ELEKTRA-Video

ELEKTRA – Energy System and Push Boat

© Dr. S. Gaida

First experience:
Design – Engineering – Construction and first sea trials

Prof. Dr.-Ing. Gerd Holbach
CAESES User Conference - Berlin
22. September 2022

Gefördert durch: Bundesministerium für Digitales und Verkehr
Koordiniert durch: NOW GMBH.DE
Projektträger: PtJ

Lecture motto

close to
Johann Wolfgang von Goethe

ELEKTRA 2016 – 2022

Zwar durfte ich viel lernen, doch möcht' ich alles wissen

I have learned very much, but I like to know everything

ELEKTRA: not only a Study to the preceding Study

Overview

Requirements, Construction and Realization

Idea & Layout

- Ship
- Energy System
  - Accumulator System
  - Fuel Cell System
  - Hydrogenstorage

Infrastructure

- Shoreside Electricity
- Hydrogen

First (subjective) experience

Summary

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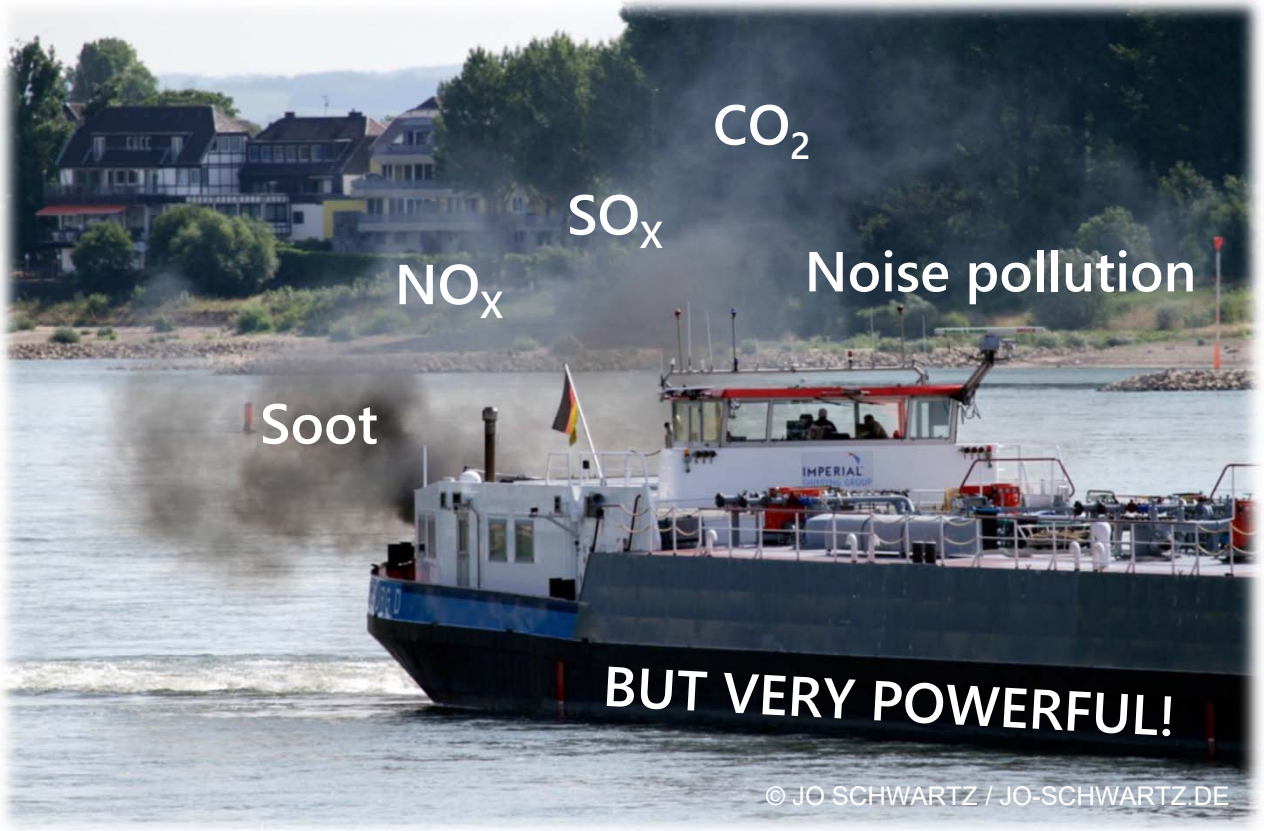
Summary

ELEKTRA = protection of the environment

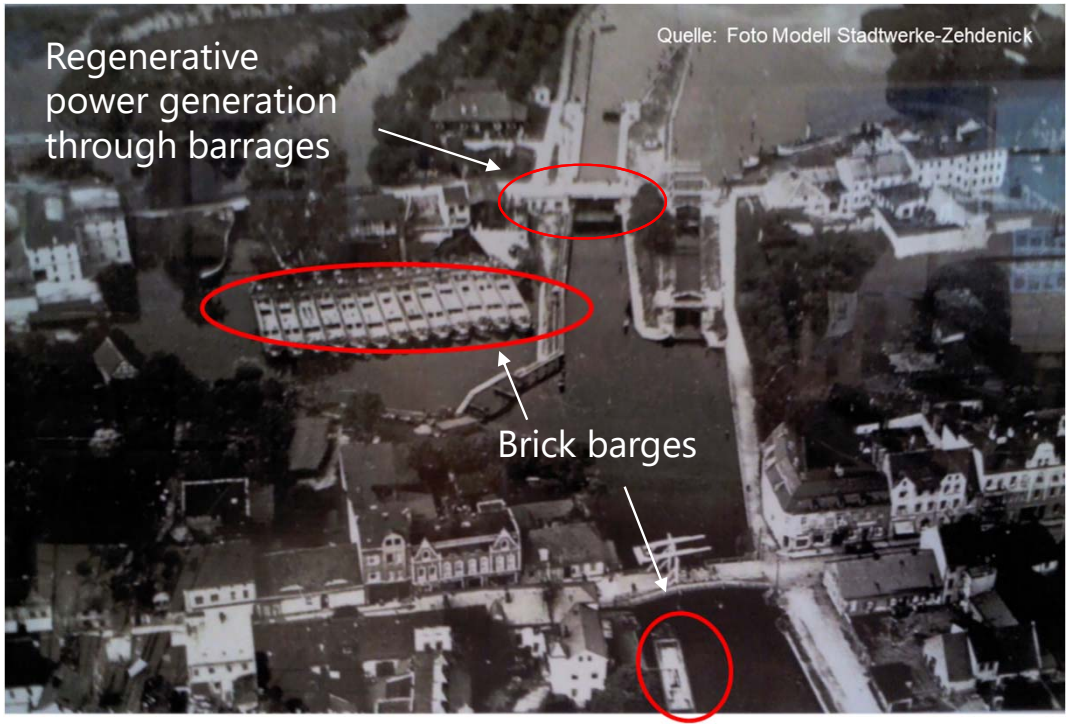
- 1880
  Berlin resident complain
  about steam ships =>
  Berlins first electroboat 1886

- at 1910
  approx. 120 accumulator powered
  cargoships for the supply of Berlin



ELEKTRA = protection of the environment, but not really new

In 1886, the Berlin-based company Siemens tested the first electro passenger boat – called "ELECTRA" – with 25 passengers at a velocity of 14 km/h on the river Spree.

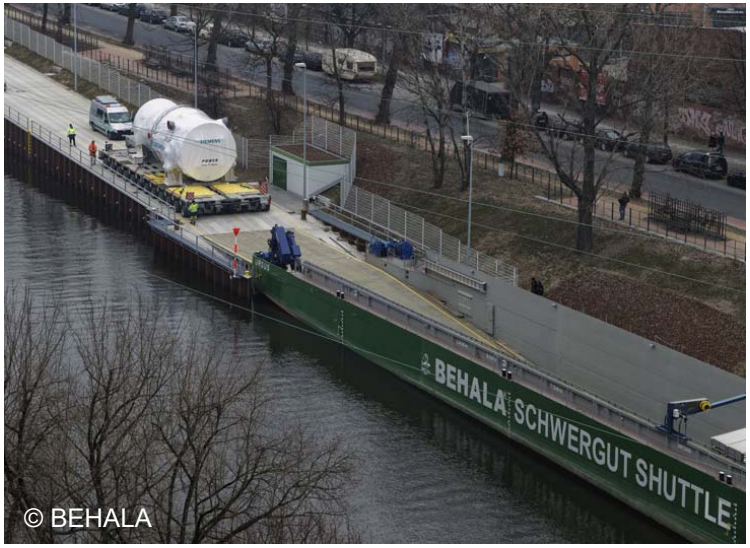


Electric charging stations for inlandwater vessels at Zehdenick around 1910, charging with green energy from barges.

