

50-100%

Fuel Flexibility

Applicable Fuel

LNG
Hydrogen
Bio Gas
Mixed Gas

SOFC System Product Line Up

220kW Class (Commercialized)

For Commercial & Industry User
(Building, Hospital, Hotel…)

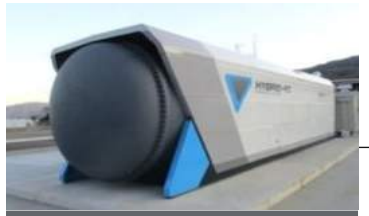
1MW Class (market launch in 2021/22)

For Utility, Large Industrial Plant &
Micro-grid

SOFC Supply Record

220kW class | with H2 Rich Fuel

1MW class

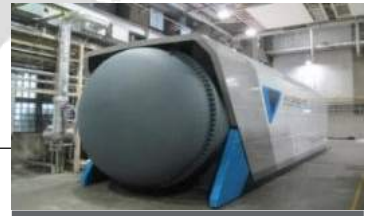


J Power

Mono-generation

TAISEI Corp.

Co-generation/ Hot water



Tokyo gas

Co-generation /Hot water

Kyushu Univ.

Mono generation
Operation time : 23,000hrs

HAZAMA ANDO Corp.

Co-generation /Hot water

1MW demonstration

Mono generation

NGK Spark Plug

Co-generation/Steam

Toyota Motor

Co-generation/Steam

MITSUBISHI ESTATE

Co-generation/Steam

Blue Hydrogen via Carbon Capture and Storage & Carbon Capture and Utilisation

Carbon Capture - Worldwide Commercial Experience

MHI holds the NO.1 market share in CO_2 recovery systems from exhaust gas.

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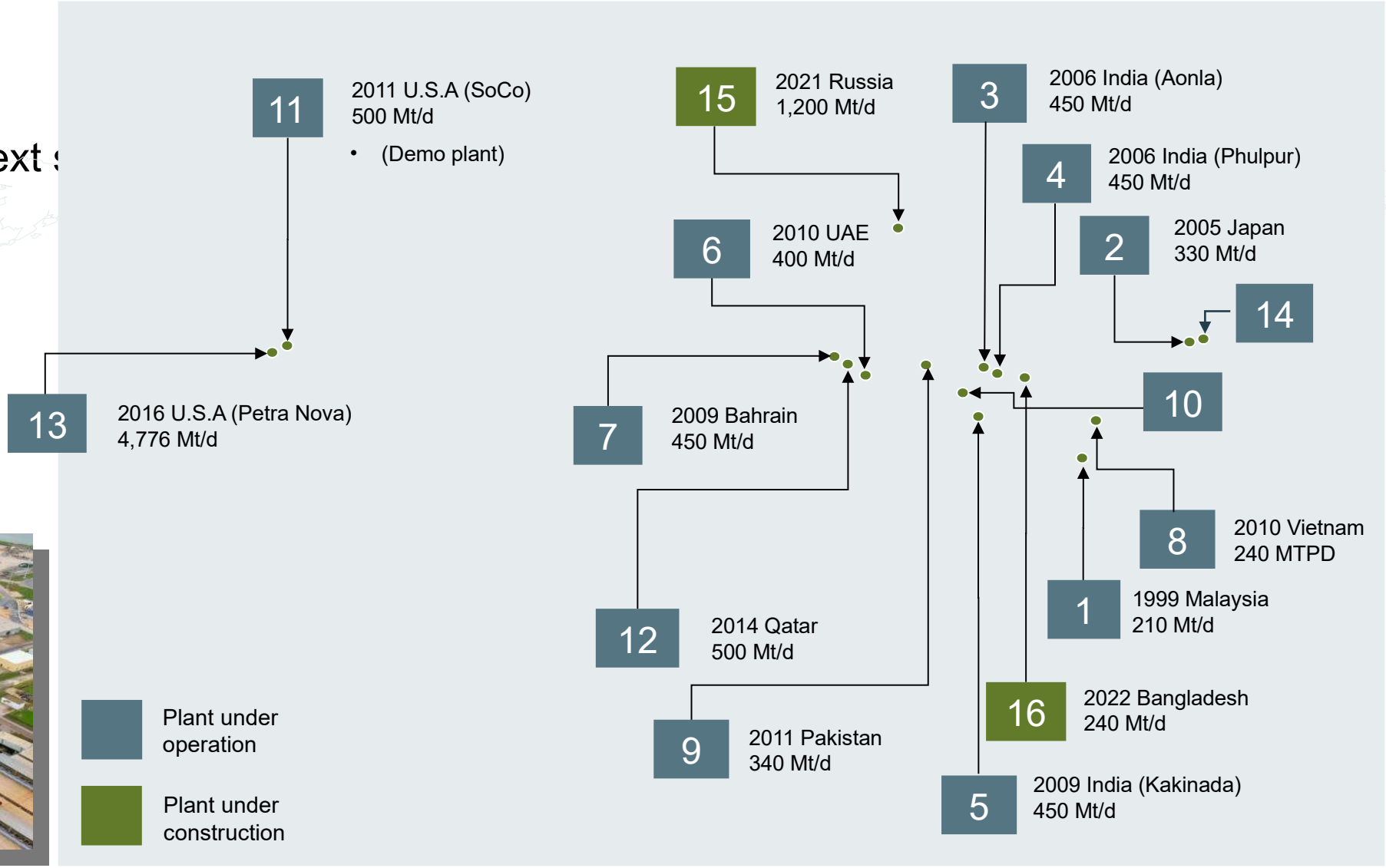
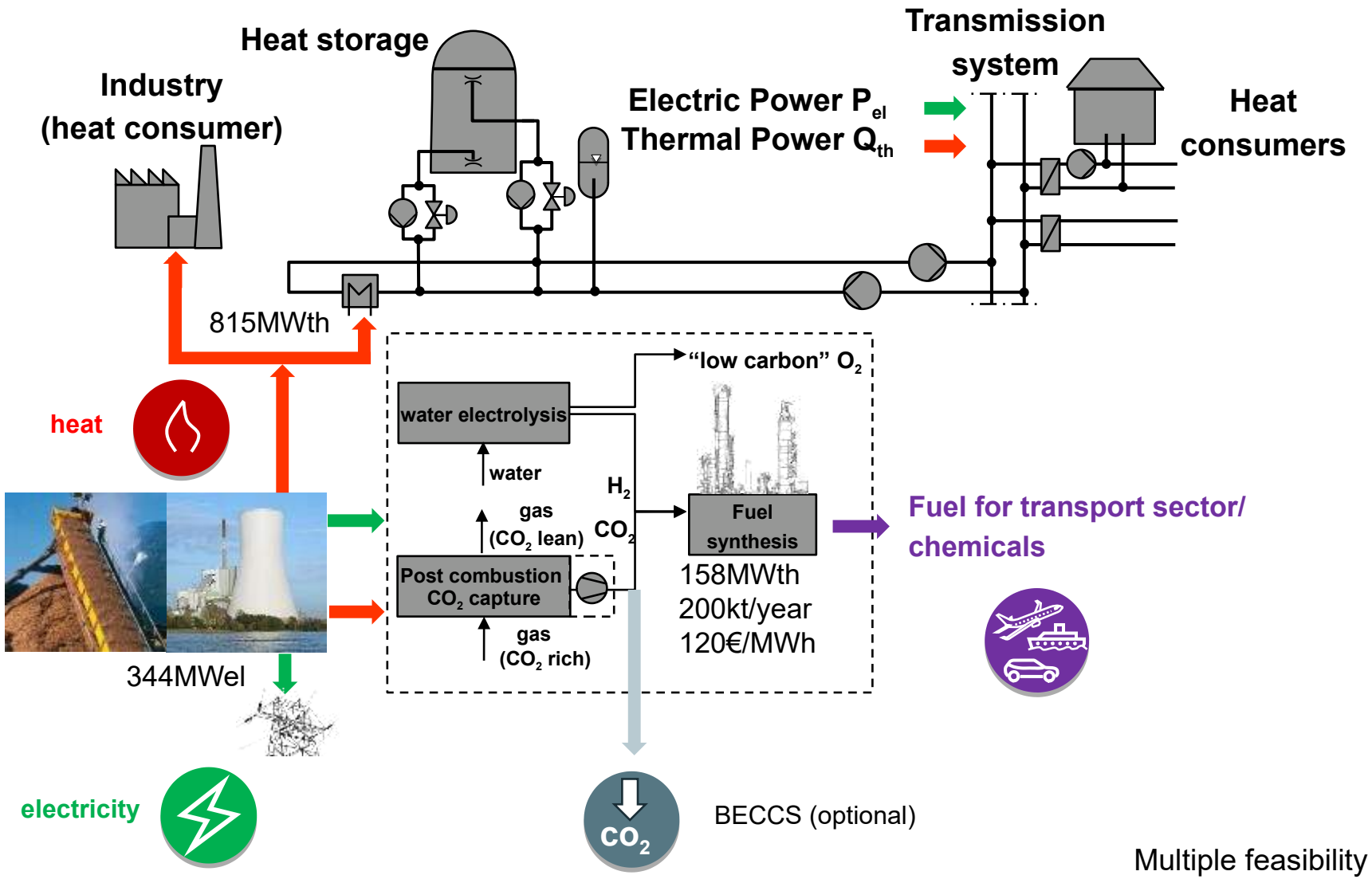
MHI's KM CDR Process™ is ready for CO_2 capture on thermal power plants, cement plants, steel manufacturing plants, factories and incineration facilities.



Biomass CHP, BECCS and CCU



The technologies are ready for deployment in commercial scale!

Products from CCU can be

- Methanol
- Methane
- SynGasoline
- SynDiesel
- SynKerosine
- etc.

Bioenergy CCS (BECSS) is under consideration in UK, Scandinavia

Multiple feasibility studies completed for demonstration projects

Integrated green hydrogen solutions

Mitsubishi Heavy Industries EMEA, Ltd.

Hydrogen for multi-sectoral approach, storage, grid services

Renewable Electricity

electricity

Grid service

Hydrogen compression & storage

Electrolyser

CHP
(GT, SOFC, gas engines)

(0-100%)

NG or NH3

Battery Container

Electric heater

environmental heat (river, geothermal, waste water)

electricity

waste heat

waste heat

Heat pump / cooling

cold

heat

flue gas heat

ENERGY Cloud (intelligent control)

CCU

H_2

Hydrogen for Mobility or Chemical use

cooling applications

Heat storage

Heat (grid)

Services & Income streams

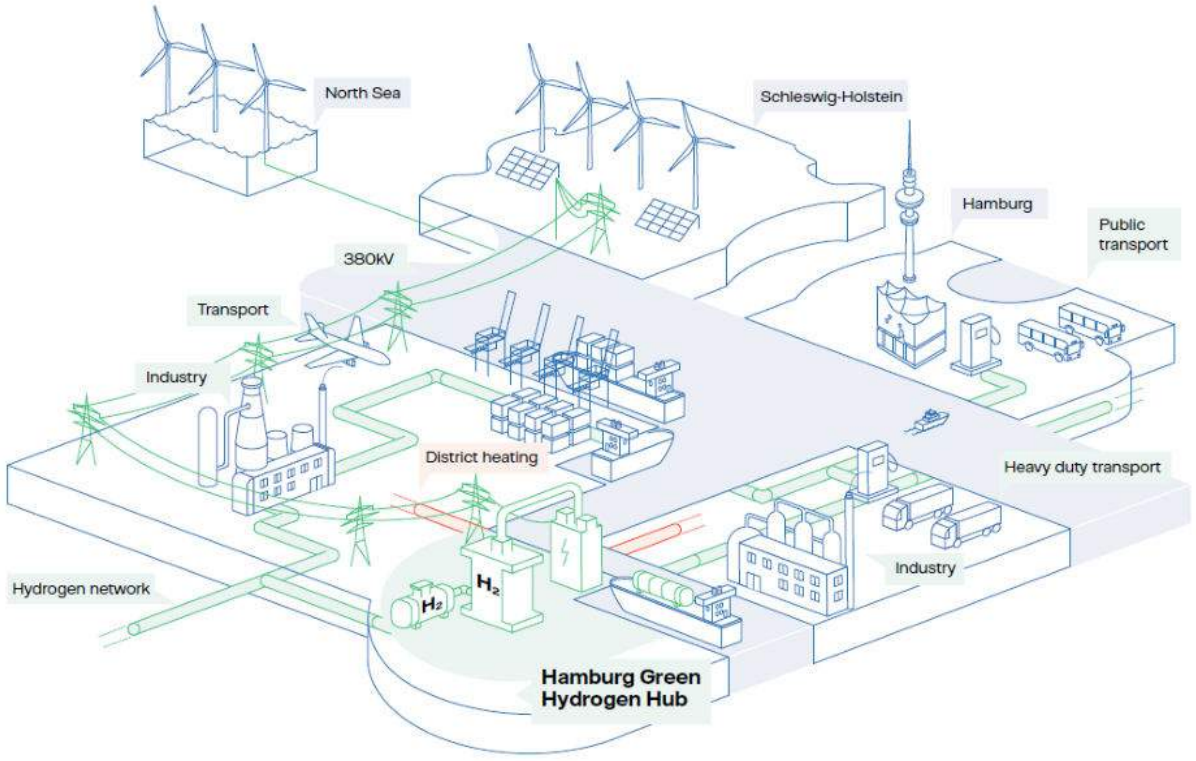
- Multiple grid services (flexible operation)
- H_2 sales
- Heat sales
- O_2 sales
- "storage"

Scalable: from 10 MW to multi 100MW

>80% total energy efficiency for electrolysis by waste heat utilisation

Hamburg Green Hydrogen Hub (Germany)

Hamburg Green Hydrogen Hub envisages transformation of former site of coal plant into green hydrogen production site with initial output of 100 MW and further development of site into a “Green Energy Hub”



Electrolyzer Capacity	100 MW
Grid connection	380 kV (TSO 50Hertz)
Location	Hamburg, Germany

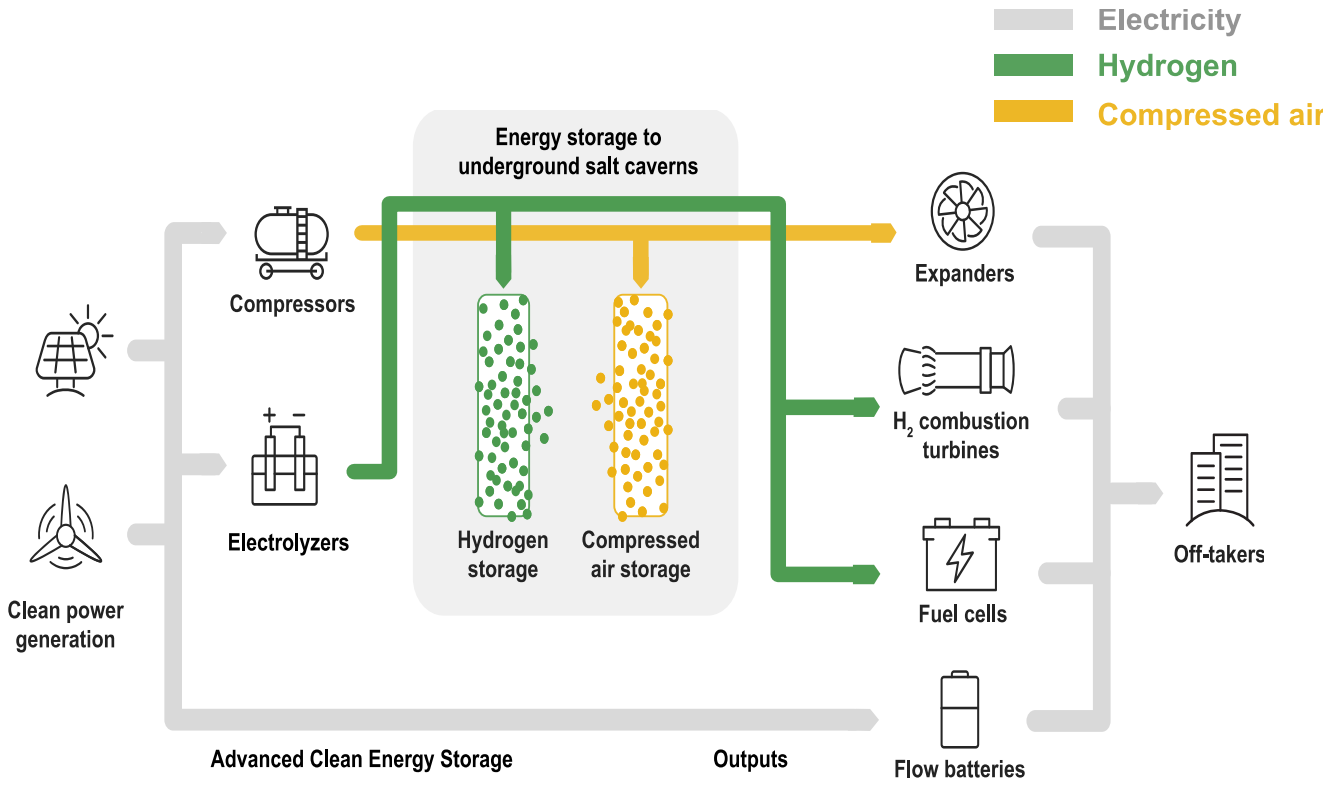
- Production of green hydrogen to be utilized mainly in industrial applications), but also heavy transport
- Direct matching of renewables assets and electrolyser (24hrs storage in 6km pipeline)
- Optimal utilization of electrolyser ‚waste‘ streams: oxygen for industry and waste heat for the Hamburg district heating grid (80˚C, with HP increased to 180˚C)
- Joint project with Vattenfall, Shell, Wärme Hamburg

Advanced Clean Energy Storage Project (USA)

The Advanced Clean Energy Storage Project is the world's largest renewable energy storage project

Click to edit Master text styles

Storage Capacity	1,200 MWh
Location	Utah, USA



- Project launched in May 2019 by Mitsubishi Power, Magnum Development and the Governor of Utah
- Different storage technologies in use: renewable hydrogen, compressed air, large scale flow batteries and solid oxide fuel cells.
  - Plan to store hydrogen and/or compressed air in underground salt caverns in Utah
- Replicability potential in Europe

Intermountain Power Plant (USA)

Intermountain Power Agency orders Mitsubishi Power's Hydrogen JAC Gas Turbines for Renewable Hydrogen Hub, a utility-scale project aiming to show a path towards 100% renewable power no later than 2045.

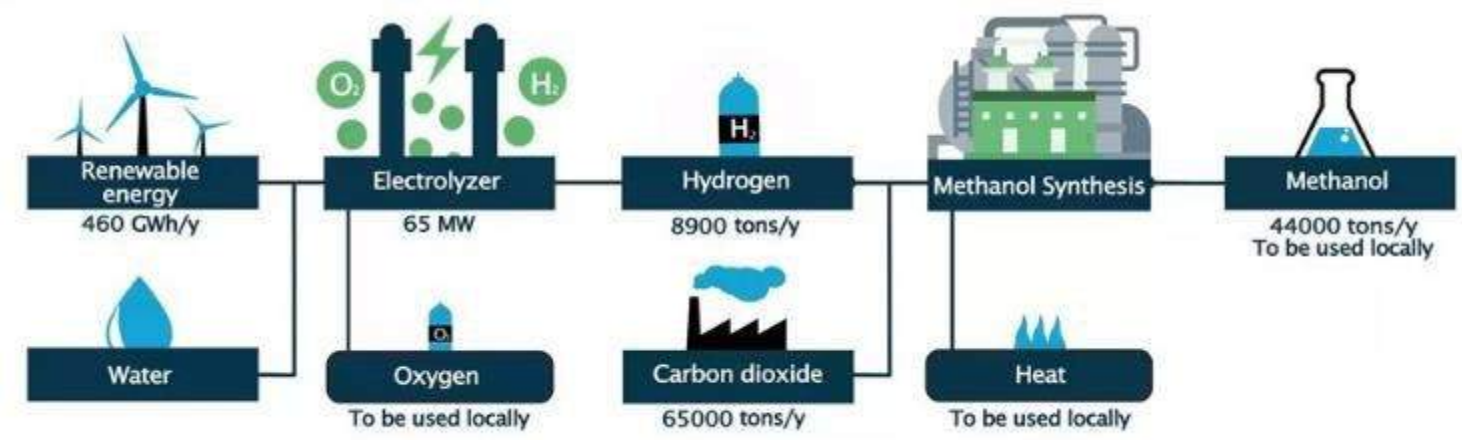
Click to edit Master text styles

Gas Turbine Model	M501JAC
Power Output	840 MW (by 2 CCGT)
Location	Utah, USA

- **Mitsubishi Power's Hydrogen Gas Turbines** is central to Utah's comprehensive decarbonisation plan: 1) fuel switch from coal to natural gas and 2) from natural gas to renewable hydrogen.
- Transition will start in 2025 using a mix of 30% hydrogen and 70% natural gas. This mixture will reduce carbon emissions by more than 75% compared to the retiring coal-fired technology.
- Between 2025 and 2045, the hydrogen capability will be systematically increased to 100% renewable hydrogen, enabling carbon-free utility-scale power generation.
- Power plant is connected to the Los Angeles power grid by an existing high voltage direct-current (HVDC) transmission line.

Nort-C-Methanol, Gent, Belgium

https://northccuhub.eu/north-c-methanol/



- Harbor of Gent/Belgium
- 65MW(el) Synthetic methanol from CO_2 and green hydrogen
- Oxygen use for steel mill
- Waste heat to industrial user

Carbon-free Ammonia Production (Australia)

Making use of abundant renewable energy in the area, MHI will produce hydrogen and ammonia. In addition to contributing to the region's industries such as nearby steel mills, we will try to export carbon-free ammonia

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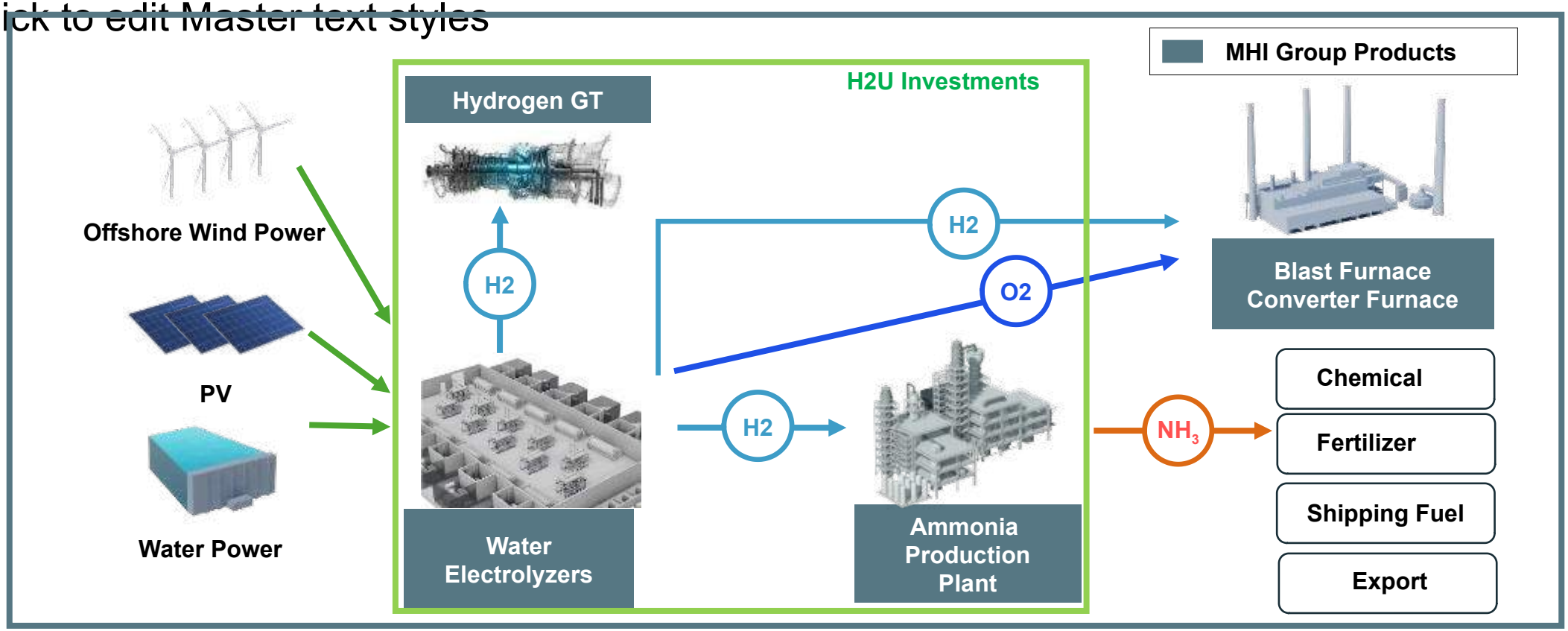
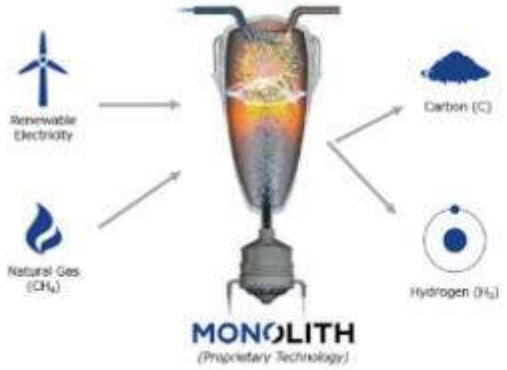


- 75 MW electrolysis plant, 120-tonne per day ammonia production
- 40,000 tonnes of green ammonia per year.

Turquoise hydrogen, low carbon transport fuels

Mitsubishi Heavy Industries Invests in Monolith Materials
-- Leader in Innovative Technology for Reducing Environmental Impact --

2020-11-30



Monolith Process

Olive Creek1(OC1), commercial-scale facility in Nebraska, United States

- turquoise hydrogen and carbon black from natural gas
- plasma-based methane pyrolysis technology, which uses renewable energy as its heat source.

