Flagship Project
TransHyDE

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AppLHy! – Transport and Application of Liquid Hydrogen

Michael Wolf, KIT, 28.03.23

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Hydrogen flagship projects

- Project duration: 04/2021 – 03/2025
- Funding: approx. 705M €
- > 230 Partners

The three hydrogen flagship projects are a central contribution of the Federal Ministry of Education and Research (BMBF) to the implementation of the National Hydrogen Strategy. Taken together, they represent one of the BMBF's largest funding initiative on the subject of energy transition.

Flagship Project
H_2Giga

Flagship Project
H_2Mare

Flagship Project
TransHyDE

Flagship Project
H_2Giga

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H_2Giga

H_2Giga researches and develops technologies for the industrialization and upscaling of water electrolysis – a prerequisite for producing green hydrogen on a gigawatt scale.

Photograph ©: Siemens Energy AG, thyssenkrupp AG, H-TEC Systems GmbH, ITM Power Linde GmbH, Sunfire GmbH (from top left to bottom right)

H_2Mare

H_2Mare is researching the offshore production of green hydrogen and other Power-to-X products with novel wind energy applications. They have an integrated electrolyser and storage tank and do not require a grid connection.

Source: © Siemens Gamesa Renewable Energy

TransHyDE

- Project duration: 04/2021 – 03/2025
- 83 + approx. 20 associated partners
- Project volume: approx. 181M €,
  - Funding: approx. 135M €

TransHyDE develops various supra-regional storage and transport infrastructures for green hydrogen, evaluates, demonstrates and scales them up.

Coordinators

Robert Schlögl

MAX PLANCK GESELLSCHAFT

Mario Ragwitz

Fraunhofer IEG

Jimmie Langham

cruh21 enabling energy innovation

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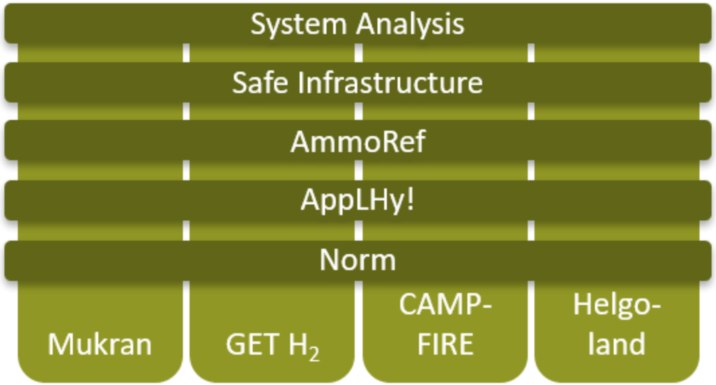
Organizational Structure



- Four projects are implementing pilots for H_2 transport technology options and demonstrating industrial scaling.
- They are supported by five research associations through
  - developing solutions to obstacles that arise.
  - evaluation of technologies and necessary framework conditions.
  - developing an implementation plan as a recommendation to policy makers.

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TransHyDE-Project AppLHy! – Transport and Application of Liquid Hydrogen (LH_2)

- Project duration: 04/2021 – 03/2025
- Project volume: approx. € 17 million, funding: approx. € 15 million
- 8 partners, 1 associated partner

amprion

HTW – Hochschule für Technik und Wirtschaft Dresden – University of Applied Sciences