Tasks - local und global without dangerous emissions

The main task of "ELEKTRA" in conjunction with "URSUS":

- RoRo – project loads
- regional / supra-regional transport of heavy-duty goods, e.g., gas turbines from the Siemens AG / Berlin plant

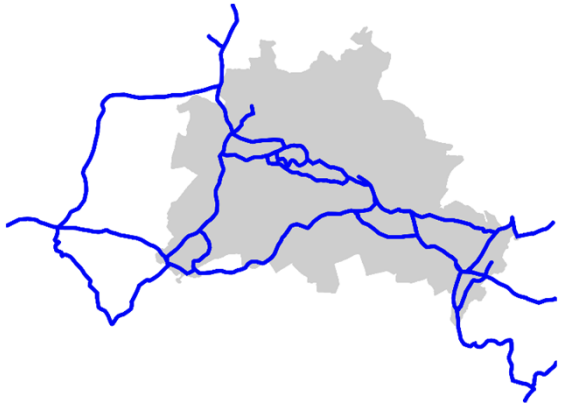


Heavy Cargo RoRo-Barge "URSUS"
Length 64.50 m | Width 9.50 m
Displacement 1,400 t | Draught 1.30 m – 3.06 m

Loading ramp
length 265 m

REQIREMENTS & CONSTRAINTS – Design Case

REGIONAL OPERATION



- Berlin area
- Approx. range of 65 km / day (8h)
- Service speed: 8 km/h, up to 10 km/h
- Drive: primarily battery-electric

- Berlin ↔ Hamburg
- Operating area: Zone 3+4 (without Rhine)
- Approx. range of 130 km / day (16h)
- Average service speed: 8.5 km/h
- Drive: hybrid-electric (FC/batteries)

SUPRA-REGIONAL OPERATION

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First (subjective) experience

Summary

Ship Layout – Canal-Pushboat ELEKTRA

Main dimensions

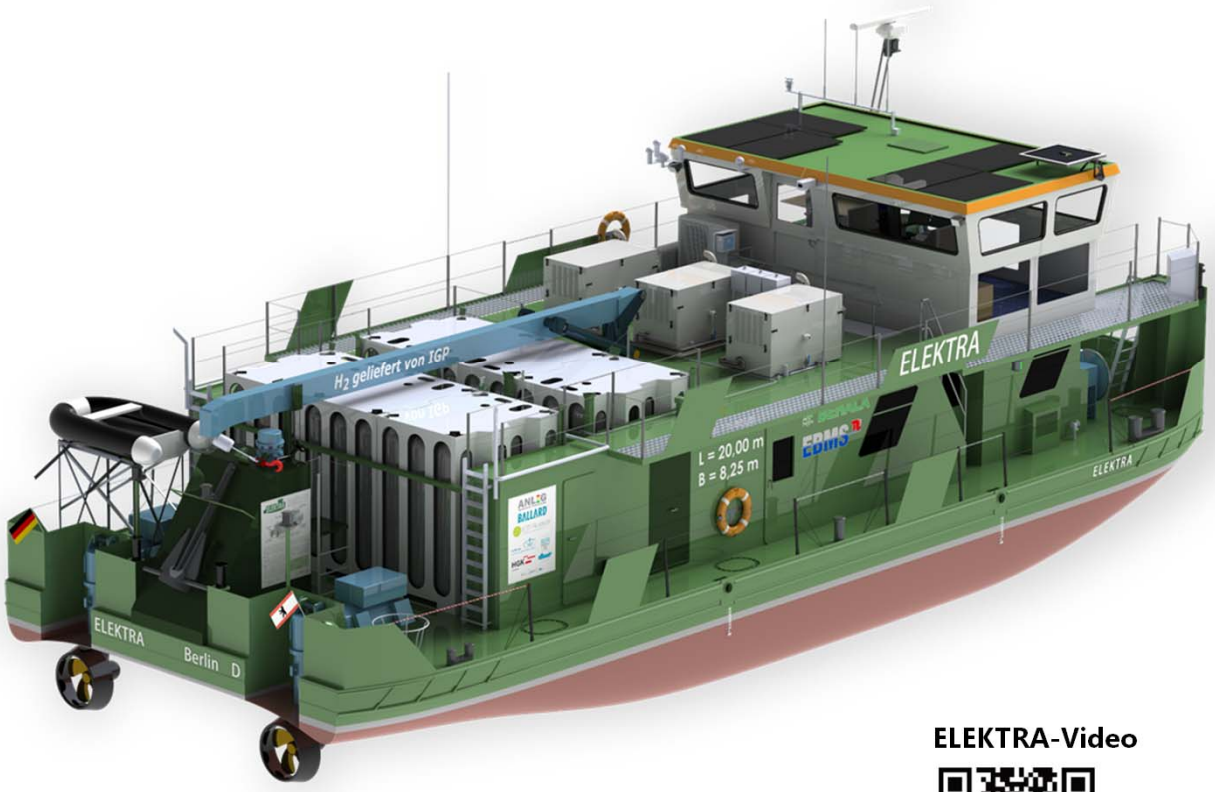
- Length: 19.96 m
- Width: 8.25 m
- Draught: 1.28 m
- Displacement: approx. 132 t

Operational range

- Total range with 1,400 t push load approx. 400 km
- Battery-electric: 8 h / 65 km / day
- Hybrid-electric: 16 h / 130 km / day

Propulsion

- Water-cooled electric motors: 2 x 210 kW
- Rudder propeller



ELEKTRA-Video

Layout – Überblick Energiesystem

ELEKTRA-Video

Hydrogen system
6 x H2-MEGC tanks
à 125 kg at 500 bar
750 kg

Fuel Cells
(LT-PEM)
3 x 100 kW

Photovoltaic system
2.1 kWp

Push load
of 1,400 t

Range
min. 400 km

Electric motors
2 x 210 kW

Energy management,
Main switchboards
and AC/DC
shore connection

Rudder propeller
With nozzle, 360° rotatable

Batteries (lithium-ion)
2,552 kWh
divided into two units

Rules and Regulations – He who is not interested finds reasons not to do anything, others will find solutions

CESNI/PT (18) 80 rev. 1
14. Juni 2018
Or. de/en fr/de/nl/en, Anl. de/en

ARBEITSGRUPPE FÜR TECHNISCHE VORSCHRIFTEN

Empfehlung für die Verwendung von Wasserstoff als Brennstoff Schubschiff „Elektra“

EUROPÄISCHE KOMMISSION

EMPFEHLUNGEN AN DIE SCHIFFSUNTERSUCHUNGSKOMMISSIONEN ZUR RICHTLINIE (EU) 2016/1629

EMPFEHLUNG Nr. 1/2019
vom 4. Juni 2019

ELEKTRA

Das Schubboot „Elektra“, einheitliche europäische Schiffsnummer (noch nicht vergeben - GDWS-Aktennummer 13230), darf abweichend von der Richtlinie (EU) 2016/1629 unter Einsatz von Wasserstoff als Brennstoff für ein Brennstoffzellensystem zur Versorgung des Schiffs mit elektrischer Energie zu dessen Betrieb und Antrieb zugelassen werden.

