



Technology update on hydrogen-driven vessels

Tech update: Hydrogen & fuel cells at Haugaland Kraft, 22/02-2017

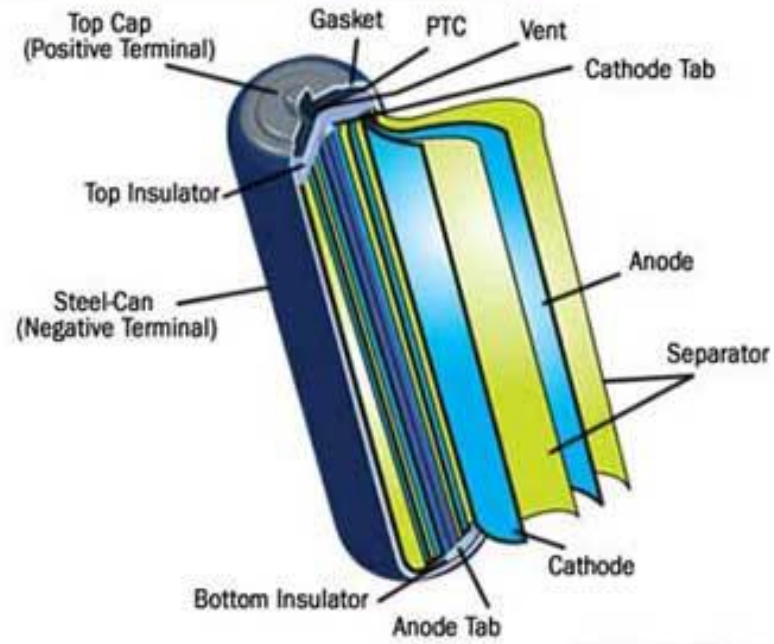
Tjalve Svendsen, CMR Prototech

Aleksander Hitland Opdahl, Norwegian Electric Systems

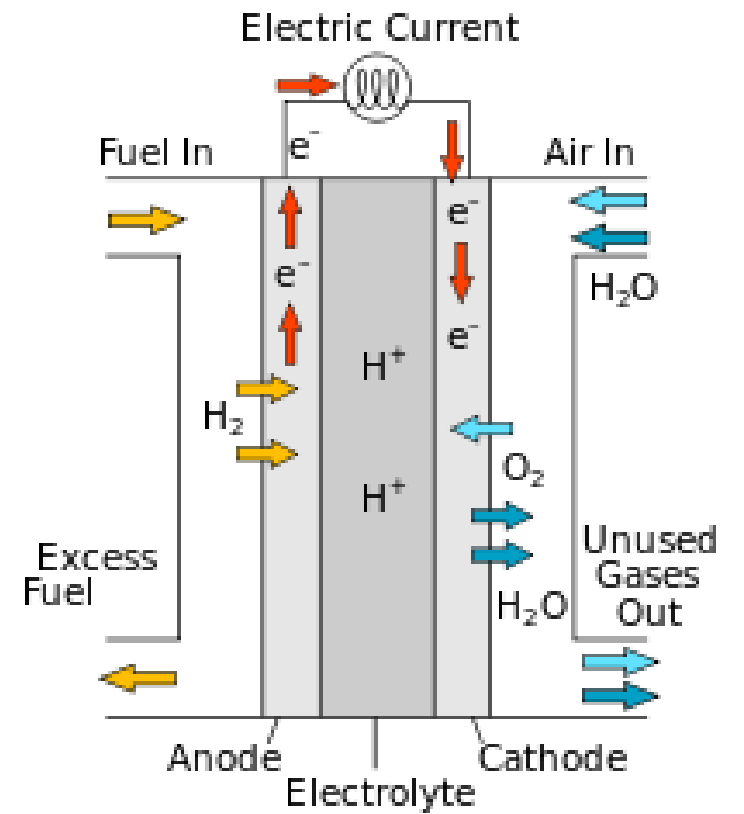
cmr Prototech

Fuel cells for maritime applications

Cylindrical lithium-ion battery

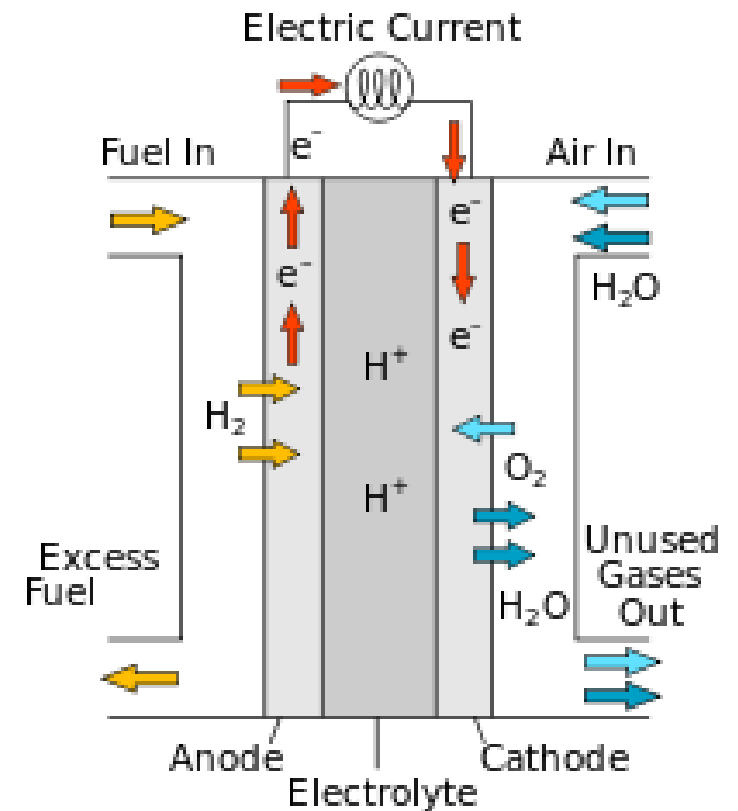


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Fuel cells for maritime applications

- Enables zero emission solutions for more vessel types and operational profiles
- Eliminates *direct emissions from vessel* $2H_2 + O_2 \rightarrow 2H_2O$
- Reduced *energy consumption*, $\eta_{FC} \sim 50 - 60 \%$ and usable waste heat
- Increased utilization of variable renewables – stabilizes power grid
- Reduced noise and vibrations
- Same performance at low temperatures
- Also relevant for other fuels
 - Bio(m)ethanol, biogas







Fuel cells for maritime applications

- Most relevant FC types
 - PEM
 - HTPEM
 - SOFC
- Hydrogen fueled PEM combined with batteries covers a wide range of applications
 - Fuel cell module/system suppliers (busses, trains, stationary)