KIT – Karlsruher Institut für Technologie

IFW – Leibniz Institute for Solid State and Materials Research Dresden

Linde – Making our world more productive

SciDre – Scientific Instruments Dresden GmbH

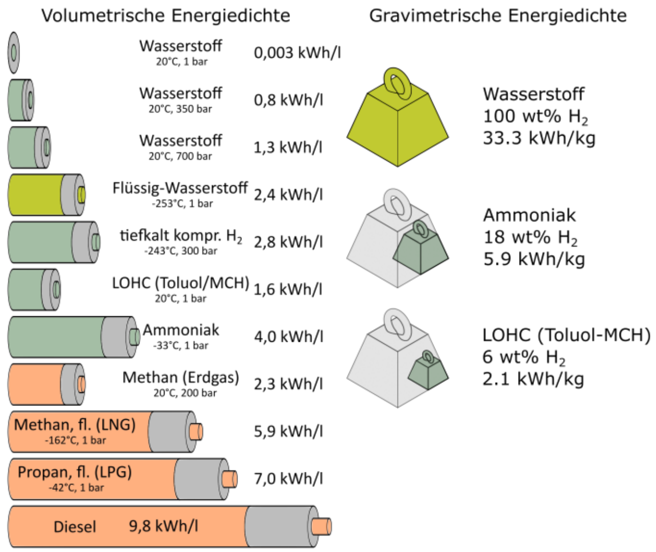
Technische Universität Dresden

THEVA

Vision® Electric Super Conductors

Properties and advantages of liquid hydrogen (LH_2)

- moderate volumetric (2.4 kWh/l) and high gravimetric (33.3 kWh/kg) energy density
- High purity
- Storage & transport at low pressure
- Energy requirement (renewable) for H_2 liquefaction at the point of H_2 generation
- No high temperatures needed for H_2 release
- Ready for use as fuel e.g. in commercial vehicles, trains, ships, airplanes and in industrial scale use for decades (e.g. semiconductor industry, aerospace)



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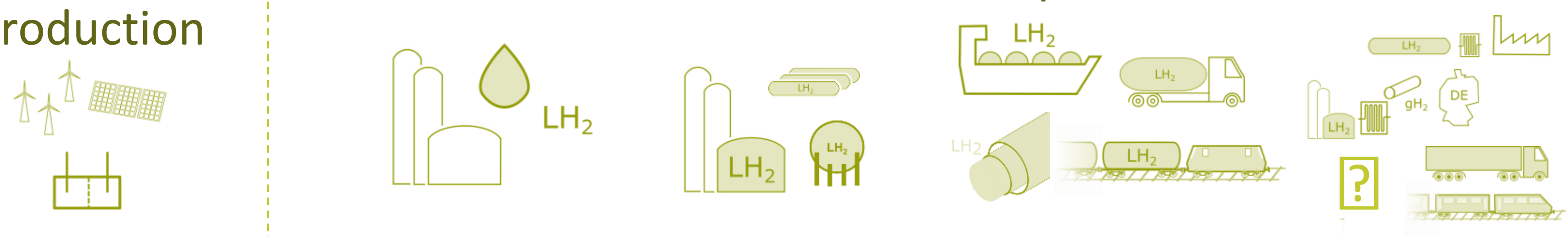
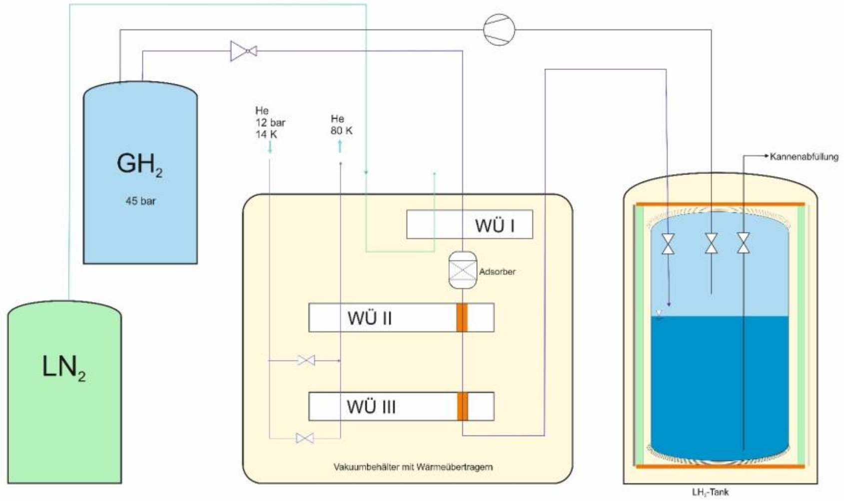
Liquid Hydrogen (LH_2) supply chain