MHI Invests in Infinium, an Electrofuels Solution Provider, to Accelerate Efforts to Decarbonize the Transportation Sector
-- Additional investors include Amazon's Climate Pledge Fund, AP Ventures, Neuman & Esser Investments, and the Grantham Foundation --

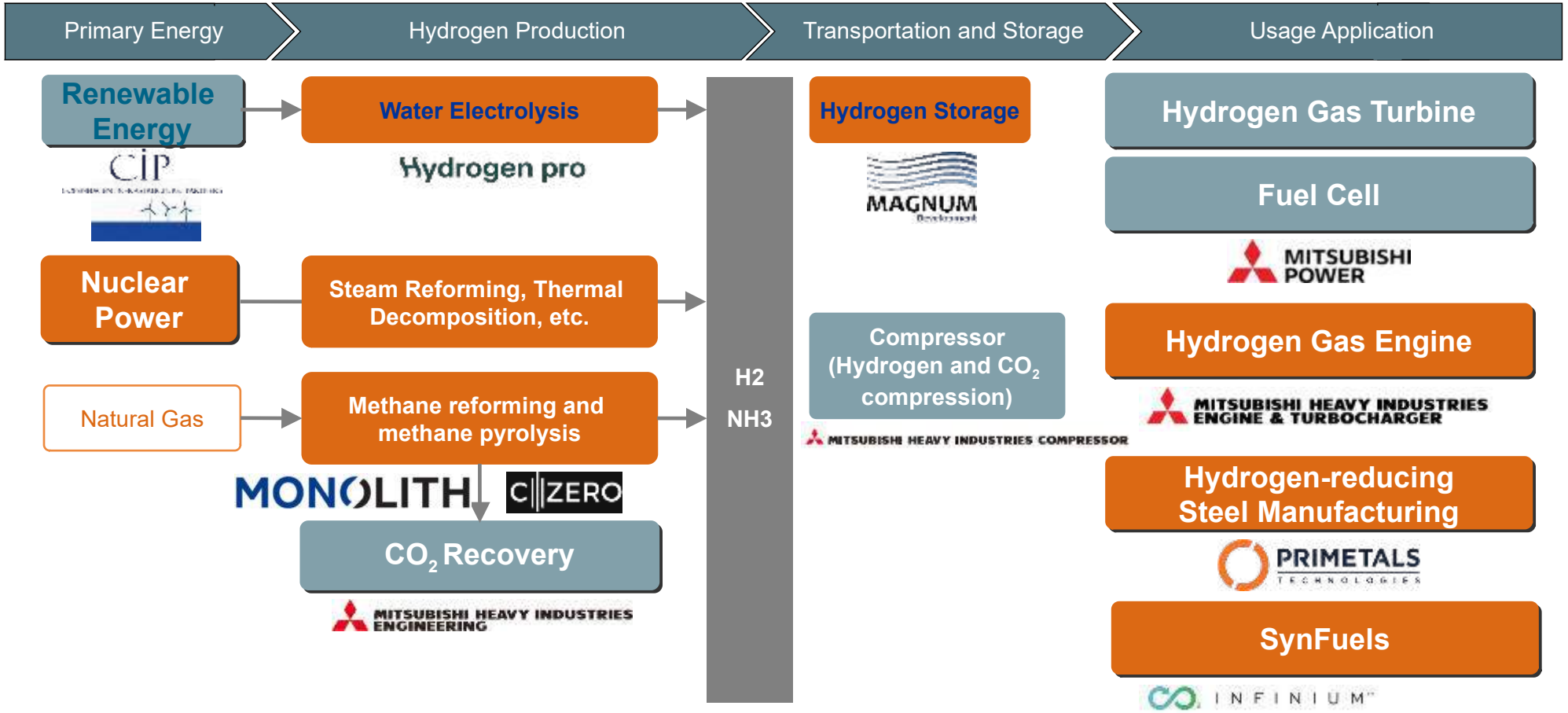
2021-01-27

CO_2 INFINIUM™

- Converting carbon dioxide and renewable power into net-zero carbon fuels
- ElectrofuelsTM can be used in today's air, maritime, and surface transportation fleets

MHI Group Hydrogen Portfolio　Capabilities across the Hydrogen Value Chain

- Contributing to the establishment of infrastructure and cost reduction through the provision of technologies, products, and services
- Creating a value chain from hydrogen production to utilization by our unique technologies and active cooperation with partners
- Transition towards utilization of ammonia



White Text: MHI technology　**Blue Text: Partnering**
CIP: Development of Offshore Wind Turbines in Hokkaido
Hydrogen Pro: Investing in Hydrogen Production Plant Supply
Magnum : Green Hydrogen Production, Storage and Supply Business Development in Utah, USA


MITSUBISHI
HEAVY INDUSTRIES

MOVE THE WORLD FORWARD

MITSUBISHI
HEAVY
INDUSTRIES
GROUP

Fuel Cell for Stationary Power Applications

Alan Kneisz

March 2021

Cummins, World Leader in Engines

190

Countries & territories*

57,825

Global employees

1.3M

Engines built in 2020**

9,000

Cummins certified dealer locations

$903M

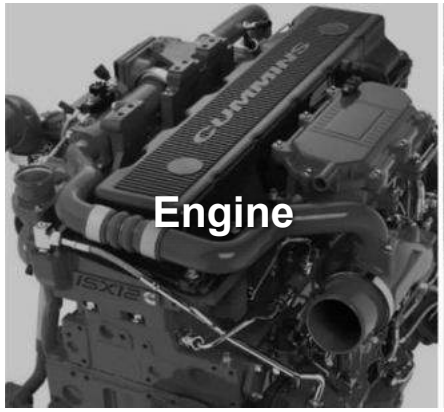
Invested in research & technology in 2020

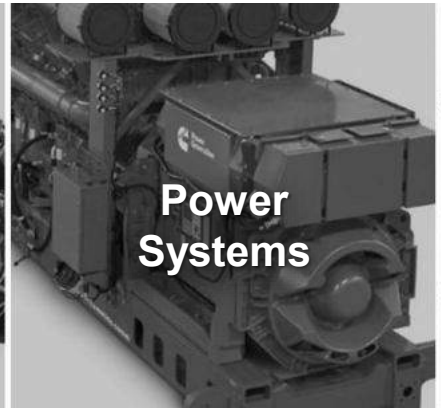
102

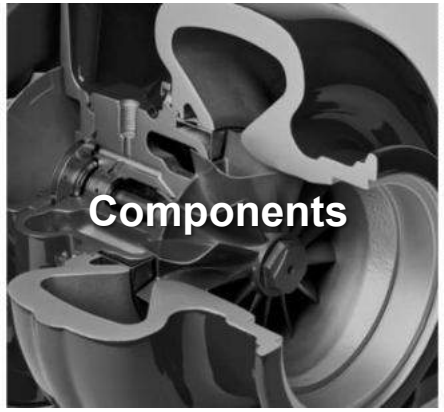
Years of industry leadership

**Approximation of countries and territories with Cummins service*
***This includes engines from both our custodial plants and unconsolidated joint ventures. As published in the 2020 10K found on cummins.com*

New Power business segment







Electrified Power

Fuel Cell & Hydrogen Technologies

Increased visibility

Stronger coordination

Positioned for growth

NEW POWER

Core Technologies

ELECTRIFIED POWER

Creating technologies and products for commercial battery electric vehicles

- On-highway: transit bus, school bus, medium-duty truck, walk-in van
- Off-highway: construction equipment, terminal tractor, material handling

FUEL CELLS

Creating and integrating components for hydrogen fuel cell electric vehicles and rail

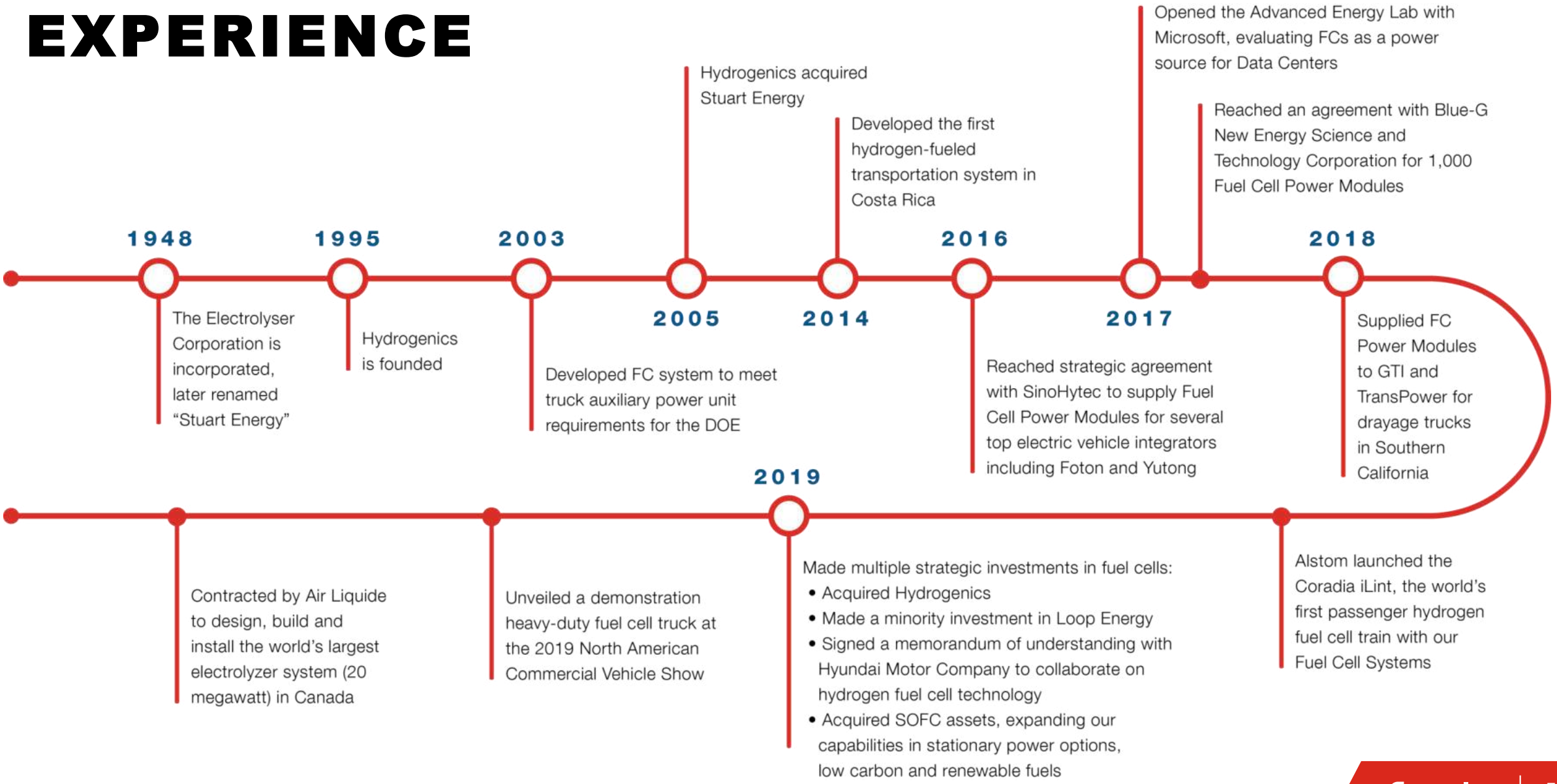
- Electric vehicles: urban transit bus, commercial fleet, utility vehicle, electric lift truck
- Installation: freestanding electrical power plant

HYDROGEN GENERATION

Creating solutions for industrial and commercial hydrogen generation and MW-scale energy storage

- Industrial processes and fueling stations: PEM generator, alkaline hydrogen generator
- Critical and uninterruptible power supply, power-to-gas technology

70 YEARS OF HYDROGEN EXPERIENCE



NEW POWER

Footprint

The Full Hydrogen Ecosystem

Hydrogen Production → **Hydrogen Storage** → **Fuel Cell Module** → **Fuel Cell Composition**

- On-site & on-demand generation
- PEM & alkaline technologies
- <100kg - >10T per day capability

Cummins NPROXX

- Recent JV confirmed with world leader in Hydrogen storage

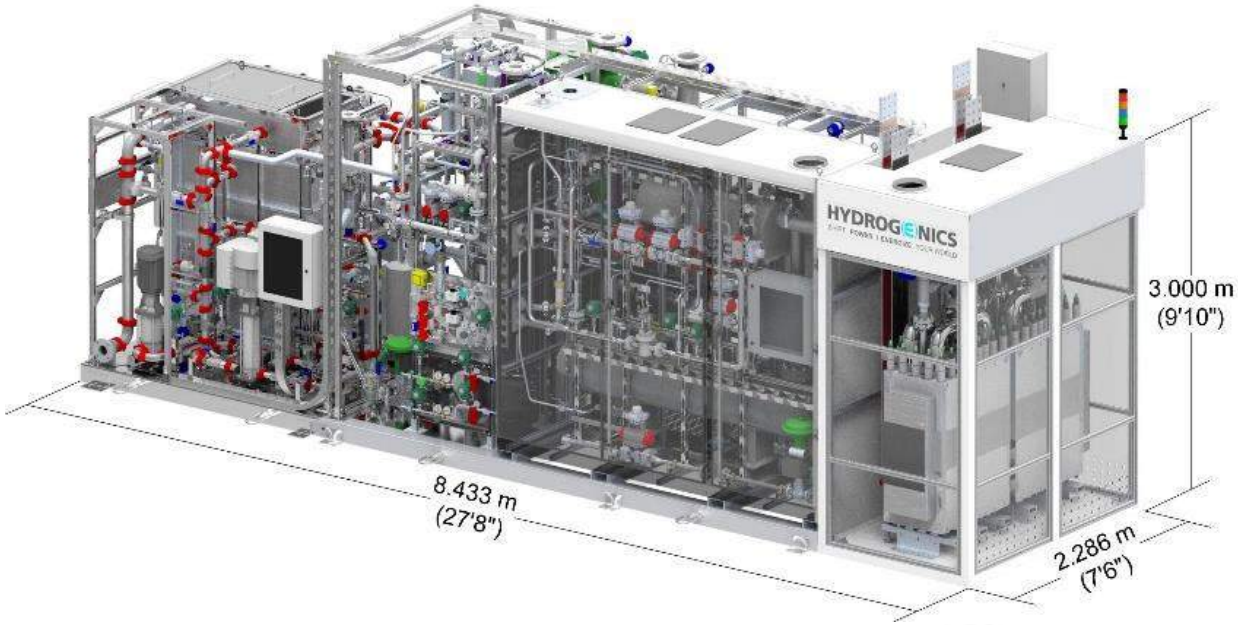
- Low cost, high reliability fuel cell modules
- Integrated BOP
- PEM and SOFC

- Multi-module systems for widest range (kW-MW)
- IP-rated enclosure

Cummins, Global leader on Electrolysis

Cummins

- Deployed over 1500 systems over 70 years
- Cummins acquired Hydrogenics in 2019
- Diverse hydrogen technology portfolio:
  - Alkaline Electrolysis, PEM Electrolysis, including major Power to X and supporting 70 fueling stations



Why Cummins ?

World Class

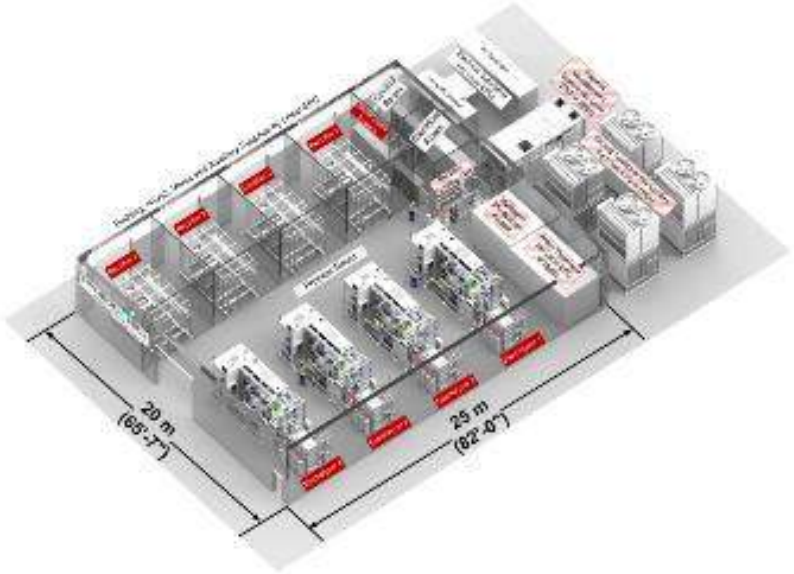
Global presence
+190 countries
+60,000 employees
Own distributors
100 years of experience

Technology leadership

Leader on electrolysis technology with MW PEM HyLYZER®-1000 Proprietary technology

First 20 MW project in commissioning

First reference project with PEM HyLYZER®-1000 for Air Liquide in Canada, which will serve as a blueprint for future projects



Leading the EVolution in PEM Fuel Cells

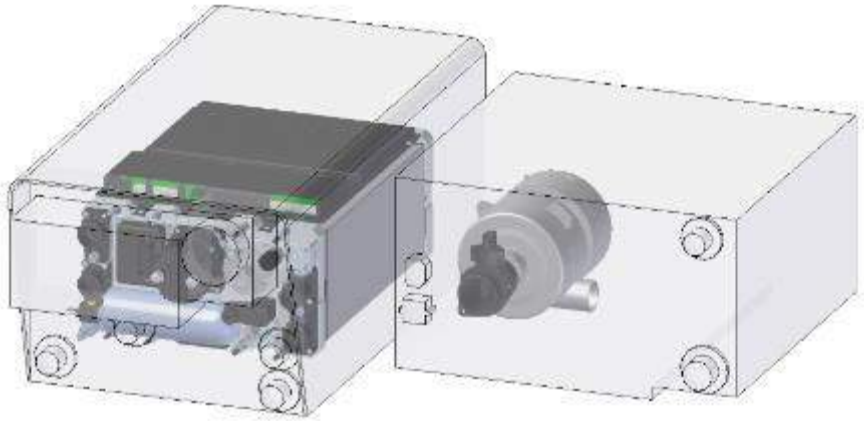
HD Platform leads the market

- Experience: Over 2500 systems working and deployed globally in Mobility and stationary applications
- Leading in Transport Applications:
  - Worlds largest fuel cell bus fleet in China confirmed
  - Worlds largest Fuel cell Project, Trains in Europe
  - New Heavy Duty Trucks platforms with Scania and UPS
- Worlds only MW fuel cell Stationary Power running 24/7

Trusted by the worlds leading companies:

World's Most Advanced Fuel Cell Modules

Fuel cells use hydrogen to create electricity for mobility and critical power applications with most advanced technology on the market



1. **Highest Power Density Module Density, weight and size the lowest in the industry**

2. **Differentiated Technology**
   Non-humidified, low-pressure stack allows for greatest reliability and stack life

3. **High Reliability**
   Unlimited start/stop, sub-zero operation, long life Balance of plant for lowest OPEX

4. **Flexible Architecture**
   Scalable stack for mobility and stationary applications, allows for greatest range of products

Large Scale Power

The only company PEM fuel cell company with the experience, know how and understanding of the long duration large scale Power applications.

- PEM Fuel cells are the most deployed fuel cell technology globally
- Our PEM Fuel cells are reliable and use our HD30 platform which has been deployed in over 1,000,000 hours of real operational conditions
- Have run our MW fuel cell for thousands of hours, running 24/7 applications
- 100kw blocks allow for flexibility and greater reliability
- We often work with local integrators for local content and support in many countries

The ultimate solution for reliable clean fuel cell power applications

Critical Power Solutions

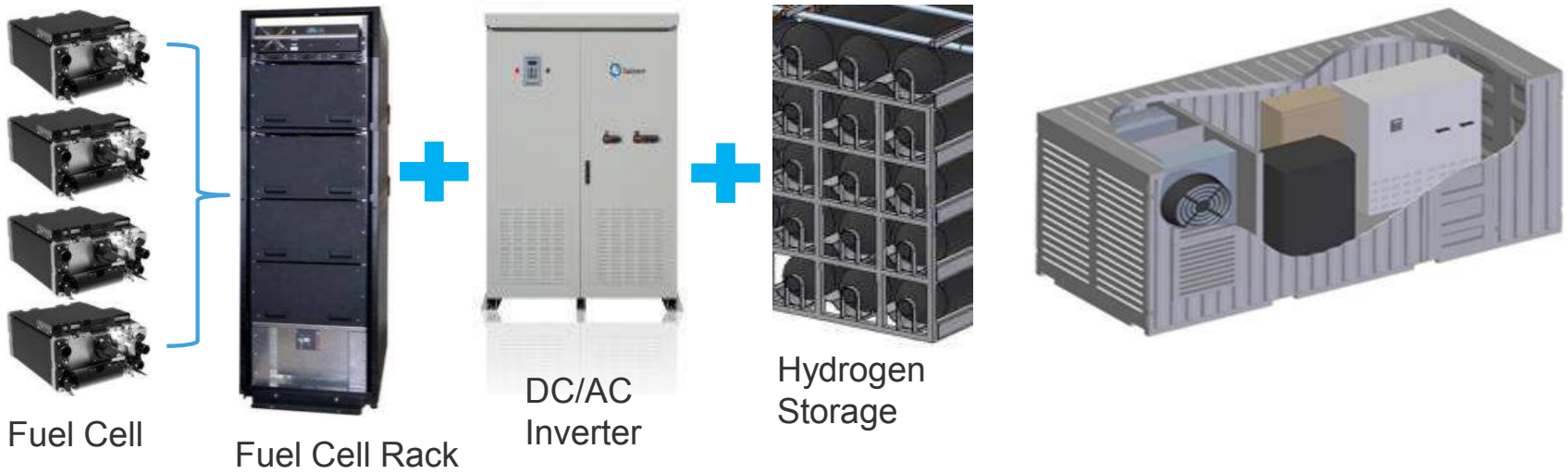
- **HyPM™ power modules set the technology benchmark for meeting intermittent and continuous power needs.**

- **Designed for superior performance**
- Fully integrated stack with balance-of-plant and flexible options
- Industry-leading compact footprint with scalable design solutions to meet runtime needs
- 15,000+ hour stack lifetime with unlimited stop and start cycles
- **Greatest range of systems available: 3kW – 50 MW**

The ultimate solution for reliable backup, standby and continuous power applications

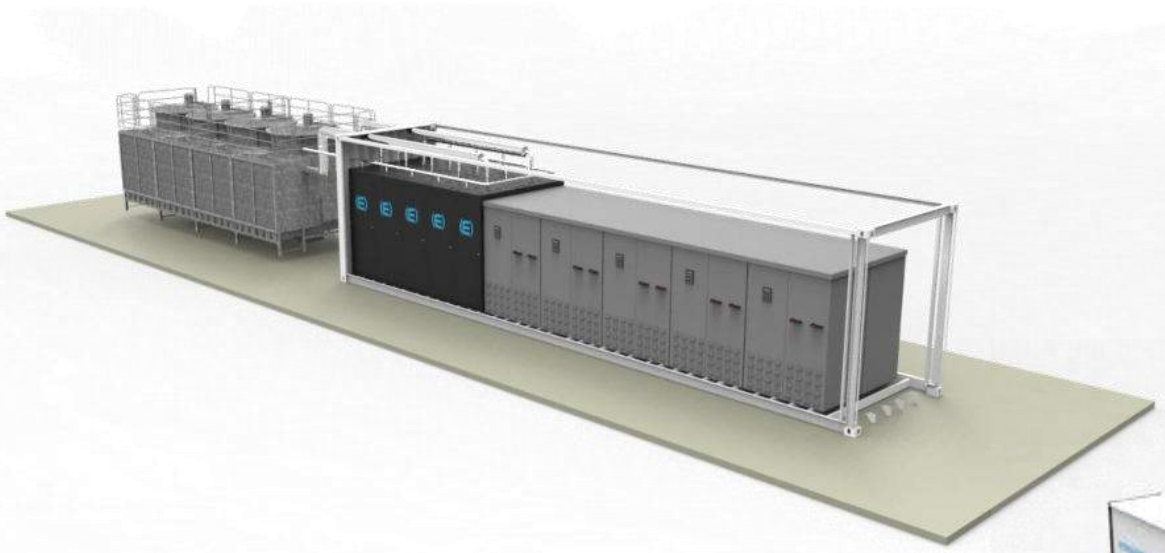
Rack Based Fuel Cell Systems

- Standard ISO container design offers versatility for system enclosure and transportation
- Features :
  - Ambient (-40 to 50 ºC)
  - Scalable from kW to MW
  - Integrated H2 storage (optional)
  - Harsh environment operation
  - Built in redundancy
  - Thermal control system
  - Environmental conditioning
  - Improved reliability



MW Fuel Cell Plant

Using the building block of our next generation Fuel Cell Power Modules, greater density and performance is achieved on a utility scale.