Construction – Transfer the newbuilding to the slip, March 2021

Construction – Berlin Westhafen – December 2021

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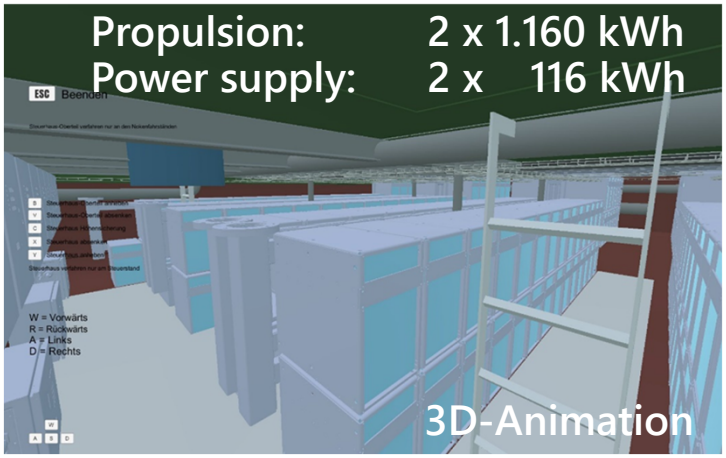
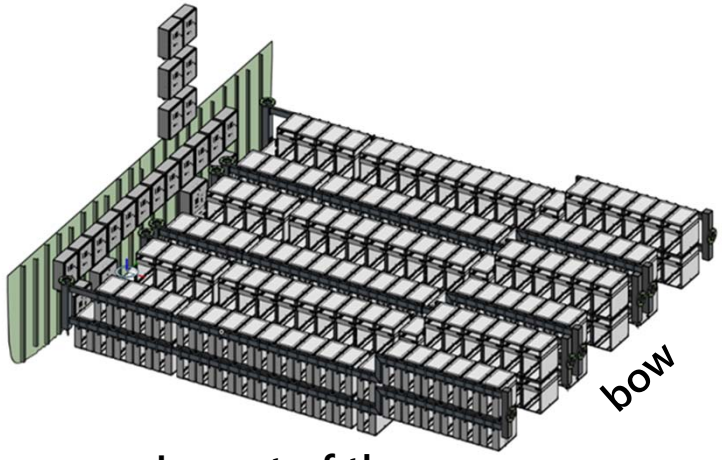
Summary

Layout Energysystem – Accumulator room





Layout of the room

- **cell chemistry:**
  NMC (nickel manganese cobalt oxide)
- **total capacity:**
  - 2,552 kWh (installed) (~ 2,160 kWh usable)
  - approximately 1,800 kWh @EOL
    (theoretically ~15-20 years)
- **total system weight:** approx. 25 tonnes
  (15 % of the ELEKTRA overall weight)
- incl. **temperature management** and **integrated fire protection system**
- no active fire protection in the room
- fully **charged** via shore connection in 7 to 8 hours

Layout Energy system – Accumulator room / Shore connection

Fitting of accu racks

One from three passageways

CEE 16, 32, 63, 125 A
DC- Marechal DS2 (700 V_{DC})
Powerlock-System (400 V_{AC})

ELECTRICS – Main Switch Boards

- approx. 3,000 m electr. Cable
- More than 2,000 sensor

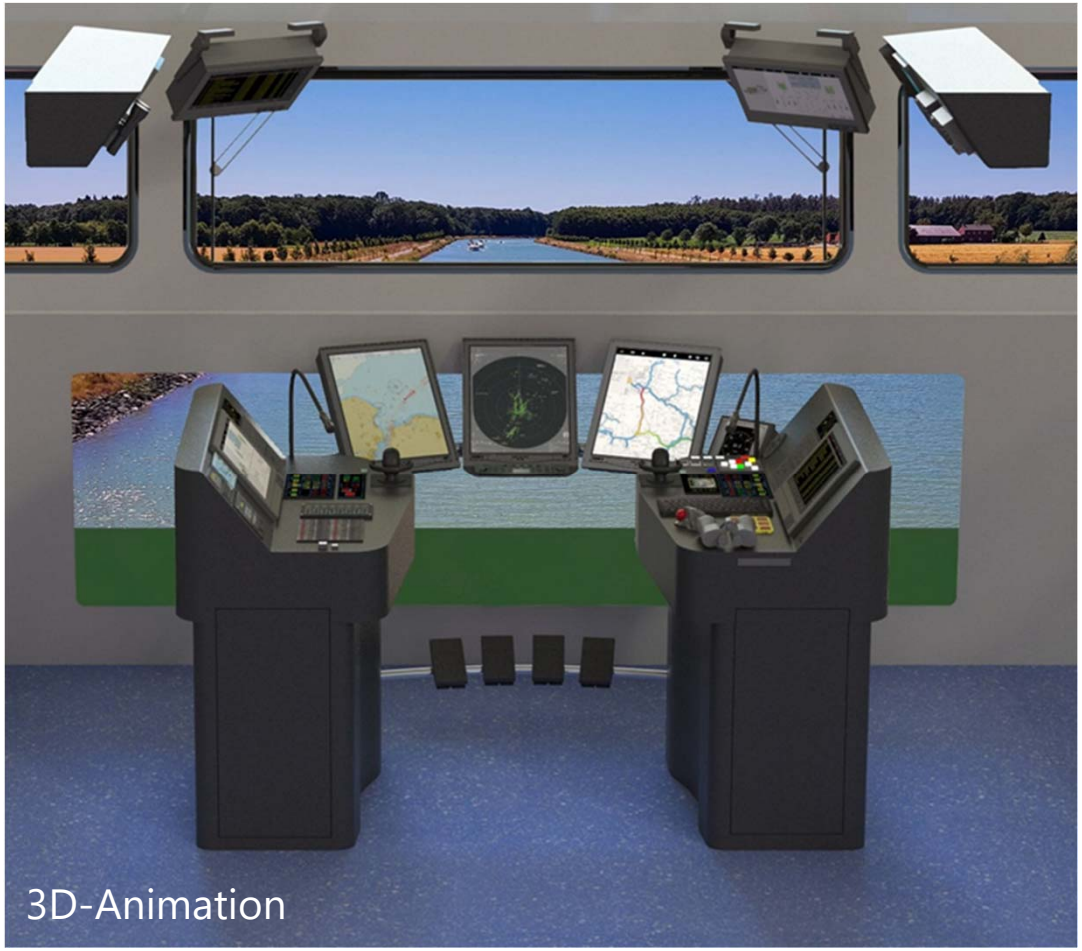
Power management
Fuel Cells
Displays EMS

Power management
Accumulator /
shore charging DC *Stb.*

Power management
Propulsion & Pumps
Stb.

AC Shore charging

Layout – Helmstand

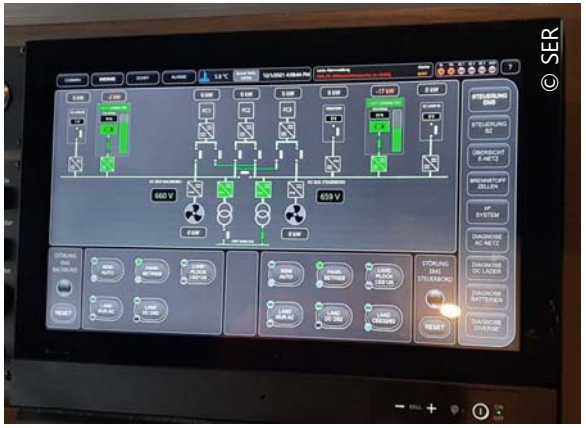


Layout - Helmstand

Propulsion power, velocity, battery SoC

Ship managment

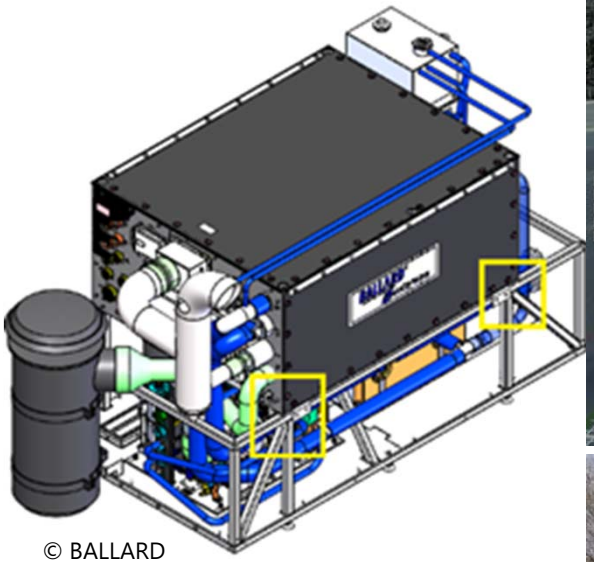
Helmstand layout EBMS - TU Berlin (nautic & energy system)