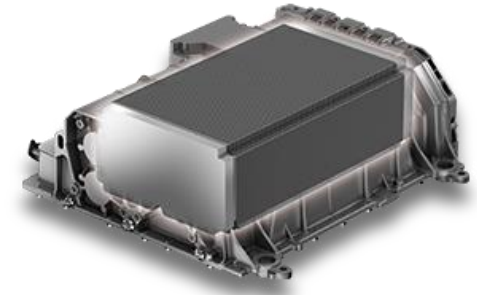
Hydrogenics HyPM



Ballard FCveloCity

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PowerCell S3 stack



Race For Water



MARANDA FCHJU project

Fuel cells for maritime applications

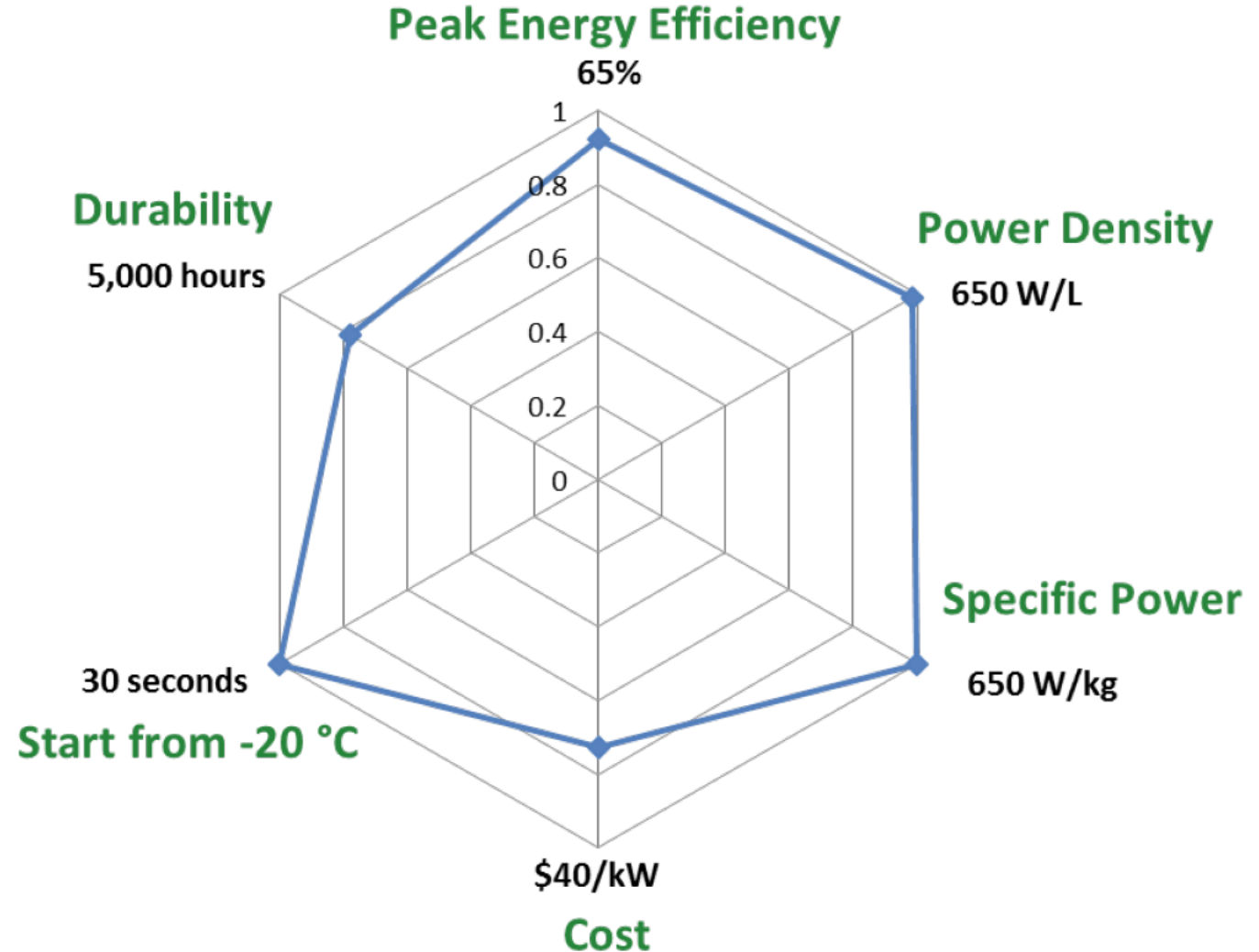
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- Methanol/LNG-fueled HTPEM/SOFC for APU and high-energy ships/routes