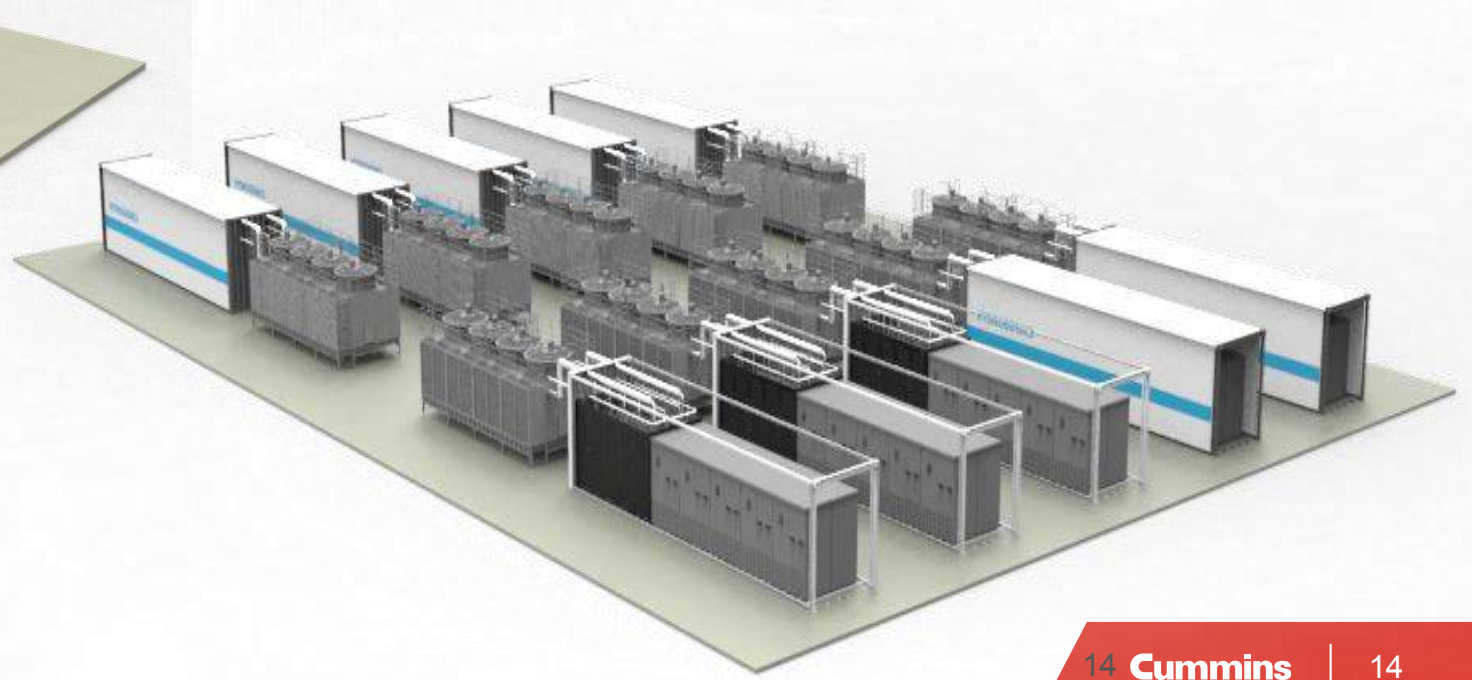


Benefits

- Scalable plant Layout
- Built in redundancy
- Thermal control system
- High durability

Features

- 380-400Vac 3 phase,
- High Efficiency Fuel Cells
- Low noise
- Controls from low to full power



FROM POWER MODULES TO TURNKEY SYSTEMS

PEM SINGLE CELL

FUEL CELL POWER MODULE

FUEL CELL SYSTEM

Cells

- MEA - Membrane Electrolyte Assembly
- Bipolar plates
- Gas diffusion layer
- Gaskets

Cell stack

- Multiple cells layered
- End plates
- Tie rods
- Spring washers
- Bus bar interfaces
- Fuel cell voltage monitor

Balance-of-plant

- Fuel management
- Air management
- Water management
- Coolant pump and control
- Control hardware and software
- Power conditioning
- Hybrid energy storage
- Hybrid control hardware and software
- Cooling or heat exchanger (or CHP)
- H2 storage

HYPM™ HD CORE STANDARD PRODUCT LINEUP

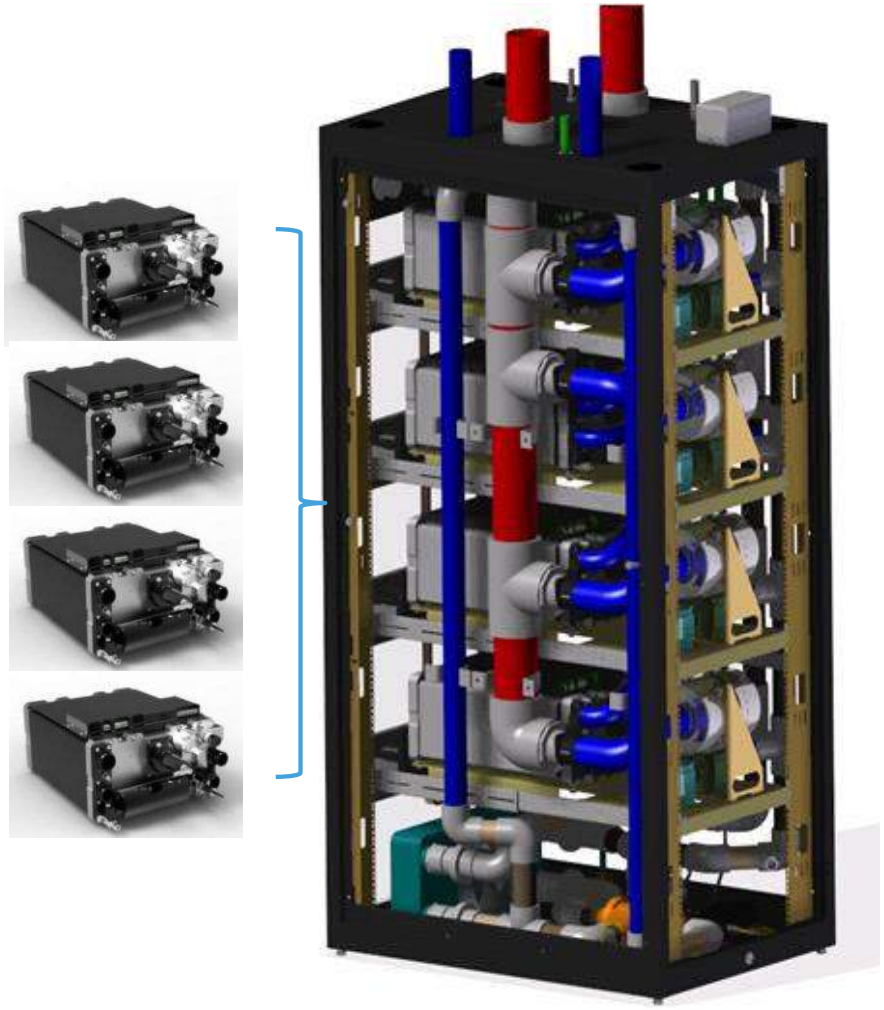
Technical Data	HD 8	HD 10	HD 15	HD 30	HD 45	HD 90	
Continuous power (kW)	8.5	10.5	16.5	31	45	93	HIGH POWER CONFIGURATIONS
Dimensions (LxWxH) (mm)	379 x 406 x 261[b]	408 x 406 x 261[b]	494 x 406 x 261[b]	719 x 406 x 261[b]	848 x 406 x 255	1582 x 1085 x 346[b]	
Volume (L)	41[b]	44[b]	52[b]	76[b]	88[b]	594[b]	
Mass[a] (kg)	52	47	55	72	95	360	Multiple **HD30, HD50** or **Celerity** units can be **combined for higher output capacities.**
Operating current (A_{dc})	0…380	0…425	0…425	0 to 500	0 to 450	0 to 500	
Operating voltage (V_{dc})	20…40	24…48	32…64	60…120	88… 180	180…360	
Peak efficiency[a] ($\%_{LHV}$)	51	53	53	59[c]	59[c]	53	
Expected lifetime (h)	10,000+	10,000+	10,000+	10,000+	10,000+	10,000+	

Available in lightweight, higher voltage And aerospace configurations

a) Coolant pump excluded
b) Coolant pump and air delivery excluded
c) Not including externally powered blower

Fuel Cell Advantages:

- 99.95% reliability means high uptime.
- 90 sec to takeover complete load.
- Low Maintenance cost
- Fueling solution with Electrolyser and cylinders under Cummins scope.
- Requires less space and chances of less theft
- Modular design – Expand as per future requirements
- Remote monitoring capability
- Zero Emissions
- No Degradation over time
- Ability to recycle



REFERENCES

DAESAN, South Korea

Mulit-MW continuous clean power for the grid

BACKGROUND

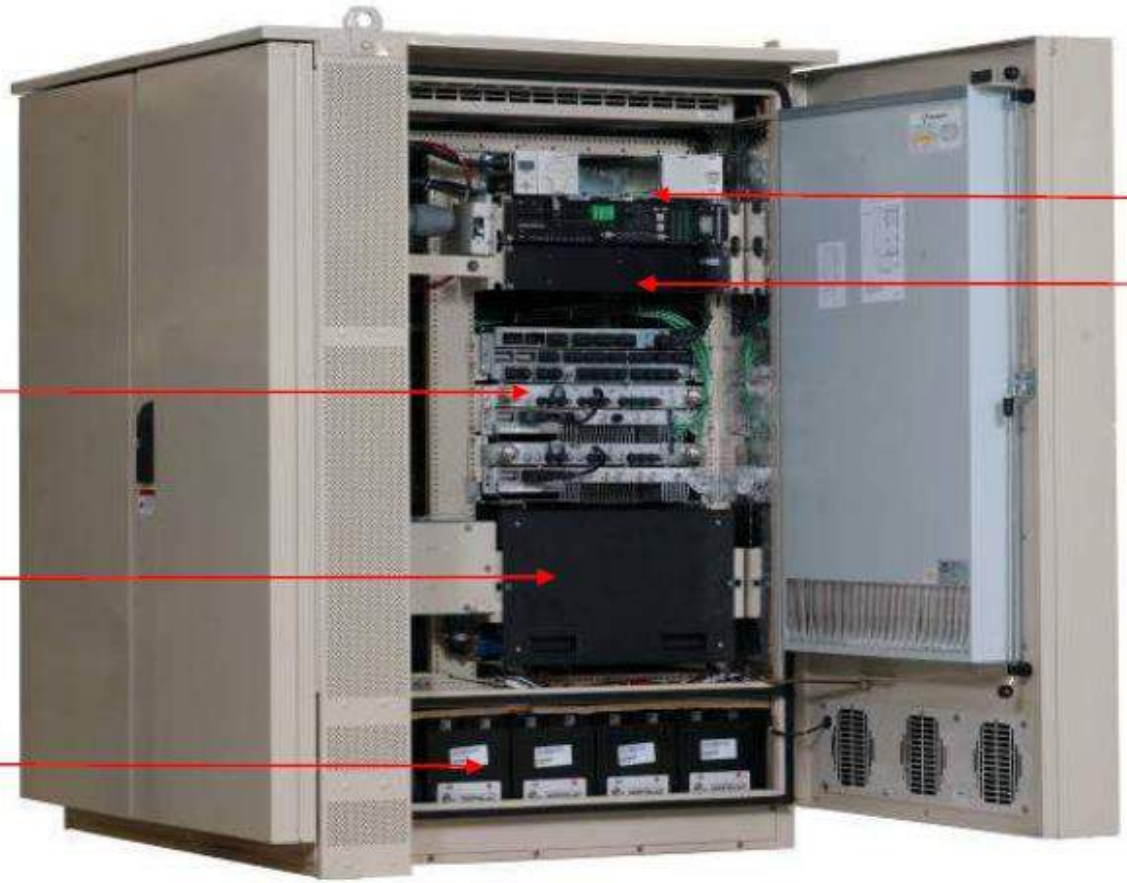
- Process Plant with by-product hydrogen
- Korean government provides incentives (feed-in) for power produced from hydrogen

SOLUTION

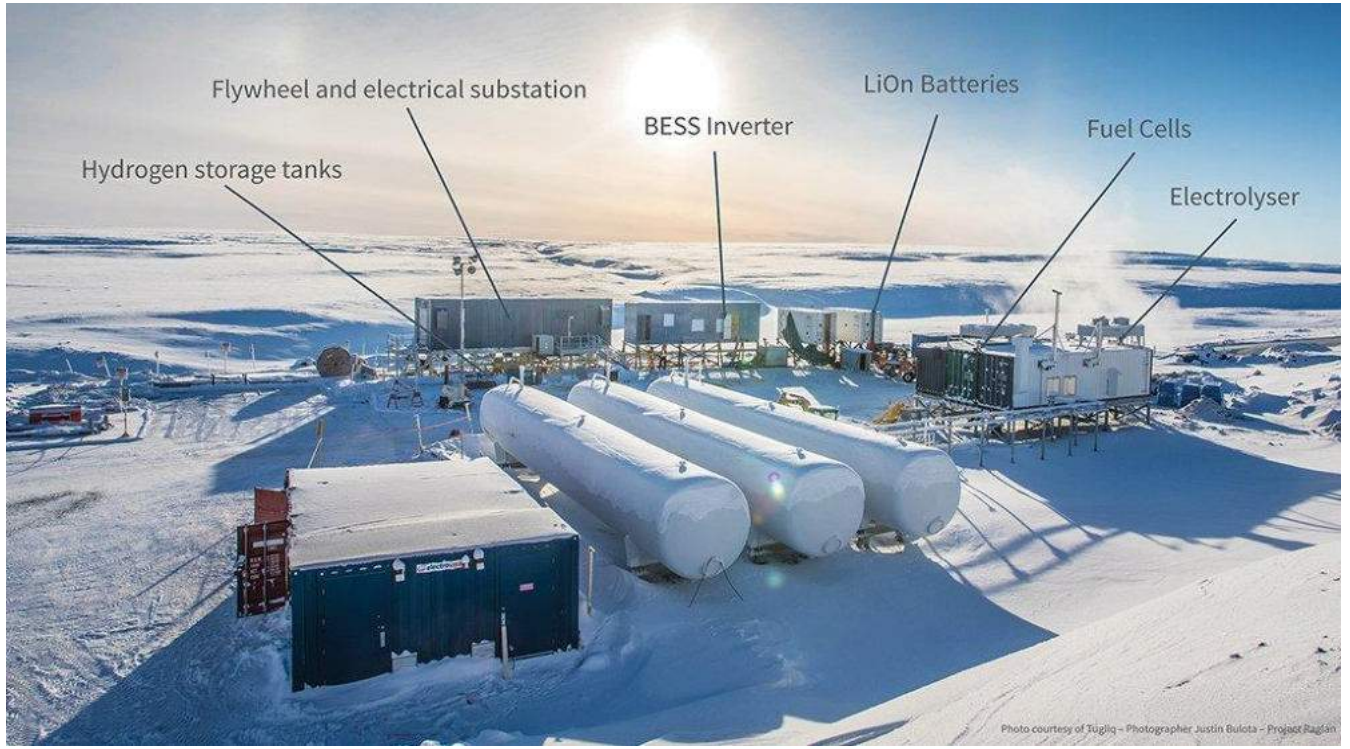
- >1 MW HyPM-R based on HyPM-R120 fuel cell racks
- Grid feed inverters, outdoor containers
- Joint venture power purchase agreement (PPA)
- Commissioned October 2015
- 2x40ft containers

1 MW Stationary Fuel Cell Plant

Sample 8 KW Fuel Cell with Cabinet 300 sites T Mobile



Cabinet dimensions: W 45” (1143mm) x D 52” (1321mm) x H 63” (1600mm)



Raglan Mine, Nunavik (Northern Quebec, Canada)

PROJECT DESCRIPTION

- Nickel and Copper Mine
- Extreme tip of Northern Quebec, 400 km North of the tree line
- Average annual temp -10 degrees C (Permafrost 550 m deep)

SOLUTION
- 3.0 MW Arctic Wind Turbine
- 1.8 MW diesel generator
- 350 kW Electrolyser
- 200 kW Fuel Cell Syst

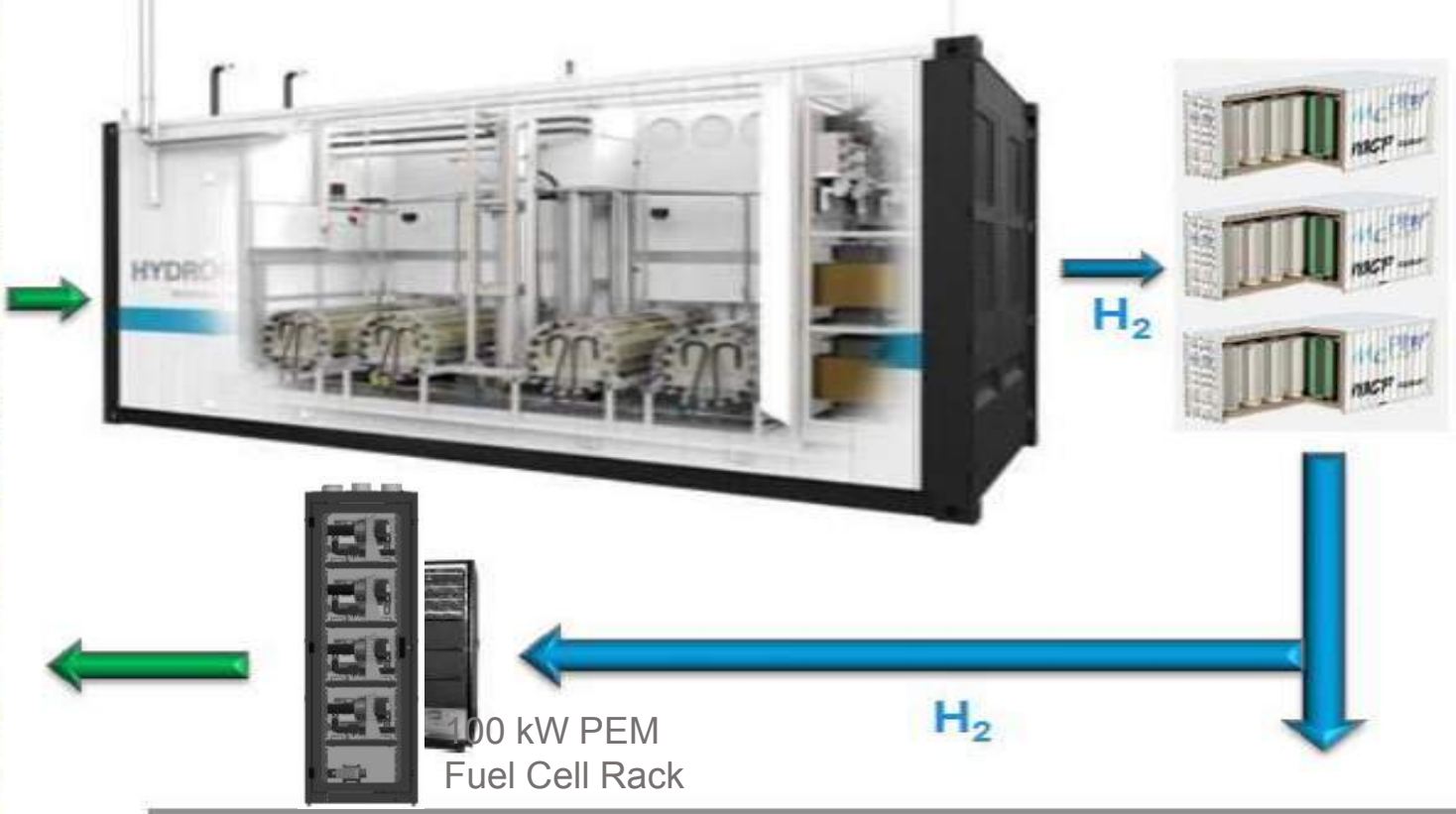
GLENCORE

Tugliq Énergie Co.
Énergie novatrice de proximité

Québec

Canada

HATCH



Puglia, Italy

INGRID (24Mio€ FCH JU project, 7 partners)

OBJECTIVES

- Allow increased penetration of highly fluctuating RE into the grid using electrolysis and supply-demand balancing.
- Improvement of distribution operation through active/reactive power control for optimal voltage regulation and power quality.
- Use H_2 for transport, industry, grid balancing and injection into the gas network.

SOLUTION:

- 1MW HySTAT® electrolyser 40Ft. outdoor solution with all peripherals to produce 200Nm³/h H_2.
- 60kW Fuel Cell backup system.
- 39 MWh, 1'000kg solid hydrogen storage system.

HYDROGENICS
SHIFT POWER | ENERGIZE YOUR WORLD

Enel

Project Don Quichote, Colruyt, Halle (Brussels, Belgium)

65 kg/day, 350 bar dispensing

- Located at one of the warehouse of Colruyt, one of the biggest Belgian retail company
- Hydrogen is used to fill fork lift trucks, additionally it can refuel other vehicles
- The station has a 30 Nm³/h alkaline electrolyser, 50 kg storage and -20° chiller the customer's SAEJ 2601 refueling sequence.
- Funded by InterReg project (Waterstofregio Vlaanderen Zuid-Nederland)

- DON QUICHOTE - Extension - FCH JU (2015) - www.don-quichote.eu
- + 30 Nm³/h PEM electrolyser
- Electrochemical compressor HYET
- + 100 kW Fuel Cell
- Smart grid operation

20 foot ISO Sea Container

HyPM-R120 FC Rack

Sandia National Labs Maritime Hydrogen Fuel Cell Project

Port of Honolulu, Hawaii

- U.S. DOE's FC Office and the U.S. DOT's Maritime Administration funded six-month deployment
- FC Unit replaces diesel generators providing auxiliary power on board to ships at berth
- Four 30-kW fuel cells (Total 100 kWnet), power-conversion equipment and 75 kg of on-board hydrogen storage
- Enough energy to power 10 refrigerated containers for 20 continuous hours of operation

http://www.hydrogenics.com/about-the-company/news-updates/2015/09/01/nothing-but-water-hydrogen-fuel-cell-unit-to-provide-renewable-power-to-honolulu-port

EGAT Lam Takhong
Wind Hydrogen Hybrid Project Thailand (2017)

Curtailed energy from 24 MW wind farm is used to generate hydrogen that is then used to power the facility using **300 kW fuel cells**

HyLyzer®

EGAT
Power for Thai Happiness

Q+A


Cummins

PEM-Brennstoffzellen zur dezentralen Energieversorgung

2. Workshop: Erzeugung von grünem Wasserstoff

Wasserstoff - Rückverstromungstechniken (27.05.2021)

Dr. Philippe Gorse – Director Fuel Cell Solutions at Rolls-Royce Power Systems

A Rolls-Royce solution


Generation of
Zero-Emission
Electricity
happens now!

Drivers in PowerGen Energy Transition in “Coal Regions”

Environmental protection

Cabinet agrees on climate protection law

Status: 12.05.2021 12:10 Uhr

The Federal Cabinet has agreed on a stricter climate protection law: With it, Germany sets itself the goal of becoming climate-neutral by 2045. Consumers are to be relieved in terms of CO2 prices. The Federal Cabinet has launched the new climate protection law. It aims to make Germany climate-neutral by 2045. The law provides for two stages on the way to climate neutrality: By 2030, CO2 emissions are to be reduced by 65 percent compared to 1990. By 2040, they are to have already been reduced by 88 percent compared to the year of comparison. The law still has to be discussed in the Bundestag and Bundesrat.

Source: www.tagesschau.de

A Rolls-Royce solution

Utilisation of on-site renewable energies through sector coupling with Power-to-X (PtX)

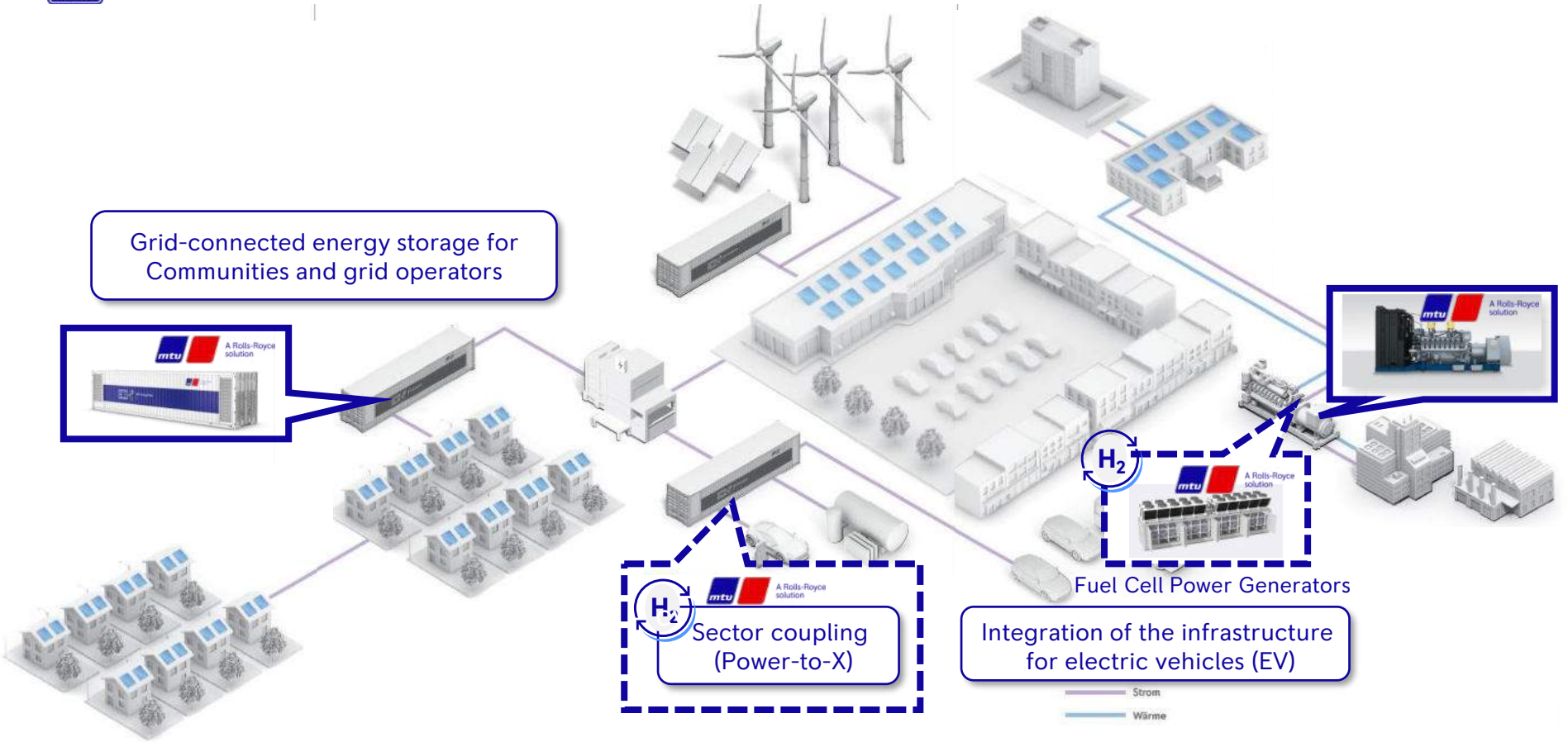
- **Strongly affected by the transformation** process of the energy transition
- **Pioneer in the expansion of renewable energies** (>80 % of gross electricity consumption).
- **Hydrogen and sector coupling** as part of the energy strategy.
- Pioneer in **biodiesel** production[2]

➔ **Continuation** of the initiated **transformation process** to become a **green energy** and fuel producer through the development of power-to-X plants for the use/refinement of renewable energies in a **decentralised manner on site.**

Sources:
MWAE, Energiestrategie 2030
[1] BNetzA 2020, Monitoringbericht 2019
[2] Diekmann et al. 2019, Vergleich der Bundesländer: Analyse der Erfolgsfaktoren für den Ausbau der Erneuerbaren Energien 2019

Microgrids a Key Element of the Energy Transition

Decentralised Power Generation Systems from Rolls-Royce Power Systems



Choice of Fuel Cells
LT-PEM Technology is ready!

Many fuel cell technologies

Different Operating Principles

Different Materials

Different Fuels

Different Geometries

Different Maturity

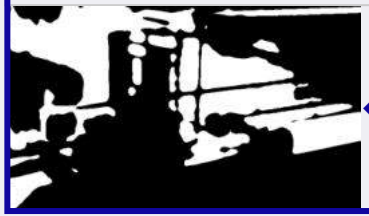
Only main type of fuel cells shown.