Green H_2 Production | Liquefaction | Storage | Transportation | Use



AppLHy! addresses relevant aspects along the LH_2 supply chain

Hydrogen liquefaction

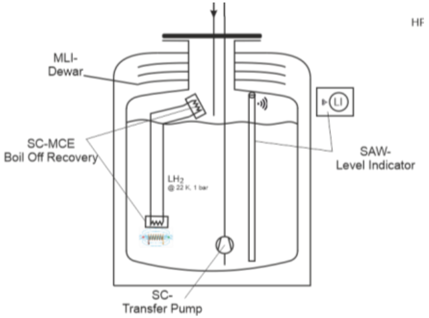


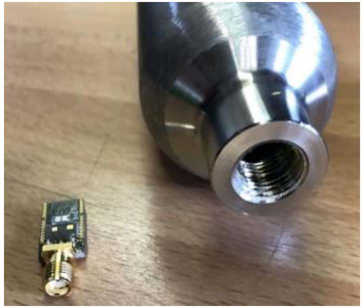
- Key parameters of the H_2 liquefier under development at KIT:

- LN_2 pre-cooling
- Further cooling & OP-Shift using a Helium mass flow from an 600 W Helium cryoplant

- Targeted LH_2 flow rate: ~ 175 l/h
- LH_2 storage capacity: ~ 2000 l LH_2

Efficient hydrogen storage





- Research into efficient, integrated LH_2 storage and the components required for this, such as
  - Contactless LH_2 level measurement
  - Re-liquefaction
  - LH2 pumps

- Damping of surface acoustic waves (SAW) in LH2 confirmed
- SAW sensors are working in LH2 and can be used as LH2 level meter

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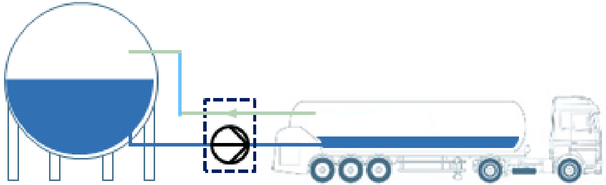
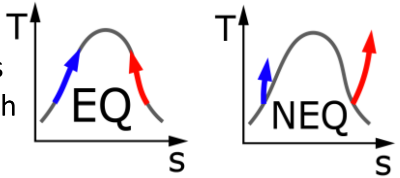
Focus: improve efficiency of LH_2 distribution



1. Modelling & Simulation of LH2 distribution chain

- Software tool for LH_2 distribution is developed
- it includes typical operation required for LH2-handling: de-pressurization of vessel by venting, loading of vessel by liquid, transport with heat inleak, pressurization by means of LH2-evaporation, off-loading, sloshing etc.
- It is based on equilibrium approach (for sloshing and de-pressurization) as well as on non-equilibrium approach for other operations

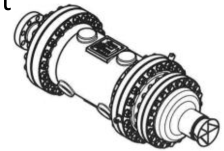


2. Observations / Learning

- Considerable difference in results between equilibrium-based and non-equilibrium-based approach
- Rapid operations are more efficient in terms of liquid loss
- Development of accelerated procedures and corresponding hardware components is required to take the advantages of rapid loading

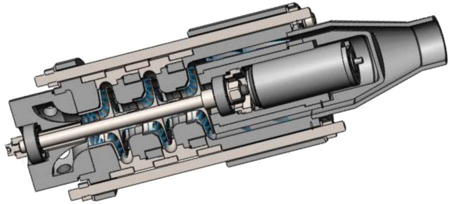
3. Development of centrifugal LH2 pump

- Centrifugal LH_2 pump can help to accelerate LH_2 transfer processes and make them more efficient
- First centrifugal LH2 pump is available from Linde´s Cryostar



Flagship Project TransHyDE · TECHNISCHE UNIVERSITÄT DRESDEN · SciDre Scientific Instruments Dresden GmbH · HyLiq · GEFÖRDERT VOM Bundesministerium für Bildung und Forschung

Efficient LH_2 transfer – development of LH_2 pumps



TU Dresden

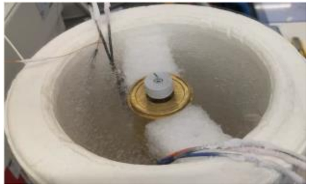
Novel LH_2 turbo pump with ball bearing for filling of LH2 tanks (low pressure)

Status

- ✓ Design of the impeller completed
- ✓ Pump in detailed engineering
- x Choice of bearing ongoing

ScIDre GmbH

Cryopump with superconducting bearings



Status

- ✓ Positioning of superconducting bearings tested in LN_2
- ✓ Safety assessment and analysis of natural frequencies completed