Energy layout

Hydrogen system

Layout - Energy system – fuel cell system



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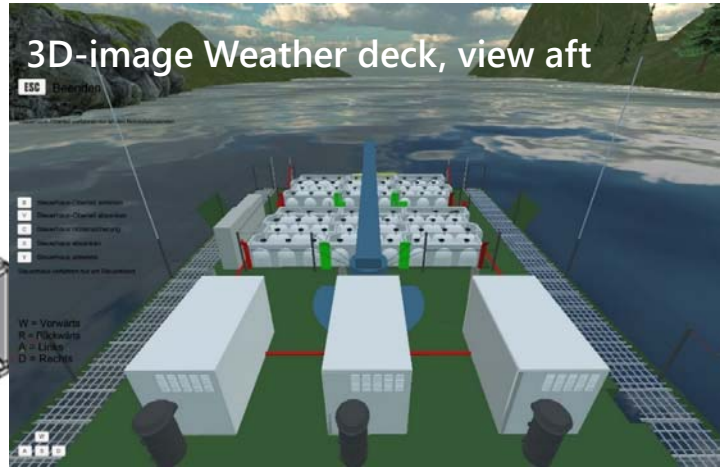


3D-image Weather deck, view aft

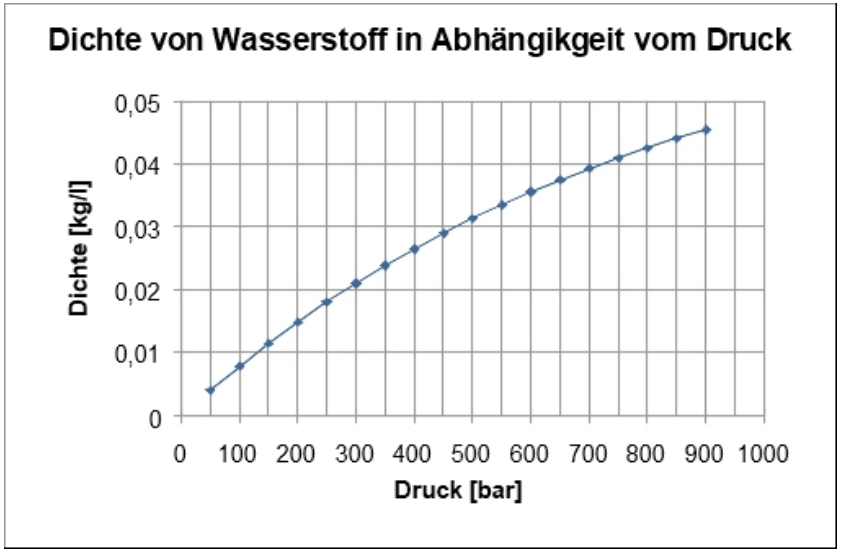
Weather deck, view aft

- **LT-PEM-FC** incl. cooling (water) and compression system
- **3 x 100 kW** units installed on board
- **Individually independent operation** possible per FC
- Goal: small load operating window ~ stationary operating behavior - approx. **200 kW base load**
  ~16 h continuous operation window
- Frost-proof
- Remote diagnostic capability
- Integrated H_2-sensor monitoring
- Service life up to 15 years, then refit if necessary

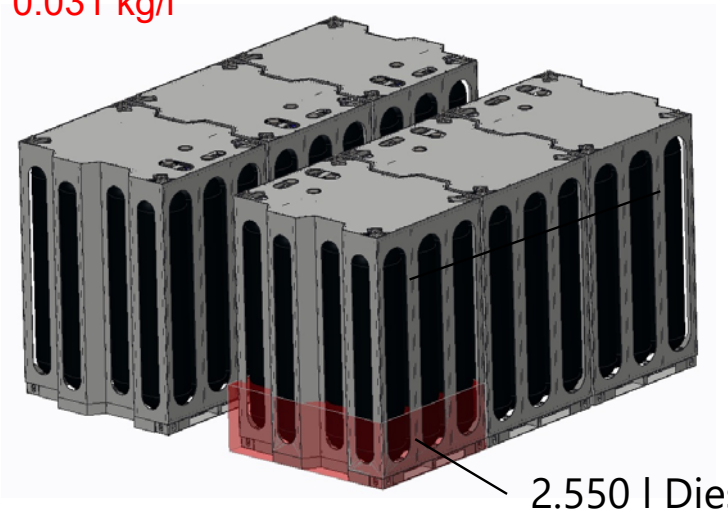
Layout - Energy system – Hydrogen Storage

The “hydrogen dilemma”

- Energy content of hydrogen: 33.3 kWh/kg
- Energy content of diesel: 11.95 kWh/kg
- Density of gaseous hydrogen at a pressure of 500 bar: 0.031 kg/l
- Density of diesel: 0.82 kg/l



Daten: ARGO ANLEG, Wasserstoff-Masse-Druck-Diagramm MEGC



750 kg hydrogen ~ 24.975 kWh

2.550 l Diesel ~ 24.990 kWh

Layout - Energy system – Hydrogen storage

- **MEGCs (Multiple-Element Gas Containers)**
- **Type IV (carbon) high pressure cylinders, GH_2 500 bar**
- **6 modules on board, 6 in circulation**
- **individually crane-able and fork-lift truck capable**
- **Transport by truck trailer or rail***
- **Total mass: approx. 18 t**
- **750 kg GH_2 usable on board**

** possible, current not realized*

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First (subjective) experience

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ENERGY SUPPLY INFRASTRUCTURE – CURRENT SITUATION

- **Shore power** connections with **16 A CEE** plugs are **currently available** at some berths -> primarily used to **supply the on-board power supply**