TEMPERATURE

1000° C

60° C

Fuel Cell Type	Membrane permeable to:	Allowable fuel:
Solid Oxide (SOFC)	O--	Hydrogen / hydrocarbons
Molten Carbonate (MCFC)	CO3--	Hydrogen / hydrocarbons
Phosphoric Acid (PAFC)	H+	Hydrogen from hydrocarbons
Alkaline (AFC)	OH-	Hydrogen
High Temperature PEM (HTPEM)	H+	Hydrogen
Low Temperature Proton Exchange Membrane (LT-PEM)	**H+**	**High purity hydrogen**



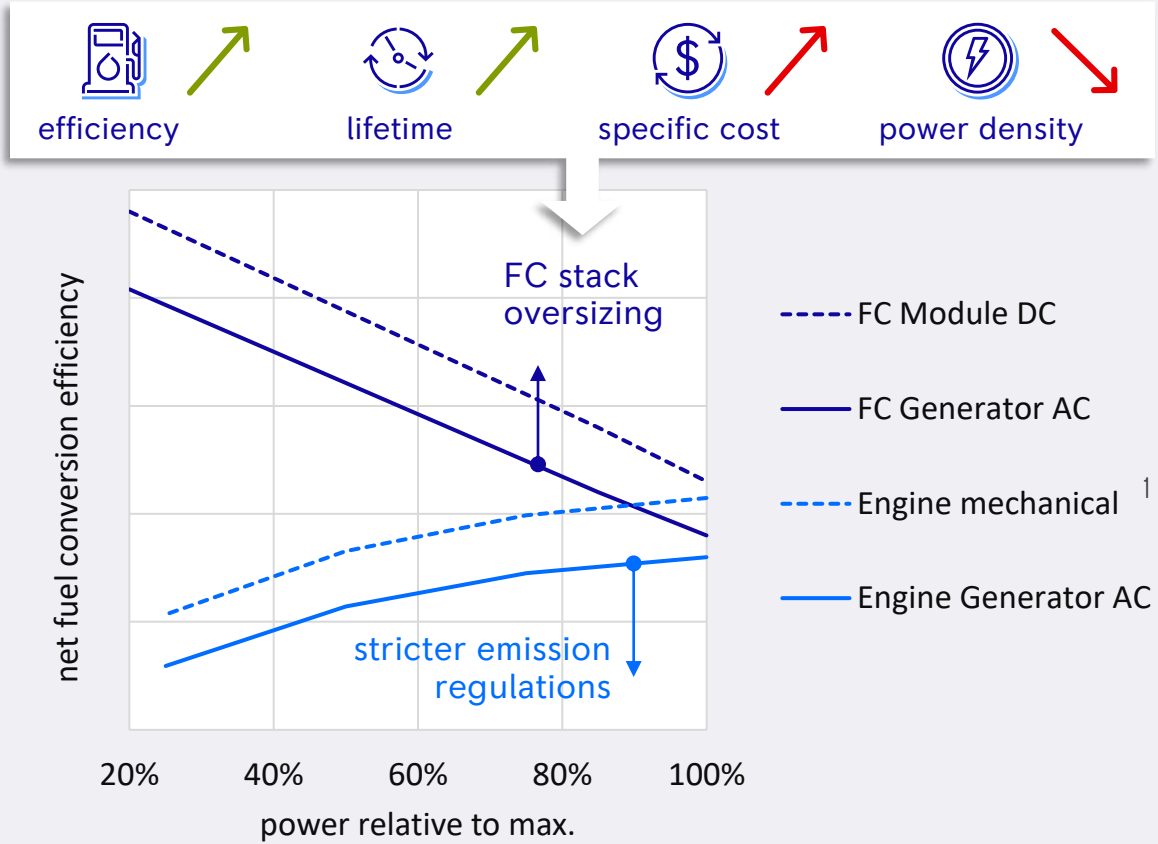
Key-Drivers for Fuel Cells

← Onroad-Truck

PowerGen for Datacenter →

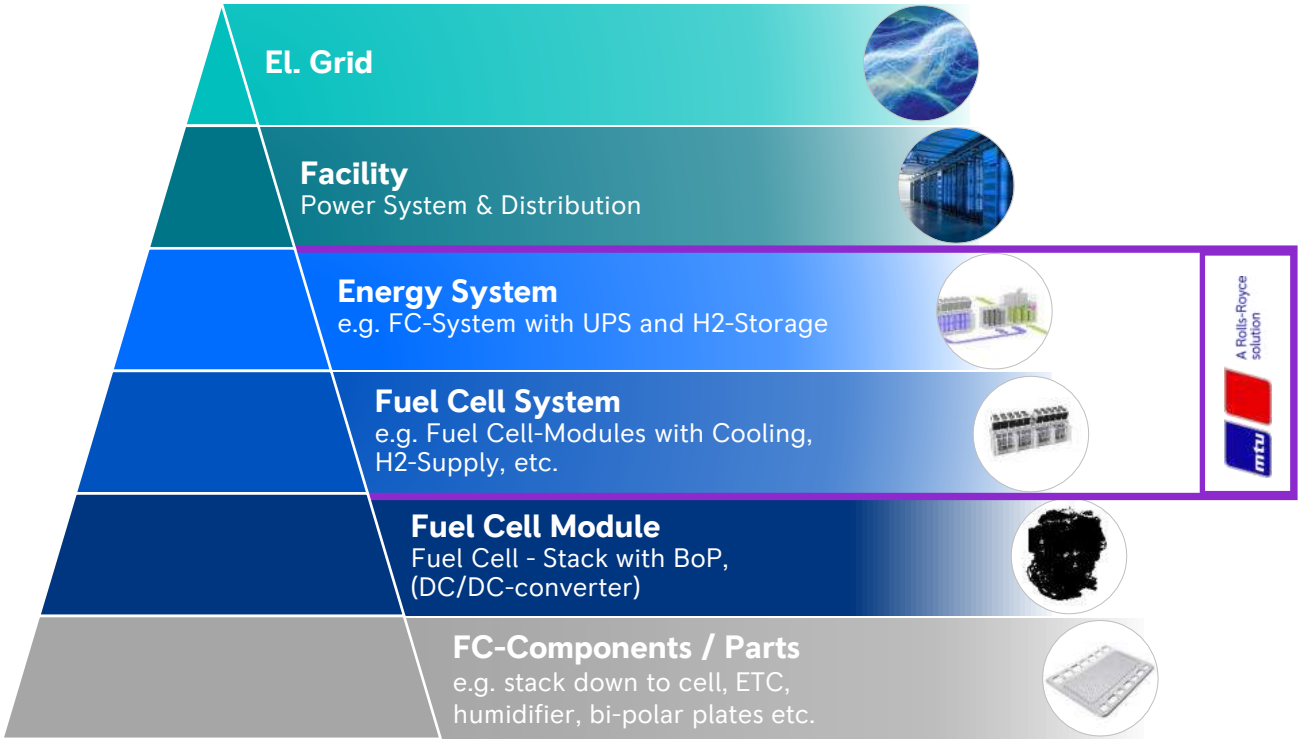
A Rolls-Royce solution

Fuel Cell Efficiency
Design-to-Purpose

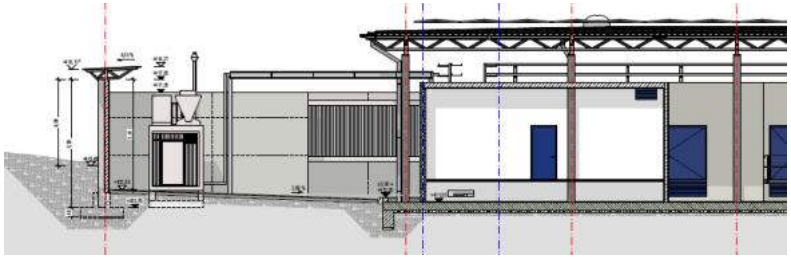


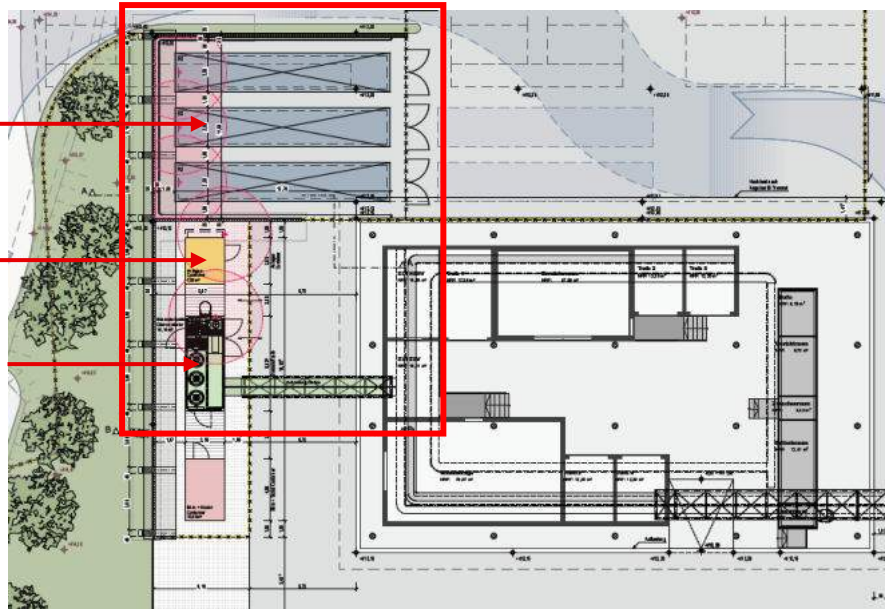
1 Diesel Engine 20V4000 G94F in emission optimized configuration, as used in 20V4000 DS3600 genset; Including cooler consumption.

LT-PEM Fuel Cells in PowerGen
Playground of Rolls-Royce Power Systems



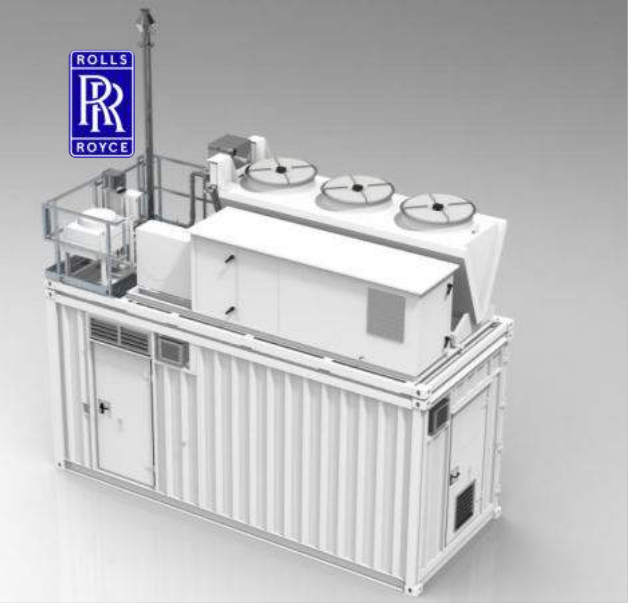
FC-Demonstrator (250 kW)
Integrated in our Microgrid Test Center





Technical Data FC-Demonstrator:

- max. Hydrogen Consumpion : 18 kg/h
- Electrical Power : 250 kW
- Voltage : 400 V AC 50 Hz
- H_2-Capacity : 2 x 300 kg
  - → Range 25% Load factor : 120 h
  - → Range 100% Load Factor : 30 h

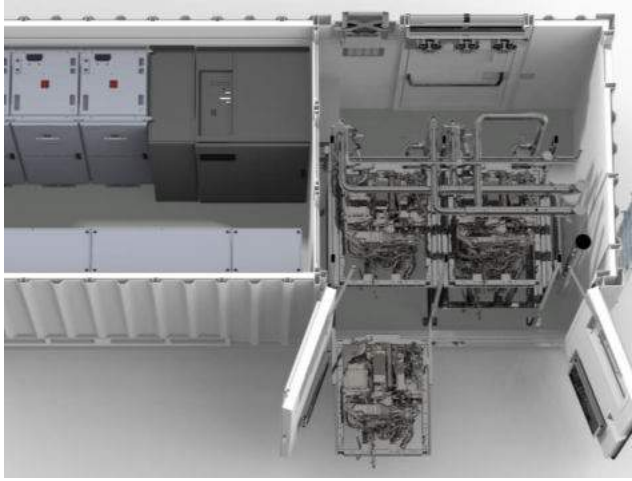


Integrated.

By being operable under the open sky without any infrastructure apart from hydrogen, the standalone Fuel-Cell Demonstrator is much more than a test bench.

Versatile.

Equipped with a cutting-edge static online-UPS system and Li-Ion batteries, the demonstrator can be adapted for various different customer use-cases.

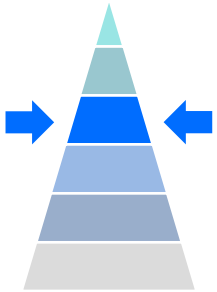


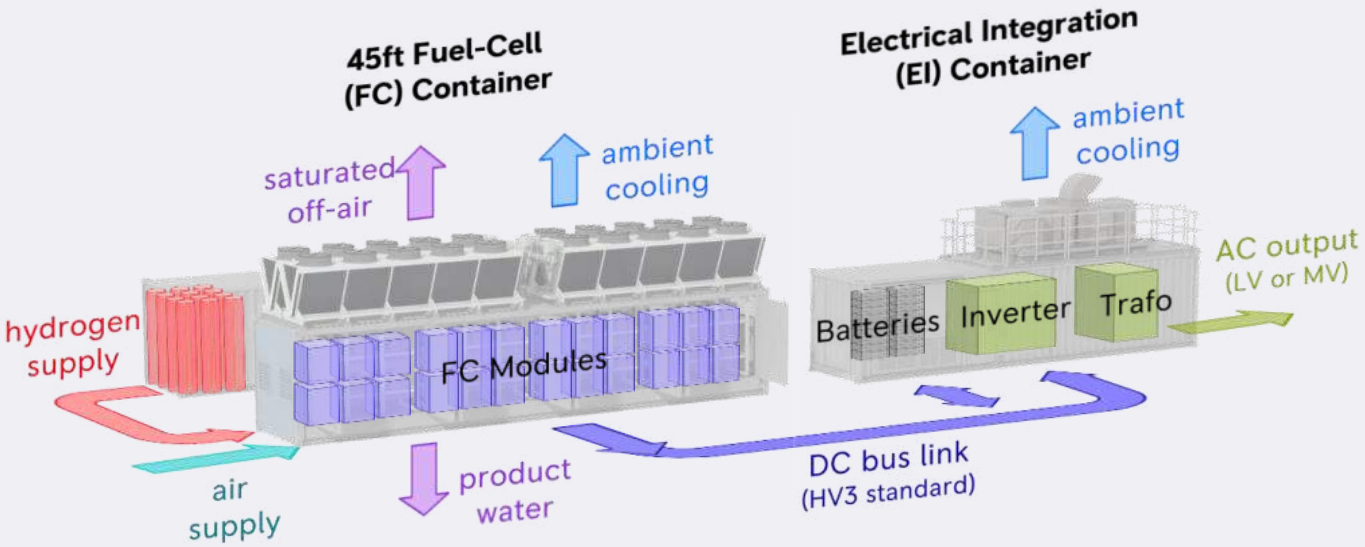
Pioneering.

Demonstration of new concepts for modular FC system integration will set the foundation for large scale power generation from PEM fuel cell technology.

A Rolls-Royce solution

FC-Energy Systems
PEM Fuel Cell Generator





Fuel Cell Container:

Fully integrated standalone solution for outdoor usage at customer-defined power scale.

Electrical Integration:

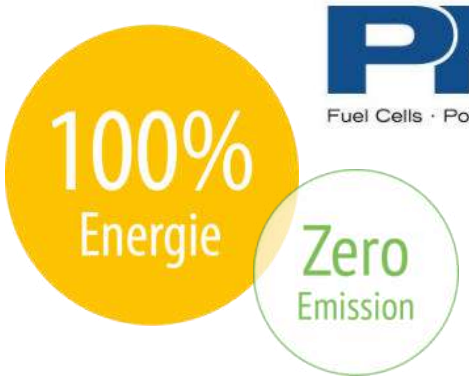
Multitude of different customer-specific integration solutions conceivable.

A Rolls-Royce solution

Thank you for your attention!

A Rolls-Royce solution

CLEANTECH COMPETENCE



Fuel Cells · Power Systems

Proton Motor Fuel Cell GmbH

Stationary Fuel Cell Systems
Brennstoffzellentechnologie und Anwendungsbeispiele

Fuel Cells · Power Systems

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E-Mail: sales@proton-motor.de
Web: www.proton-motor.de

Proton Motor Fuel Cell GmbH

Proton Motor Fuel Cell GmbH provides solutions for clean energy supply and clean mobility.

German manufacturer of fuel cell stacks and fuel cell systems for maritime, stationary and mobile applications.

Proton Motor Fuel Cell GmbH,
Headquarters Puchheim,
production plant, labs & offices on ca. 6000 m^2.

PEFC development since 1994 (Magnet Motor),
PM founded 1998 as independent company,
today 93 employees

Proton Motor is a subsidiary of:

Proton Power Systems PLC

(Holding, listed at LSE since 2006)

Proton Motor History

Start development of Fuel Cell Technology

1994

Bayernbus set into operation

2000

Fuel Cell Ship “Alsterwasser” in operation

2008

Road approval Newton with HyRange®

2011

Presentation of FC REEV vehicle

2016

FC-System for garbage collector truck from ETrucks

2019

1998

Foundation Proton Motor Fuel Cell GmbH

2001

World first Fuel Cell Fork Lift

2009

World first Triple Hybrid City Bus

2016

EPS-System BOS Application

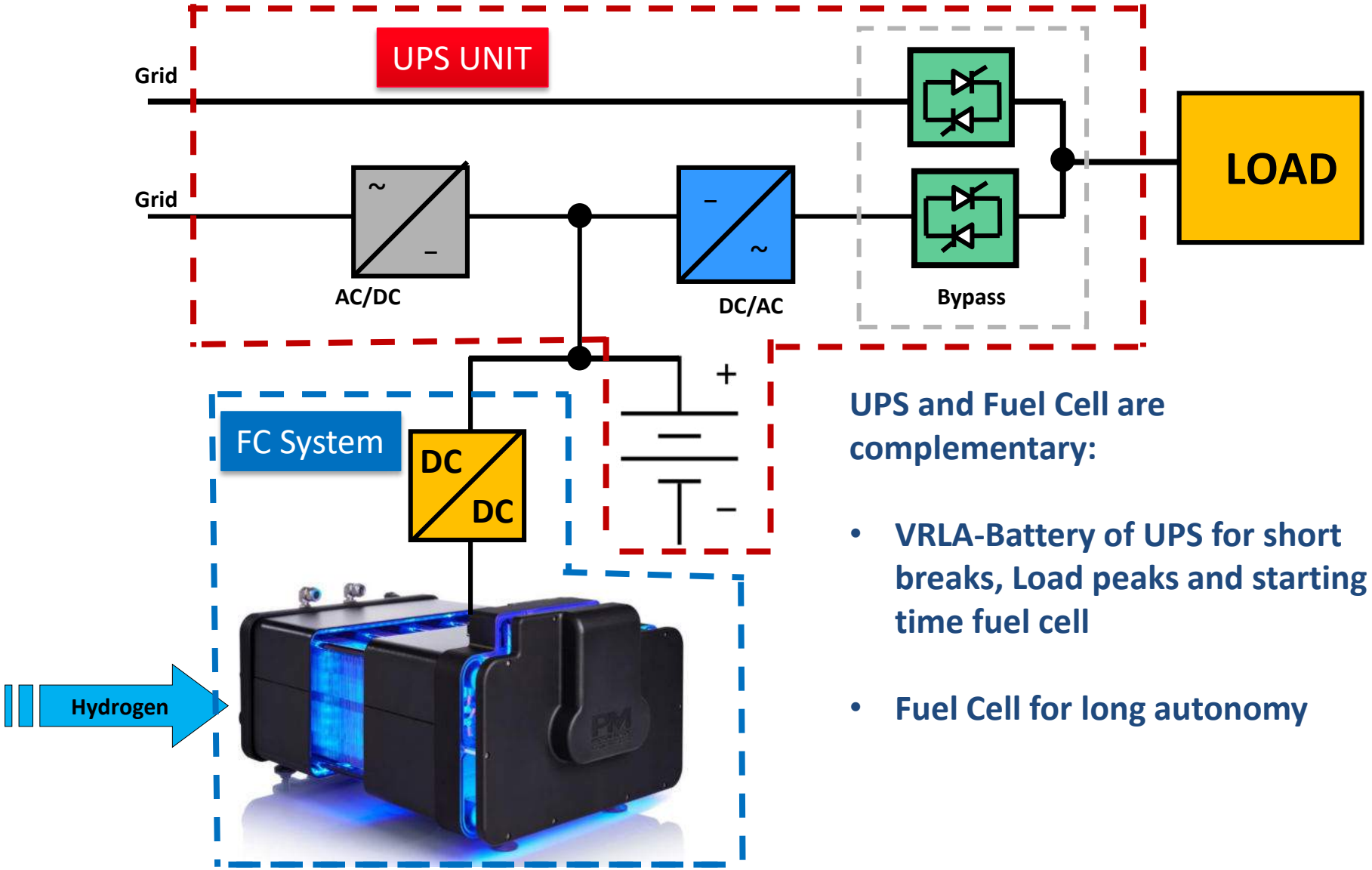
2018

FC-EPS System at DB Netz AG

2020

100 kVA Container for APEX

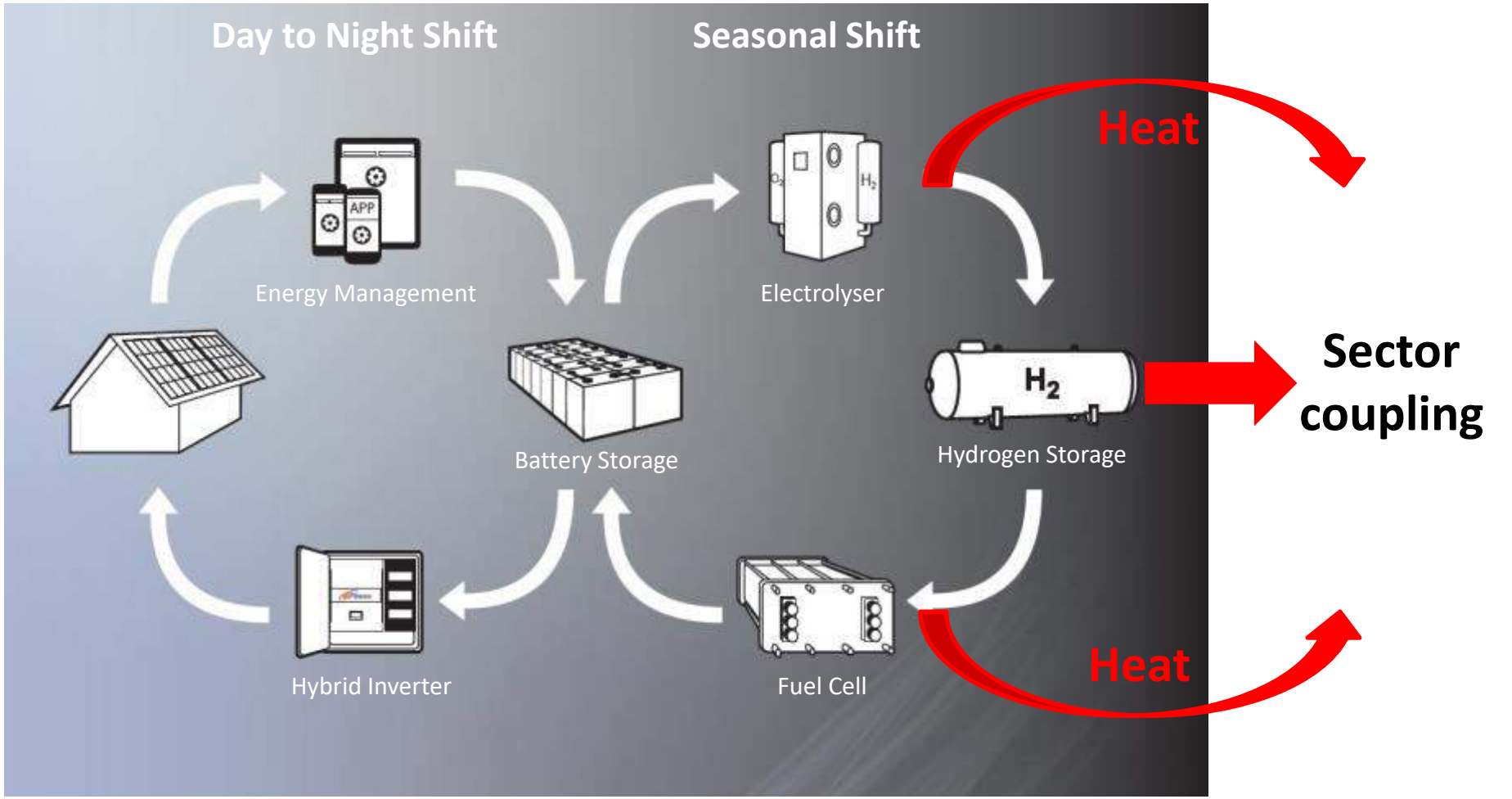
Critical Infrastructure - UPS Application



UPS and Fuel Cell are complementary:

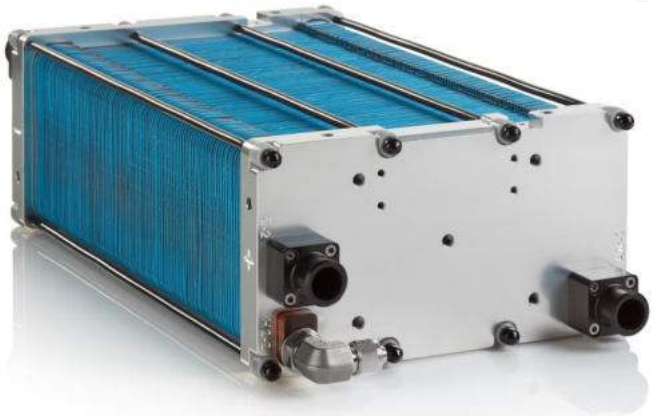
- **VRLA-Battery of UPS for short breaks, Load peaks and starting time fuel cell**
- **Fuel Cell for long autonomy**

Energy Autonomy (Energy Shift)



PM Fuel Cell Stack

Two models: PM 200 and PM 400 Stack



PM200

- effective cell area ca. 156 cm²
- rated power 2…16 kW

PM400

- effective cell area ca. 409 cm²
- power range 15 to 75 kW

→ **for operation with ambient air (filtered) and pure hydrogen**

→ **no external humidification needed**

Modular Highly Integrated Fuel Cell Stack Modules

Stationary

Automotive

Rail

Maritime

PM200 Stack Module

Power Range: 2,1…14,8 kW_{el} (2 kW steps)

Current range: 0…150 A

PM400 Stack Module

Power Range: 14,2…71,0 kW_{el} (7 kW steps)

100 kW…10 MW (multi stack systems)

Current range: 0…500 A

Efficiency:	47…67%	Ambient Temp.:	-35 to +45 °C
Life time:	> 20.000 operating hours	H2 pressure:	3,5 / 8,0 bar_g
Protection class:	IP65	Conformity:	CE, EN 62282-2

Freeze storage and freeze start capable (since 2010)

Without need for humidification

Liquid cooled

PM Frame and System Components

Mechanical Design
- Indoor or Outdoor Cubical

Secondary cooling Circuit
- air/water heat exchangers
- Plate heat exchanger

Voltage Adaption with Power Electronics
- DC/DC or DC/AC
- 1 phase or 3 phase

Main Controller and Monitoring System
- communication with external systems

Hybridisation with Battery System
- Start Up Power for Offgrid Solutions
- Covering of Peak Loads

Safety Measures
- leakage monitoring
- Alarms
- Emergency stop

FC System Example 25kW

Exemplary Reference Stationary Applications

UPS / Emergency Power Supply

UPS Telecom

Customer: DB Bahnbau

FC Power: 6 & 9 kW

UPS Road Tunnels

Customer: To be announced

FC Power: 23, 28, 36, 43 kW

Seasonal Energy Shift / Peak Shaving

Houses & Appartments

Projects: Hy2Green (I)

Brütten (CH)

FC Power: 9 kW

Housing Block

Customer: Vonovia

FC Power: 36 kW

Exemplary Reference Stationary Applications

Grid Stabilisation / Peak Shaving

FC Power: 178kW

Voltage: 400 VAC (Grid dependent)

Customer: APEX

Location: Rostock (Germany)

Power Supply Grid Independent

FC Power: 129 kW

Battery : 180 kWh

Voltage: 400 VAC (Grid independent)

Customer: Shell

Location: Munich (Germany)

100% Energie

Zero Emission

Herzlichen Dank für Ihre Aufmerksamkeit!