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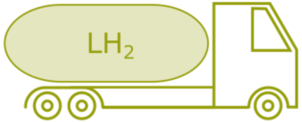
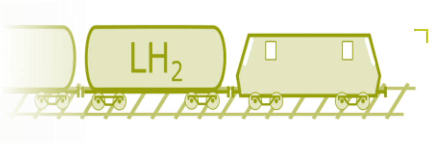
LH_2 Transport options



- LH_2 Delivery Trailer / Truck
  - Status: in operation in Germany

- LH_2 ships [7,11,12]
  - Status: capacity of largest LH_2 ship: 1250 m³ (~ 90 t) LH_2
    designs ongoing for ships up to 160.000m³ (~10.000 t)
    Large-scale import hubs for LH_2 are not existing yet.



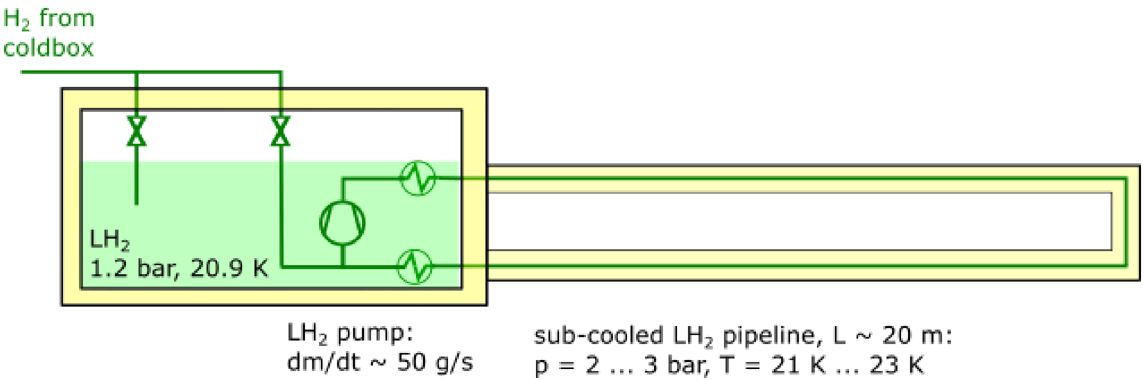
- Railway tank wagon [6]
  - Status: in operation – but not in Germany

- LH_2-Pipelines [6,13]
  - Status: in operation only in industrial facilities

Trailer-based LH_2 supply chain exists, international supply chain needed

LH_2 pipeline

- H_2 massflow from the liquefier coldbox is expanded in a LH_2 pump cryostat.
- LH_2 pump + heat exchangers supply a LH_2 pipeline with 50g/s sub-cooled LH_2



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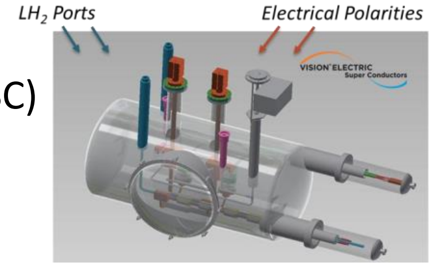
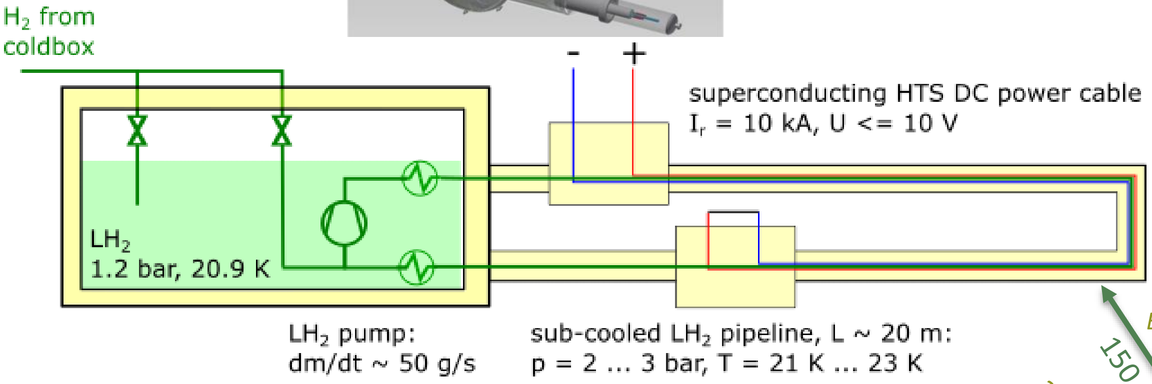
Hybrid pipeline = superconducting power cable + LH_2 pipeline