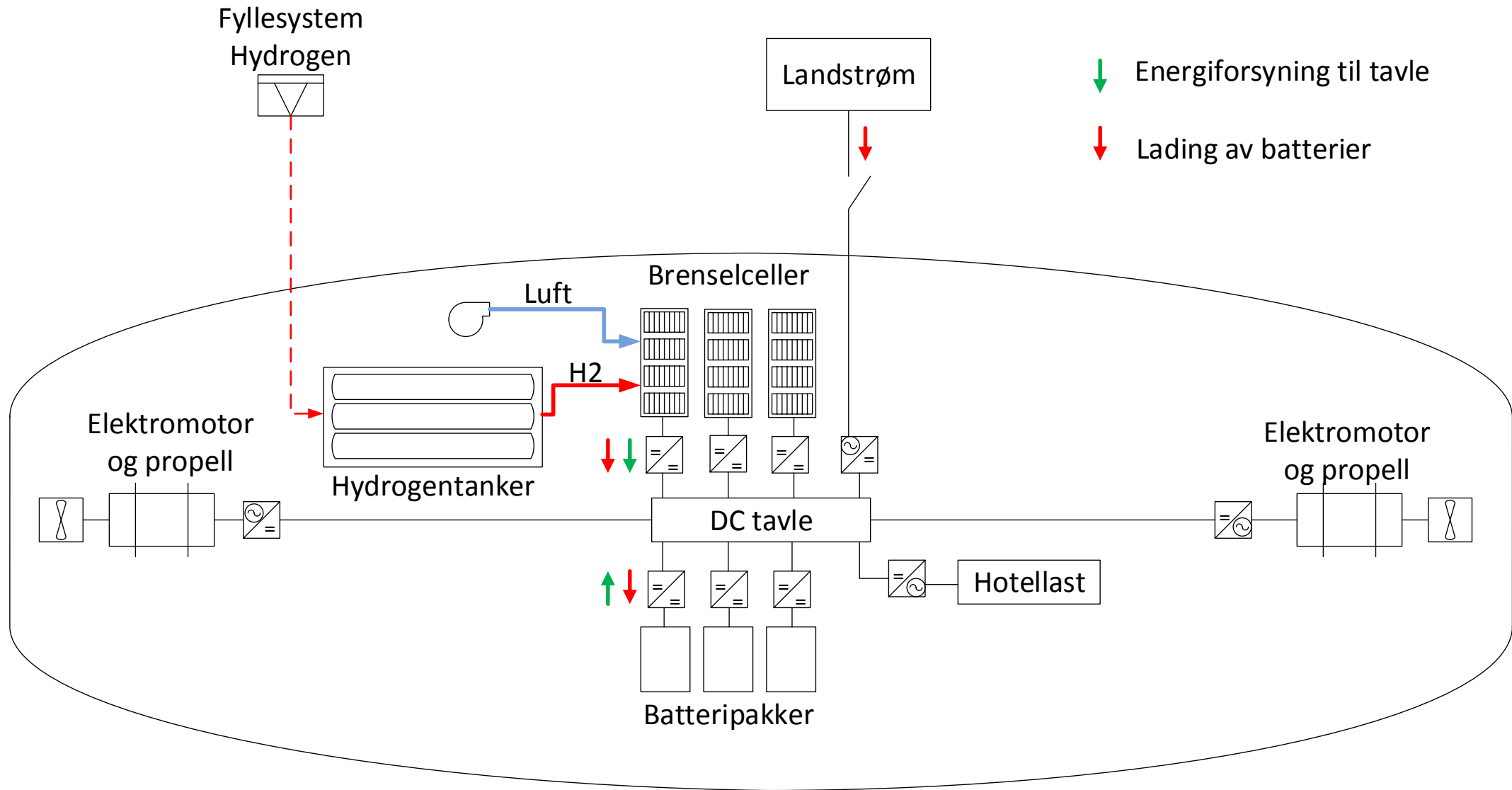


METHAPU – Wärtsilä 20 kW SOFC 2006-2010



- DOE Fuel Cell *System* targets for automotive applications
- Stationary/marine ~20,000 hours (FCHJU MAWP)
- Major cost reduction when manufactured at a volume of 500,000 units/year





Hydrogen storage

- Pressurized gas storage
 - Bus 350 bar, cars 700 bar
 - Standard for ships tbd (200 – 700 bar)
- Liquid storage
 - -253 deg C (energy demanding)
 - Cryo compressed
- Metal hydride
- Methanol/ethanol/methane as carrier



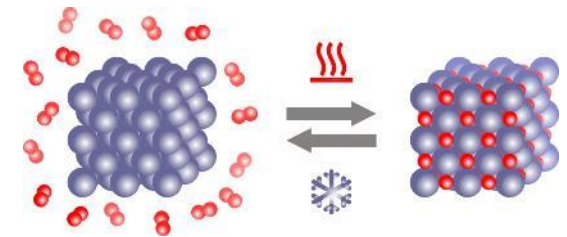
Hexagon



UMOE Advanced Composites



MH for MF Vågen



Storage comparisons

Storage solution	Fuel Density (kg/m ³)	Energy density* (kWh/l)	Specific energy* (kWh/kg_system)
Diesel	800	10	12
GH2 @ 350 bar	25	0,8	2,4
GH2 @700 bar	42	1,4	2,6
LH2	70	2,3	~25
Li-Ion batteries		0,09	0,08