Fuel Cells · Power Systems

Proton Motor Fuel Cell GmbH
Anne Duval
Sales Stationary Fuel Cell &
UPS Applications

Phone : +49 (0)89 1276265-78
Fax: +49 (0)89 1276265-99
E-Mail: a.duval@proton-motor.de
Web: www.proton-motor.de

Wasserstoff Nutzung bei Siemens

Ulrich Guenther SE GP SV CD EU
Mai 2021

Agenda

01 Die Rolle von Wasserstoff in der zukünftigen Energie-Wirtschaft

02 Wasserstoffverbrennung in Siemens Energy Gasturbinen (GT)

03 Brennstoffzellenentwicklung

04 Wasserstoff in der Mobilität

05 Zusammenfassung

01. Die Rolle von Wasserstoff in der zukünftigen Energiewirtschaft

Reduction of CO_2 emissions is critical to limit global warming to below current commitments (considered unsustainable)

SIEMENS energy

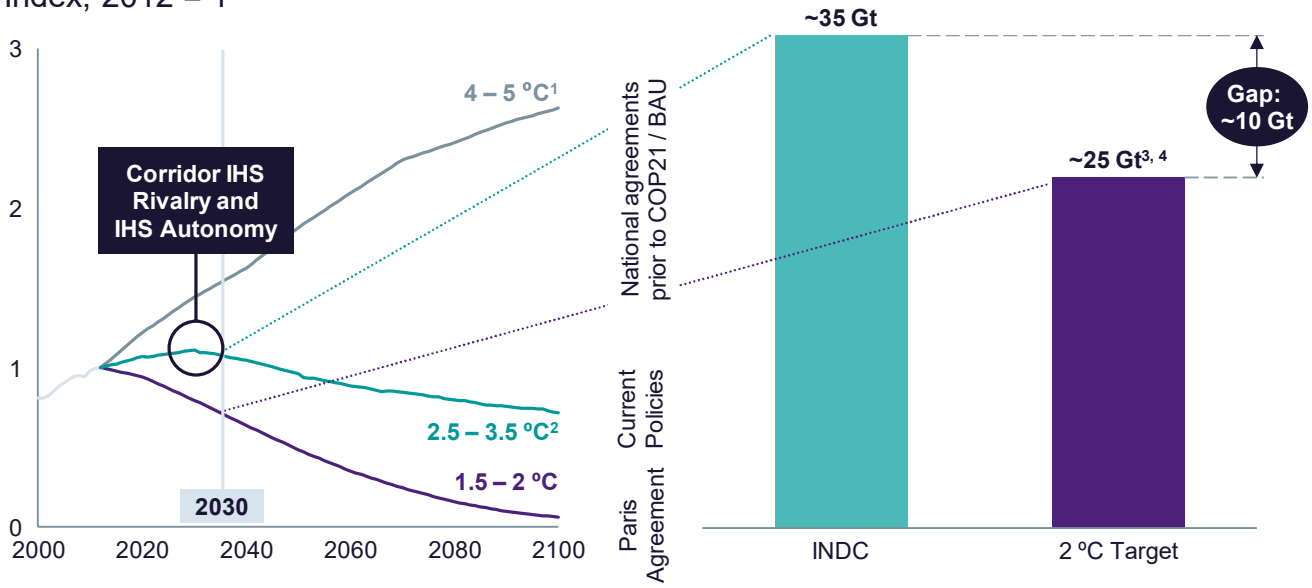
Increasingly ambitious targets from COP21 leave the world …

… with a significant CO_2 gap[3], already in 2030 …

… which needs to be closed to achieve 1.5 – 2° C target

Global warming scenarios

Index, 2012 = 1



Transition of power generation mix

- Coal to natural gas (short term)
- Aggressive renewable growth
- Natural gas to sustainable hydrogen (long term)

Efficient grid management

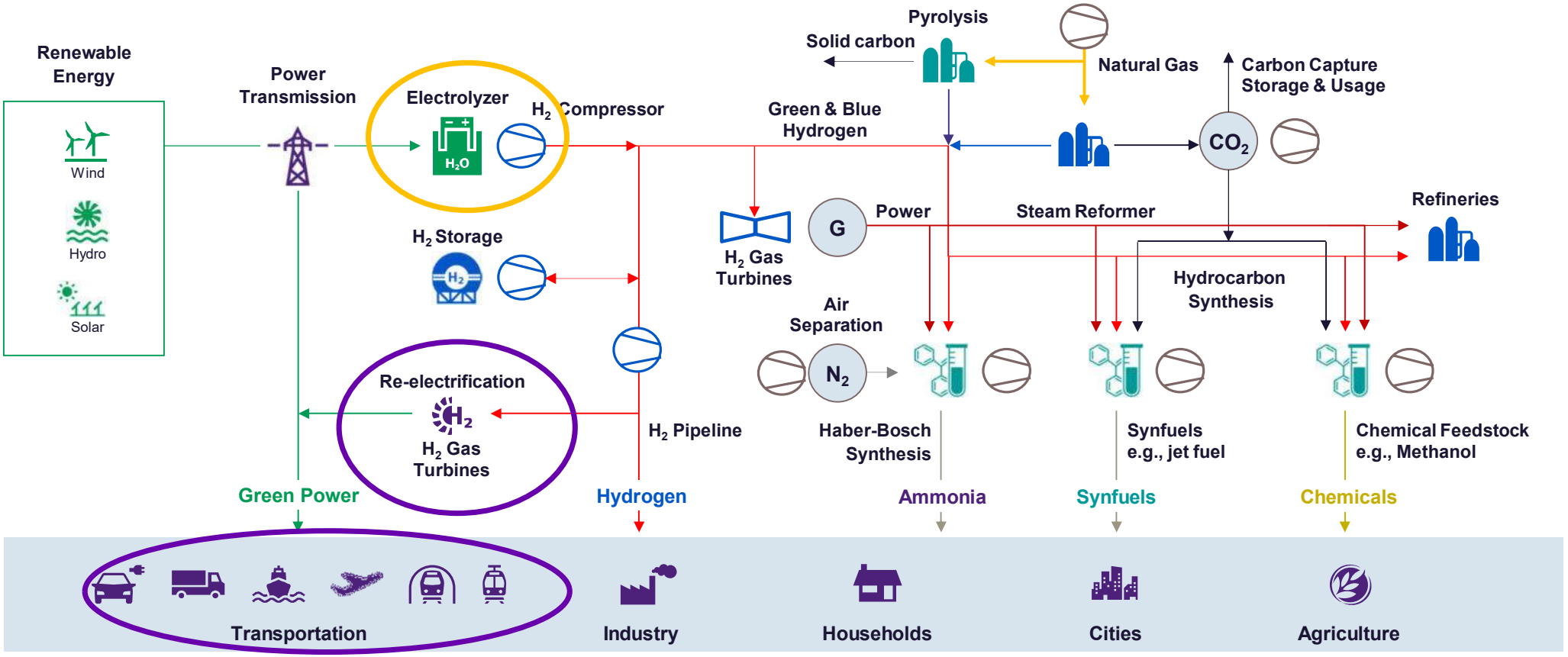
- Electricity storage for intermittent renewables
- Smart grid technology for demand response

Improved energy efficiency

- Efficient use of energy
- Green electrification of transportation and heat (sector coupling)

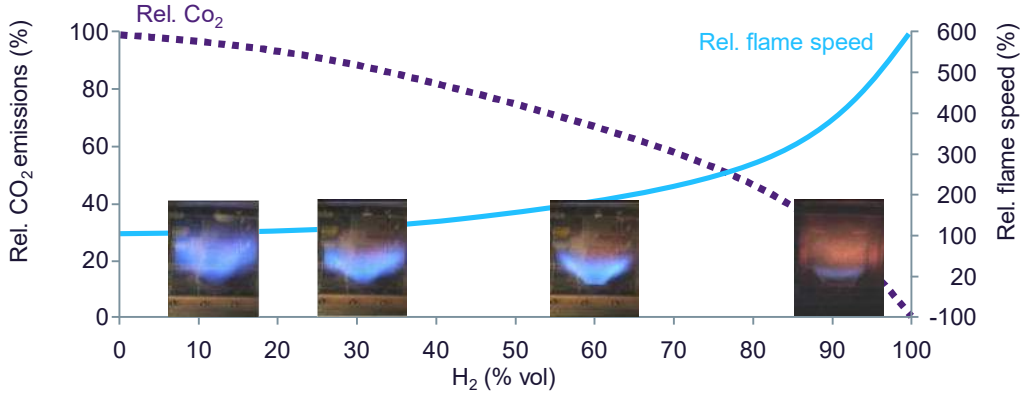
1 Business as usual (BAU), without any emission reduction effort | **2** Intended Nationally Determined Contributions (pre-COP21 commitments) |
3 BAU & INDC data based on CO_2 equiv., whereas scenarios only provide CO_2 emissions which are ~33% lower than total CO_2 equiv |
4 Following Climate Action Tracker (~38 Gt CO_2 equiv. in 2030) | **Source:** CD ST SU, PV/Energy Mix Project Team, IEA

Siemens Energy has a comprehensive offer for the complete Hydrogen Value Chain



02. Wasserstoffverbrennung in Siemens Energy GT (new equipment)

Hydrogen does not produce CO_2 emissions, but challenging physical properties require rapid design and testing cycles



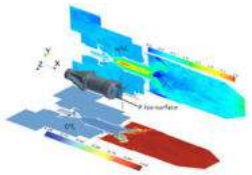
Values shown are relative to natural gas (indicative only)

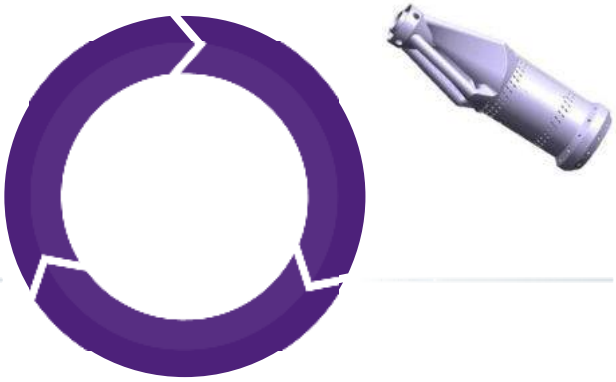
Challenges

- **H2 embrittlement** requires upgrade to stainless steel materials
- **Lower volumetric energy content** requires larger flows to be handled by fuel system
- **Higher diffusivity** requires changes/re-certification of sealing and flanges
- **Higher reactivity and flame velocity** pushes flame towards burner and increases risk of explosion or flashback
- **Higher flame temperature** can lead to local hotspots if imperfectly mixed and thus increased NOx emissions

1. High fidelity CFD
High fidelity CFD tools like LES can provide automated optimized designs

2 Rapid prototyping using AM
Additive manufacturing reduces lead time and enables better designs





3. High-pressure testing at engine conditions
High-pressure burner tests combined with full engine tests

Combustion Test Center in Berlin

Zero Emission H_2 Test center (Finspong)

Burner Tests **Engine Tests**

Siemens Hydrogen Gas Turbines for our sustainable future
The mission is to burn 100% hydrogen

Gas turbine model		Power Output[1]	H_2 capabilities in vol. %	CO_2 reduction [%]
50Hz	SGT5-9000HL	593 MW	50	23%
	SGT5-8000H	450 MW	30	11%
	SGT5-4000F	329 MW	30	11%
	SGT5-2000E	187 MW	30	11%
60Hz	SGT6-9000HL	405 MW	50	23%
	SGT6-8000H	310 MW	30	11%
	SGT6-5000F	215 to 260 MW	30	11%
	SGT6-2000E	117 MW	30	11%
50Hz or 60Hz	SGT-800	48 to 62 MW	50	23%
	SGT-750	40/34 to 41 MW	40	17%
	SGT-700	33/34 MW	55	27%
	SGT-A35	27 to 37/28 to 38 MW	15 – 100	5 / 100%
	SGT-600	24/25 MW	60	31%
	SGT-400	10 to 14/11 to 15 MW	10 – 65	3 / 36%
	SGT-300	8/8 to 9 MW	30	11%
	SGT-100	5/6 MW	30 – 65	11 / 36%
	SGT-A05	4 to 6 MW	2 – 15	1 / 5%
	Gasmotor	0,5 to 2 MW		

Values shown are indicative for new unit applications and depend on local conditions and requirements. Capability to operate on 100% natural gas is maintained (full fuel flexibility). Some operating restrictions/special hardware and package modifications may apply.

Higher H_2 contents to be discussed on a project specific basis

DLE*burner WLE**burner Diffusion burner with unabated NOx emissions

Heavy-duty gas turbines Industrial gas turbines Aeroderivative gas turbines

* DLE-Dry Low Emission, ** WLE- Wet Low Emission

Mai 2021

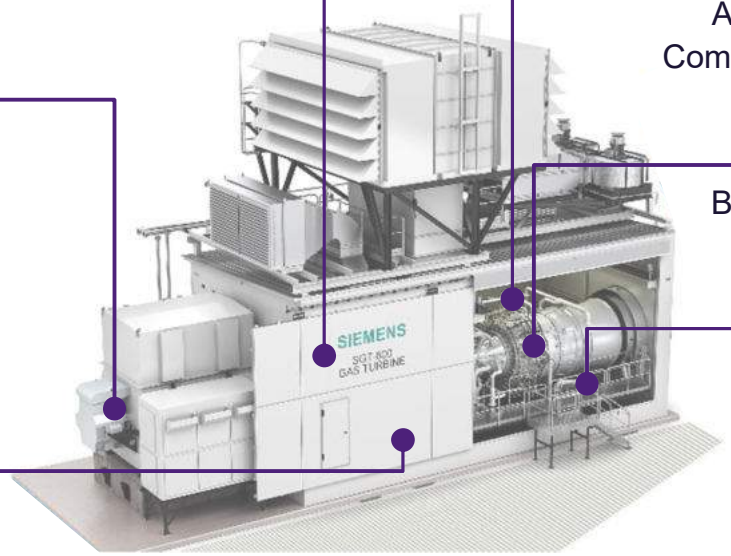
Burner Adjustment/Exchange for Industrial Gas Turbines

Main systems requiring modification when upgrading to higher H_2 content

Fire Protection System
Gas Detection System

Gas Group IIC
electrical equipment

H_2 compatibility of plant
auxiliary and peripheral systems



Additional Flame Control and
Combustion Monitoring Systems

Burner Adjustment/Exchange
Purging system

Fuel Gas System
material and set-up

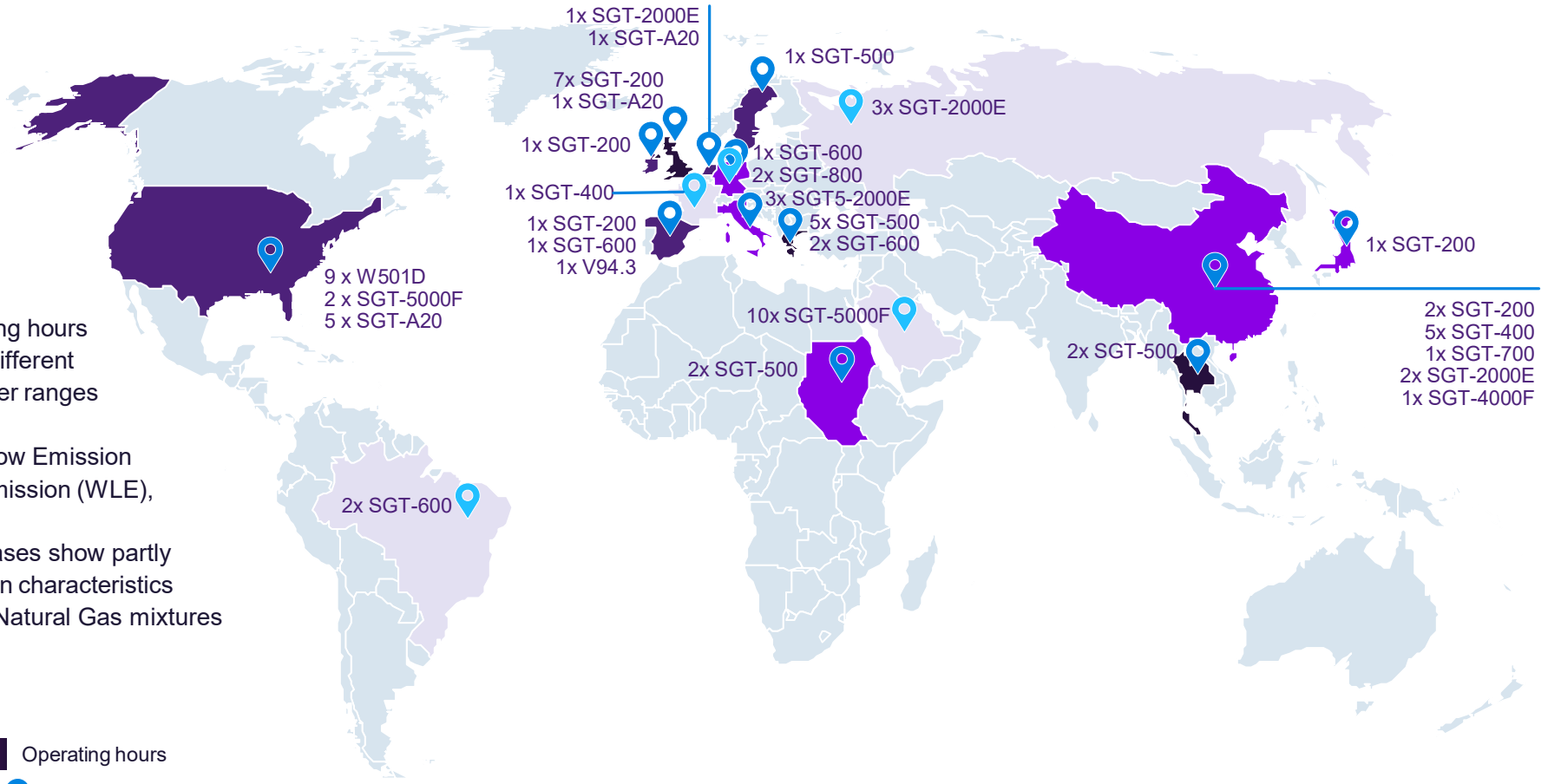
Consequences and solution

- Project specific evaluation and decision on required modifications
- Power output control to ensure compliant NOx emission levels
- Conventional/non-H_2 fuels may be required for start-up and shutdown
- Re-certification with respective authorities might be required

World fleet experience on high H_2 syngases for refineries and steel mills and other chemical industries

SIEMENS energy

- Over **53 units and 2.5 million** operating hours worldwide across different industries and power ranges since **1979**
- Combustion: Dry Low Emission (DLE), Wet Low Emission (WLE), Diffusion unabated
- Note: H_2-rich syngases show partly different combustion characteristics compared with H_2-Natural Gas mixtures



Mai 2021

Reference: Braskem (Brazil) for 60% H_2 cofiring in DLE mode

SIEMENS energy

Braskem

60% Hydrogen, baseload at 25ppm NOx

Customer: Braskem
Country: Brazil

Mai 2021

Challenge

- Use of hydrogen as fuel gas to reduce use of natural gas, up to 60% not exceeding 25ppm NOx
- Reduced need for external grid supply
- High availability and reliability, low O&M costs

Technology

- 2x SGT-600 turnkey CHP plant with 3rd generation DLE system for up to 60% H_2 co-firing at 25ppm NOx

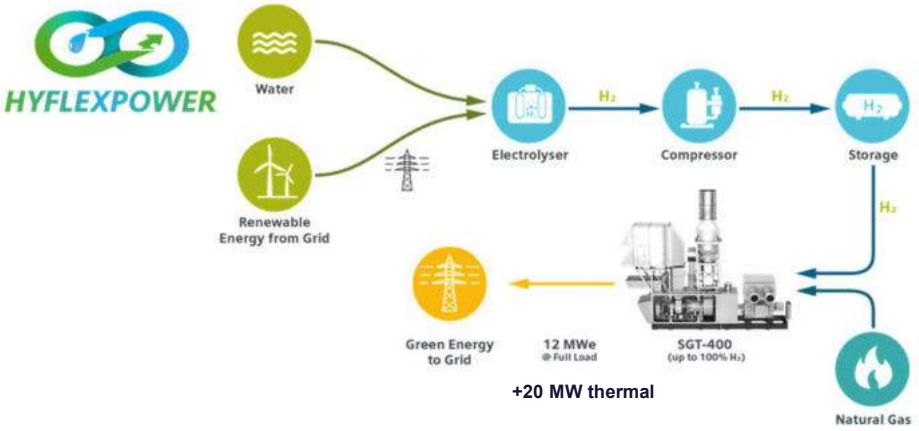
Solution

- Advanced Additive manufactured burners
- Complete plant delivery, Siemens Energy will build, own & operate the CHP, HRSG and gas compressor
- O&M contract based on delivery of steam and power

Benefits

- Fuel cost savings, operation on high levels of hydrogen with DLE, no need for water injection
- Lowest emissions using the latest DLE combustion <25ppm NOx
- Predictable operation and maintenance cost

EU-funded HYFLEXPOWER Project (France)
A CO_2 free power-to-power path using 100% H_2 in DLE combustion



Installation of the hydrogen production, storage and supply facility at pilot demonstration site

Pilot demonstration with up to 100 percent hydrogen for carbon-free energy production from stored excess renewable energy

May 2020 — **2021** — **2022** — **2023**

Contract finalization and start of engineering development

Installation of the gas turbine for natural gas/hydrogen mixtures and initial demonstration of advanced pilot plant concept

Source: http://www.hyflexpower.eu/

03. Brennstoffzellenentwicklung

Brennstoffzellen @ Siemens hat eine lange Geschichte !