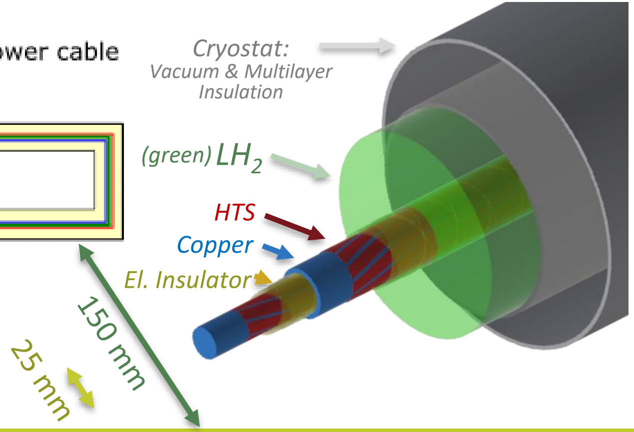
- Current Leads (design by VESC)



One conceptual design option of a hybrid pipeline:

- Electric: U_r = +/- 10 kV, I_r = 10 kA → P_{el} = 200 MW
- LH_2: dp/dx = 10 Pa/m, $\dot{m}$ = 1,67 kg/s → P_{LH2} = 200 MW





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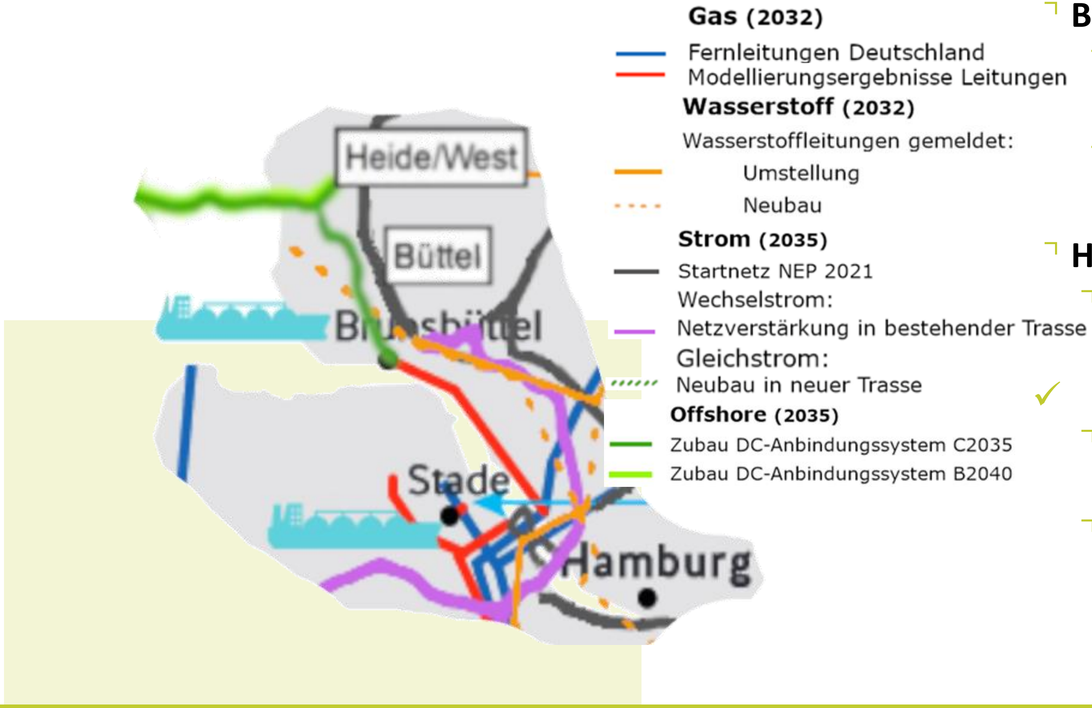
Techno-economic case study of a hybrid pipeline