*Lower heating value of fuels

Market drivers

- Regulatory
- Political
- Carbon tax risk
 - Diesel price in 2030?
- Better technology



MF «Ampere» er verdens første el-ferge. Uten utviklingskontrakt fra Statens vegvesen, ville ikke fergen blitt bygget. Nå er batteriferges blitt mer eller mindre et krav der det er mulig. (Bilde: Vidarlo/Wikimedia Commons)

STATSBUDSJETTET 2017

I 2015 ble Norge først ut med elferge. Nå skal ny milepæl nås

Norge kan i 2021 bli verdens første som tar i bruk en hydrogenferge.



AV: TORE STENSVOLD | SKIP | PUBLISERT: 6. OKT. 2016 - 14:04



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I Regjeringens forslag til statsbudsjett har Statens vegvesen fått i oppgave å få



Future is electric

- Hydrogen and FC technology complements pure battery solutions
 - Faster refueling/charging time
 - Less dependent on grid infrastructure and stability
- Enables zero-emissions on “all” ship types and operations



- Safety/Risk Management
- Affordable fuel
 - 8,2 NOK/kg MGO corresponds to ~25-40 NOK/kg H₂
- Fuel cells in marine environment
 - Total cost of ownership, Risk of investment



Need good and suitable development/demonstration projects



- Established in 2016 as supplier of complete FC-battery electric hybrid powertrains for maritime applications
- Joint Venture between Prototech and Norwegian Electric Systems
- Norwegian Electric Systems supplier of complete maritime propulsion systems for a large range of vessel types and power levels up to 40 MW
- The in-house experience and knowledge of the electric marine market totals more than 35 years including the development of 4000 different small and large electric systems



CMR Prototech know-how..

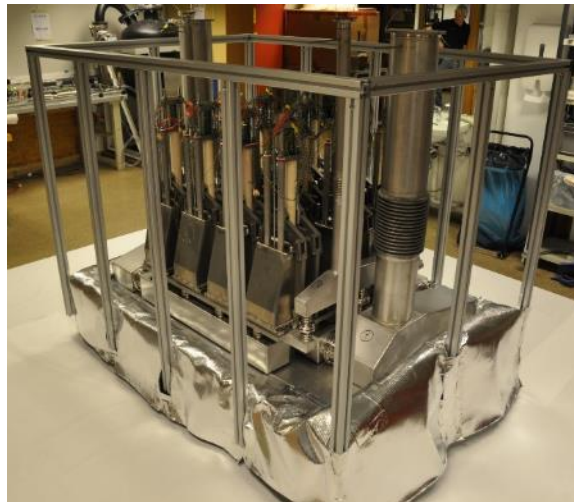
- 25 years experience with research, development and testing of hydrogen and fuel cell technology
- Design, integration and testing of 12,5 kW HTPEM fuel cell system on MF Vågen (2009-2011)
- Development of Regenerative Fuel Cell Systems in various European Space Agency projects last 15 years
- A range of SOFC, PEM, HTPEM demonstration projects



12,5 kW FC system inkl batteries and electric propulsion installed and tested on MF Vågen



Mjøllner - 10 kW SOFC Statoil, 1991-1997



20kW SOFC Module ZEG Power, 2014



Light-weight FC and ELY stacks for Space Applications

Norwegian Electric Systems



We have our own branding of our products:

- Norwegian Electric Motors
- Norwegian Electric Generators
- Norwegian Electric Switchboards
- Norwegian Electric Batteries
- Norwegian Electric Transformers
- Norwegian Electric Odin's Eye®
- Norwegian Electric QUEST® - Energy Storage System (Batteries)
- Norwegian Electric Quadro Drive®
- Norwegian Electric B.O.S.S.® (Black Out Safety System)
- Norwegian Electric R.A.S.® (Remote Assistance System)