SIEMENS

stationär

- Kraftwerke > 50 kW
- Hausheizung < 50 kW

mobil

- Automobil < 100 kW
- Busse und Industrie > 100 kW...MW?
- Seefahrt U-Boote

portabel

- Camping 1 kW
- Laptop 50 W
- Handy 2 W

Seit 1990

Siemens

2004

1997

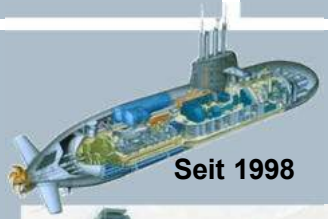
IBZ/HEXIS

2015

2007

Siemens

1997/2000



Seit 1998

Siemens

1997

1966

Siemens

2015

2001

Siemens

2004

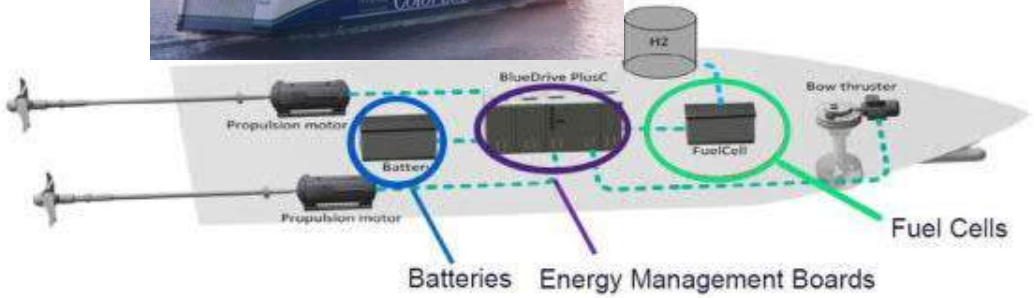
2015

Our Next Step
Solutions for High Energy Storage – H_2-powered Fuel Cells

SMM 2018, Hall B6, Booth 318

Siemens and PowerCell to collaborate in fuel cell systems for ships

- Partnership between Siemens and PowerCell Sweden AB
- Planned collaboration for maritime energy systems based on fuel cells



Heavy Duty Fuel Cell Stack MS-100

Nom. Power = 100 kW
High electrical Efficiency
Very high Power Density < 300 l/100kg

DC Energy and Propulsion Concepts
Example @ low voltage scale

- DC Power Distribution
- DP Operation with joined by coupling device (ILC)
- Generators with variable rotation
- Integrated ACDC Converter
- Integrated DCAC Converter
- Integrated Grid Supply
- Integrated VFD- or DC-auxiliary supply
- Dual feed for drives
- Optional Integration of Storage Solutions such as Batteries or Super Caps
- Thermal management by water cooling
- Approved by :
- **Integration of Fuel Cells**

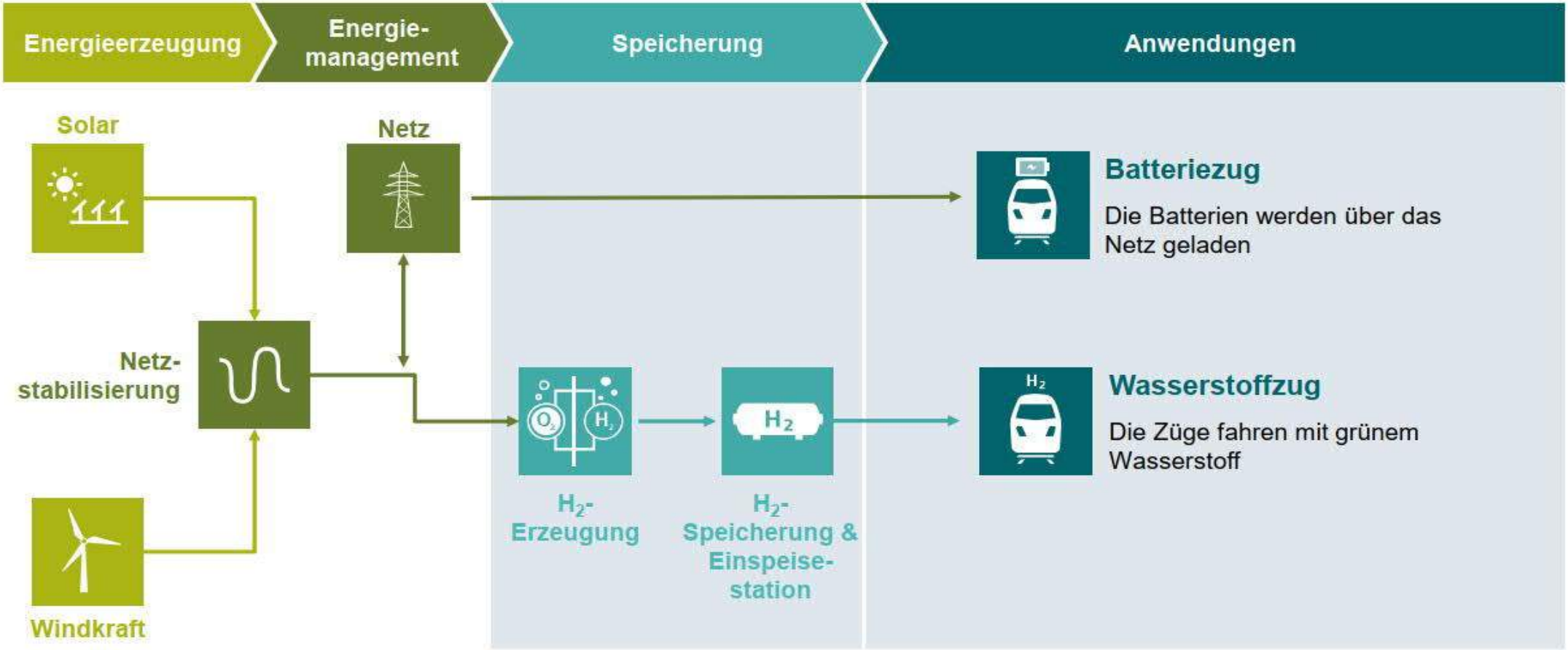
Pure ZERO Emission – Hybrid Solutions for CO_2 free operation

DNV·GL Lloyd's Register ABS

04. Wasserstoff in der Mobilität

Well-to-wheel – über Oberleitung oder Wasserstoff

SIEMENS
Ingenuity for life

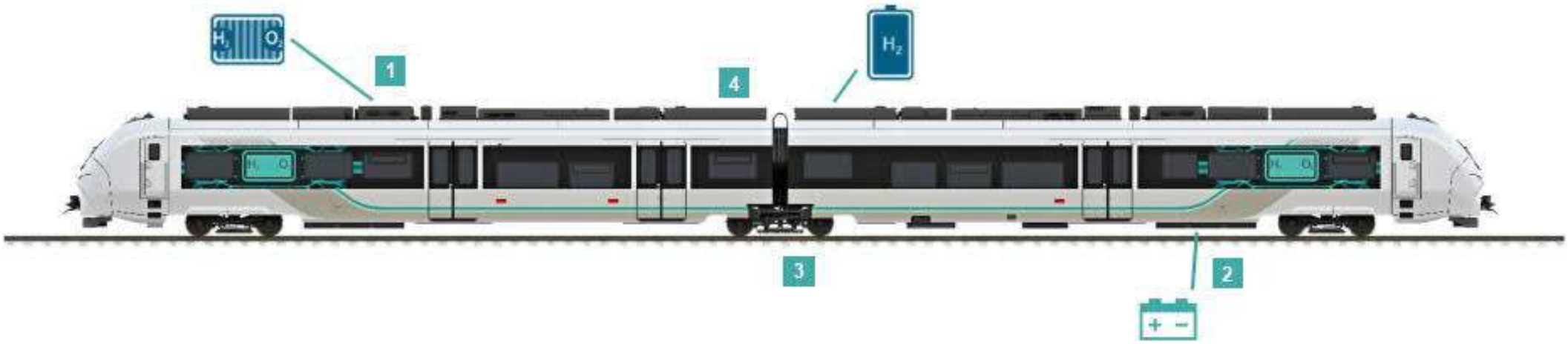


Der Mireo Plus H ermöglicht anspruchsvollen Betrieb ohne Oberleitung

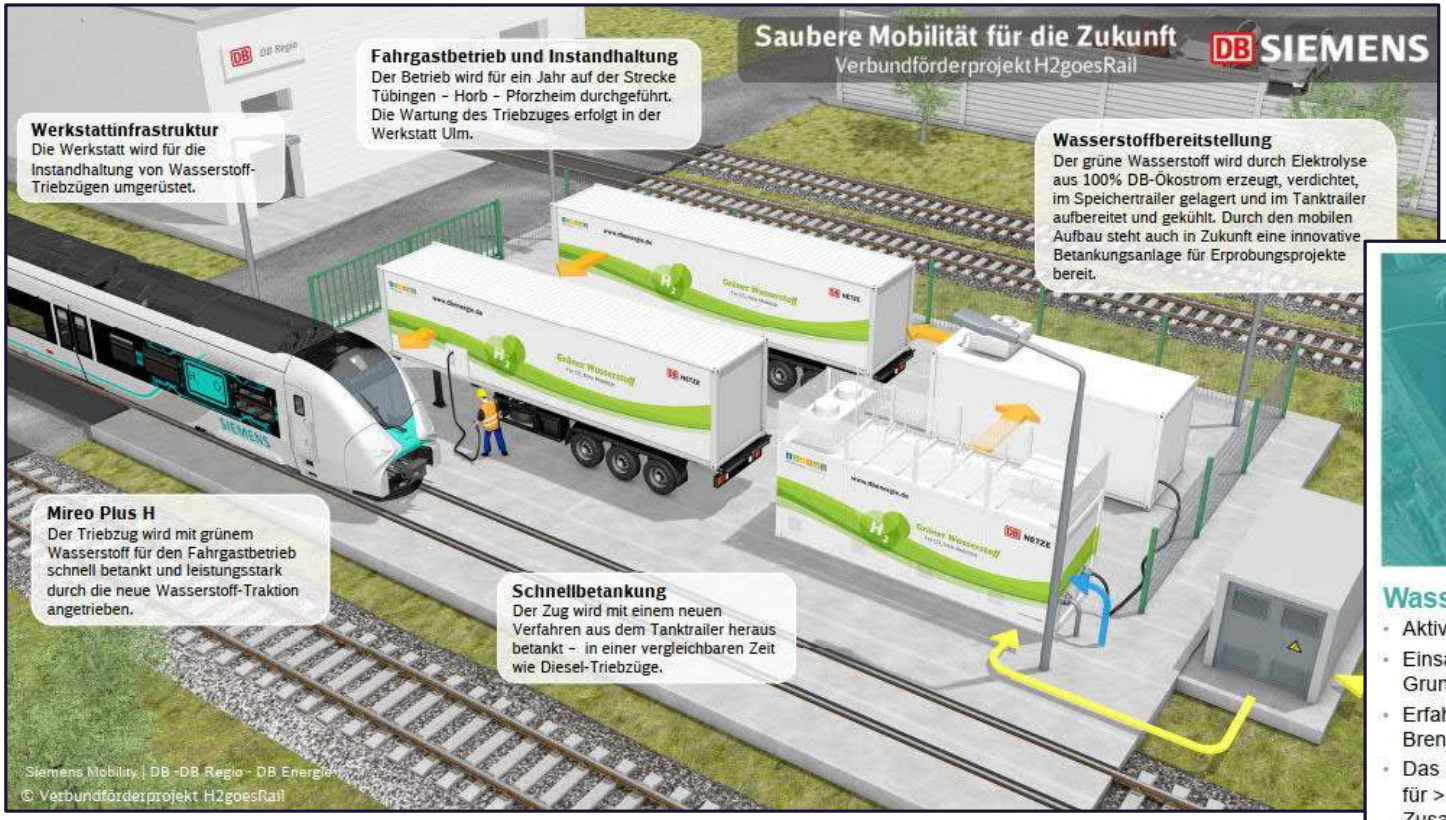
SIEMENS
Ingenuity for life

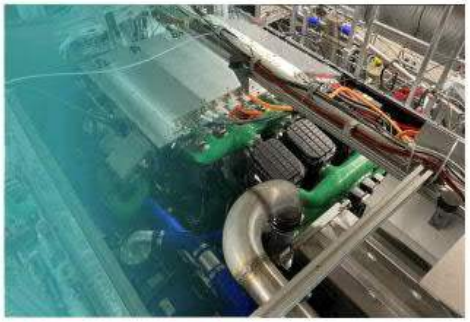
- EMU Performance
- Sehr energieeffizient / geringer Stromverbrauch durch SiC
- Vmax 160 km/h
- Geringe Lebenszykluskosten

1. Hocheffiziente Brennstoffzelle – hohe Reichweiten möglich
2. Langlebige Batterien durch LTO-Technologie
3. Intelligentes System zur Schnellbetankung
4. Geringer Stromverbrauch u. a. durch Nutzung der Abwärme der Brennstoffzelle für Fahrgastklimatisierung



Entwicklungsprojekt Deutsche Bahn und Siemens





H_2

Wasserstoffsystem

- Aktiv in Wasserstoffsystemen seit den 1960ern
- Einsatz im Marinegeschäft sowie für Elektrolyseure legten Grundstein für die Weiterentwicklung für Mobilitätsanwendungen
- Erfahrener Partner Ballard Power für die Entwicklung des Brennstoffzellensystems der nächsten Generation
- Das neue Brennstoffzellensystem wurde in einem Systemtestlabor für > 2000 Stunden im Betrieb ausführlich getestet, um das Zusammenspiel zwischen Brennstoffzelle und Batteriesystem zu optimieren

Siemens Mobility | Rolling Stock

05. Zusammenfassung

Siemens ist ein hervorragender Partner für die Entwicklung weg von der fossilen- hin zur wasserstoffbasierten Wirtschaft

Wasserstoffanwendungen bei Siemens

- Die neuen GT Generationen sind in der Lage unterschiedliche Brennstoffgemische zu verarbeiten
- 100% Wasserstoff als Brennstoff für GT muss in Abhängigkeit der Randbedingungen geprüft werden
- Bestandanlagen können für den H2-Betrieb ertüchtigt werden
- Siemens Energy plant die Möglichkeit 100% Wasserstoffnutzung für alle GT Typen bis 2030
- Brennstoffzellen finden Zugang im Mobilitätssektor und der Energiewirtschaft

Conclusions

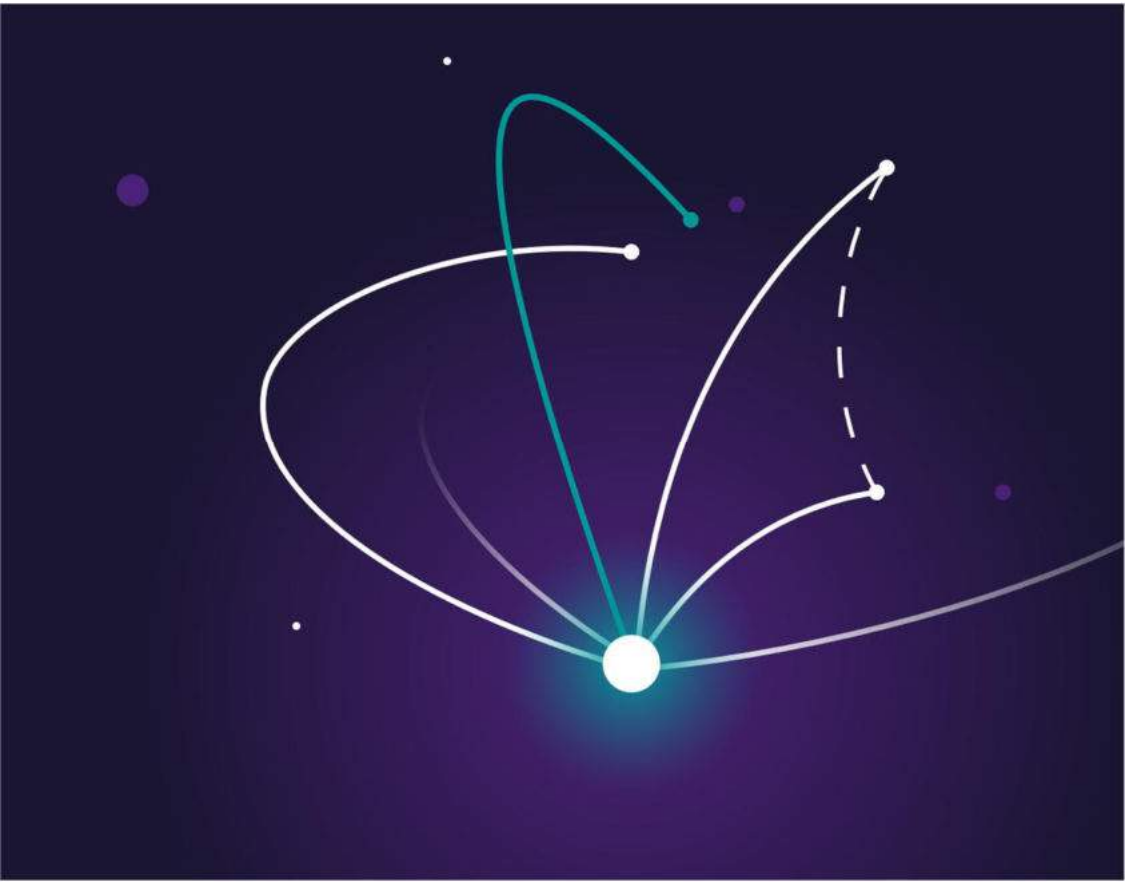
Bestehende Anlagen umrüsten und zukünftige Investitionen in GT und BZ sind **profitable Investitionen** auch in einer komplett dekarbonisierten Welt

Kohlenstoff freie Energie Erzeugung mit grünem Wasserstoff ist möglich

Hohe Brennstoffflexibilität für H2 und Erdgas sind möglich

Siemens GT erfüllen alle **Emissionsanforderungen** bei der Nutzung von Wasserstoff

Kontakt



Published by Siemens Energy

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MAN Energy Solutions
Future in the making

Rückverstromung mit MAN-Gasturbinen

Frank Reiß
MAN Energy Solutions
17.05.2021

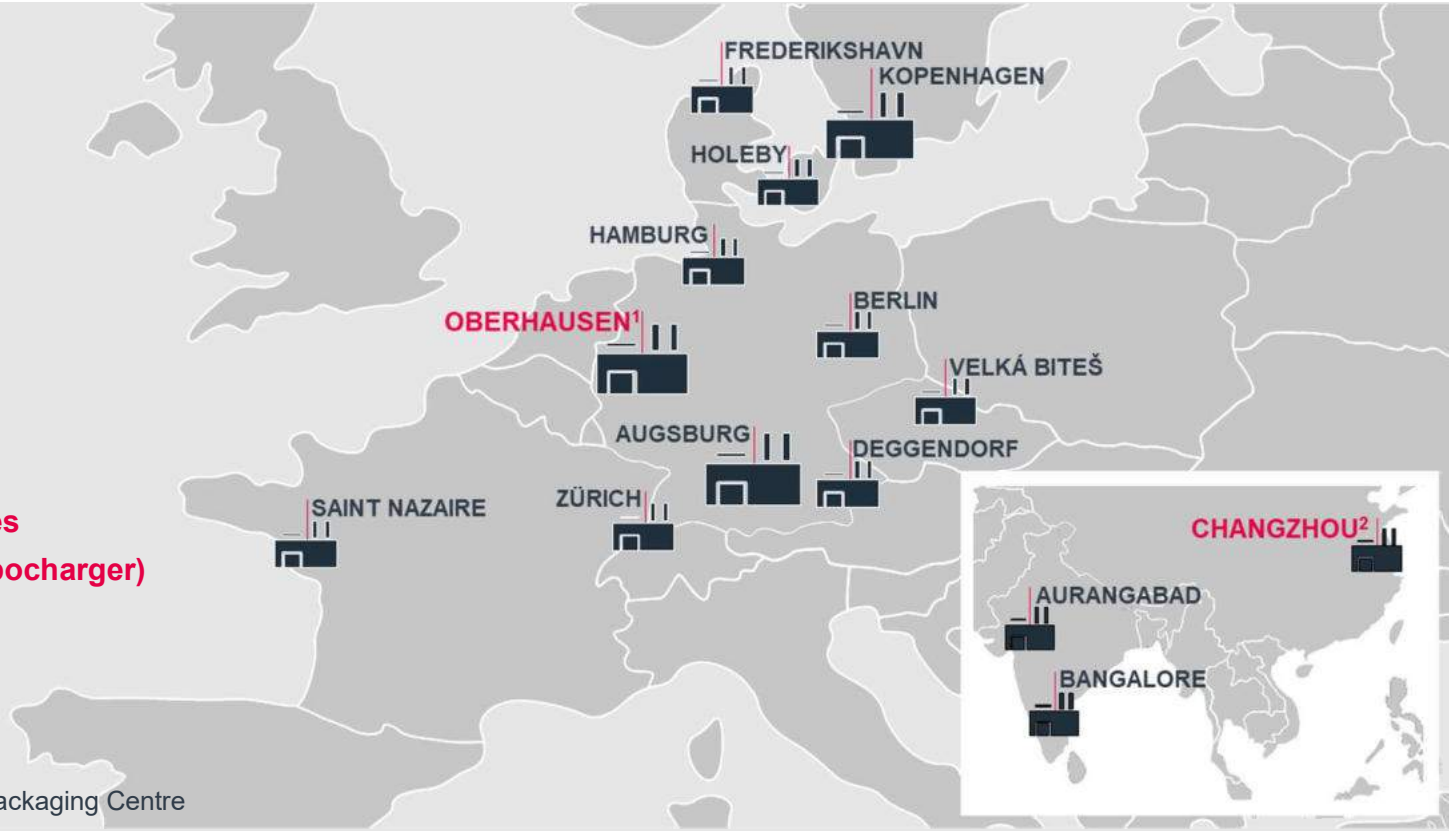
Design and production network

MAN Sites across Europe and Asia

11 **Production sites in Europe**

3 **Production sites in Asia**

30 **Licensees in 7 countries (two- and 4-stroke, turbocharger)**



[1] Gas Turbine Product Centre [2] Gas turbine packaging Centre

Product Center

Oberhausen, Germany

Product Center

Oberhausen, Germany

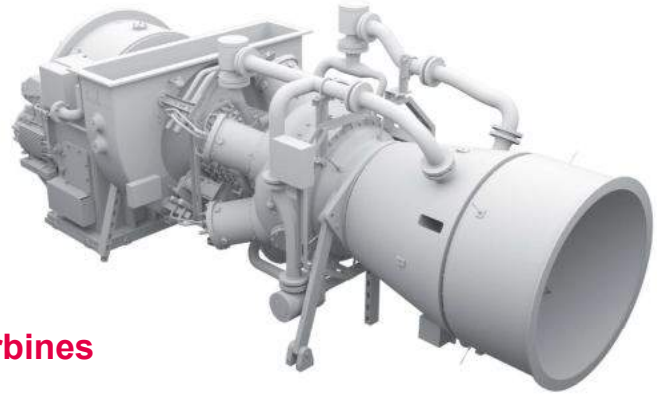
Competences

Engineering, R&D, laboratory

Production, testing (incl. string test capability)

After-sales service, sales, project management

Quality and HSE (ISO 9001)



Gas Turbines

Steam Turbines

Axial Compressors

Centrifugal Compressors

Process-Gas Screw Compressors

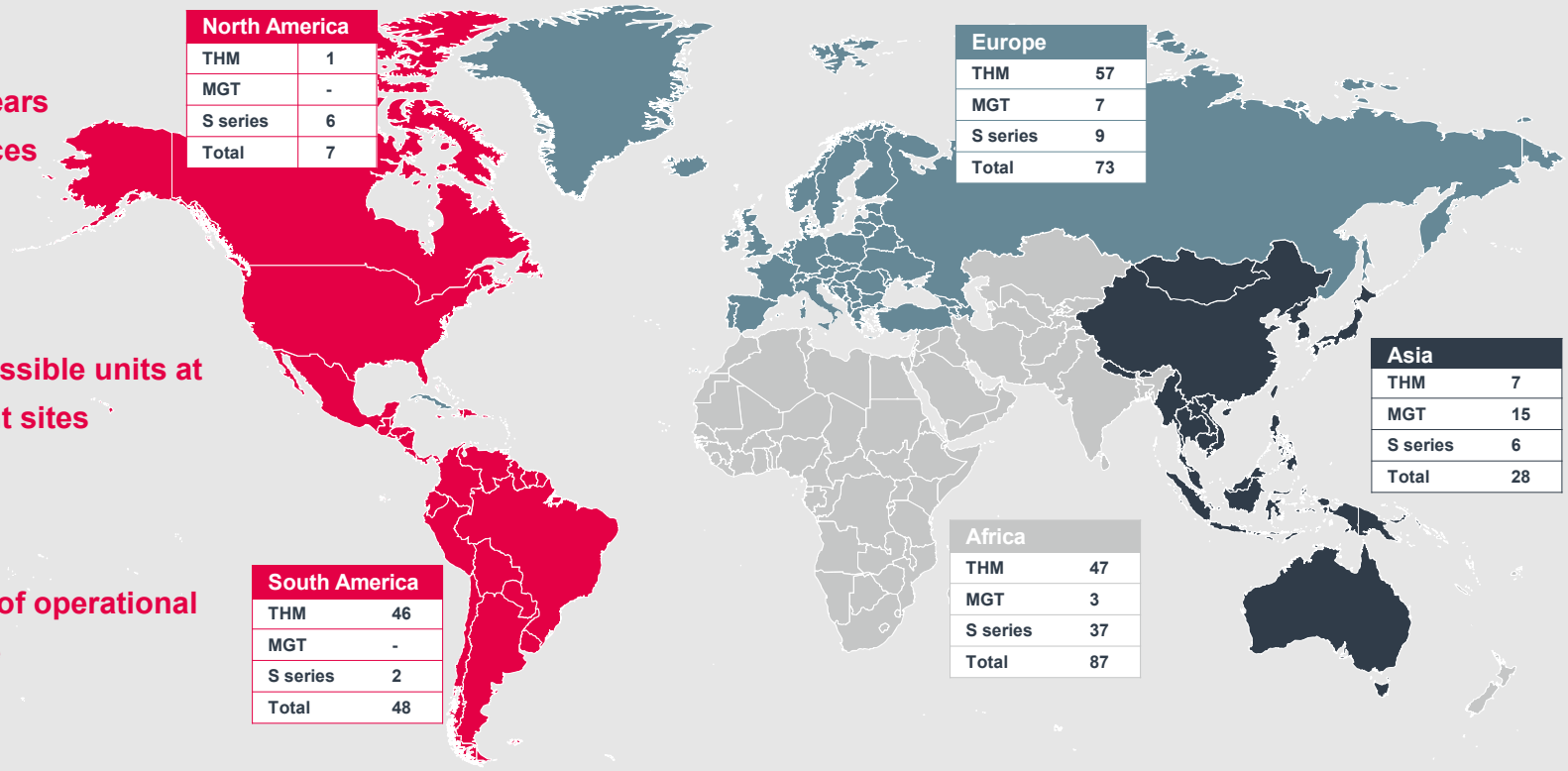
MAN Energy Solutions Gas Turbines

Global References

30 and more years of experiences

243 accessible units at client sites

50 Mio hours of operational experience



North America	
THM	1
MGT	-
S series	6
Total	7

Europe	
THM	57
MGT	7
S series	9
Total	73

Asia	
THM	7
MGT	15
S series	6
Total	28

Africa	
THM	47
MGT	3
S series	37
Total	87

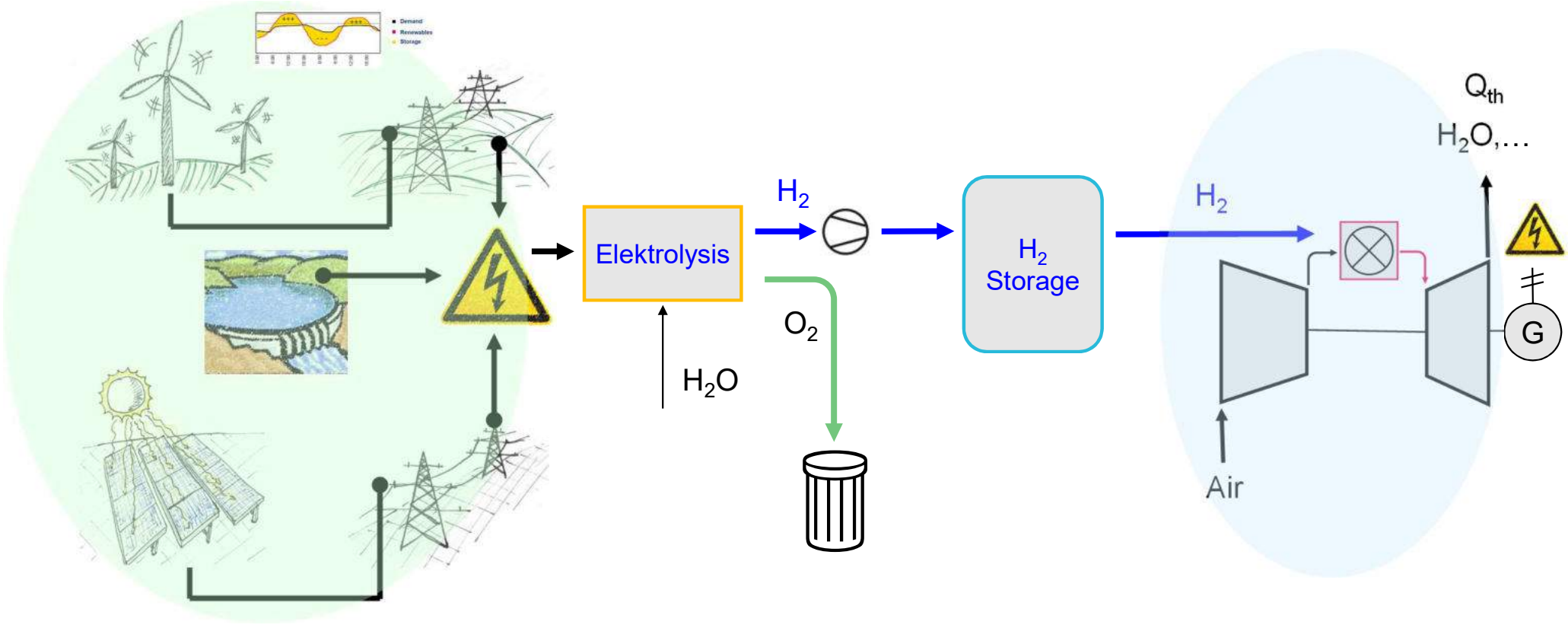
South America	
THM	46
MGT	-
S series	2
Total	48