Considering Existing Network & Grid Development Plans



- **Brunsbüttel**
  - LNG Terminal (2022/2023): In Future Potentially a LH_2 Terminal
  - Electrical Grid Interconnection Point: Onshore & Offshore
- **Hamburg**
  - Large H_2 Demand: 5-7,6 TWh/a in 2030 – Industry, Ships and Aircrafts
- ✓ **Brunsbüttel → Hamburg**
  - High Flows of Hydrogen and Electrical Energy
  - More Hydrogen Pipelines and Electrical Grids Needed

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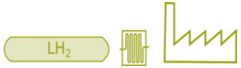
Applications of Liquid hydrogen (LH_2)



- Goal: Local H_2 supply
- Benefits: high volumetric energy density of LH_2, high purity of H_2 from LH_2
- Status: Existing, e.g. in semiconductor industry, H_2 fueling stations (gH_2 and LH_2)

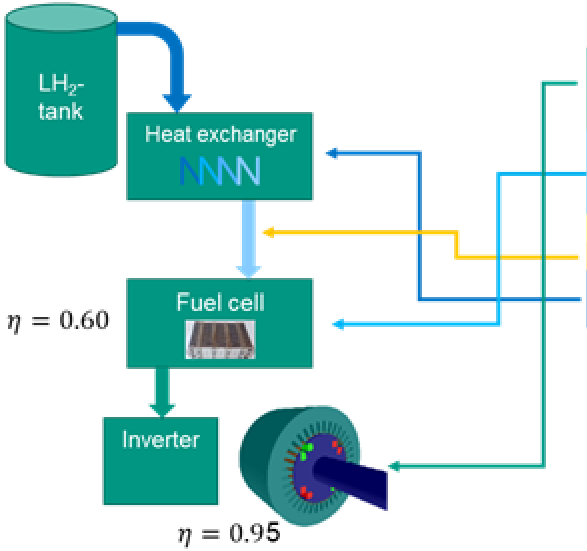
- Goal: supply of large-scale gH_2 grids, peak shaving
- Benefits: volumetric energy density of LH_2, highly dynamic feed-in, no further processing
- Status: not realized on grid-scale

- Goal: CO_2-free aviation fuel
  Benefits: high gravimetric and volumetric energy density of LH_2
- Status: Research and Development ongoing

- Goal: CO_2 free fuel of large and heavy vehicles on non-electrified tracks
  Benefits: high volumetric energy density of LH_2, use of LH_2-cold for cooling
- Status: Research and Development ongoing / pre-series truck presented

Local LH_2-based supply chains exist today, many future applications – both stationary and mobile

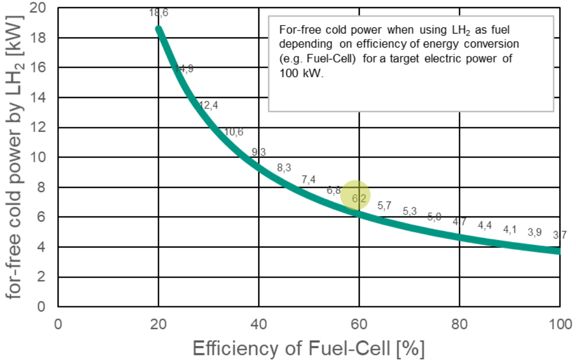
LH_2 –cooled motor with conventional drive-train



shaft power	100,00 kW
efficiency drive	0,95 n.a.
electric power input to drive	105,26 kW
Fuel cell output power	105,26 kW
efficiency FC	0,60 n.a.
input power to FC (H2)	175,44 kW
energy density H2	33,30 kWh/kg
mass flow H2	5,27 kg/h
cold energy LH2-gH2	1,24 kWh/kg
cold energy by mass flow H2	6,53 kW

Good fit:

- Drive train loss: 5 kW
- for-free-cold: 6.53 kW



Cold of required LH_2 may be used to compensate the loss of conventional electric drives.