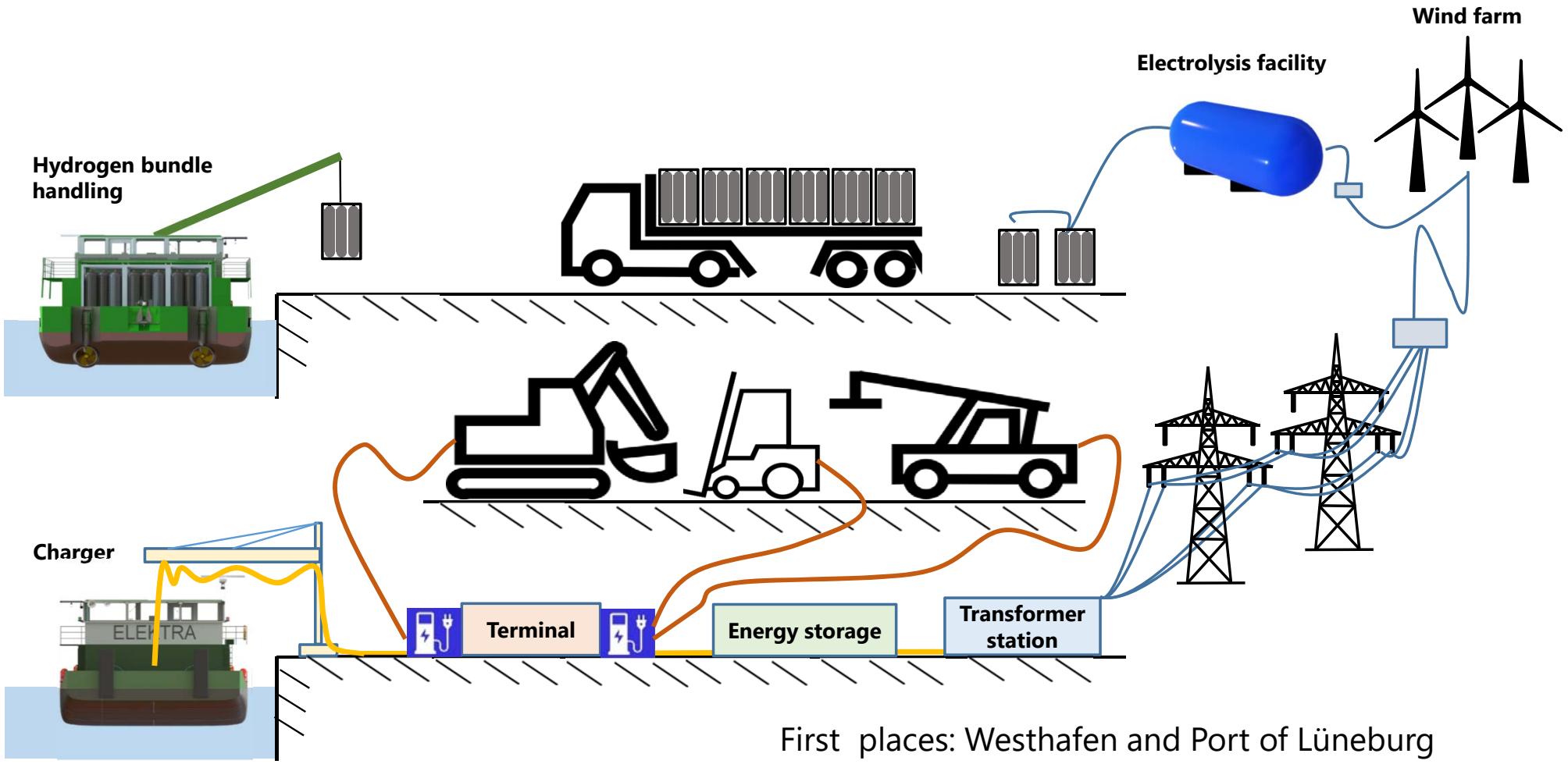
- **Medium-term expansion** of electrification of waterways **up to 32 A CEE system** -> ensure shore-side on-board power supply and avoid operation of ship's engines to generate electricity in port, **still not sufficient for charging**!

- Transmission of larger amounts of energy for storage in short periods of time, as is the case with electric vehicles, is **not covered by the described infrastructure. 63 A CEE** would be **sufficient, 125 A CEE even better** (both possible with the ELEKTRA AC-/DC shore connection).

- **PowerLock system** for the supply of river cruise ships for emission-free mooring times established -> Handling, however, is **very material- and labour-intensive**

- **Freight shipping** -> crew manpower should not be tied up unnecessarily for connecting the shore loading infrastructure, taking into account working time laws

Infrastructure - Concept for hydrogen and electricity supply



First places: Westhafen and Port of Lüneburg

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First (subjective) experience

Summary

First (subjective) experience – Design and Construction

projected: conning bridge movable down

Change of rules during construction

projected: conning bridge movable up and down

projected: Pusch tow up to 84,50 m

Owners wish during construction

realized: Push tow up to 150 m

First (subjective) experience – Design, Construction and Testing

- **Weight calculation** is always an issue in shipbuilding, especially for smaller vessels, but now with **new components there is no data base** (historical data to utilize)
- **Space** is a thing of high value and is to be carefully used
- **Light-weight construction** with sense of proportion is to be realized. Small things could help a lot
- **Test and trials** are new for everybody involved, in particular, yards and suppliers

➔ **New technology, no established and maritime supplier**

➔ **new strategies for design, engineering, construction and testing necessary!**

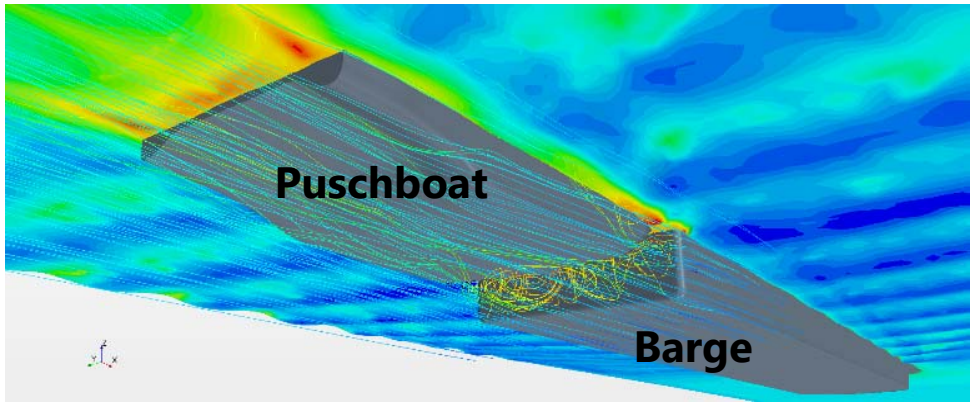
First (subjective) experience – Electric

E-Balance:

- **Operation profile** is much more important as in comparison to a combustion engine
- Review traditional **factors for simultaneousness** using of electric consumer (energy storage to high)
- **E-Balance for harbour and stand by** is important for the economic success

First (subjective) experience – Ship design - Hydrodynamics

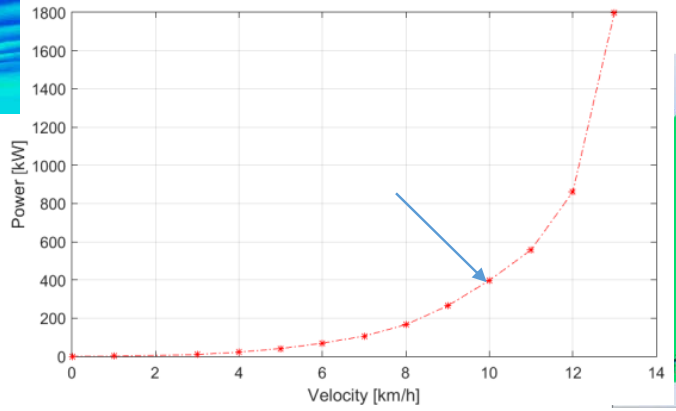
- CFD-Simulation

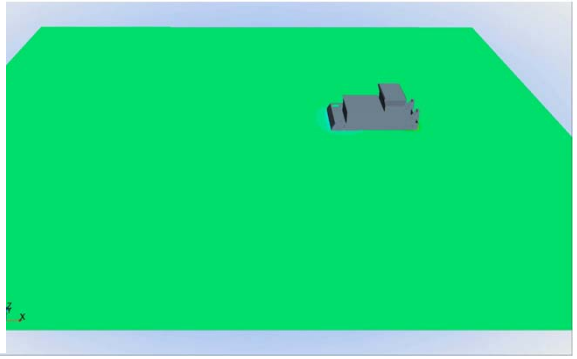


Aims

Saved energy is the best energy!

- o Resistance prediction
- o Propulsion power at shallow water in canals





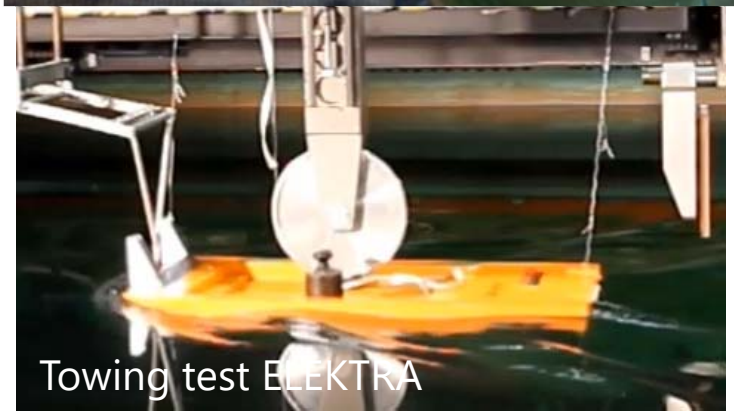
- Model tests for validation

First (subjective) experience – Ship design - Hydrodynamics

- **Model tests for validation**


Deep water canal VWS Berlin


Manoeuvering tests


Towing test ELEKTRA


Towing tests ELEKTRA with barge

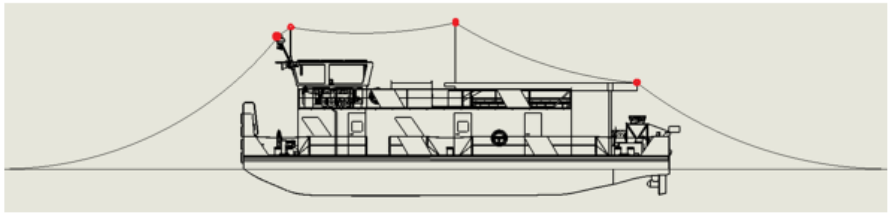
First (subjective) experience – Lightning protection