Status Q1/2021

Re-electrification with Gas Turbines

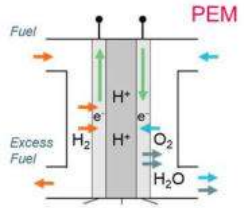
Renewable Energy Sources

Gas Turbine



Comparison: Gas Turbine, Engine and Fuel Cell

Re-electrification

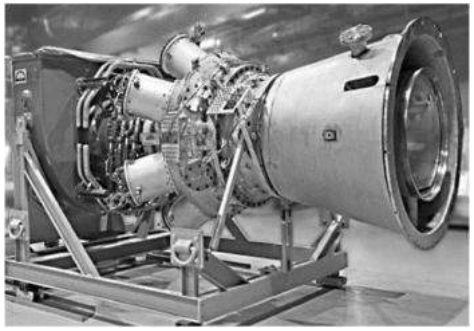
	Gas Turbine	Gas Engine	Fuel Cell, PEM
			
CAPEX	low	low	high
heat / power	power + heat	power + heat	power
efficiency	≈ 90% (CHP)	≈ 90% (CHP)	≈ 50% (el.)
power density	high	medium	low
maintenance costs	low	low	high
start-up time	medium	medium	short

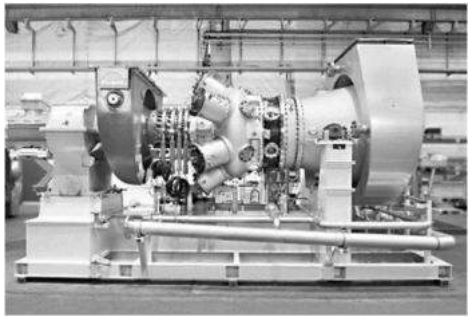
FC …Fuel Cell, CAPEX…Capital Expenditure, OPEX…Operational Expenditure, CHP… Combined Heat and Power

Gas Turbines by MAN Energy Solutions

Portfolio

MGT Series		THM Series
MGT6000 **Single shaft**	MGT6000 **Twin shaft**	THM1304-10/12N **Twin shaft**
6.63 – 7.8 MW_{el}	**6.9 – 8.3 MW_{mech}**	**10.0 – 11.5 MW_{el}** **10.5 – 12.0 MW_{mech}**



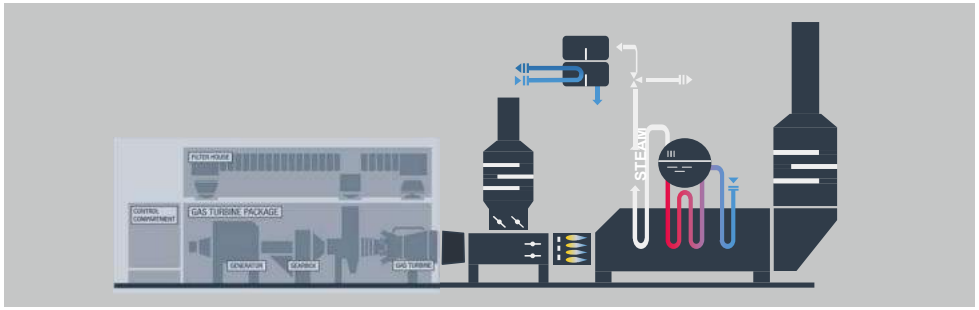


MGT Gas Turbine Series

Industries for CHP Applications

Power Supply

Medium voltage el. power



Heat Supply

Hot water

Steam

Chilled water

…

Power + Heat → Overall efficiency up to 92%

Industries with high demand for heat and power


Automotive


Tires


Chemicals


Textiles


Pulp & Paper

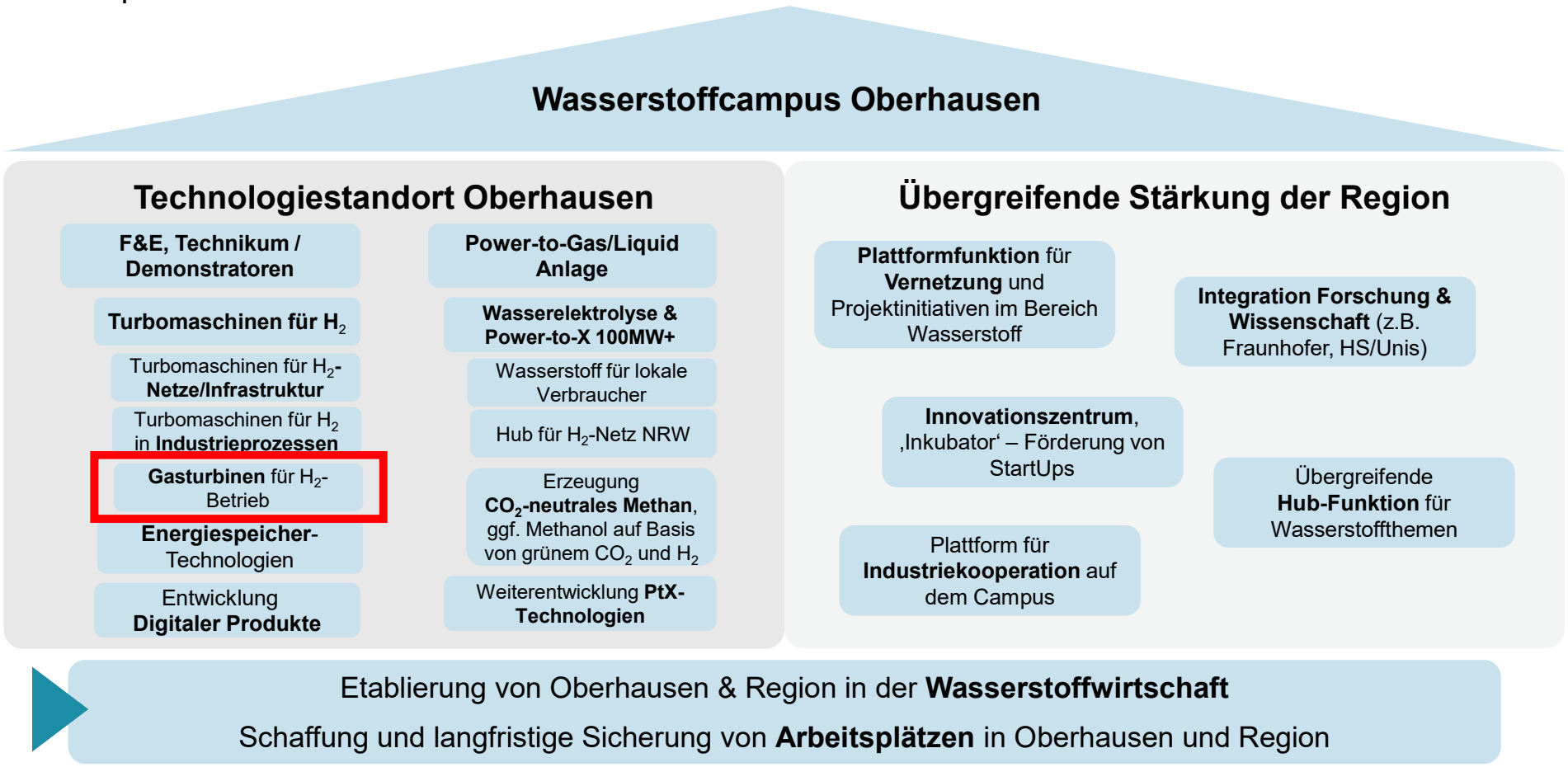

Food Processing


Breweries


District Heating

Wasserstoffcampus Oberhausen

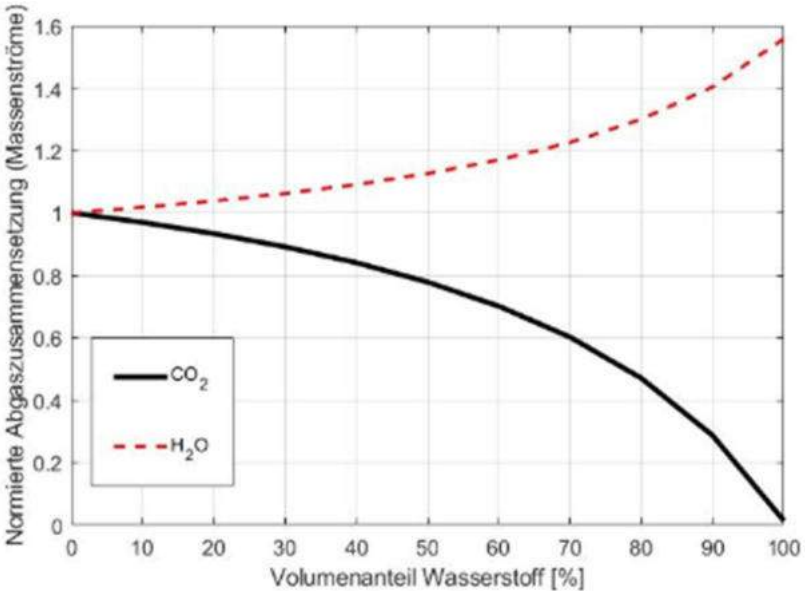
Grobkonzept Überblick



Decarbonization

Driver of our strategy

How much CO_2 can be saved with hydrogen?



Large hydrogen shares are needed to significantly reduce of CO_2

MAN Gas Turbines to use Hydrogen Fuel

Fuel Flexibility – Hydrogen (Status 04/2021)

GT Type	Combustor	Hydrogen content	Status
THM 1304 – 10/12N 	Standard (Diffusion) 	60 vol-%	✓ ready
THM 1304 – 10/12N 	ACC (Dry Low Emission) 	20 vol-%	✓ ready
MGT6000 	ACC (Dry Low Emission) 	20 vol-% 100 vol-% Target	✓ ready under development

ACC …Advanced Can Combustion

Currently Available Standard MAN Hydrogen Capabilities

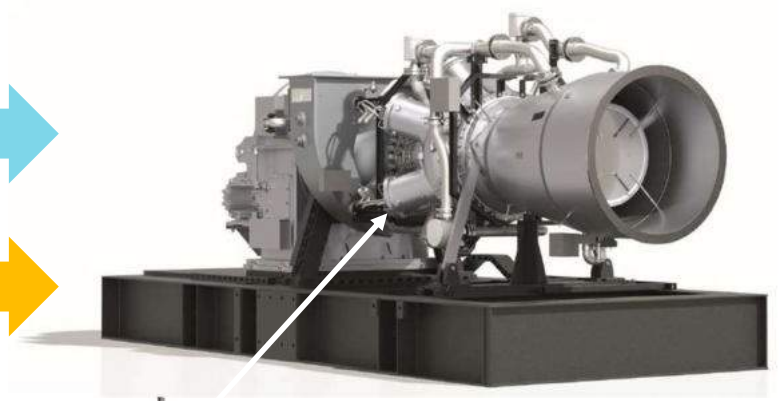
MGT6000

20 vol-% H_2

~55kg/h

80 vol-% Natural Gas

~1425kg/h



Proven radial swirl burner

6.63 MW_{el} Electrical Power

11.6MW_{th} @505°C Thermal Power

< 9 ppm NOx

< 16 ppm CO

→ Standard MAN Energy Solutions gas turbines can handle up to 20 vol-% H_2 with low emissions

→ No changes to standard package necessary

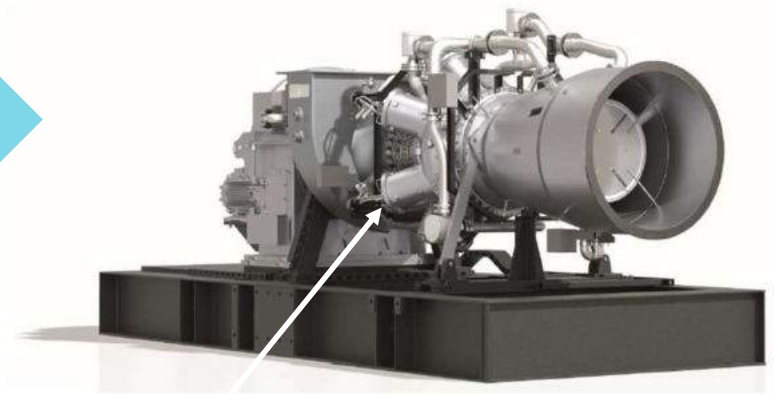
→ No restrictions to engine and package up to 20 vol-% H_2 (no dual-fuel needed, start-up possible)

Roadmap MAN Hydrogen Capabilities

MGT 6000

100%-vol H_2

~625kg/h



6.63 MW_{el} Electrical Power

11.6MW_{th} @505°C Thermal Power

New Multi Tube Burner

<15ppm NOx

→ MAN Energy Solutions is working on a 100 vol-% H_2 solution with low emissions

→ Wobbe-Index is similar, no change of fuel piping necessary

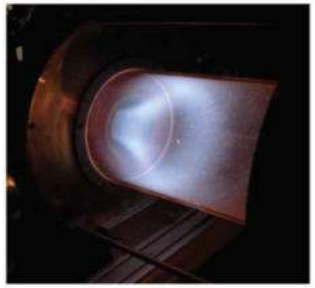
→ We are looking for a demonstrator project to showcase our joint capabilities

MGT gas turbine series

Fuel Flexibility

Hydrogen Road Map

2020	• MGT & THM are released for 20 vol-% H_2 content in the fuel gas • No modification of the standard engine or package necessary
2021	• 100 vol-% H_2: Start R&D project in collaboration with TU Berlin
2023	• Further increased fuel flexibility (including 60 vol-% H_2) • 100 vol-% H_2: development of prototype burner
2024	• 100 vol-% H_2: proof of technology in high pressure combustion tests
2025 earliest	• Sales release MGT depending upon market demand



Radial Swirl Burner, Atmospheric burner test at TU Berlin

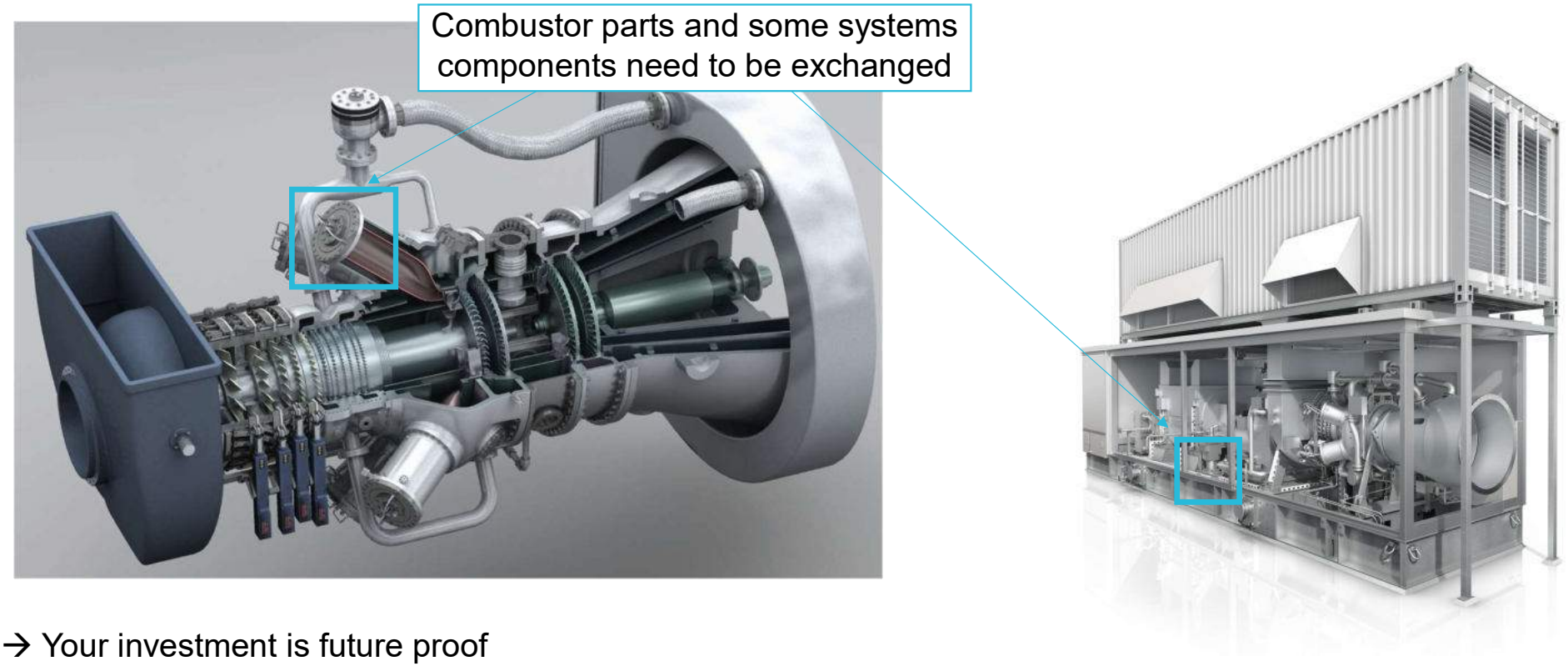
New Multi Tube Burner

2020
20 vol-% H_2

2023
(60 vol-% H_2)

2025
100 vol-% H_2

MGT Hydrogen Upgrade Strategy for 100 vol-% H_2



→ Your investment is future proof

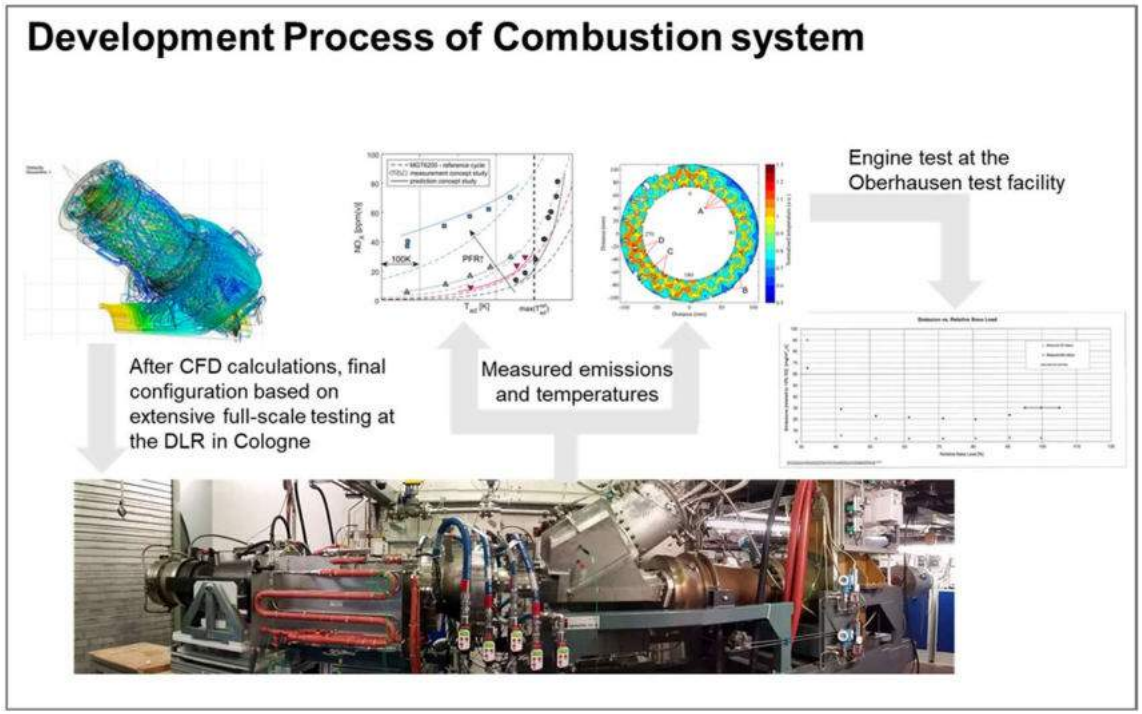
→ Retrofit for combustor needed for up to 100 vol-%H_2 (48h exchange)

→ Exchange of some systems components (valve etc.) needed due to Ex-Zone regulations

Combustor Development

Development Process

Competences



Experience - Hydrogen Combustion - MAN ES Gas Turbines

H_2 - Fuel Flexibility

Operation / Project	Combustor / Burner	Hydrogen content	Status
THM1304–8, Reichstett	Standard (Diffusion) 	max. 38 vol-%	✓ Engine Operation 144 000 OH
High Pressure Combustor Tests, DLR Cologne	ACC (Dry Low Emission) 	20 vol-% approved	✓ HP - Test done
	ACC ++ (Dry Low Emission) 	60 vol-%	in development
Atmospheric Combustor Tests, TU Berlin	Multi Jet Burner 	100 vol-% Target	in development

ACC …Advanced Can Combustion

MGT6000 gas turbine series

MGT6000 benefits at a glance

Heavy duty design: **very robust**

Fuel Distribution System: **easy, reliable and robust**

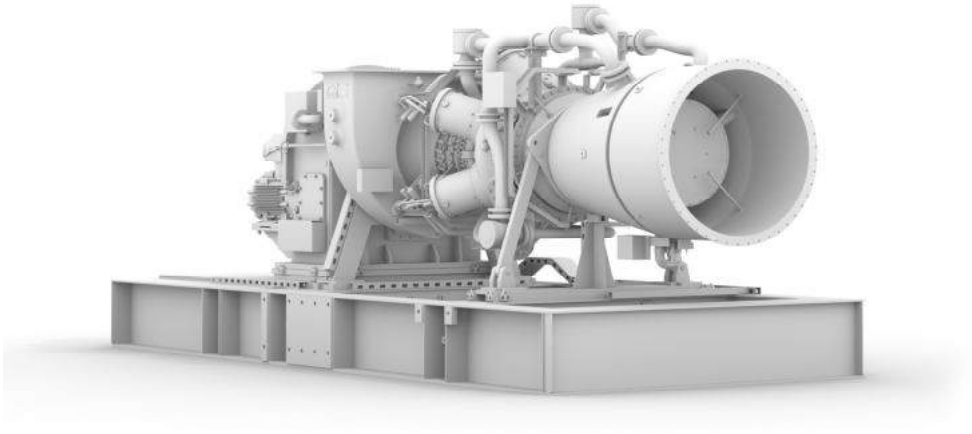
Low emissions: **NO_x < 9 ppm, CO < 16 ppm**

Long overhaul interval: **40,000 EOH**

Short installation and commissioning time: **~7 weeks**

High CHP efficiency: **up to 92%** *

World class service: **global after sales presence**



Dry Low Emission Combustor system (ACC) can operate with 20 vol-% hydrogen

We aim for a first industrial 100 vol-% H2 low NOx solution by 2025 developed within the publicly funded project “Innoturbine”

* w/o Supplementary firing, depending on process, EOH…Equivalent Operation Hours

MGT gas turbine series

Global references

Q1 2021

Total equivalent operating hours of the global MGT fleet:

> 195,000

MGT gas turbine series

Fuel Flexibility

evo Energieversorgung Oberhausen AG

1 x MGT

- Hot water production
- Ready for 20 vol-% H_2

SWK Stadtwerke Kaiserslautern

4 x MGT

- Steam production
- Ready for 20 vol-% H_2

Supply of German utilities with gas turbines ready for 20 vol-% hydrogen started.

MAN Energy Solutions
Future in the making

Thank you very much!

Frank Reiß
MAN Energy Solutions SE
frank.reiss@man-es.com
17.05.2021

Disclaimer

All data provided in this document is non-binding.
This data serves informational purposes only and is especially not guaranteed in any way.
Depending on the subsequent specific individual projects, the relevant data may be subject to changes and will be assessed and determined individually for each project. This will depend on the particular characteristics of each individual project, especially specific site and operational conditions.