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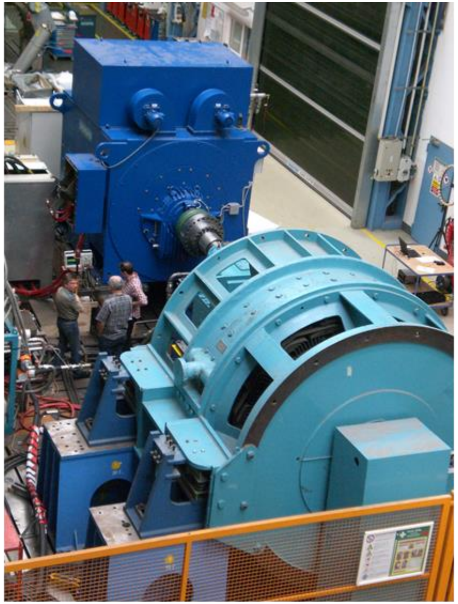
LH_2 –cooled superconducting motor (KIT)



Courtesy: Siemens AG

HTS-Motor:

- power: 4 MW
- weight: 36 ton
- speed: 120 rpm
- poles: 8
- efficiency:
- cold loss: <115 W_{max} < 0.003% << 6.2%

Nick, W., et al. (2012). "Test results from Siemens low-speed, high-torque HTS machine and description of further steps towards commercialisation of HTS machines." Physica C: Superconductivity and its Applications **482**: 105-110.

LH_2-fuel cell energized HTS-motors can be realized w/o additional cooling systems→high efficiency!

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LH_2 –cooled superconducting Motor (KIT)

Example: high performance compact HTS motor for electric aviation

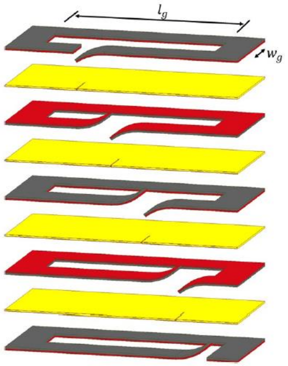
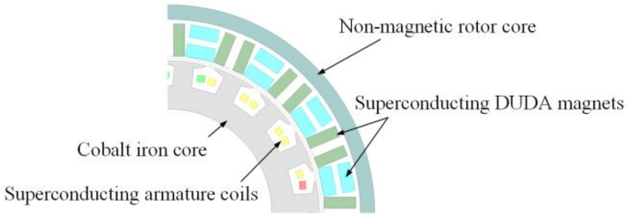


Figure 3. Exploded view of rectangular DUDA with gap of width w_g and length l_g. Red: HTS layers, grey: substrate, yellow: intermediate Kapton layer.



Stator topology	AC losses (W)	Iron losses (W)	Armature current density (A/mm²)	Specific power density (kW/kg)
Parallel teeth and 4 mm coils	1302	6980	102.30	9.98
Parallel slots and 4 mm coils	1317	6830	105.04	10.32
Parallel teeth and 2×2mm coils	1348	6520	105.87	10.89
Parallel slots and 2×2mm coils	1384	6160	110.75	11.55

The losses and specific power density of the four stator topologies while achieving an efficiency of 98%.

[Arndt, T., et al. (2021).
"New coil configurations with 2G-HTS and benefits for applications."
Superconductor Science and Technology **34**(9).]

[R. Wang, Y. Liu, J. Cao, L. Li, X. Liu, H. Xue, T. Arndt „Preliminary design optimization of a fully superconducting motor based on disk-up-down-assembly magnets“ accepted manuscript Superconducting Science and Technology - to be published soon]

DUDA is enabling extremely compact high-current density windings of outstanding performance (>11 kW/kg @98%)

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Conclusion

- **TransHyDE** develops storage and transport infrastructures for green hydrogen and addresses various H_2 transport vectors (gH_2 in pipelines and containers, LH_2, NH_3, LOHC)
- The TransHyDE project **AppLHy!** focuses on LH_2 and addresses key elements along the LH2 supply chain:
  - H_2 liquefaction
  - Efficient storage systems
  - LH_2 transportation and transfer
  - Hybrid Pipelines
  - Applications and synergies of LH_2 – e.g. LH2-cooled superconducting motor of high power density
- A **whitepaper LH_2** was prepared from authors of the AppLHy! project, available online:
  - Link to the Whitepaper on LH_2