Necessary because of hydrogen on board

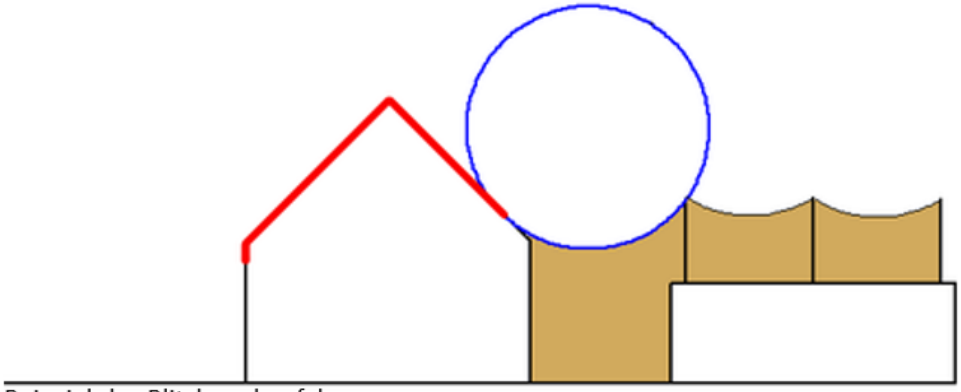
Tool: Lightning ball method

usually not necessary for ships

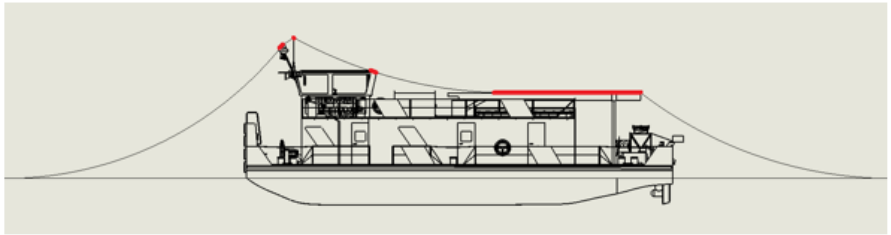
- Blitzschutzklasse I: r = 20 m



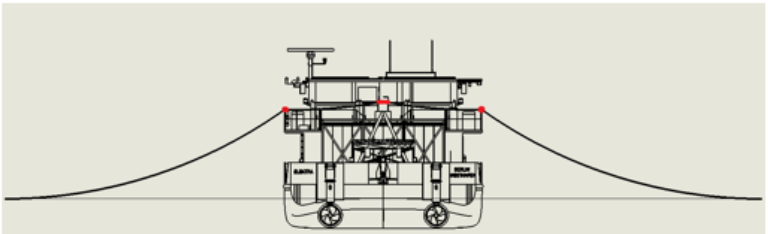
Blitzkugelverfahren Seitenansicht mit Fangstange



Beispiel des Blitzkugelverfahrens



Blitzkugelverfahren Seitenansicht ohne Fangstange



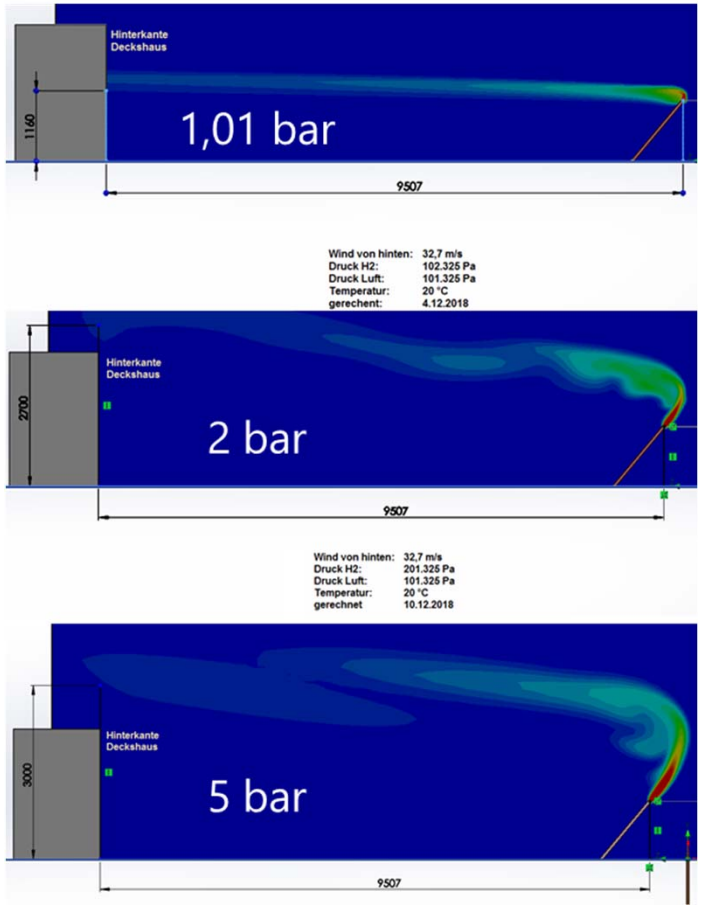
Blitzkugelverfahren Heckansicht ohne Fangstange

First (subjective) experience – Hydrogen Dispersion

Emergency case
blow out of hydrogen

Aim:
no hydrogen in steering house
and defined areas

Case: Hurricane aft



500 bar

First (subjective) experience – HVAC – Accumulator room and super structure

Accu room (Case – cool down)

- **Winter**

aft. 1 h

aft. 4 h

aft. 8 h

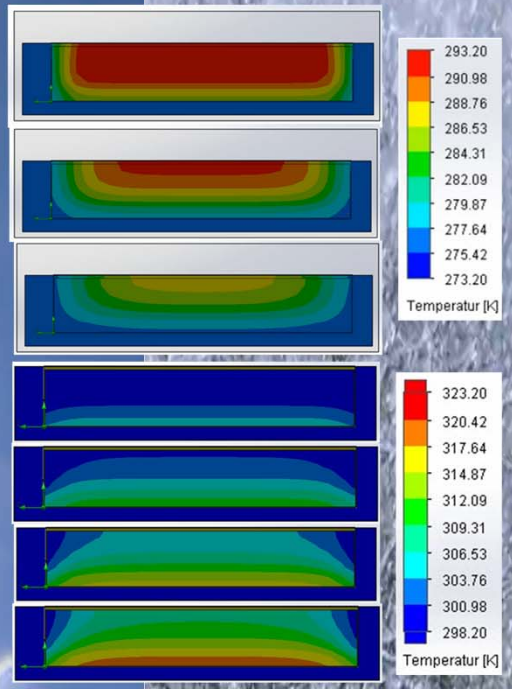
- **Summer**

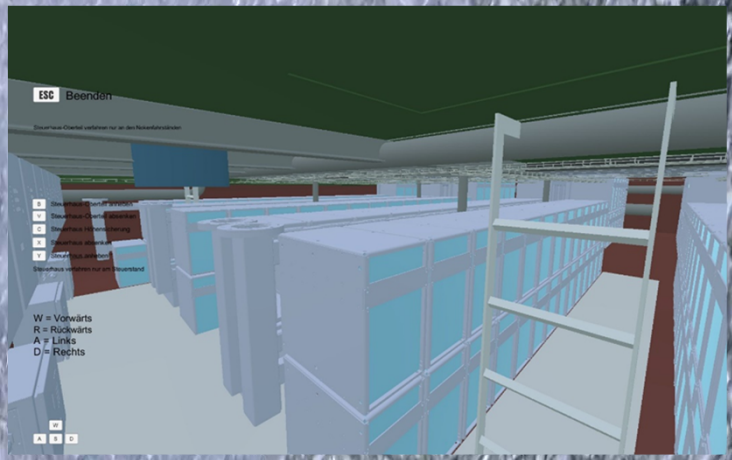
aft. 4 h

aft. 8 h

aft. 12 h

aft. 16 h





The Fuel Cell is no combustion engine and a heat pump is no oil burner.