EXCELLENCE IN ELECTRIC

NES HAS DELIVERED NEARLY 50 COMPLETE SYSTEMS THE LAST 6 YEARS



HD832 MKII
Fafnir Offshore
Hull no 120



VARD CLV01
Siem Offshore
Hull no 2886/1



Geo Atlantic
GC Rieber
Reconstruction



HD857
Marine Platforms Ltd
Hull no 115



SK-3100V
Larsnes Mek Verksted
Hull no 51



HD820
Atlantic Offshore
Hull no C735



Fishing vessel
Smaragd
Hull no 121



Jack-up rig
Gulf Marine Services
Hull no 6104



HD832
Global Offshore
Hull no 116



River Thames
battery electric
ferry
Transport for
London (TfL)



Battery electric
ferries
Havyard Ship
Technology,
Fjord1

EXCELLENCE IN ELECTRIC

Ongoing projects/initiatives



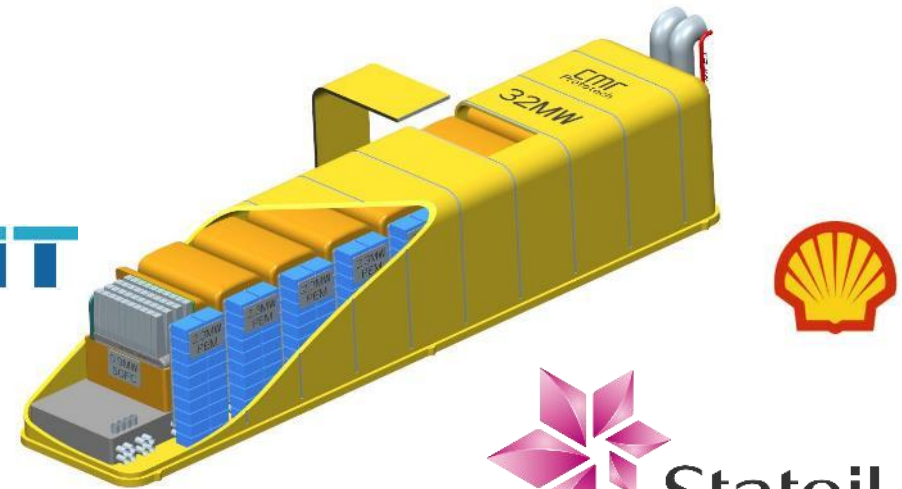
Develop test platform for marine Fuel Cells/batteries on MF Ole Bull



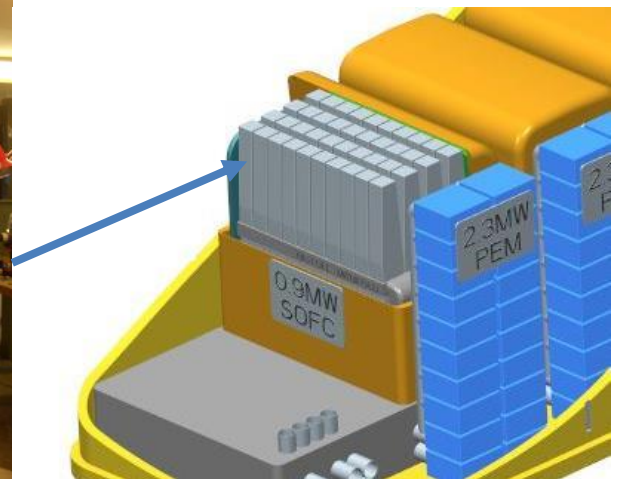
Urban Water Shuttle
Zero-emission high speed passenger vessel

CLIMIT

Forskningsrådet



CHEOP – Clean Highly Efficient Offshore Power



Ongoing projects/initiatives cont.



Fish farming service vessels

- *High speed passenger vessels*
- *Car ferries*
- *Fishing vessels*
- *Cruise ships*
- *Container ships*
- *Supply ships*
- ...



Hydrogen Viking – Sunseeker Predator 95
Max speed: 46 knots!



Thank you for your attention!