KAWASAKI HYDROGEN ROAD

– DEVELOPMENT OF INNOVATIVE HYDROGEN GAS TURBINES –

KAWASAKI Gas Turbine Europe GmbH

Combine Heat and Power (CHP)

Kawasaki
Powering your potential

Kawasaki Heavy Industries - Sections

Motorcycle & Engine 20.6%

Others 6.2%

Aerospace Systems 32.4%

FY '19 Total Sales JPY1.64 Trillion (EUR 12.8 Mrd)

Rolling Stock 8.3%

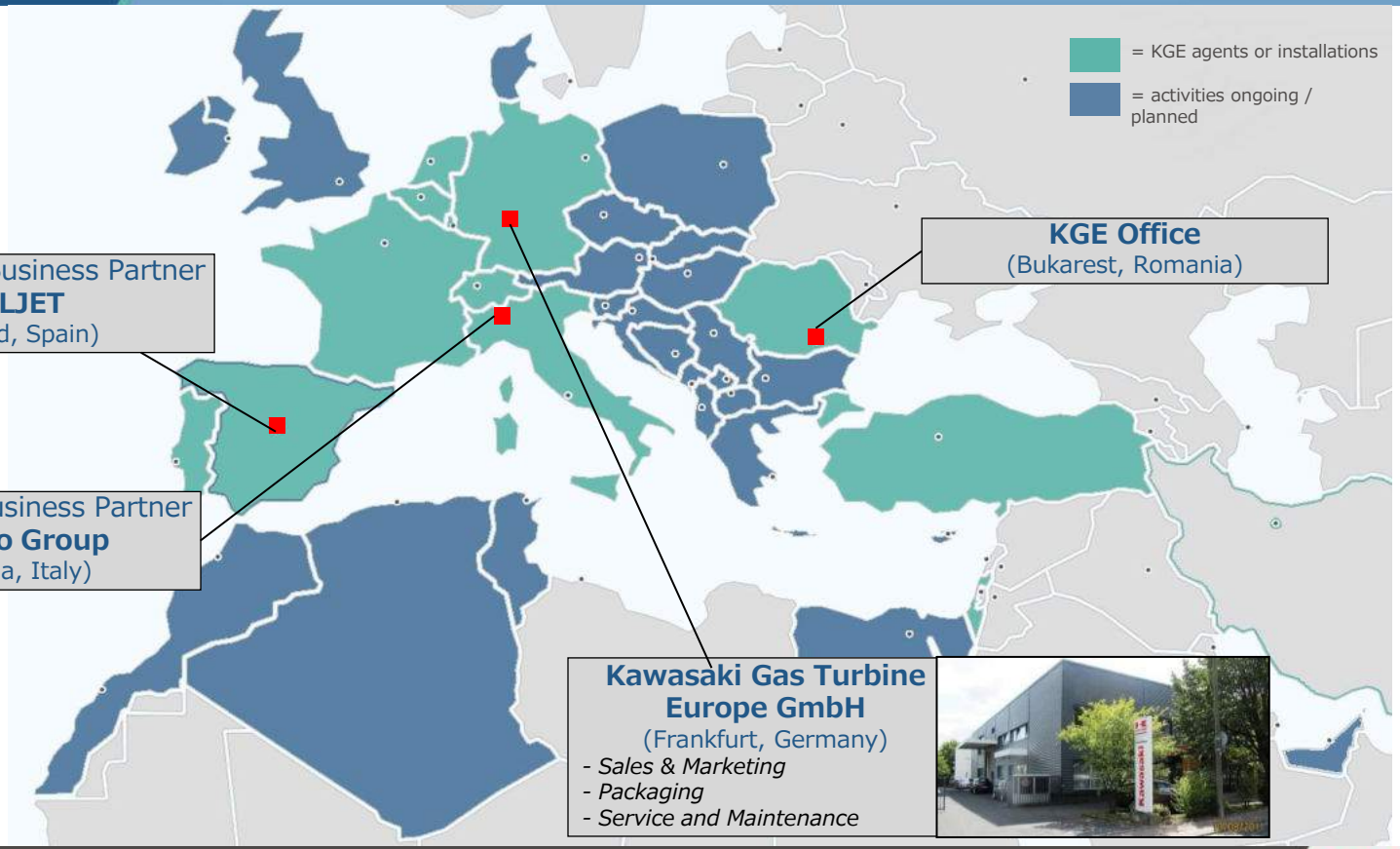
Ship & Offshore Structure 4.4%

Precision Machinery & Robot 13.2%

Energy System & Plant Engineering 14.8%

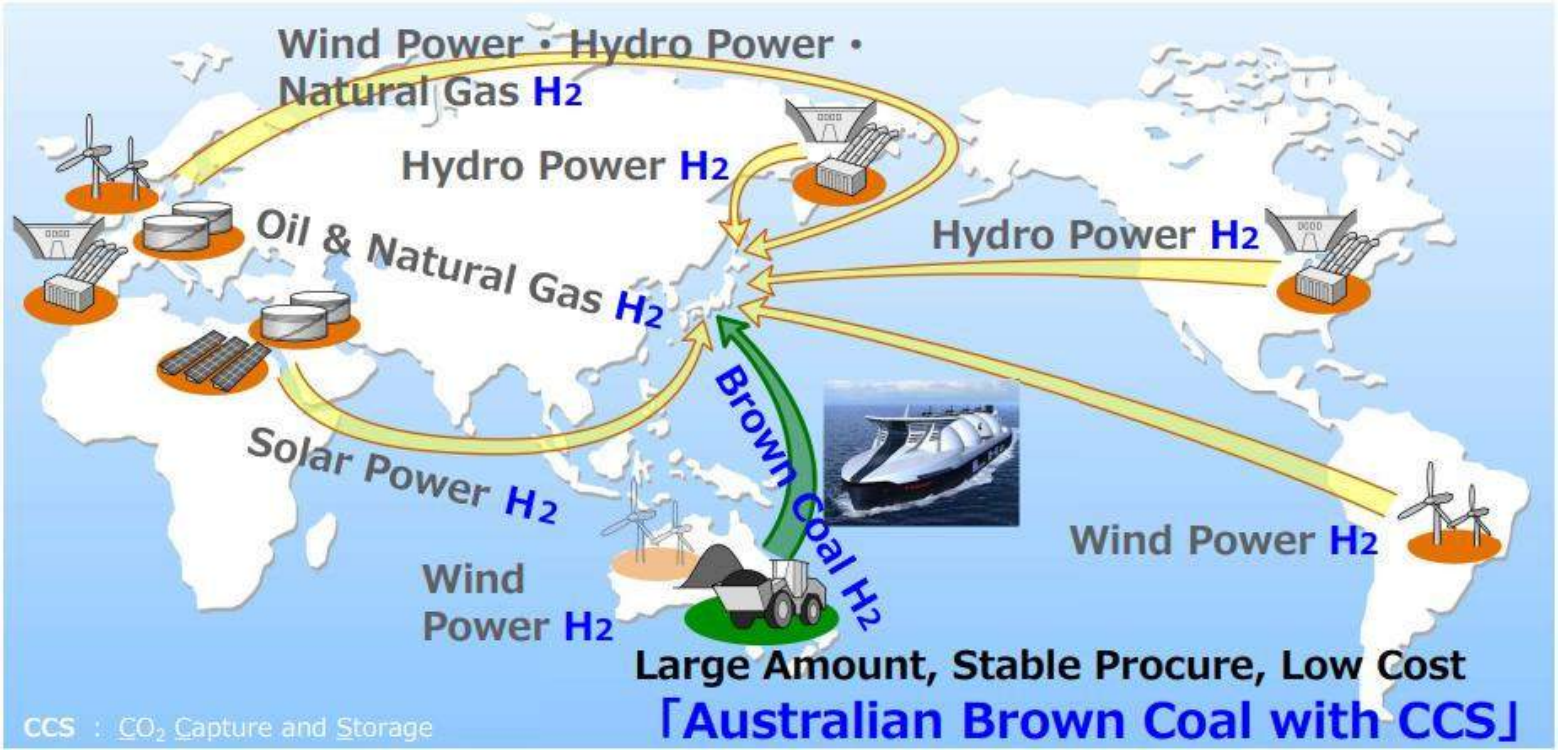
*Business year starts from Apr. 1 and end on Mar. 31
**As of the business year ending Mar. 31 2020
***On a consolidated basis
****Ex. Rate: 1 ¥ =0,0078 €

KGE - Regions of Activity



Hydrogen Road of Kawasaki Heavy Industries (KHI)

CO_2-Free Hydrogen Resources in the World



Hydrogen Road of Kawasaki Heavy Industries (KHI)

Production & Liquefaction of H_2

H_2-Gas Turbines
H_2-Compressors

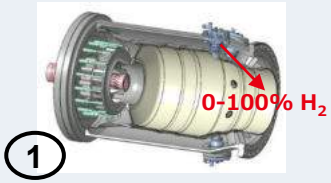
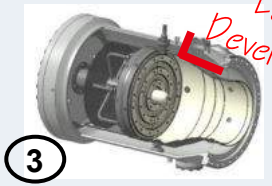
H_2-Storage Tanks

H_2-Oversea Transportation

H_2-Land Transportation

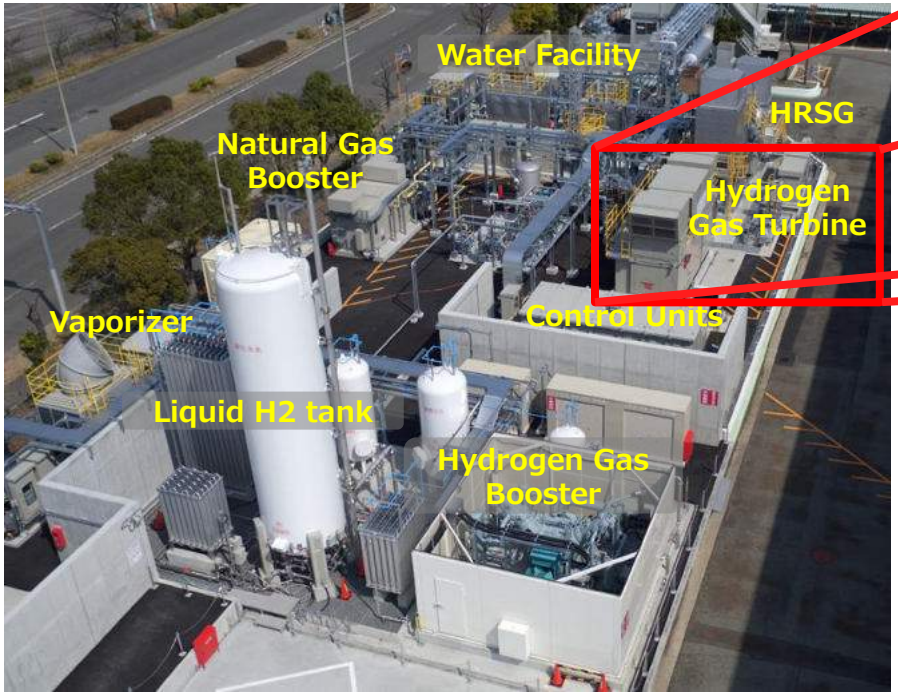
Developments for Hydrogen Gas Turbines @ KHI

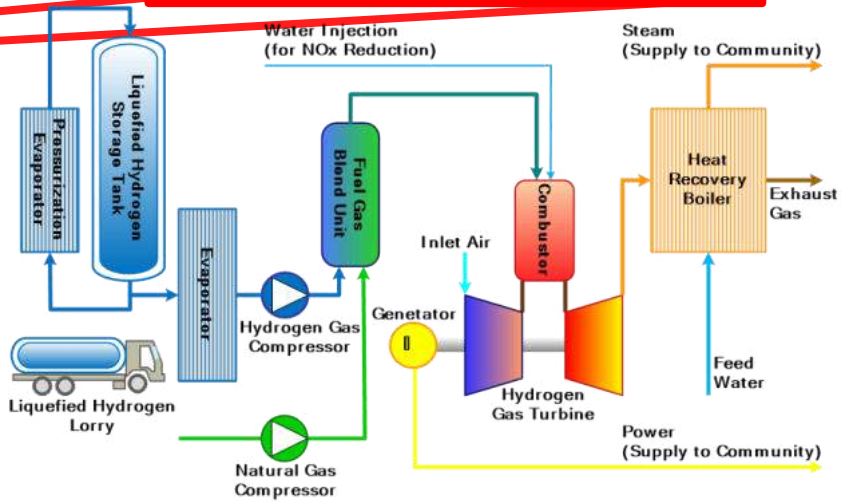
Overview of Combustor Developments

Combustor Configuration	DLE Combustor for Natural Gas	Diffusion Flame Combustor	DLE Micro-Mix Combustor
NOx Reduction	"Dry"	"Wet" Water/Steam	"Dry"
			
Max. H2 Content	60vol%	100vol%	100vol%
Status	Engine Demonstration in Akashi Works, 2014 	Final Combustor Test, 2016 Applied to KOBE Demonstration Plant, 2018 	Final Combustor Test, 2018 Applied to KOBE Demonstration Plant, 2020 

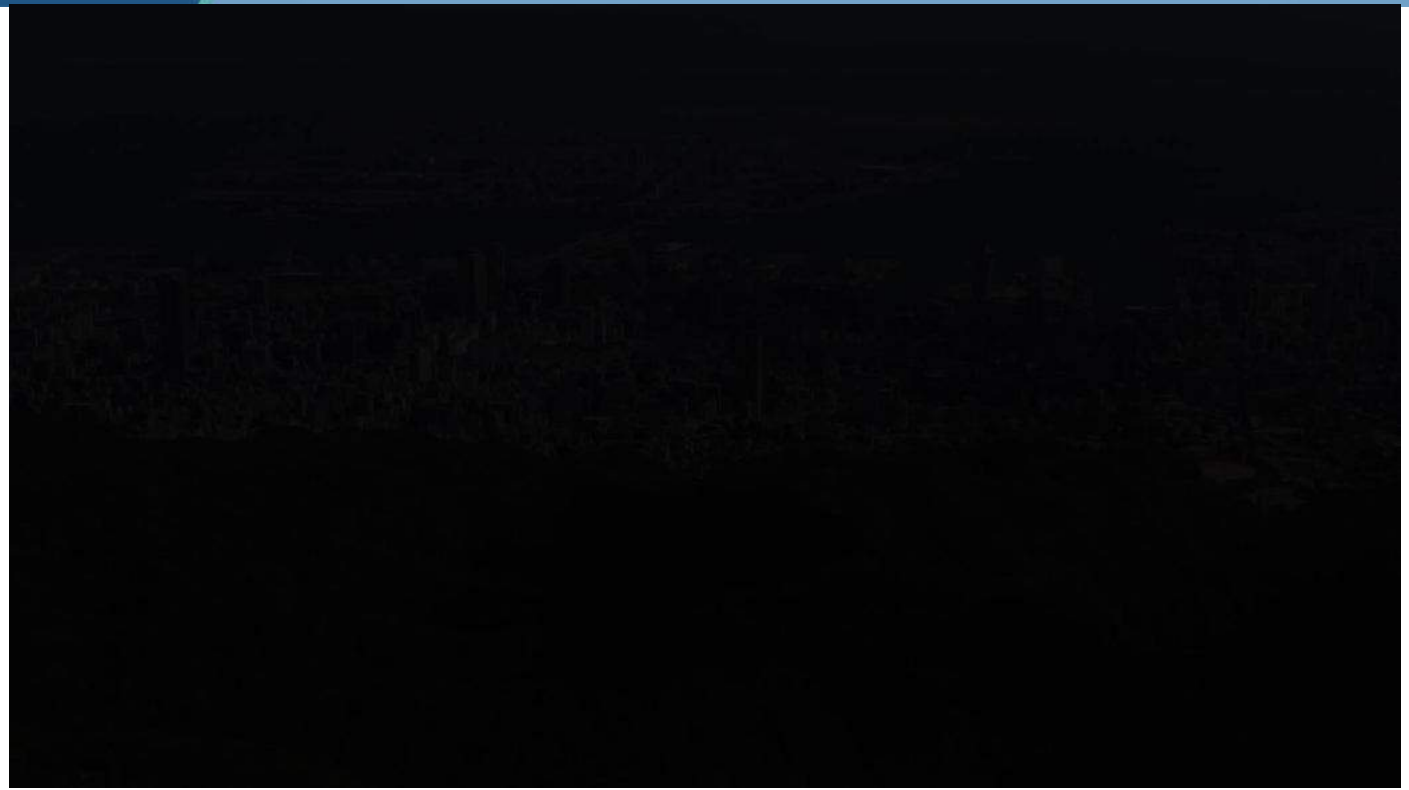
Main Difference between NG & H2 Gas Turbines is the Combustor

World's First 100% H2-CHP Power Plant at Kobe Port





World's First H2-Power Plant at Kobe Port

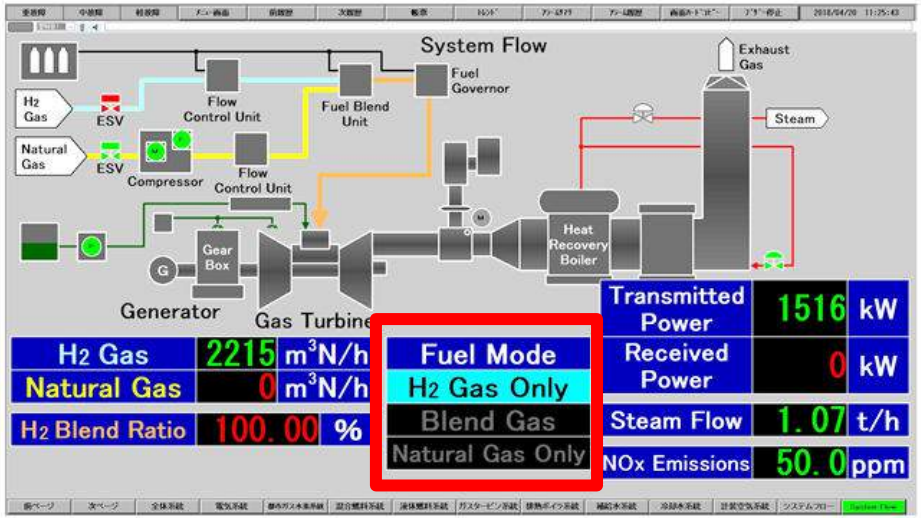


https://www.youtube.com/watch?v=dC7AZWHC2UM

Note: Follow or Copy the Hyperlink

World's First H2-Power Plant at Kobe Port

User Control Interface



Comparison between NG & H_2

Gas Turbine Type		M1A-17	M1A-17
Fuel type		Natural Gas	Hydrogen
Electrical power	kW	1,848	1,902
Fuel input	kW	6,845	6,907
Efficiency	%	27.0	27.5
Exhaust gas mass flow	kg/s	7.98	7.89
Exhaust gas temperature	°C	529	528
Generator voltage	kV	0.4 / 6.3 / 10.5	0.4 / 6.3 / 10.5
Steam mass flow 8 bar(g) saturated	t/h	5.2	5.2
NOx Reduction method		Water injection	Water injection
Emissions (NOx)	ppm	37	73
Emissions (CO2)	%	3	**0.0**

Performance at 15°C, 60% RH, at Generator Terminal,
Inlet Pressure Loss 0,98 kPa, Exhaust Pressure Loss 2,45 kPa

11 000 tons of CO2 emissions reduction annually

(1.8 MW Gas Turbine)

World's First H2-Power Plant at Kobe Port

Interchangeable Combustor Equipment on the Gas Turbine Set

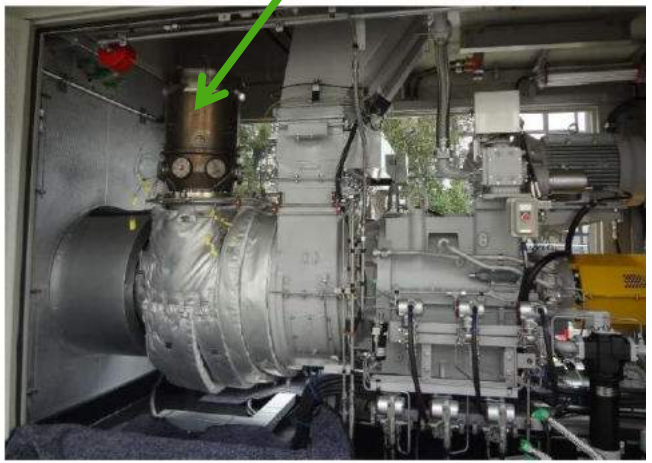
Diffusion Flame Combustor

Tests & Demonstration 2018-2020

- Best Choice for Mixture
- Highest Fuel Flexibility
- Water/Steam Injection

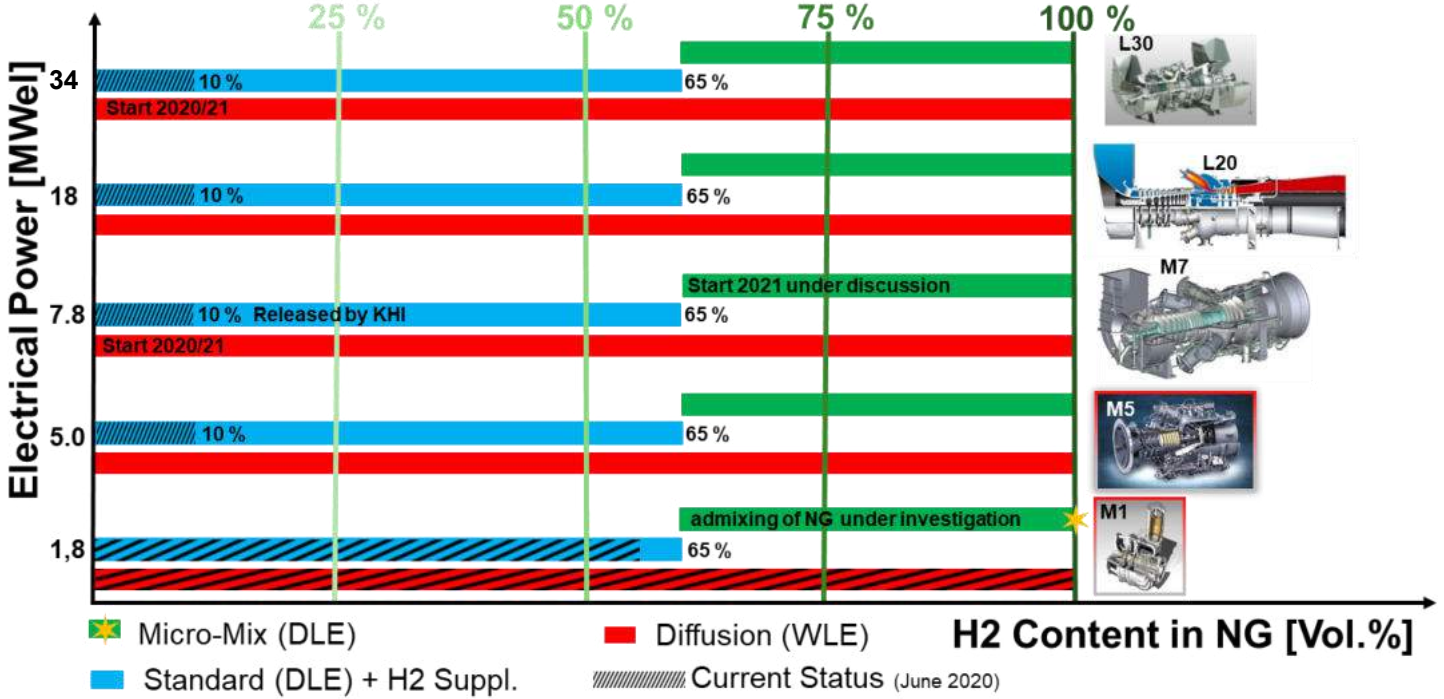
Micro-Mix DLE Combustor

Tests & Demonstration 2020-2022

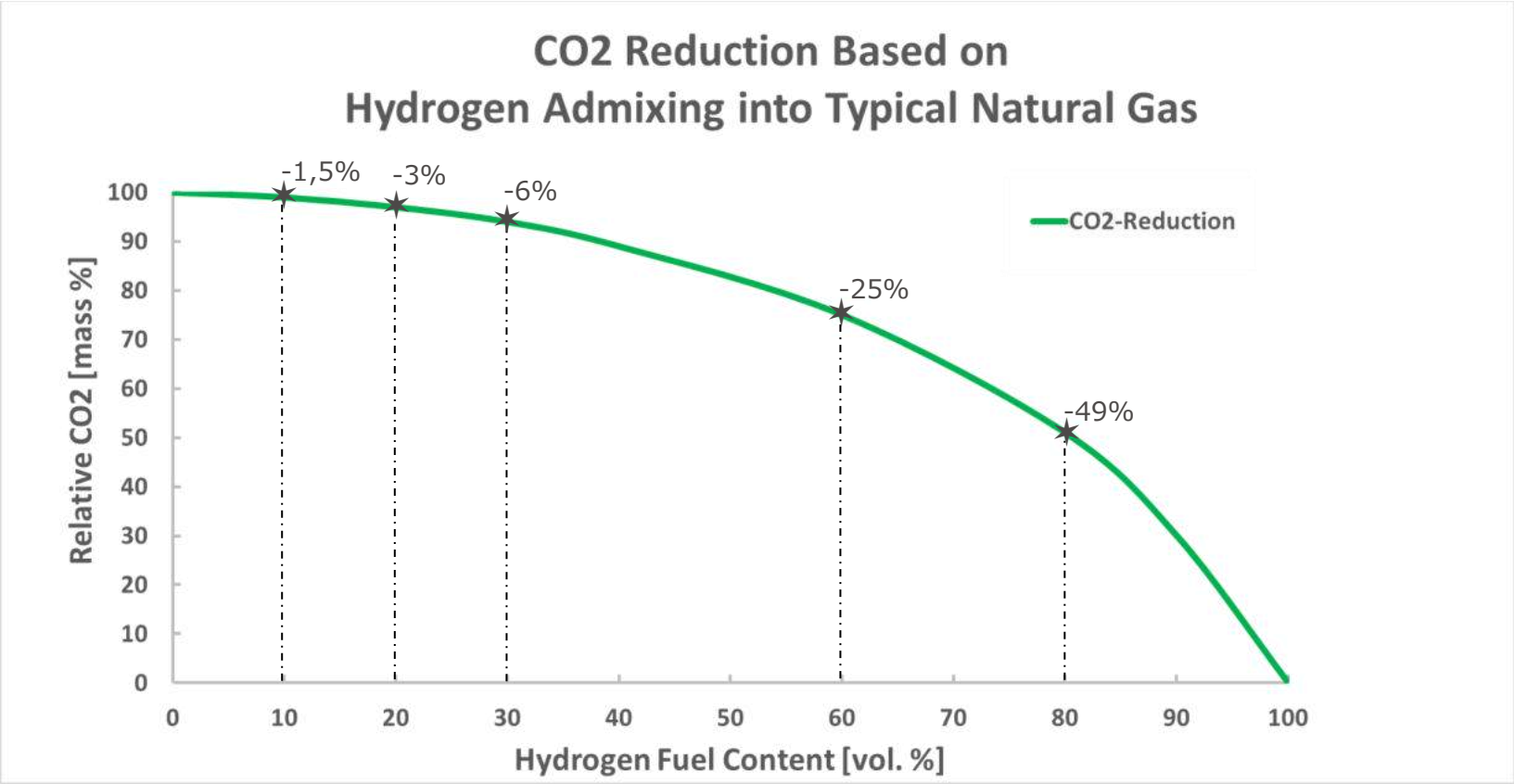


- 100% H_2-DLE
- Technological Breakthrough
- Dry Combustion

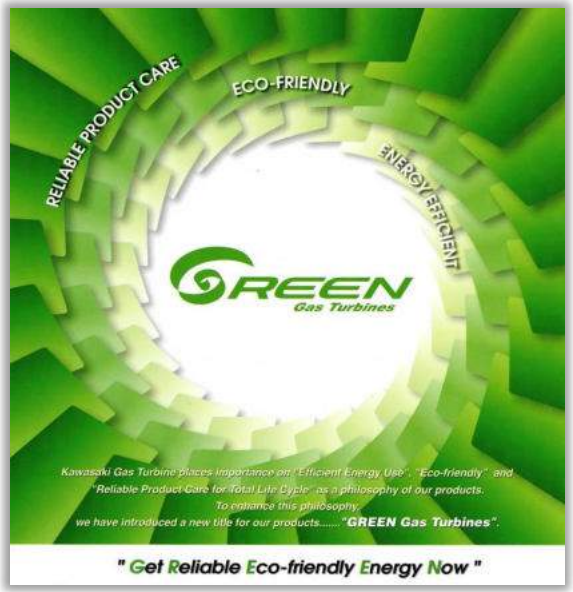
Hydrogen Capability of Gas Turbines @ KHI



Impact of Hydrogen Admixing on CO2 Reduction



KAWASAKI Gas Turbine Europe – Contact details



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