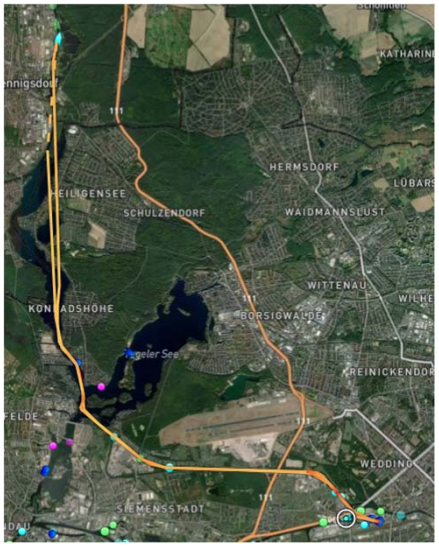
➔ **Low level energy standards from shore side are to be studied and applied.**

First (subjective) experience – First Trials - Tracking

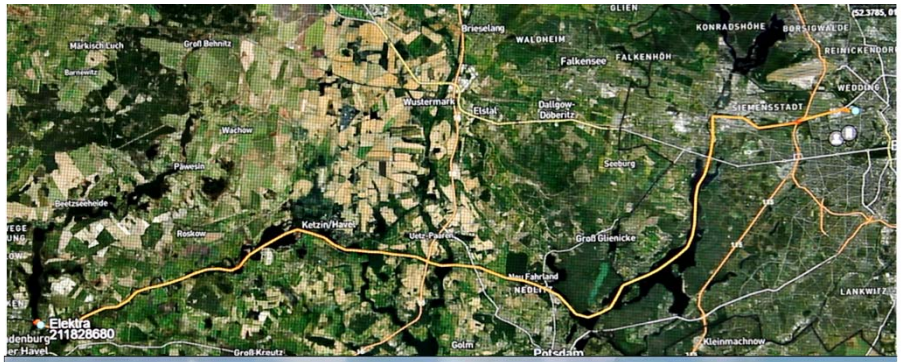
Tegeler See

Source of maps: Marine Traffics

Lehnitzsee / Niederfinow



Town of Brandenburg / Wusterwitz



In the meantime total appr. 1,500 km at Berlin / Brandenburg / Sachsen Anhalt

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Summary *(1 von 2)*

I. **Local and global low-emission** (= CO_2 and pollution-free) waterborne transport in metropolitan regions and supra-regional **is feasible today** (**zero-emission transport**, locally and globally, achieved through the further use of green hydrogen and green electrical power).

II. Further **development of** the **charging and H_2-infrastructure** is **necessary.**

III. Cost for green hydrogen and green electricity **must come down.**

IV. Efficient inland waterway vessels and coastal shipping with H_2 fuel cells and battery energy storage systems **are feasible.**

V. Rules and Regulations enabling economic use of the technology **need to be created** and are **necessary** for reliable **investments** today.

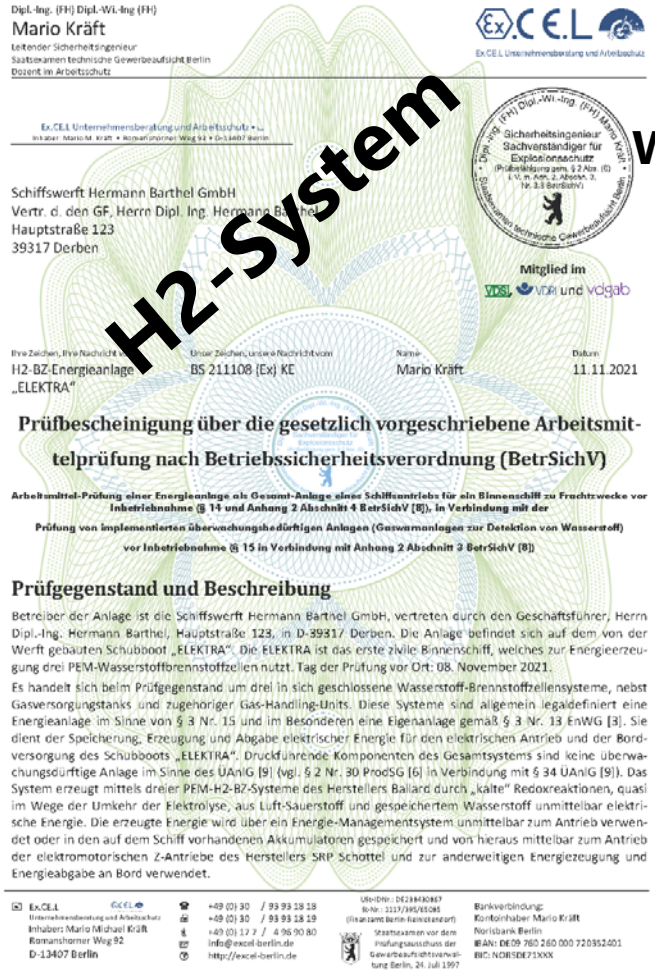
VI. The energy system of the ELEKTRA is a **blueprint for inland and coastal shipping.**

Summary *(2 von 2)*

Certificates grant means job done?

No!

We learned a lot, but there is much more!



Dipl.-Ing. (FH) Dipl.-Wi.-Ing (FH)
Mario Kräft
Leitender Sicherheitsingenieur
Staatsexamen technische Gewerbeaufsicht Berlin
Dozent im Arbeitsschutz

Ex.CE.L Unternehmensberatung und Arbeitsschutz

Schiffswerft Hermann Barthel GmbH
Vertr. d. den GF, Herrn Dipl. Ing. Hermann Barthel
Hauptstraße 123
39317 Derben

Sicherheitsingenieur Sachverständiger für Explosionsschutz

Mitglied im VDSI, VDI und vdgab

H2-System

Ihre Zeichen, Ihre Nachricht v.	Unser Zeichen, unsere Nachricht vom	Name	Datum
H2-BZ-Energieanlage „ELEKTRA"	BS 211108 (Ex) KE	Mario Kräft	11.11.2021

Prüfbescheinigung über die gesetzlich vorgeschriebene Arbeitsmittelprüfung nach Betriebssicherheitsverordnung (BetrSichV)

Arbeitsmittel-Prüfung einer Energieanlage als Gesamt-Anlage eines Schiffsantriebs für ein Binnenschiff zu Frachtzwecke vor Inbetriebnahme (§ 14 und Anhang 2 Abschnitt 4 BetrSichV [8]), in Verbindung mit der

Prüfung von implementierten überwachungsbedürftigen Anlagen (Gaswarnanlagen zur Detektion von Wasserstoff) vor Inbetriebnahme (§ 15 in Verbindung mit Anhang 2 Abschnitt 3 BetrSichV [8])

Prüfgegenstand und Beschreibung

Betreiber der Anlage ist die Schiffswerft Hermann Barthel GmbH, vertreten durch den Geschäftsführer, Herrn Dipl.-Ing. Hermann Barthel, Hauptstraße 123, in D-39317 Derben. Die Anlage befindet sich auf dem von der Werft gebauten Schubboot „ELEKTRA". Die ELEKTRA ist das erste zivile Binnenschiff, welches zur Energieerzeugung drei PEM-Wasserstoffbrennstoffzellen nutzt. Tag der Prüfung vor Ort: 08. November 2021.

Es handelt sich beim Prüfgegenstand um drei in sich geschlossene Wasserstoff-Brennstoffzellensysteme, nebst Gasversorgungstanks und zugehöriger Gas-Handling-Units. Diese Systeme sind allgemein legaldefiniert eine Energieanlage im Sinne von § 3 Nr. 15 und im Besonderen eine Eigenanlage gemäß § 3 Nr. 13 EnWG [3]. Sie dient der Speicherung, Erzeugung und Abgabe elektrischer Energie für den elektrischen Antrieb und der Bordversorgung des Schubboots „ELEKTRA". Druckführende Komponenten des Gesamtsystems sind keine überwachungsdürftige Anlage im Sinne des ÜAnlG [9] (vgl. § 2 Nr. 30 ProdSG [6] in Verbindung mit § 34 ÜAnlG [9]). Das System erzeugt mittels dreier PEM-H2-BZ-Systeme des Herstellers Ballard durch „kalte" Redoxreaktionen, quasi im Wege der Umkehr der Elektrolyse, aus Luft-Sauerstoff und gespeichertem Wasserstoff unmittelbar elektrische Energie. Die erzeugte Energie wird über ein Energie-Managementsystem unmittelbar zum Antrieb verwendet oder in den auf dem Schiff vorhandenen Akkumulatoren gespeichert und von hieraus mittelbar zum Antrieb der elektromotorischen Z-Antriebe des Herstellers SRP Schottel und zur anderweitigen Energiezeugung und Energieabgabe an Bord verwendet.

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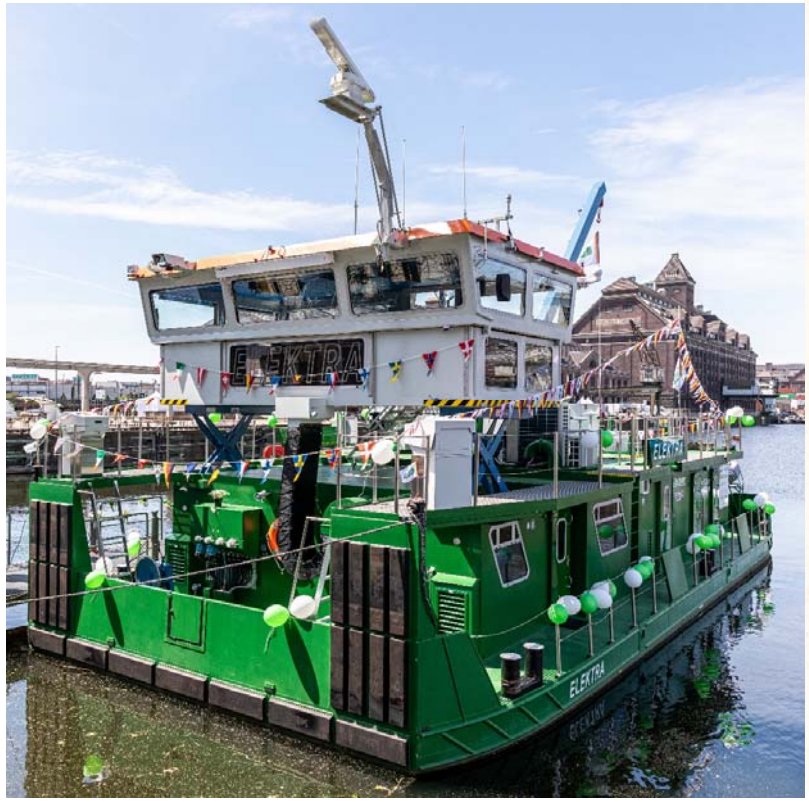
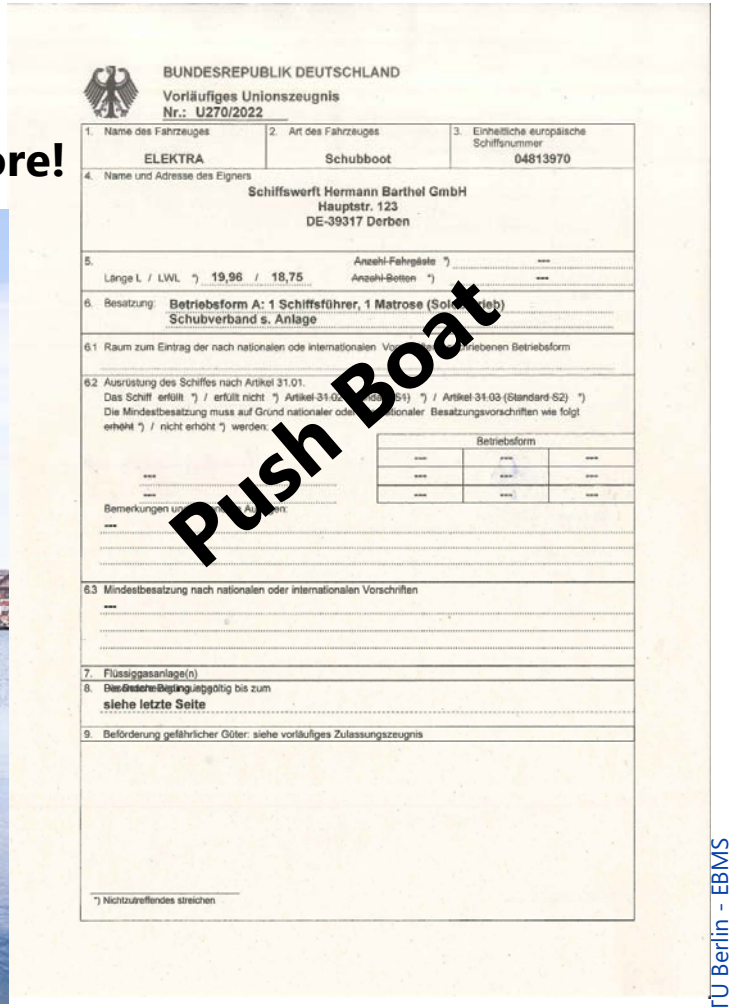
St-Nr.: 3117/393/65085
(Finanzamt Berlin-Reinickendorf)

Staatsexamen vor dem Prüfungsausschuss der Gewerbeaufsichtsverwaltung Berlin, 24. Juli 1997

Bankverbindung:
Kontoinhaber: Mario Kräft
Norisbank Berlin
IBAN: DE09 760 260 000 720352401
BIC: NORSDE71XXX





BUNDESREPUBLIK DEUTSCHLAND
Vorläufiges Unionszeugnis
Nr.: U270/2022

1. Name des Fahrzeuges	2. Art des Fahrzeuges	3. Einheitliche europäische Schiffsnummer
ELEKTRA	Schubboot	04813970

4. Name und Adresse des Eigners
Schiffswerft Hermann Barthel GmbH
Hauptstr. 123
DE-39317 Derben

5. Anzahl Fahrgäste *) ---
Länge L / LWL *) 19,96 / 18,75 Anzahl Betten *) ---

6. Besatzung: Betriebsform A: 1 Schiffsführer, 1 Matrose (Solo-Betrieb)
Schubverband s. Anlage

6.1 Raum zum Eintrag der nach nationalen ode internationalen Vo... ...iebenen Betriebsform

6.2 Ausrüstung des Schiffes nach Artikel 31.01.
Das Schiff erfüllt *) / erfüllt nicht *) Artikel 31.0... ...S1) *) / Artikel 31.03 (Standard-S2) *)
Die Mindestbesatzung muss auf Grund nationaler ode... ...ionaler Besatzungsvorschriften wie folgt erhöht *) / nicht erhöht *) werden:

Betriebsform		
---	---	---
---	---	---
---	---	---

Bemerkungen un... ...Auflagen:

6.3 Mindestbesatzung nach nationalen oder internationalen Vorschriften
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7. Flüssiggasanlage(n)

8. Das Zeugnis ist gültig bis zum
siehe letzte Seite

9. Beförderung gefährlicher Güter: siehe vorläufiges Zulassungszeugnis

*) Nichtzutreffendes streichen

Push Boat

Technische Universität Berlin

Entwurf und Betrieb Maritimer Systeme

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ELEKTRA Video https://youtu.be/gdBwd

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ELEKTRA-Video